Copy #8 Captain Wally Schirra

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

LUNAR LANDING TRAINING VEHICLE NO. 1
ACCIDENT INVESTIGATION BOARD REPORT

(DECEMBER 8, 1968)

i.

— 1-E-2

— 1-F(a)-52
arrows only

(1 F b-4
INK corr.)

(1 F b-11
INK)

2-A-15

2-A-16

2-A-22

(2-A-30
INK)

2-B-1

(2-B-6 ink)

2-B-2

i-F(b)-18
change H to W

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

March 12, 1969

INDEXING DATA

DATE	OPR	#	T	PGM	SUBJECT	SIGNATOR	LOC
03-12-69	MSC		R	TNG	(Title)	MSC	081-52

TABLE OF CONTENTS

(Form 1388)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MISHAP REPORT *(Accidents, Incidents, Mission Failures)* TABLE OF CONTENTS

INSTRUCTIONS

1. Indicate material included or not included in this report by placing an *"X"* in the appropriate box.

2. Whenever *"Applicable - Not Included)* column is marked for any of the items listed, information must be entered under *"Remarks"* to indicate what action has been taken or will be taken to obtain the required attachment.

3. Lettered tabs shown below will be inserted for corresponding included items; i.e., tab 2-D will always be used for statements, tab 1-Q for orders appointing investigating board, etc. Tabs will be omitted on those items not applicable. Cross-hatched blocks shown below in *"Not Applicable"* column indicate minimum content of all mishap reports.

REPORT SECTION	TAB LETTER	i. Table of Contents (NASA Form 1388) DESCRIPTION	INCLUDED	NOT APPLICABLE	APPLICABLE-NOT INCLUDED
PART 1 - FACTUAL	1-A	MISHAP REPORT *(Accident/Incident) (NASA Form 1389)*	X	▨	
	~~1-B~~	~~SPACE VEHICLE MISHAP REPORT *(NASA Form 1390)*~~		X	
	1-C	AIRCRAFT FLIGHT MISHAP REPORT *(NASA Form 1391)*	X		
	~~1-D~~	~~INDUSTRIAL MISHAP REPORT *(NASA Form 1392)*~~		X	
	1-E	METHOD OF INVESTIGATION	X	▨	
	1-F	NARRATIVE FACTUAL DESCRIPTION OF MISHAP	X	▨	
	1-G	FLIGHT/OPERATIONS PLAN	X		
	1-H	MAINTENANCE AND INSPECTION RECORDS	X		
	1-I	COMMUNICATIONS, RECORDINGS, TRANSCRIPTIONS	X		
	1-J	LIST OF DAMAGED PARTS	X		
	1-K	PARTS TEARDOWN REPORTS	X		
	1-L	LAB REPORTS	X		
	~~1-M~~	~~PHOTOGRAPHS~~	X	In other sections	
	~~1-N~~	~~DIAGRAMS~~	X	In other sections	
	1-O	MEDICAL AND AUTOPSY REPORT EXTRACTS	X		
	1-P	BOARD PROCEEDINGS	X		
	1-Q	DIRECTIVES APPOINTING INVESTIGATING BOARD	X		
	1-R	OTHER FACTUAL INFORMATION (weather)	X		
PART 2 - ANALYSIS	2-A	NARRATIVE DESCRIPTION OF MISHAP *(Based on conclusions by Board)* *	X	▨	
	2-B	SUMMARY OF FINDINGS AND RECOMMENDATIONS	X	▨	
	~~2-C~~	~~GROUP REPORTS~~	X	In other sections	
	2-D	STATEMENTS	X		
	~~2-E~~	~~REBUTTALS~~		X	
	~~2-F~~	~~CONTRACTOR REPORT(S)~~		X	
	2-G	ADDITIONAL SUBSTANTIATING DATA (Wind tunnel tests)**	X		~~X~~
	~~2-H~~	~~COMPLETE MEDICAL AND AUTOPSY REPORTS~~		X	
	~~2-I~~	~~REPORTS OF OTHER ANALYSES~~		X	

REMARKS

*Analysis of 1-F

** Preliminary data included, analysis not complete.

NASA Form 1388 OCT. 68

GPO 866-850

1-A

MISHAP REPORT (Form 1389)

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MISHAP REPORT *(Accident/Incident)*

A. MISHAP DATA

1. CLASS OF MISHAP ☒ a. TYPE A ACCIDENT ☐ b. TYPE B ACCIDENT ☐ c. INCIDENT

2. DATE OCCURRED December 8, 1968

3. TIME OCCURRED 0729

4. LOCATION OF MISHAP Ellington Air Force Base, Texas

5. DESCRIPTION *(Type of mishap)* Vehicle Crashed During Flight

6. WHAT WAS INVOLVED *(Vehicles, systems, material, equipment, etc.)* Lunar Landing Training Vehicle No. 1

7. COGNIZANT INSTALLATION
Manned Spacecraft Center
Houston, Texas 77058

8. PROGRAM/CONTRACT *(Title and number)* N/A

9. ORGANIZATION CONDUCTING OPERATION *(NASA or contractor)* NASA Manned Spacecraft Center

10. OTHER ORGANIZATIONS INVOLVED *(Agency, public or contractor)* None

11. ESTIMATED COST FOR REPAIR/REPLACEMENT 2-million dollars

12. ESTIMATED DELAY TIME of LLTV Program 90 days

13. RECOVERY STATUS *(Use additional sheets if necessary)*
Vehicle beyond recovery because of impact and fire

B. PERSONS INVOLVED *(Continue on reverse or additional sheets if necessary)*

NAME *(Last, first, middle initial)*	GRADE *(CS/Mil.)* a.	SOCIAL SECURITY NO. b.	ORGANIZATION OR COMPONENT c.	INJURY d.	DAYS LOST e.
Algranti, Joseph S.	GS 16	242 30 2744	Chief of Aircraft Operations MSC	Minor Bruise	$1\frac{1}{2}$

C. AUTHENTICATION *(Board President or Investigator)*

1. TYPED NAME AND TITLE Conway H. Roberts, Investigating Officer

2. SIGNATURE Conway H. Roberts

3. DATE February 5, 1969

NASA FORM 1389 OCT 65

GPO 866-846

1-C

AIRCRAFT MISHAP

Form 1391

1-C-1

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

AIRCRAFT FLIGHT MISHAP REPORT

(To be filled out for principal aircraft involved. Appropriate blocks only should be filled out on secondary aircraft)

1. CLASS OF MISHAP ☒ a. TYPE A ACCIDENT ☐ b. TYPE B ACCIDENT ☐ c. INCIDENT	2. DATE OCCURRED 8 Dec 68	3. TIME OCCURRED 07:29 CST
4. AIRCRAFT SERIAL NO. LLTV #1	5. TYPE, MODEL, SERIES, BLOCK NO. LLTV #1	6. FACILITY OF ASSIGNMENT MSC

7. IF LEASED, STATE AGENCY AND ORGANIZATION OWNING AIRCRAFT AT TIME OF MISHAP
N/A

8. IF AIRCRAFT WAS BEING FERRIED OR DELIVERED, INDICATE GAINING AND LOSING ORGANIZATION, DATE OF TRANSFER, ULTIMATE DESTINATION
N/A

9. CLEARANCE
a. FROM Ellington AFB, Texas
b. TO Local
c. TO ---
d. FILED ☒ (1) VFR ☐ (2) VFR-ON TOP ☐ (3) IFR ☒ (4) LOCAL ☐ (5) OTHER ☐ (6) AIRWAYS ☐ (7) DIRECT ☐ (8) (CONTROLLED)

10. FLIGHT DATA
☒ a. VISUAL ☐ b. INSTRUMENT ACTUAL ☐ c. SIM. ☐ d. OTHER ☐ e. UNKNOWN
f. DURATION OF FLIGHT (1) HOURS --- (2) MINUTES 4
g. MISSION Flight Test #15

11. ALTITUDE DATA

a. ALTITUDE *(Feet)*				b. TIME FLOWN HIGHEST ALTITUDE	
(1) CLEARED MSL	(2) ABOVE TERRAIN ACCIDENT SEQUENCE BEGAN	(3) MSL IMPACT POINT	(4) HIGHEST MSL FLOWN	(1) HOURS	(2) MINUTES
1,000 feet	480 feet	40 feet	725	---	10 seconds

12. FIRE AND EXPLOSION DATA
a. FIRE (1) TYPE ☐ (a) NONE ☐ (b) IN-FLIGHT ☒ (c) GROUND (2) BY GROUND IMPACT ☒ (a) YES ☐ (b) NO
b. EXPLOSION (1) TYPE ☒ (a) NONE ☐ (b) IN-FLIGHT ☐ (c) GROUND (2) BY GROUND IMPACT N/A ☐ (a) YES ☐ (b) NO

13. AIRFIELD DATA*

a. FIELD ELEVATION IN USE *(Feet)*	b. LENGTH OF RUNWAY IN USE *(Feet)*	c. LENGTH OF OVERRUN *(Feet)*	d. DISTANCE OF TOUCHDOWN FROM RUNWAY *(Feet)*	e. RUNWAY HEADING *(Degrees)*
40 feet MSL	5,000 feet	N/A	600 feet laterally	350° MH

f. COMPOSITION OF RUNWAY ☐ (1) ASPHALT ☒ (2) CONCRETE ☐ (3)
g. COMPOSITION OF OVERRUN Dirt
h. SURFACE CONDITION of runway ☒ (1) DRY ☐ (2) WET ☐ (3) ICY ☐ (4) Of dirt - Wet
i. CONDITIONS AFFECTING OCCURRENCE OF ACCIDENT *(Instrument or lighting approach aid used, obstructions, barrier, airspeed, gross weight, forced landing, etc.)*
Airspeed

14. VIOLATIONS
a. TYPE *(Discuss under Tab 1-F)* ☐ (1) NASA ☐ (2) FAA None

15. PHASE OF OPERATION *(Takeoff roll, initial climb, normal flight, acrobatics, landing approach, flareout, etc.)*
Landing Approach

16. TYPE OF ACCIDENT *(Gear-up landing, midair collision, abandoned aircraft, fire or explosion in flight, undershoot, overshoot, etc.)*
Loss of Control - Abandoned Vehicle

17. WEATHER AT TIME AND PLACE OF ACCIDENT

a. SKY CONDITIONS	b. VISIBILITY	c. WIND DIRECTION AND VELOCITY	d. TEMPERATURE	e. DEW POINT	f. ALTIMETER SETTING
Clear	15	At Surface Lt/Vabl	34°F	25°F	30.51

g. OTHER WEATHER CONDITIONS
Strong temperature inversion and surface windshear.

** Applicable to takeoff and landing accidents occurring within 2 miles of the airfield.*

NASA FORM 1391 OCT 68

PILOT(S) / FLIGHT CREW INVOLVED *(If more than two pilots involved, report same information required on additional sheet for each)*

18. **OPERATOR** *(Person at controls at time of accident)*

a. NAME *(Last, first, middle initial)* Algranti, Joseph S.	b. GRADE *(cs/Mil.)* Civ	c. COMPONENT *(NASA, Mil. or contractor)* NASA	d. SOC. SEC. NO. 242-30-2744	e. NATIONALITY US	f. BIRTH YEAR 1925

g. POSITION IN AIRCRAFT AT TIME OF ACCIDENT ☒ (1) FRONT OR LEFT SEAT ☐ (2) REAR OR RIGHT SEAT

h. ASSIGNED DUTY ON FLIGHT ORDER ☒ (1) AC ☐ (2) IP ☐ (3) P ☐ (4) CP ☐ (5) OTHER ______

i. ASSIGNED ORGANIZATION

(1) PROGRAM LLTV Flight Test	(2) INSTALLATION NASA MSC EFD	(3) CONTRACTOR N/A	(4) FACILITY Ellington AFB, Texas
j. ATTACHED ORGANIZATION FOR FLYING *(NASA, Mil., contractor official address)* NASA MSC Houston, Texas		k. ORIGINAL AERO RATING AND DATE RECEIVED NACA Research Pilot 1951	l. PRESENT AERO RATING AND DATE RECEIVED NASA Research Pilot 1958

m. INSTRUMENT CARD		n. JOB SPECIALTY	
(1) TYPE NASA Special	(2) DATE OF EXPIRATION Feb 28, 1969	(1) PRIMARY Chief Aircraft Operations Off.	(2) DUTY Same

19. **OTHER CREW MEMBER** *(List additional crew members on separate sheet)*

a. NAME *(Last, first, middle initial)*	b. GRADE *(cs/Mil.)*	c. COMPONENT *(NASA, Mil. or contractor)*	d. SOC. SEC. NO.	e. NATIONALITY	f. BIRTH YEAR

g. POSITION IN AIRCRAFT AT TIME OF ACCIDENT ☐ (1) FRONT OR LEFT SEAT ☐ (2) REAR OR RIGHT SEAT

h. ASSIGNED DUTY ON FLIGHT ORDER ☐ (1) AC ☐ (2) IP ☐ (3) P ☐ (4) CP ☐ (5) OTHER ______

i. ASSIGNED ORGANIZATION

(1) PROGRAM	(2) INSTALLATION	(3) CONTRACTOR	(4) FACILITY
j. ATTACHED ORGANIZATION FOR FLYING *(NASA, Mil., contractor official address)*		k. ORIGINAL AERO RATING AND DATE RECEIVED	l. PRESENT AERO RATING AND DATE RECEIVED

m. INSTRUMENT CARD		n. JOB SPECIALTY	
(1) TYPE	(2) DATE OF EXPIRATION	(1) PRIMARY	(2) DUTY

20. **FLYING EXPERIENCE**

ASSIGNED DUTY *(List flight times to nearest hour)*	ACFT. CDR.	INST. PILOT	PILOT	~~CO-PILOT~~	~~OTHER~~
NAME *(Give last name only)* ▶	(1)	(2)	(3)	Helicopter (4)	LLRV/TV Flts/Time (5)
a. OVERALL FLYING HOURS *(Incl. AF, student, other)*			11305.8	1070.2	33/3.8
b. JET					
c. 1ST PILOT/IP, ALL AIRCRAFT			NA	NA	NA
d. WEATHER INSTRUMENT					
e. 1ST PILOT/IP, THIS MODEL	NA	NA			
f. 1ST PILOT/IP, LAST 90 DAYS			85.9	14.2	12/1.9
g. 1ST PILOT/IP, LAST 90 DAYS THIS MODEL					
h. 1ST PILOT/IP, WEATHER AND HOOD LAST 90 DAYS			NA	NA	
i. PILOT, NIGHT, LAST 90 DAYS					NA
j. PILOT, LAST 30 DAYS			41.7	4.9	
k. 1ST PILOT/IP, LAST 30 DAYS					
l. 1ST PILOT/IP, LAST 30 DAYS THIS MODEL			NA	NA	5/0.8
m. PREVIOUS FLIGHT, THIS MODEL *(Date & duration)*					11/22/68 0.1
n. LAST PROFICIENCY FLIGHT CHECK *(Date)*					

21. DAMAGE *(Extent of damage to aircraft and any property damage incurred. Use additional sheets if necessary)*

Vehicle a total loss-- No additional property damage.

22. **AUTHENTICATION** *(Board President or Investigator)*

a. TYPED NAME AND TITLE W. M. Schirra, Chairman	b. SIGNATURE WMSchirra	c. DATE 3 Mar 69

1-E

METHOD OF INVESTIGATION

Method of Investigation

Due to the nature of the LLTV, a fairly complete instrumentation system is installed which provided 61 channels of telemetered data. All channels were recorded, and 35 channels were displayed in the TM van for real time monitoring and flight coordination (Section 1-F(a)-2). This data was displayed as follows: 16 meters, 16 Sanborn real time [redacted] plots, and 27 event lights. These telemetry data systems, color movies, and recorded TV coverage are used to provide permanent records for each flight. These records, the reasonably good condition of certain critical vehicle components, the availability of the pilot and numerous observers have made the investigation rather straightforward. However, the large amount of data to be analyzed has made this a lengthy process.

~~Data reduction has been a problem during this investigation because the LLTV program at MSC was designed as an operational program and not a test program. The many parameters recorded were either a held over from the flight test program at FRC and/or were intended to be used as real time information in the operation of the LLTV's. Consequently, the method of data reduction for this accident investigation was a practical one aimed at developing the findings of the Board and not aimed at turning out accurate and detailed information not needed by the Board.~~

All TM data was stripped out and analyzed for anomalies and used to reconstruct the flight. Since the TM data is such a detailed and accurate record of the actual flight compared to after-the-fact data acquisition, very little effort was made to reconstruct the accident from either the wreckage or witness statements other than to grossly corroborate the TM data. The color movie proved helpful to the investigators in giving them a three-dimensional, real time concept of the dynamics of the flight and therefore a better understanding of the significance of some of the TM data.

Early in the investigation it became apparent that the vehicle had exceeded its aerodynamic/attitude-control capabilities. Since the aerodynamic operating envelope of the vehicle had never been accurately determined, it was decided to run a wind tunnel test on the LLTV vehicle in the Langley low-speed, full-scale wind tunnel. The LLTV did not have an accurate and reliable system for measuring the aerodynamic parameters for such an analysis, nor were data reduction and analysis resources available as mentioned above.

The accuracy and completeness of the analysis decreases after approximately 07:29:21 because several channels of data became unreliable. Large attitude~~s~~ excursions were experienced after this time, which complicated data reduction. The crash was certainly inevitable by 07:29:21. Rough, spot calculations were made to close out all parameters at 07:29:27 (impact time) in order to validate some assumptions made about certain parameters during this period.

1-F(a)

SYSTEM DESCRIPTION

DESCRIPTION OF THAT PART OF THE LUNAR LANDING TRAINING VEHICLE SYSTEMS PERTINENT TO THE ACCIDENT

General

Operation of the Lunar Landing Training Vehicle (LLTV) (Fig. 1-F(a)-1) during a research or training flight is a highly coordinated effort. This effort involves the pilot in the flight vehicle and a group of operations engineers in a ground control van (Fig 1-F(a)-15). A description of the vehicle system must therefore include both the vehicle and control van operation. A typical LLTV flight trajectory is shown on Figure 1-F(a)-25. Significant events of such a flight are lift-off in the gimbal locked or VTOL mode, followed by a translation upwind to a hovering position at an altitude of approximately 600 feet and a downrange distance of about 2,500 feet. This event is followed by a 180° hovering turn, pilot actuation of the lunar simulation mode, and pitching nosedown to generate horizontal and vertical velocities simulating a lunar approach trajectory prior to entering the lunar simulation. The pilot then commands a pitchup attitude to provide a braking thrust vector from the lift rockets and continues the descent to arrive over the touchdown point in a hover, and makes the touchdown in the lunar simulation mode. Typical flight times for this operation are approximately 2 to 3 minutes of VTOL mode operation prior to entering lunar simulation mode, and 40 to 60 seconds in lunar simulation mode operation to complete a landing.

This description is presented in four sections as follows:

1-F(a)-1	Vehicle	1-F(a)-3	Personnel
1-F(a)-2	Van	1-F(a)-4	Mission Rules

Figure 1-F(a)-1.- LLTV In Flight

Section 1-F(a)-1

Vehicle

The LLTV is neither an airplane nor a spacecraft but an aircraft designed to simulate a spacecraft while it (the LLTV) is operating in the earth's atmosphere and subject to the earth's gravitational field. The LLTV is designed to be operated at altitudes of 0 to 1,000 feet and counteract gravity with the turbofan engine only, or with both the turbofan engine and the two 500 pound thrust lift rockets. The vehicle is limited in flight duration to approximately 8 minutes of turbofan engine time and 80 seconds of lift rocket time, has numerous maintenance and design problems, and has severe operational limits. The vehicle operation is limited by the turbofan engine, lift and attitude control rocket system, and flight dynamics and aerodynamics of the vehicle.

2

The lift and attitude control rocket systems have operational limits on helium (He) source pressure, hydrogen peroxide (H_2O_2) tank pressure, and lift rocket chamber pressure. These engine limitations are indicated by caution or warning lights on the pilot's instrument panel.

Depending on the mode of control (VTOL or Lunar Simulation), the vehicle is limited to various combinations of pitch and roll attitudes and rates. It is also limited by aerodynamic and descending velocities.

Wind limitations are established, depending on the degree of training of the pilot, that vary from less than 5 mph for the first checkout flight flight to 15 mph for a fully qualified pilot in a training flight (See Section 1-F(a)-4). These wind restrictions are based on previous experience with control problems in high winds due to aerodynamic forces.

In the lunar simulation mode, the LLTV has a drag compensation system that automatically controls the thrust vector direction of the turbofan engine to cancel aerodynamic drag. The vehicle is affected by gusts in both VTOL and Lunar Simulation modes. These wind gust disturbances must be compensated for by the attitude control system. The presence of these two factors resulted in the establishment of the low wind limits in early flight training operation and maximum permissible winds of 15 m.p.h. after pilots are fully trained. The wind is usually measured on the surface by an anemometer on the van (Figure 1-F(a)-15).

The vehicle is powered by a centrally located turbo fan engine and two lift rockets and is flown by a single pilot. The vehicle is of aluminum alloy tubing and sheet metal construction and includes a cockpit cab (Figs. 1-F(a)-2 through 1-F(a)-7), center body, aft equipment platform, and four leg assemblies. There are no fixed surfaces on the vehicle that were designed solely to create aerodynamic forces. However, the cockpit cab is a large aerodynamic surface located well forward of and above the center of gravity. The cockpit cab has an opening on the front and left side. Aerodynamically, this opening is much like an anemometer cup with the opening pointing approximately 30 degrees to the left (Fig. 1-F(a)-2). To better simulate the LM pilot's visual capability, the opening was designed to be partially covered by a door and window (Fig. 1-F(a)-4). The vehicle had not been flown with the door on at the time of this accident. A rocket type ejection seat, instrument displays, oxygen system, and pilot controls are provided for use by the pilot.

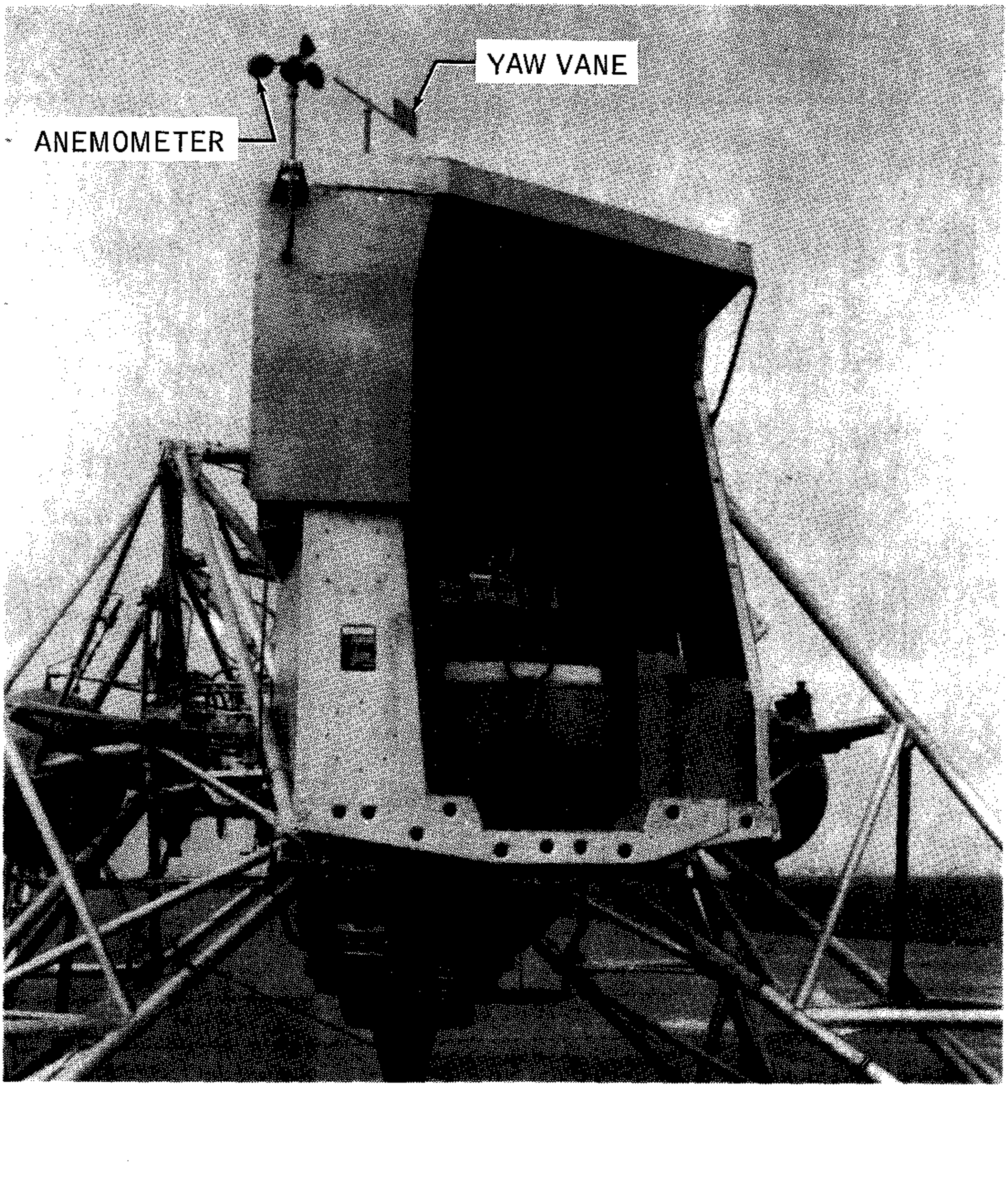


Figure 1-F(a)-2.- Closeup of Cab (Door Off) Front View

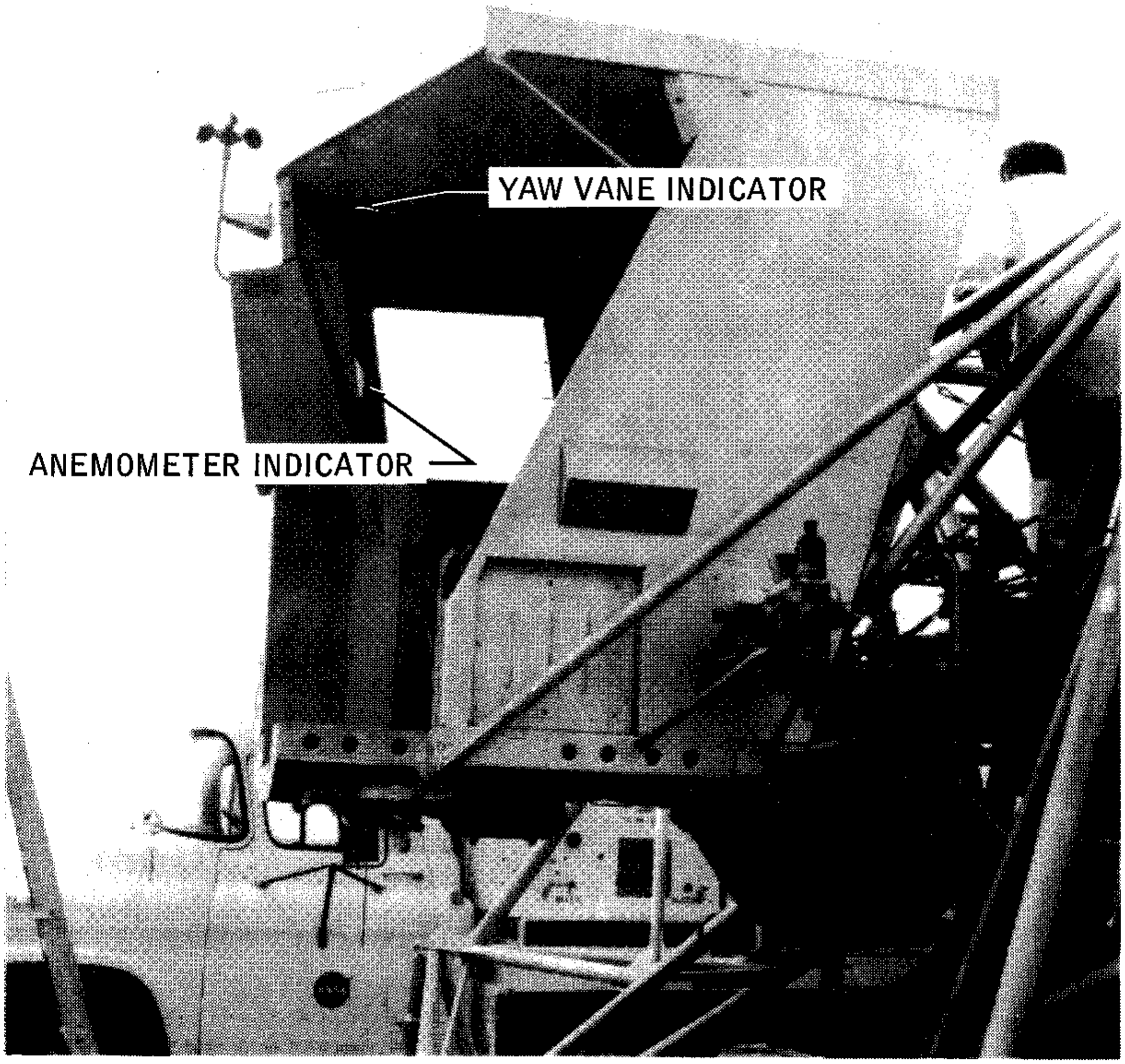


Figure 1-F(a)-3.- Closeup of Cab (Door Off) Side View

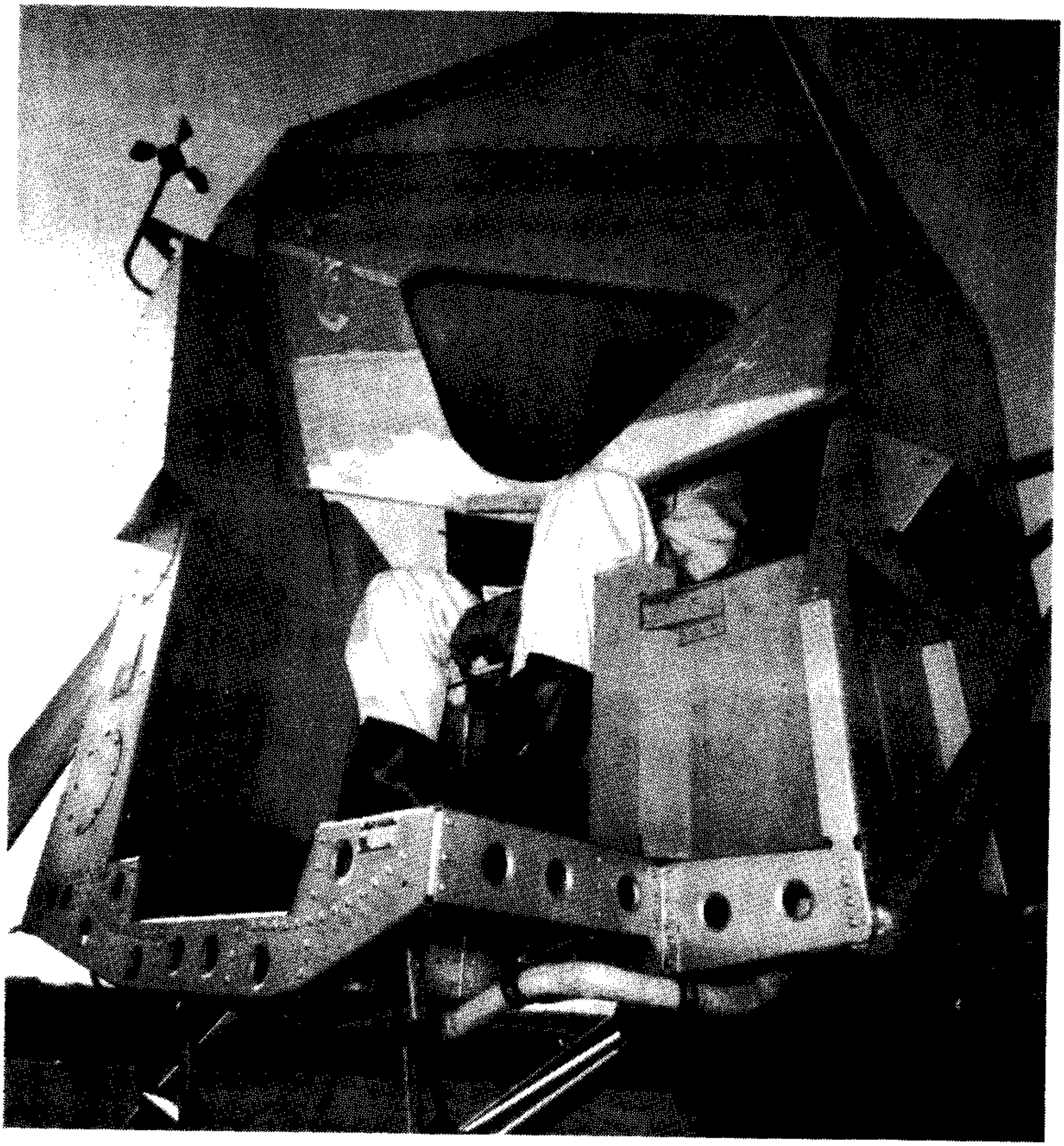


Figure 1-F(a)-4.- Closeup of Cab (Door On) Front View

(Simulated LM Window)

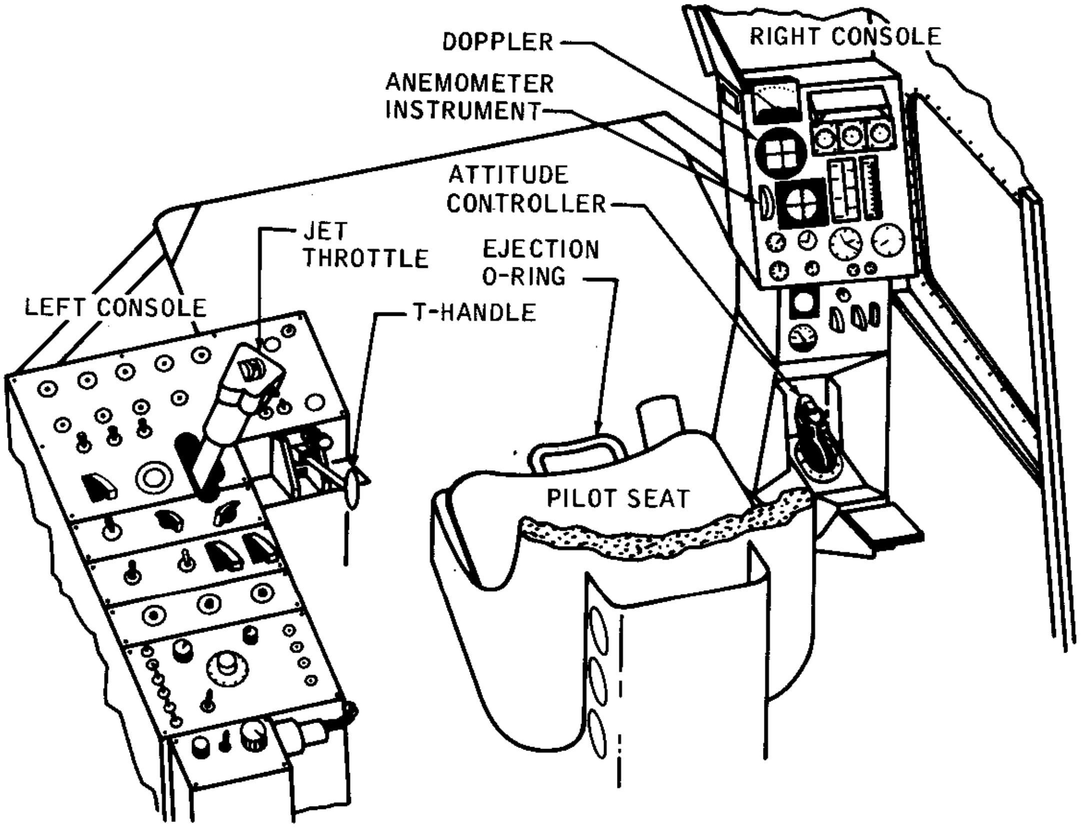


Figure 1-F(a)-5.- Sketch of Pilot Cockpit Looking Forward, Showing Flight Controls and Data Display

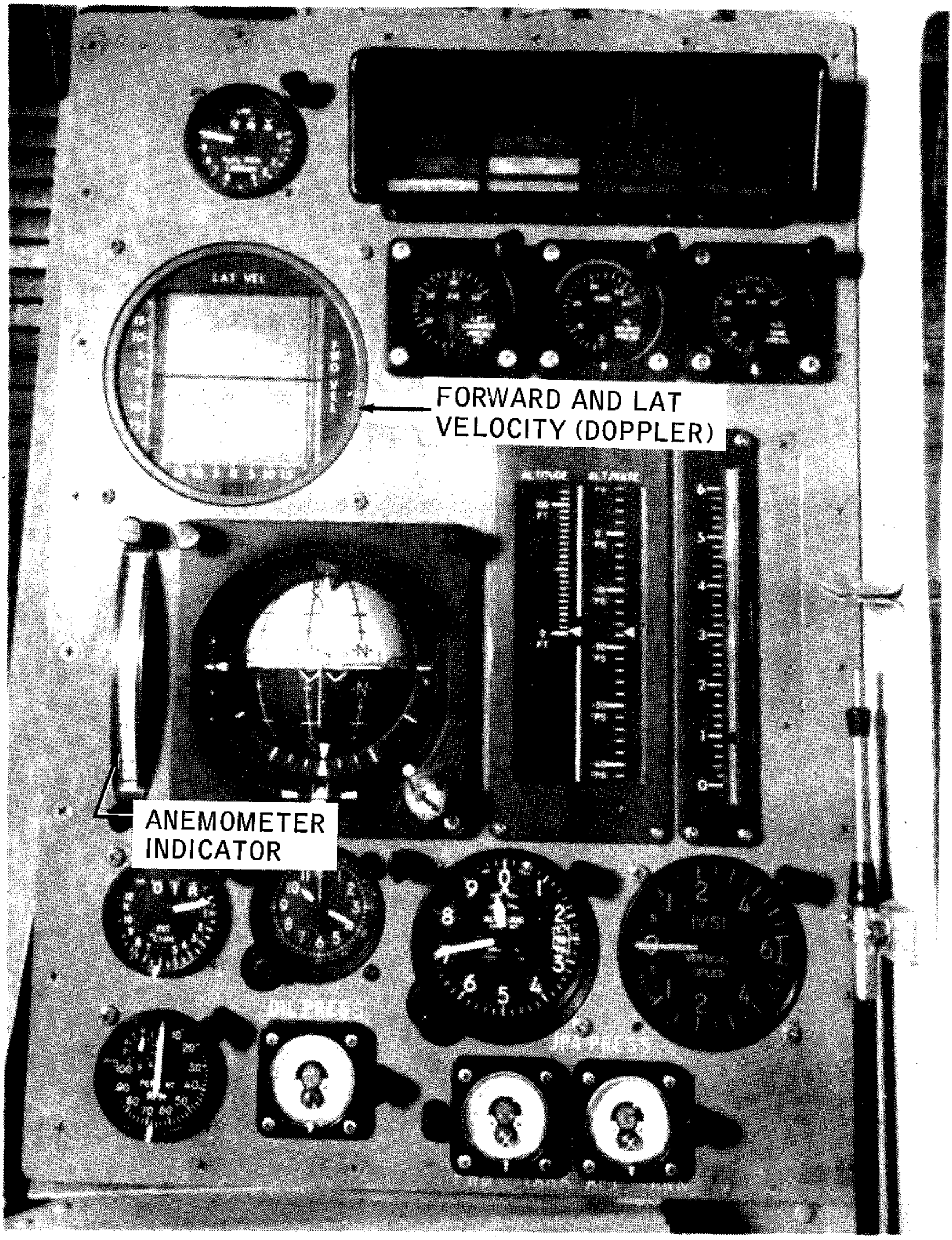


Figure 1-F(a)-6.- LLTV Instrument Panel

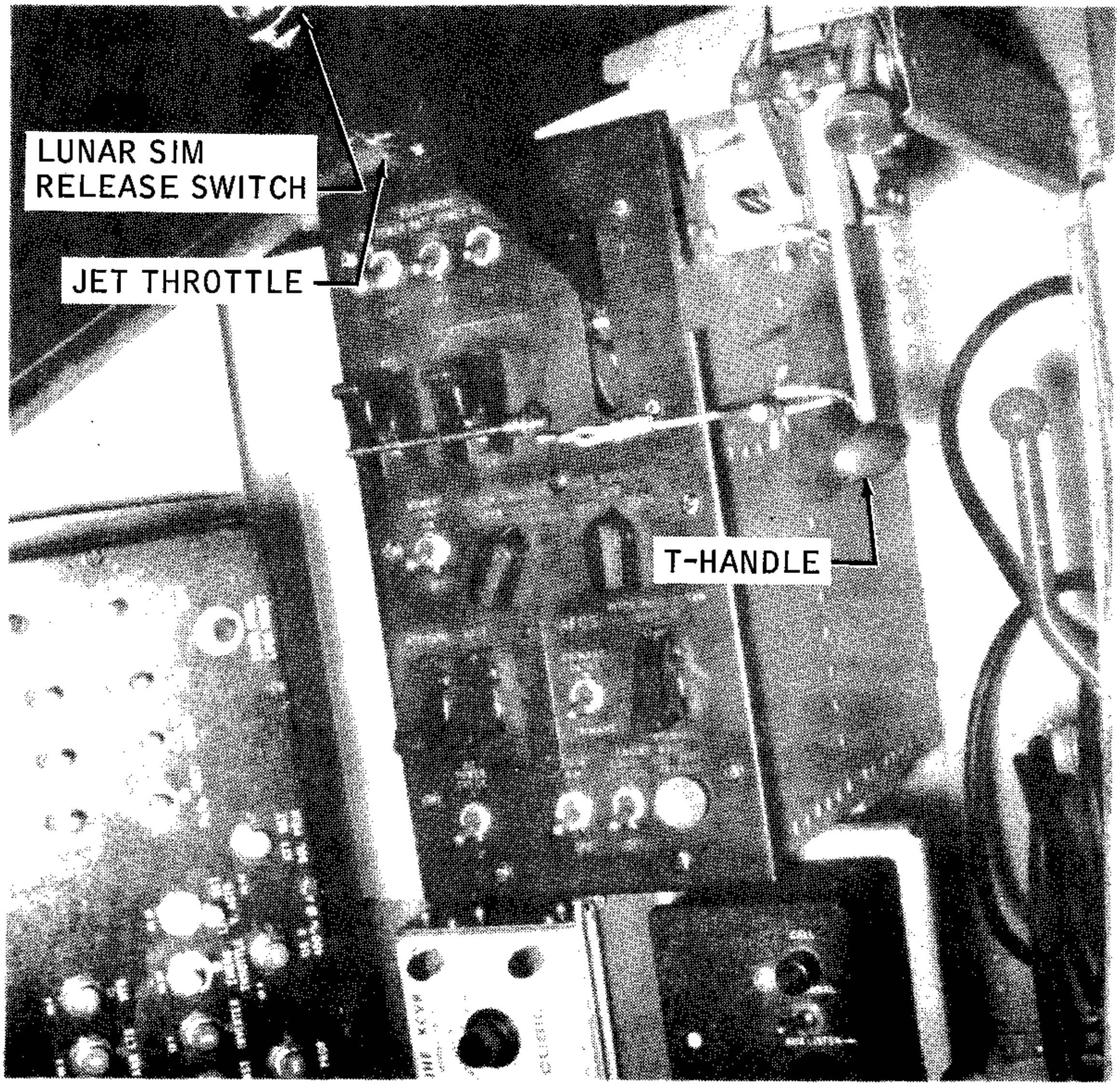


Figure 1-F(a)-7.- LLTV Left Console

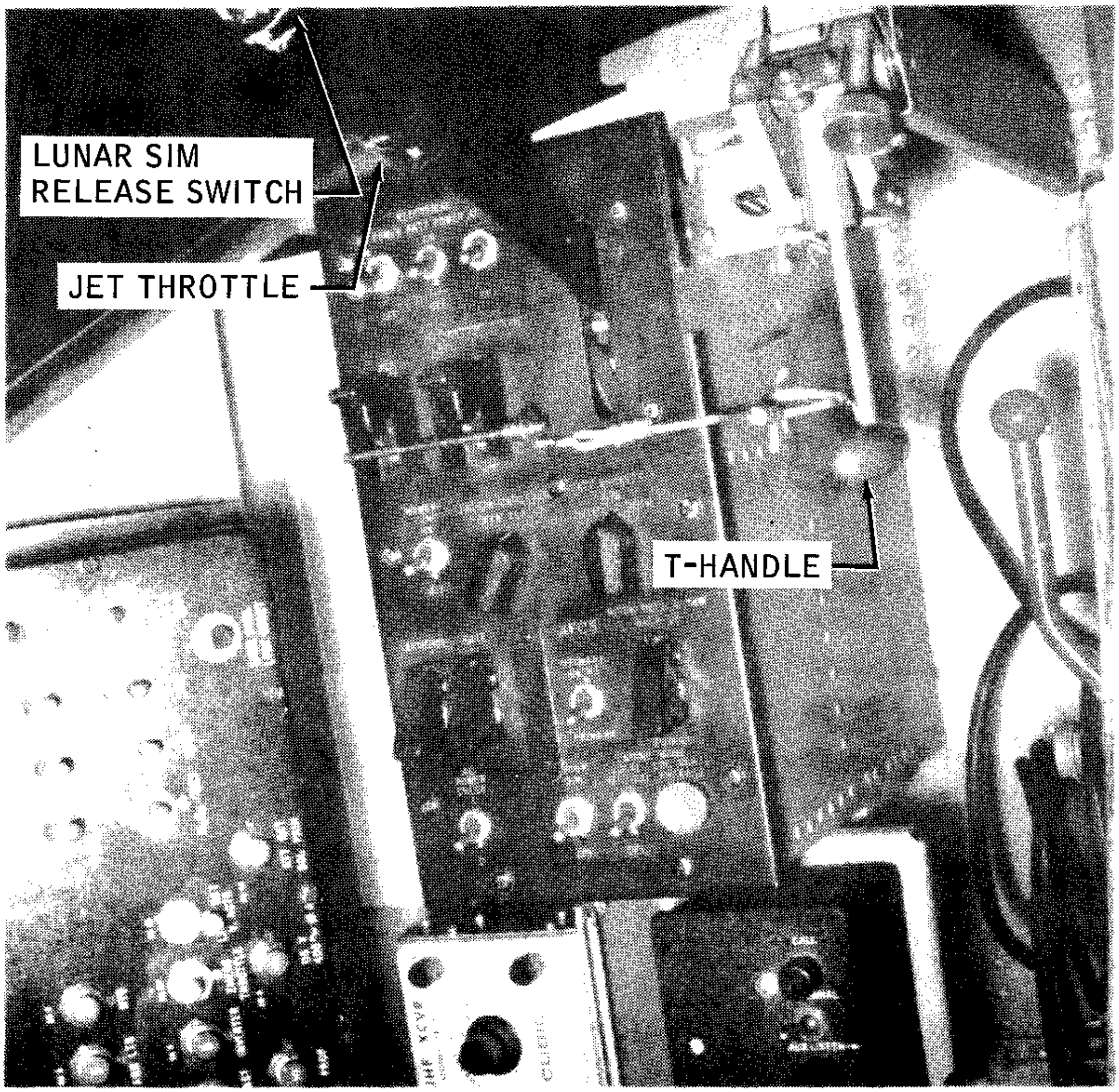


Figure 1-F(a)-7.- LLTV Left Console

The lift rockets, a gimbal mounted turbofan engine, and the turbofan attitude control system are mounted on the center body. Four clusters of four attitude control thrusters each provide vehicle control in pitch, yaw, and roll (Fig. 1-F(a)-8). These sixteen rockets are arranged in two independent attitude control systems (Fig. 1-F(a)-11) and provide an emergency backup system for this critical function. Approximately 680 pounds of hydrogen peroxide propellant for both the lift rockets and the attitude control system is contained in two spherical tanks located on each side of the vehicle. Two spherical tanks located fore and aft of the turbofan engine contain JP-4 fuel for this engine. The nominal takeoff gross weight of the vehicle is 3,870 pounds.

The LLTV may be operated in either of two principal modes, VTOL or lunar simulation. The VTOL mode is when the turbofan engine is held fixed relative to the vehicle frame and provides full support for the vehicle. The lunar simulation mode is when the turbofan engine thrust is automatically controlled to support 5/6 of the vehicle weight, the gimbal angle of the turbofan engine is automatically controlled to provide a thrust vector correction for the aerodynamic forces that the vehicle experiences, and two fixed lift rockets provide variable thrust for the remaining 1/6 of the weight of the vehicle and provide a thrust component for translation when the vehicle is tilted by using the attitude control system.

On the right console is the pilot's instrument panel. The caution and warning annunciator lights and yaw vane and anemometer meters are located near the top of this console. The yaw vane is outside the

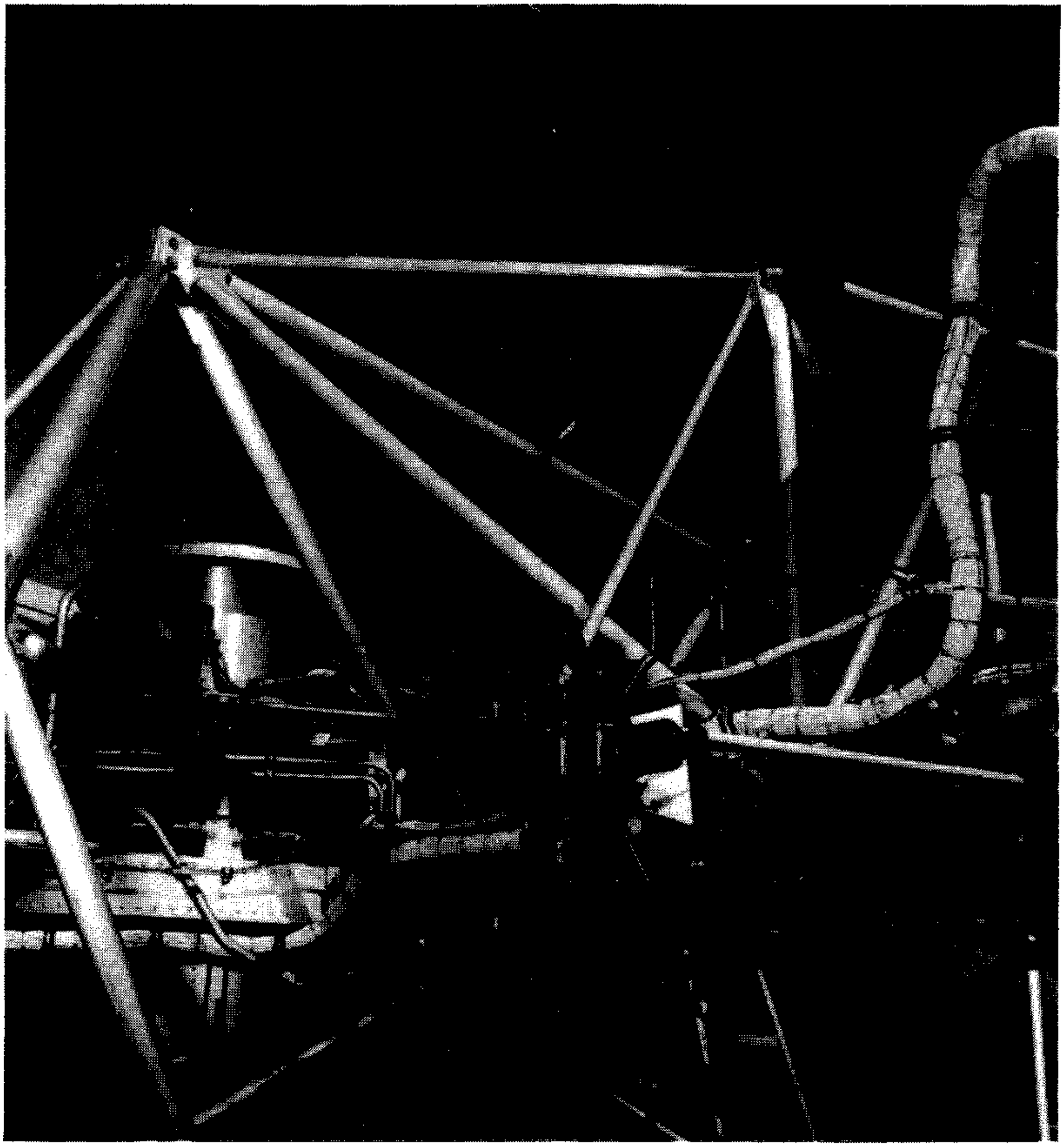


Figure 1-F(a)-8.- Attitude Thrusters Cluster

pilot's primary viewing area. Below the right console is a three axis attitude controller that is similar to the one to be used on the lunar module. On the left console are the turbofan and lift rocket (engine) throttles. The turbofan engine throttle, on which is mounted the Lunar Simulation Release Switch, is controlled either manually by the pilot in the VTOL mode or automatically in the lunar simulation mode. Lift rocket thrust is controlled by a T-handle, which is similar to that used on the LM. The attitude control rocket system selector switch is just below the jet throttle.

> The following information was extracted from the LLTV Flight Manual, Section II, Systems Description, dated December 5, 1968. Those portions of this section that are germane to this accident have been indicated by a solid line down the right-hand margin. A double line is used and some key words have been underlined by the Board to further emphasize pertinent points.

SECTION II

SYSTEMS DESCRIPTION

2-1 GENERAL

This section contains an operational description of the turbofan jet engine, gimbal hydraulic, rocket propulsion, electrical, and electronic systems.

2-2 Jet Engine System

The system includes a turbojet engine, fuel system, gimbal hydraulic system, and a power control system. There are two basic modes of operation. In the Engine Centered and Gimbal Locked modes the engine aligned with the vehicle vertical (Z) axis provides thrust to support the complete vehicle weight. The vehicle is maneuvered by tilting the vehicle frame and vectoring the jet engine thrust appropriately. In the Local Vertical and Lunar Simulation modes the jet engine thrust vector is controlled by the electronic and gimbal hydraulic systems and the vehicle is maneuvered by use of lift rockets. In the Local Vertical mode the engine thrust vector is maintained vertical relative to the Earth. In the Lunar Simulation mode the jet engine thrust is automatically controlled to support five-sixths of the vehicle's weight and in addition the thrust is vectored appropriately to counteract aerodynamic drag forces.

2-2-1 Jet Engine.- The jet engine is a General Electric CF 700-1CV aft fan turbojet engine with a sea level static thrust of 4200 pounds.

2-2-1-1 Engine Installation.- The engine is provided with bellmouth type inlet fairings for the gas generator and aft fan inlets. The engine is mounted in a vertical position on gimballing mounts, which permit approximately ±40° pitch and approximately ±25° roll movement relative to the X and Y axes of the vehicle respectively.

2-2-1-2 Engine Instrumentation.- Instruments for cockpit monitoring of engine performance are: oil pressure gauge, low oil pressure warning light, exhaust gas temperature gauge, and gas generator rpm gauge. These parameters are also telemetered for ground station monitoring. The jet throttle position, compressor discharge pressure, and jet engine fan RPM are only telemetered for ground station monitoring. Normal flight operating oil pressure is about 40 psig. The oil pressure low warning light illuminates when the oil pressure falls below 15 psig. When the engine oil is hot, about 80 percent rpm may be required to attain 16 psig.

CAUTION

> Inadequate turbofan engine lubrication can occur if the vehicle is operated longer than 1 minute at ±14 degrees from the local vertical, or for more than 10 seconds at greater angles; these can occur in the Gimbal Lock mode.

2-2-3 Jet Engine Throttle Control System.- A combination hydraulic and electrical manual throttle provides the pilot with a primary and backup control of the jet engine main fuel control, respectively. An automatic electronic throttle control subsystem controls the jet thrust during lunar simulation. The pilot can manually override or disengage the automatic throttle clutch at any time. Override forces are usually high and disengagement is the preferable means of coming out of the autothrottle mode.

2-2-3-1 Hydraulic Throttle Control.- The primary engine fuel control is a manual throttle which operates two identical hydraulic actuators, one at the jet throttle and one at the engine main fuel control. This provides direct control of engine fuel control for all flight modes except when electronic auto throttle is being used for the Lunar Simulation mode. A spring operated temperature compensator absorbs the pressure buildup caused by temperature changes of the throttle system.

Figure 1-F(a)-9 is a schematic of the jet engine gimbal hydraulic system.

2-2-3-3 Automatic Jet Throttle.- The automatic jet throttle is used during the lunar simulation. The pilot arms the automatic throttle with the Lunar Simulation switch (fig. 1-F(a)-7) on the left console. By increasing lift rocket thrust until the chamber pressure is greater than 100 psia, the system then engages the auto throttle and commands the jet thrust to five-sixths of the vehicle weight.

WARNING

If an auto throttle malfunction occurs, the pilot should not select the emergency electric throttle.

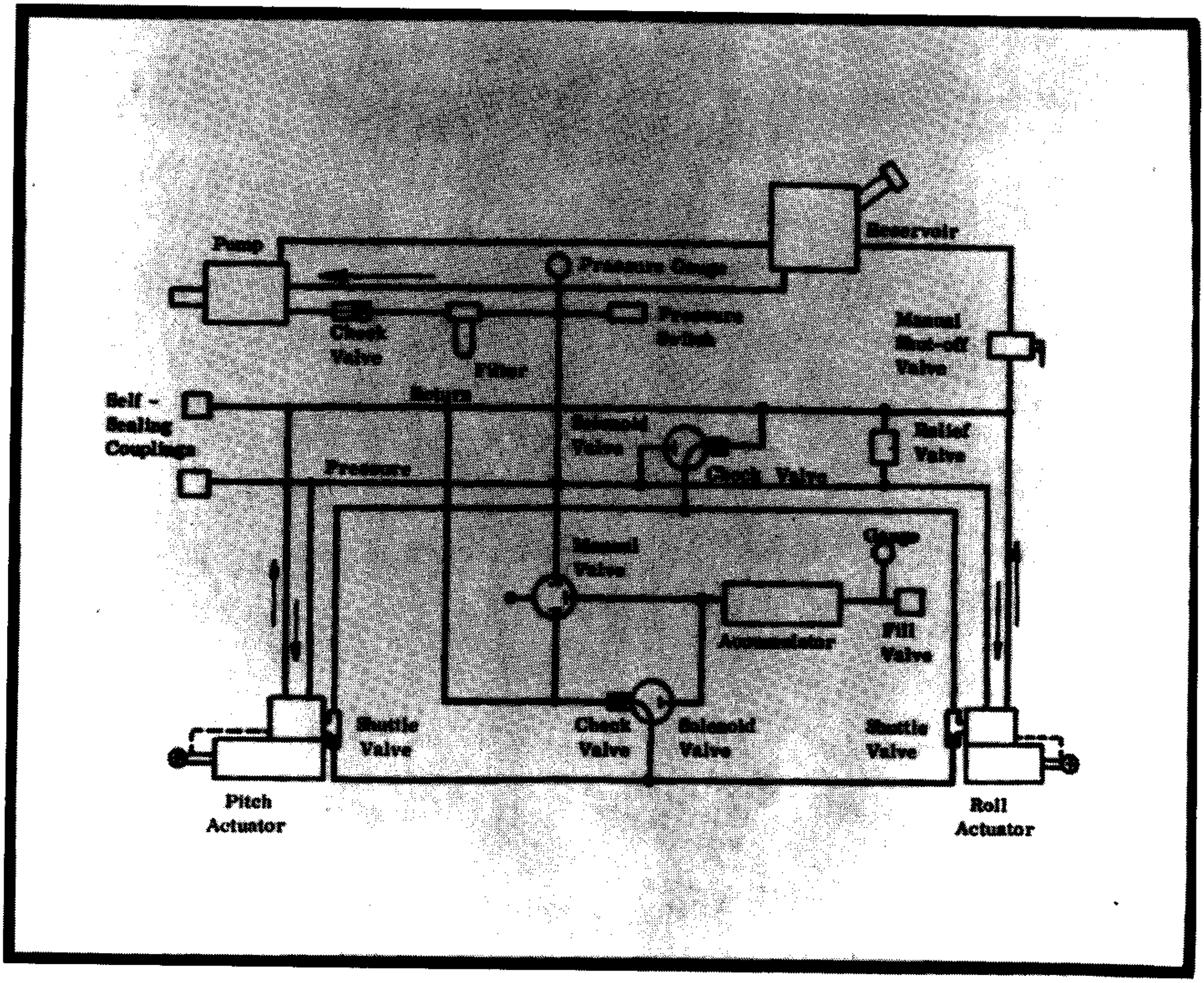


Figure 1-F(a)-9.- Jet Engine Gimbal Hydraulic System Schematic

2-2-3-3-1 Override and Disengage Capability.- The auto throttle system is provided with a clutch which permits the pilot (using a force of about 20 to 30 pounds in the normal operating range) to override the automatic system with the hydraulic throttle control without disengaging the automatic system. A SIM REL pushbutton on the throttle also permits disengagement of the auto throttle at any time to cancel the Lunar Simulation mode, restore the previously selected flight mode and permit hydraulic throttle control. The SIM REL will normally throw the Lunar Simulation switch to OFF. If this does not occur, however, the pilot may try to disengage Lunar Simulation mode by placing Lunar Simulation switch to OFF.

2-2-3-3-3 Throttle Instrumentation.- A potentiometer is installed on the jet throttle for ground monitoring and recording of throttle position.

2-2-4 Yaw Control Installation.- An air jet blowing from a nozzle on the aft equipment platform utilizes jet engine compressor bleed air to counteract jet engine exhaust gas swirl induced yaw moments on the vehicle. The system is sized to reduce yaw moments from about 80 ft-lb to less than 20 ft-lb.

2-2-5 Jet Engine Gimbal Hydraulic System.- The hydraulic system supplies power to two electro-hydraulic servo-actuators for pitch and roll attitude control of the jet engine during the Gimbal Locked, Local Vertical, Engine Centered, and Jet Stabilization modes of operation. Figure 1-F(a)-9 presents a schematic of the gimbal hydraulic system. The gimbal hydraulic system positions the jet engine in response to commands generated by the jet engine attitude control system. Refer to paragraph 2-5-2 for further detail on the modes of operation. The Jet Stabilization (Lunar Simulation mode) and Gimbal Locked modes (during takeoff) are used normally. During normal operation, the primary hydraulic system provides pressure to the servo actuators. In the event of loss of primary hydraulic pressure, a reserve hydraulic pressure source (accumulator) automatically centers the engine in the Emergency Gimbals Locked mode. The gimbal locked position is normally selected manually by the pilot any time by activating the solenoid control valve with the Gimbal Lock switch on the attitude controller grip. Under these normal conditions the hydraulic power is directed through the main solenoid control valve to the actuators which are equipped with an internal valving mechanism for hydraulically centering and locking the jet engine in a vertical axis coincident with the vehicle axis. When normal hydraulic pressure is low the accumulator provides a separate hydraulic pressure source for centering the engine in the Emergency Gimbals Locked mode from any displaced position. When normal hydraulic pressure is less than 1350 ± 50 psi, the Emergency Gimbals Locked light illuminates and the pressure switch activates the solenoid valve, causing stored accumulator pressure to automatically center the gimbals. This permits automatic emergency operation of the Emergency Gimbals Locked mode in the event of either of the following:

1. Pressure loss in main hydraulic system.
2. Failure of the jet stabilization system to

restore engine angle to within 15° of the local vertical within 0.35 to 1.0 (nominally 0.5) second. (Refer to Electronics Systems, Paragraph 2-5).

When low hydraulic pressure causes the accumulator to lock the gimbals, the accumulator can be recharged only by the ground crew. Primary hydraulic pressure is supplied by an engine-driven, variable displacement-type pump. Check valves at pump outlet and in the accumulator pressure line prevent reverse flow. The relief valve prevents (1) system over-pressurization in event of pump compensation malfunction. Self-sealing couplings facilitate connecting ground hydraulic power and manual shutoff valves allow isolation of the hydraulic system during ground checkout.

2-2-5-1 Gimbal Hydraulic Instrumentation.- Hydraulic and accumulator pressure gages provide preflight ground checkout capability only. Only accumulator pressure is telemetered. A pressure switch set at 1350 ± 50 psi, which senses primary gimbal hydraulic pressure, controls the Emergency Gimbals Locked warning light for cockpit and in-flight ground monitoring. When low hydraulic pressure occurs and the Emer. Gimbals Locked light illuminates, the system automatically switches to the Emergency Gimbals Locked mode with pressure supplied by the accumulator.

2-3 Rocket Propulsion System

The three major subsystems are: (1) a propellant pressurization subsystem containing high pressure helium which is regulated down to pressurize propellant tanks, (2) a propellant storage subsystem consisting of two hydrogen peroxide tanks with associated plumbing and valves, and (3) a propellant utilization subsystem consisting of two variable thrust lift rockets and 16 pulse-type fixed (ground adjustable) thrust attitude control rockets. The attitude control system is designed so that firing is generally effected in pure couples about the vehicle's axes. In this way the symmetry of the 4 attitude control rocket clusters on the 4 corners of the vehicle does not cause translational movement of the vehicle.

NOTE

Negligible translation occurs during combined pitch-roll maneuvers when single rockets fire.

Figure 1-F(a)-10 presents a schematic of the rocket propulsion system and identifies the major components. The rocket system design is redundant to the extent necessary to prevent a single anticipated component failure from affecting the safe recovery of the vehicle from any phase of the flight mission. All valves operated by electrical solenoids or actuators have dropout voltages with adequate margins of safety to permit operation under the maximum loaded emergency bus voltage condition of 25 VDC. When electrical actuators are mounted to the valve body, redundant seals are used with overboard drains between the redundant seals. Propellant fill, drain, and vent valves are capped during flight with orificed caps.

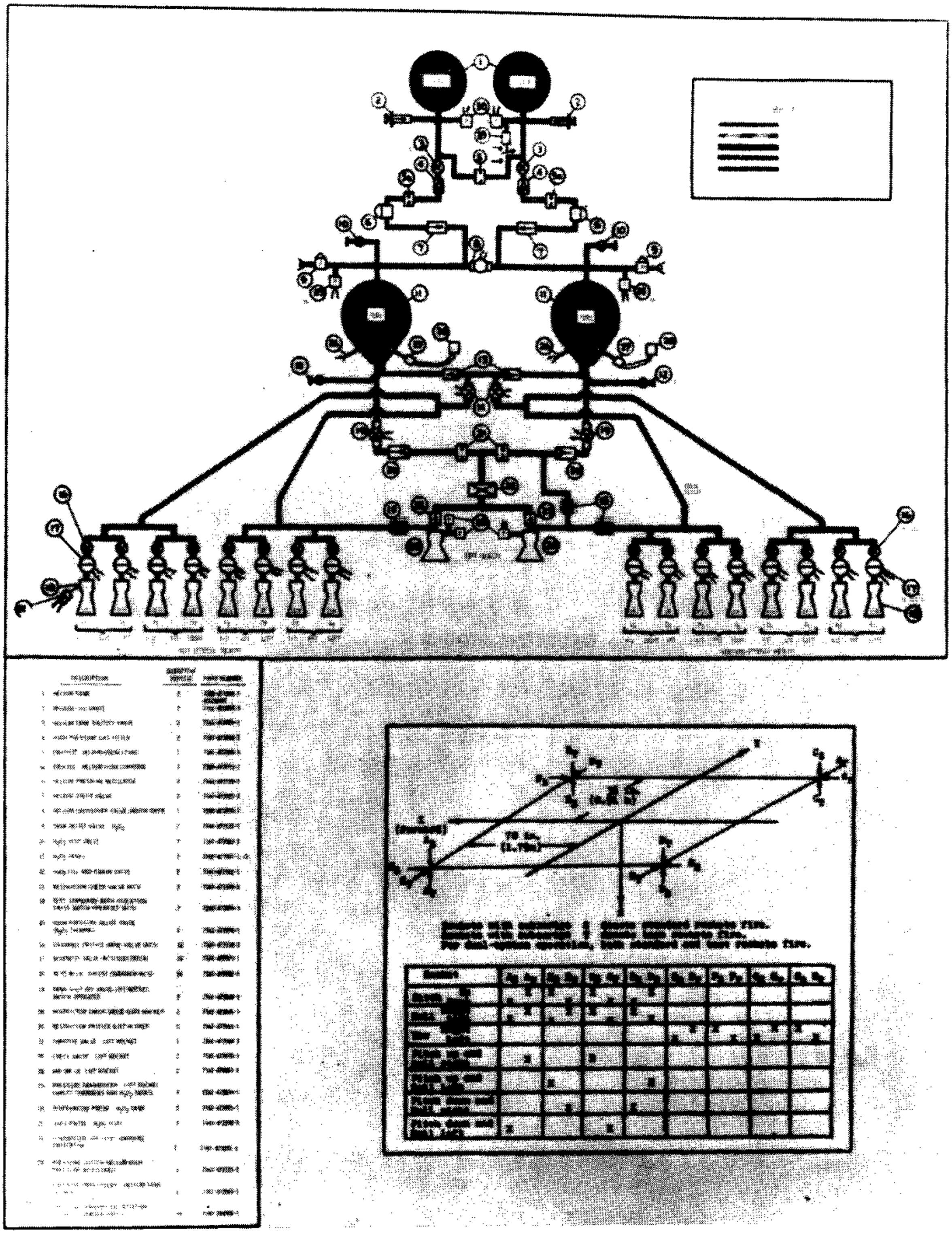


Figure 1-F(a)-10.- Rocket Propulsion System Schematic

2-3-3 Propellant Utilization Subsystem

2-3-3-1 Attitude Control Rockets.- Two sets of eight attitude control rockets (18, fig. 1-F(a)-10) with separate fuel lines provide redundancy. Two motor-operated isolation valves (14) permit the pilot to select the standard, test, or both sets of attitude rockets for flight operation or to isolate one set of attitude rockets in the event of failure of either system and effect a safe landing. The valves are controlled through the Attitude Rockets Test-Standard-Both switch in cockpit (fig. 1-F(a)-7). Each rocket chamber has an associated solenoid valve (17, fig. 1-F(a)-10) to control the flow of propellant and a variable orifice hand valve (16) to provide ground adjustment of the rocket thrust between 30 and 90 pounds; normal setting is 60 pounds. A guarded attitude control system switch marked ACS-SAFE (fig. 1-F(a)-7) inhibits or arms the attitude control rocket system.

2-3-3-2 Lift Rockets.- Two lift rockets provide a variable lift thrust nominally equal to one-sixth of the vehicle weight when the remaining five-sixths of the weight is supported by the jet engine system (simulated lunar gravity). Two motor-operated tank isolation valves (19, fig. 1-F(a)-10) controlled by the Rocket Propellant switch in cockpit, provide isolation capability of the lift system should a leak occur, and shutdown redundancy in event the lift rockets (24, fig. 1-F(a)-10) fail to shut down on command by the normal control lever (T-handle, fig. 1-F(a)-7). The throttle valve (22, fig. 1-F(a)-10) varies propellant flow such that the lift thrust is proportional to throttle valve crank angle position. This valve is electrically controlled from the cockpit through the T-handle. A friction control knob at the base of the lift rocket T-handle may be rotated clockwise to increase friction on the T-handle shaft so that the lever will remain in any position. The check valves (23) retain propellant in lines to minimize thrust response time and are matched to minimize thrust imbalance. High pressure relief valves (15) prevent pressure buildup in propellant lines due to thermal expansion and decomposition of residual hydrogen peroxide in fuel lines.

2-3-3-3 Rocket Instrumentation.- Pressure transducers monitor all 16 attitude control rocket chamber pressures for: (1) the stuck valve malfunction detection circuit (activates stuck valve warning light in cockpit and is monitored in telemetry van) and (2) for in-flight ground monitoring. Two pressure transducers monitor both lift rocket chamber pressures for cockpit display and ground monitoring. A third transducer supplies signals for the T/W avionic computer, the H_2O_2 – remaining computer, and for activating the automatic jet throttle for lunar simulation.

2-5 Electronic Systems

The major electronic systems are the Vehicle Attitude Control System, the Jet Engine Attitude Control System, and the Lunar Simulation System which includes the jet engine stabilization control, thrust/weight computer, and automatic jet throttle control.

2-5-1 Vehicle Attitude Control System (ACS).- The vehicle attitude control system provides the intelligence to fire 16 attitude control rockets to produce control moments in response to pilot commands and/or vehicle motions. The ACS system consists of a primary control system, backup control system, and monitor systems for detection of failures and for automatically switching the control system to a safe mode of operation. Table 1-F(a)-I lists the basic attitude control system characteristics.

2-5-1-1 Operation (General).- The vehicle attitude control is normally performed with the primary electronics. When operating in this mode with the AFCS Primary/Backup switch on left console to PRIMARY (fig. 1-F(a)-7), two primary modes are available – Primary-Rate command with attitude hold and Primary-Direct command. The two modes of operation (rate/direct) may be manually selected independently in pitch, roll and yaw by three attitude control mode (rate-direct) switches, located above the 3-axis hand controller. These two primary control modes may be used with or without the moment compensation-model (refer to Paragraph 2-5-1-2-3). The pilot has the option of engaging or disengaging moment compensation in all three axes simultaneously, with an on/off Moment Compensation switch (fig. 1-F(a)-7) in the cockpit. No single axis selection is provided. The normal flight mode is Primary Rate command. Two emergency modes are provided for this mode. These are (1) Rate Backup, which uses a completely separate electronic channel, and (2) Primary Direct-no model (as an emergency mode), which uses the Primary channel electronics. A monitor comparator compares the primary

TABLE 1-F(a)-I.- ATTITUDE CONTROL SYSTEM CHARACTERISTICS

Mode	Max. Angular Rate Command	Angular Rate Threshold	Drift in Attitude Hold	Attitude Threshold	Angular Acceleration
1. Primary-Rate command with Attitude Hold and Model* *Model is portion of moment compensation system.	Adjustable from ±10°/sec to ±20°/sec. Each axis is independent. Exclusive of Hand Controller.	Adjustable from 0.2 to 2°/sec. Each axis independent. Exclusive of Rate Gyro.	Average drift shall be 0.5°/minute for Pitch and roll 1.25°/min. yaw These values are maximum. Includes Gyros See Note 4.	Adjustable from 0.3 to 1.5°. Each axis independent Exclusive of Attitude Gyros.	Average acceleration adjustable from 4 to 12 ±0.5 deg/sec^2. See Note 1 and 2 for peak acceleration and Note 3 for conditions for 2 Jet and 4 Jet logic.
2. Primary-Rate command with Attitude Hold-no Model	Same as (1)	Same as (1)	Same as (1)	Same as (1)	as per Note 1, 2, and 3
3. Primary-Direct with Model	N/A	N/A	N/A	N/A	Same as (1)
4. Primary-Direct without Model	N/A	N/A	N/A	N/A	Same as (2)
5. Backup-Rate command	Same as (1)	Same as (1)	N/A	N/A	Same as (2)

NOTES:

1\.

Axis	Peak Accel.	(60 lb. thrusters)
Pitch	25.3 to 26.9	°/sec^2 (both sets of thrusters std. and test)
	12.6 to 13.5	(one set of thruster std. or test)
Roll	35.8 to 50.3	(both sets of thrusters std. and test)
	18.0 to 25.2	(one set of thrusters std. or test)
Yaw	15.2 to 22.7	(both sets of thrusters std. and test)
	5.15 to 7.72	(std. set of thrusters)
	10.0 to 15.0	(test set of thrusters)

2\. Peak accelerations shown for both sets of 60 lb. thrusters. For other sized thrusters, T lbs/thruster, peaks given by multiplying listed values for both sets by $\frac{T}{60}$ if both sets are used or by $\frac{T}{120}$ if one set is used.

3\. When model is used in the rate command mode the system simulates 2 Jet logic when the Model rate error is less than 1 ± 0.1°/sec. Average accelerations are then 1/2 those listed above (4 to 12° sec^2 which are for simulated 4 Jet logic). Simulated 4 Jet logic is effective when the model rate error is greater than 1 [illegible] 0.1°/sec. In the Direct Mode only 4 Jet logic is used.

4\. Accuracy to be met under:

a. 70° to 100° F

b. 20° to 70° F

electronic channel to an equivalent monitor electronics channel and will automatically switch the primary-rate system to the Rate Backup mode when disagreement exists between the primary and monitor electronics. In addition, excess rate detection circuitry and hand controller malfunction detection circuitry are used to automatically switch the system to the Rate Backup mode or to the Primary-Direct (no model) mode depending on the type of failure situation. The moment compensation model is not available in the Rate Backup mode or when the Primary-Direct is used as an emergency mode.

2-5-1-2 Primary Attitude Control System.- The primary attitude control subsystem is normally used for the entire mission (including lunar simulation phase). The primary attitude control system includes Primary Rate command with attitude hold, Primary Direct, moment compensation, attitude rocket logic, and stuck valve detection circuits.

2-5-1-2-1 Primary-Rate Command with Attitude Hold.- In this mode, a vehicle angular rate[1] is commanded proportional to stick deflection when the stick deflection exceeds the hand controller deadband of approximately ±1.5 degrees. Attitude hold is engaged whenever the stick is in the detent position and the vehicle rate is less than the rate switching value (adjustable from 1 to 3°/sec, presently set at 3°/sec). When operating in attitude hold, the vehicle attitude is maintained with an average drift less than 1/2°/min in pitch and roll and 8°/min in Yaw.

---

[1] 0 to 22°/sec

Refer to Table 1-F(a)-I. There is no option given the pilot for engaging or disengaging the attitude hold feature in Primary Rate command. When above conditions are met the attitude hold feature is always present in the Primary Rate command.

2-5-1-2-2 Primary Direct Command (On/Off Mode).- When this mode is selected, the attitude rockets fire continuously whenever the hand controller deflection exceeds approximately 2-1/2° in any direction. The vehicle angular accelerations depend upon the number of rockets fired and the rocket thrust levels (ground adjusted). Refer to Table 1-F(a)-I for accelerations available in pitch, roll, and yaw. When the control is returned to the neutral position, the vehicle attitude will continue to change at a fixed rate in the direction originally commanded. To stop the vehicle rate, the control must be deflected in the opposite direction for an equal time duration (assuming no external disturbances).

2-5-1-2-3 Moment Compensation.- With this portion of the system engaged, the electronic model commands an equivalent of $8°/\text{sec}^2$ nominal angular acceleration in each axis in response to pilot commands. The vehicle acceleration capability is independent of rocket thruster settings or the number of rockets firing. Therefore, selection of Both sets of rockets, for example, will have no effect on vehicle acceleration capability. External disturbances on the vehicle can limit vehicle acceleration below the $8°/\text{sec}^2$ value even though the system will continue attempting to achieve this value. The accelerations are ground adjustable. When the system is operating in the Direct mode, the preset angular acceleration is commanded when the three-axis controller stick is deployed in excess of 2-1/2° of the neutral position. After the controller is returned to within 2-1/2°, the control system maintains the velocity developed. It also compensates for all uncommanded angular moments automatically.

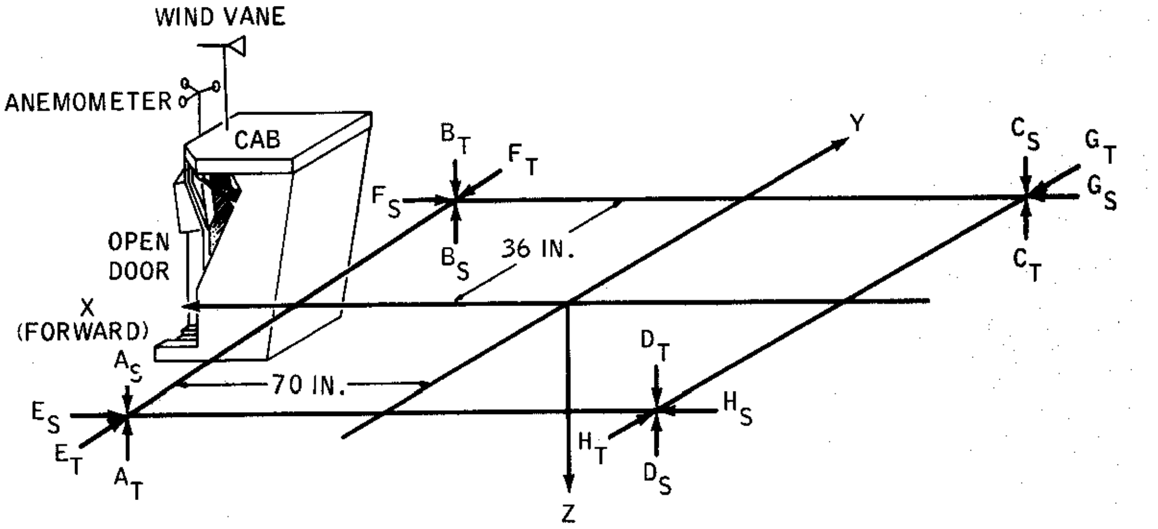
When the system is operating in the Rate command mode, an angular rate is commanded proportional to hand controller rotation. The angular acceleration command to acquire the desired rate is preset into the model.

The pilot does have the option of engaging or disengaging moment compensation. However, manual separate axis selection is not provided; all three axes are engaged or disengaged together.

WARNING

Whenever flying with Moment Compensation ON, the TEST set of Attitude Rockets should be selected.

2-5-1-2-4 Rocket Thruster Logic.- The attitude rocket engines fire in an On/Off manner according to the logic shown in figure 1-F(a)-11. Two sets of 8 control rockets each (Test and Standard) are provided. Normally those designated as Test are used during lunar simulation training operations. The Standard set is used in an emergency through the backup mode when control is automatically switched to Both sets. Either one or both sets may be selected to fire to provide redundancy (refer to paragraph 2-3-3-1, Attitude Control Rockets). For individual pitch, roll, or yaw commands, the system will fire two rockets if the Standard or Test set is selected, or four rockets if both sets are chosen.



ROCKETS WITH SUBSCRIPT S DENOTE STANDARD ROCKETS FIRE.
ROCKETS WITH SUBSCRIPT T DENOTE TEST ROCKETS FIRE.
FOR DUAL - SYSTEM OPERATION, BOTH STANDARD AND TEST ROCKETS FIRE.

										PITCH AND ROLL							
ROCKET		A_S	B_S	C_S	D_S	E_S	F_S	G_S	H_S	A_T	B_T	C_T	D_T	E_T	F_T	G_T	H_T
PITCH	UP		X	X						X			X				
	DOWN	X			X						X	X					
ROLL	RIGHT			X	X					X	X						
	LEFT	X	X									X	X				
YAW	RIGHT						X		X					X		X	
	LEFT					X		X							X		X
PITCH UP AND ROLL RIGHT				X						X							
PITCH UP AND ROLL LEFT			X										X				
PITCH DOWN AND ROLL RIGHT					X						X						
PITCH DOWN AND ROLL LEFT		X										X					

YAW ONLY

TEST SYSTEM USED
ON FLIGHT NO. 15

Figure 1-F(a)-11.- Attitude Control System Rocket Firing Logic

For combined pitch and roll commands, however, only one rocket will fire if the Standard or Test set is selected, or two rockets if both sets are chosen. This selection is automatically controlled by the opposing rocket inhibit logic, which prevents opposing rockets from firing at the same time.

The system is also designed so a large command in one axis does not result in loss of control in another axis.

For example, if, with Test rockets selected a small roll right command is added to a large pitch up command, only rocket A_T shall fire when the roll threshold is exceeded. A_T will continue to fire until the small roll error is reduced to within the roll threshold. D_T will then fire along with A_T until the pitch error is within the pitch threshold. Similar situations exist for other combined commands (see fig. 1-F(a)-11).

2-5-1-2-4-1 Valve Stuck Warning.- Pressure transducers, which monitor attitude rocket chamber pressures, serve as sensors for the stuck valve circuit. The circuit, in turn, monitors the rockets in a particular combination of two, to determine if opposing rockets are firing that represent an illegitimate ACS command (see fig. 1-F(a)-13). In the event of a stuck valve indication, the logic will hold for a period of approximately 300 milliseconds before illuminating the Valve Stuck red warning light in the cockpit. This allows response time of the rocket firing coils, or rocket thrust decay caused by a previous ACS command from falsely indicating a stuck valve.

When operating with one set of rockets, control would be automatically switched to both sets. No monitoring is provided for a stuck-closed valve condition. Normally the pilot will select only one set of rockets for flight to maintain capability to counteract unexpected occurrences such as propellant unbalance or aerodynamic moments.

2-5-1-3 Rate Backup Attitude Control System.- The electronic system provides a rate backup control system. In this mode, vehicle angular rates are commanded proportional to stick deflection. The backup system is a completely separate channel including separate wiring, independent power supplies, and rate gyros. The system employs the same rockets used by the primary system. The backup system is normally only used in the event of a malfunction in the primary system. If necessary, the pilot may select the Backup mode for a short period of time, however, to insure the Backup mode is operating properly. This is accomplished by placing the AFCS Pitch, Roll and Yaw switch to BACKUP (Guard Up).

WARNING

> If the Rate Backup mode is manually selected in flight for test purposes, the pilot should be prepared to manually switch the AFCS Pitch, Roll and Yaw switch to PRIMARY.

This is required because if an excess rate is detected while in Backup, the Gyro Failure warning indicator will illuminate but no automatic switching to Primary will occur. An Auto Pilot Back Up red warning light illuminates when the ACS is either automatically or manually switched to Rate Backup.

2-5-1-4 Monitor Subsystem.- Monitor comparator, excess rate, and hand controller malfunction detection circuits are used to monitor operation of the Primary-Rate and Primary-Direct attitude control modes.

2-5-1-4-1 Monitor Comparator.- An electronic equivalent of the primary mode electronics (also referred to as the monitor channel electronics) generates equivalent rocket firing signals in the same manner as the primary electronics. When the monitor comparator determines that disagreement exists between the primary and monitor channels in any axis, the monitor automatically switches the electronics to the Rate Backup mode and illuminates the Auto Pilot Back Up red warning indicator. Switching is accomplished within 0.5 sec. Pitch and roll are switched together, and yaw is switched separately. A failure matrix has been generated for the conditions which the monitor comparator has to satisfy. From this failure matrix, the logic equation required to satisfy the failure matrix has been established. The logic equation has been implemented into active circuitry in the monitor comparator.

2-5-1-4-2 Excess Rate Detection Circuitry.- The excess rate detection circuitry provides automatic switching and cockpit displays which function as indicated by the primary or backup rate gyro. These functions, according to operating condition, include the following:

1. With the system operating in the Rate command mode with or without model, if the primary rate gyro indicates a vehicle rate of 22°/sec, the system is automatically switched to Rate Backup and the Auto Pilot Back Up light is illuminated.

2. With the system operating in the Direct mode with model, if the primary rate gyro indicates a vehicle rate of 22°/sec, the system is automatically switched to Rate Backup and the Auto Pilot Back Up light is illuminated.

3. With the system operating in the Direct mode with no model, if the primary rate gyro indicates a vehicle rate of 22°/sec the system automatically remains in the selected mode. No indication to the pilot.

4. With the system operating in the Rate command mode with or without model or in the Direct command mode with or without model, if the backup rate gyro indicated a vehicle rate of 22°/sec, the Gyro Failure red warning light illuminates and the system is inhibited from automatically switching to the Rate Backup mode.

If the primary rate gyro indicates a vehicle rate of 22°/sec or greater, the system will automatically be switched to Rate Backup. If the backup rate gyro then provides the same indication, the system will switch back to the flight selected mode. If the backup rate gyro indicates a vehicle rate of 22°/sec simultaneously or subsequent to the same indication from the primary rate gyro, the automatic switching will be inhibited and the system will remain in the flight selected mode. If the backup rate gyro signal subsequently decreases below 22°/sec, the system will be switched to Rate Backup. The primary rate gyro switching is latching; the backup rate gyro switching is not latching.

2-5-1-4-3 Hand Controller Malfunction Detection Circuitry.- The hand controller operates a synchro (differential transformer) and two direct switches in each axis: (1) logic direct switch and (2) function direct switch. The conditions where hand controller malfunctions may be encountered and the associated effects, switching and indications, are:

1. Open Synchro.- With the system in the Rate command mode with or without the model, if the logic direct switch is actuated and the corresponding synchro output is not present, the system automatically switches to the Primary-Direct mode (no model) in the affected axis as an emergency mode and Auto Pilot Back Up warning light illuminates. The action of the monitor comparator may take precedence over this circuitry, depending upon component tolerances. In the event of this failure, the system would switch to Rate Backup or to Primary-Direct depending upon the tolerances. Switching to either mode in an emergency would illuminate the Auto Pilot Back Up warning indicator and switching would occur within 0.5 sec. Either mode is a safe flight mode.

2. Hard Over Synchro.- With the system in the Rate command mode with or without model, if a synchro output exists which is greater than that equivalent to the logic direct switch position and the logic direct switch has not been actuated, the system automatically switches to the Primary-Direct mode (no model) as an emergency mode and the Auto Pilot Back Up warning indicator illuminates. As in the open synchro case (1) the system would switch within 0.5 sec to the Rate Backup or to Primary-Direct depending upon the component tolerances. Either mode is a safe flight mode and in either case the Auto Pilot Back Up warning indicator would illuminate.

3. Direct Switch Failure.- With the system in a Rate mode, if either direct switch fails, the automatic switching to Primary-Direct mode will be inhibited. The pilot can still manually select the Primary-Direct mode, but if he does, the system will automatically switch to Rate Backup and the Auto Pilot Back Up warning indicator will illuminate.

4. Direct Function or Logic Switch Failure.- With the system in the Direct mode with or without model, if the direct function or logic switch fails, the system automatically switches to Rate Backup and the Auto Pilot Back Up warning indicator illuminates. Switching is accomplished within 0.3 seconds.

WARNING

> The hand controller must be deflected 4-1/2° minimum to enable this circuit to detect this failure.

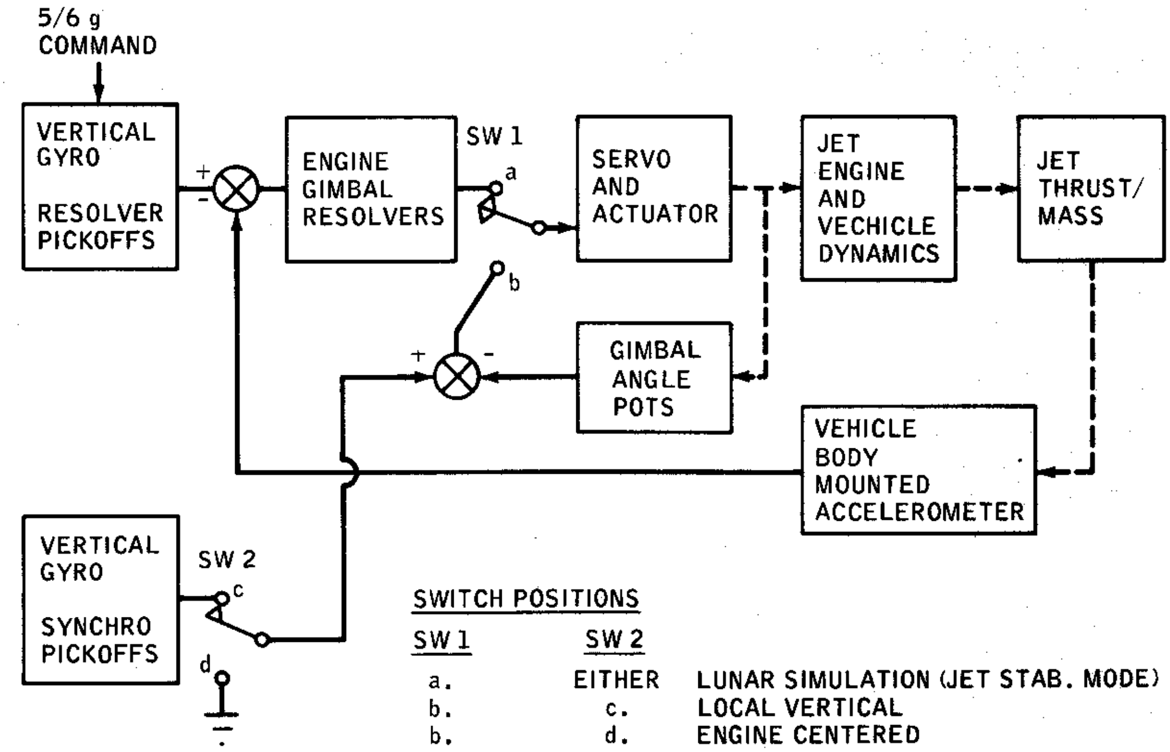
2-5-1-5 AFCS Primary-Primary Reset Switch.- This switch is spring loaded in the PRIMARY position. The function of this switch is to return ACS authority from the Rate Backup channel electronics to the Primary electronics. This is accomplished by momentarily holding the switch at PRIMARY RESET position with the AFCS Primary-Backup switch at PRIMARY. This switch is intended for ground use only. During pretakeoff checks, after operation of the Rate Backup mode has been verified, this control is used to return to the Primary electronics. Moment Compensation switch should be OFF before resetting to Primary.

WARNING

> If automatically switched to Rate Backup in flight, do not attempt to reset to Primary. Attitude control would be lost while the switch is at PRIMARY RESET if the Primary electronics were inoperative.

2-5-1-6 ACS Instrumentation.- A 3-axis ball indicator displays vehicle pitch, roll, and yaw attitudes during flight. An Auto Pilot Back Up red warning indicator illuminates when the vehicle ACS is automatically switched to a mode not selected by the pilot. A Gyro Failure red warning indicator illuminates when the excess rate detector senses a rate in excess of 22 deg/sec from the backup rate gyro. A Valve Stuck warning indicator illuminates if an ACS rocket ~~pressure transducer~~ valve is stuck open.

2-5-2 Jet Engine Attitude Control System.- The jet engine attitude control system performs in five selected modes of operation: Manual or Emergency Gimbal Locked, Local Vertical, Engine Centered, and Lunar Simulation mode (jet stabilization). A simple block diagram of the latter three modes is shown in figure 1-F(a)-12. Table 1-F(a)-II lists all the modes of operation and respective conditions in use. For flight safety, one mode has priority over another. Figure 1-F(a)-13 is a block diagram showing major components of weight/drag, jet stabilization, and auto-throttle electronics.



SWITCH POSITIONS

SW 1	SW 2	
a.	EITHER	LUNAR SIMULATION (JET STAB. MODE)
b.	c.	LOCAL VERTICAL
b.	d.	ENGINE CENTERED

Figure 1-F(a)-12. - Jet engine attitude control system.

Figure 1-F(a)-12.- Jet Engine Attitude Control System

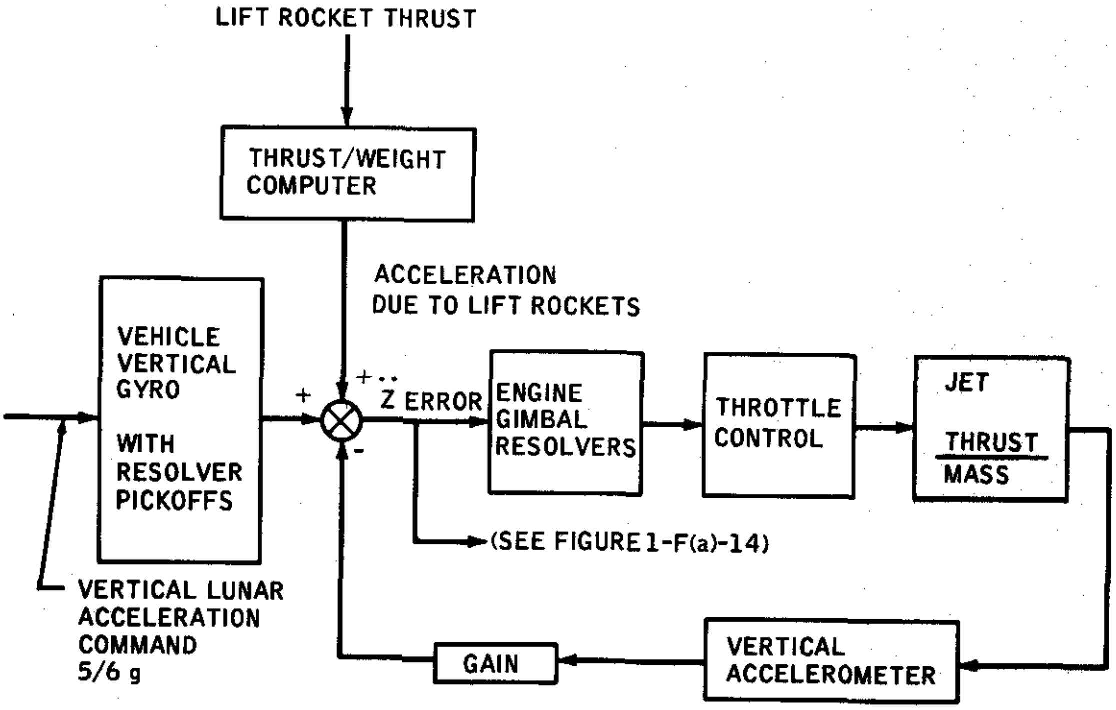


Figure1-F(a)-13. - Automatic jet throttle control system block diagram.

Figure 1-F(a)-13.- Automatic Jet Throttle Control System Block Diagram

2-5-2-1 Mode Priority.- For flight safety, the modes have the following priority. The Gimbal Locked mode, whether pilot or automatically selected, overrides all other modes. When the vehicle is on the ground or when the jet engine deflects more than 15 ± 1° from the vertical (including in the Lunar Simulation mode), the Local Vertical mode shall be automatically actuated and override all modes except the Gimbal Locked mode. If the jet engine deflects more than 15 ± 1° from local vertical and the Local Vertical modes is not automatically selected within 0.35 to 1.0 second, the system shall automatically switch to the Emergency Gimbal Locked mode. If no mode has been selected and the vehicle is airborne, momentarily depressing the Local Vertical Release button shall place the system in the Engine Centered mode.

2-5-2-2 Gimbal Lock Mode.- This mode has two major functions, i.e., normal and emergency and may be selected manually or automatically. In either case, this mode overrides all other modes of the jet engine attitude control system. Manual selection results in the normal Gimbal Lock mode and is effected by placing the hand controller Gimbal Lock switch to ON; this illuminates the green Gimbal Locked mode status light on the annunciator panel. Automatic selection results in the Emergency Gimbals Locked mode in the event of either of the following malfunctioning conditions. If primary gimbal hydraulic pressure decreases below 1350 ± 50 psi, the Emergency Gimbals Locked mode provides a separate valve and a reserve hydraulic pressure source (accumulator) to automatically align the jet engine with the vehicle vertical axis.

Then the emergency mode is also automatically selected by the electronics system whenever the jet engine exceeds an angle of 15 ± 1° from the Local Vertical and the Local Vertical mode does not restore the engine to within the 15 ± 1° in 0.35 to 1.0 seconds. Whenever the emergency mode is selected, the Emer. Gimbals Locked red warning indicator illuminates in the cockpit.

2-5-2-3 Local Vertical Mode.- The local vertical mode aligns jet engine with the local vertical as sensed by the attitude gyros, regardless of vehicle outer frame motion. The signal from the vehicle attitude gyros is compared with the engine gimbal angles obtained from potentiometers on the gimbal actuators. The resulting error signal is used as an input command to the gimbal actuator servo valves. The pilot may select this mode with a switch on the console. This mode is automatically selected when:

1. the vehicle is on the ground and any one of the four microswitches located on each of the four shock struts indicates a compression of more than one-half inch, or
2. The jet engine deviates more than 15 ± 1 degrees from the local vertical while in the Engine Centered or Lunar Simulation mode.

To manually disengage this mode, the pilot must momentarily activate the Local Vertical release switch on console, which places the jet engine attitude control in the Engine Centered mode if no other mode is selected.

2-5-2-4 Engine Centered Mode.- This mode is in operation when no other mode has been selected and the vehicle is airborne. This mode slaves the engine along the vertical vehicle body axis using the potentiometer signals on the gimbal actuators and the gimbal actuator servo valves used in all other modes except Gimbal Locked (see fig. 1-F(a)-12).

2-5-2-5 Lunar Simulation (Jet Stabilization) Mode.- This jet engine attitude control mode performs as a portion of the Lunar Simulation System (refer to Paragraph 2-5-3). During the Lunar Simulation mode, the drag compensation functions in the X and Y axes by positioning the jet engine to cancel aerodynamic drag. In the Z axis, the drag compensation is effected by automatically positioning the jet throttle to cancel aerodynamic drag and to compensate for vehicle changes in weight resulting from fuel burnoff. Refer to Thrust/Weight Computer, Paragraph 2-5-3-1 for more detailed description of the Z axes control.

2-5-2-6 Jet Engine Attitude Control Instrumentation.- Cockpit status lights indicate when Emergency Gimbals Locked (red) manual Gimbal Lock mode (green), Local Vertical mode (amber), and Stabilization mode (green) during Lunar Simulation mode have been automatically or manually selected. An Engine Maximum Tilt warning light illuminates when the jet engine tilt angle exceeds 15 ± 1 degrees in pitch or roll with respect to the local vertical or when the absolute sum (regardless of sign) of pitch and roll angles of the vehicle relative to the engine exceeds 64 degrees.

The annunciator warning signals are telemetered to the ground station along with jet engine pitch and roll attitude for in-flight ground monitoring.

2-5-3 Lunar Simulation System.- The Lunar Simulation System creates a psuedo lunar gravity field in which five-sixths of the vehicle weight is automatically supported by the jet engine and a pseudo lunar vacuum by automatically tilting and controlling the jet engine thrust to cancel aerodynamic drag on the vehicle. The system establishes a reference signal of 5/6 g, which is resolved into vehicle coordinates using a vertical gyro and gimbal resolvers. To this signal, acceleration caused by lift rockets (computed-based on rocket thrust and vehicle weight) are vectorially added. The resulting acceleration information is compared with the measured vehicle accelerations obtained from body-mounted accelerometers. The resultant errors are used as command signals to the automatic throttle and jet engine attitude control (see fig. 1-F(a)-13). The Lunar Simulation system is initiated when:

1. The Lunar Simulation switch is placed at LUNAR SIM. (Stabilization mode light shall illuminate.)
2. lift rocket T-handle is raised and chamber pressure has exceeded 100 psia (pressure transducer measurement). (Auto Throttle light shall illuminate.)
3. Gimbal Lock switch is OFF. (Gimbal Lock Mode light shall extinguish)
4. engine angle is less than 15 ± 1° from the local vertical.

The Lunar Simulation mode is disengaged by:

1. momentarily pressing the SIM REL button on the jet throttle.
2. advancing the jet throttle.
3. placing the Gimbal Lock switch to ON.

2-5-3-1 Thrust/Weight Computer.- The thrust/weight computer is shown on figure 1-F(a)-14. The computer calculates the vehicle acceleration along the body z-axis when the pilot actuates the lift rocket throttle to engage the automatic jet throttle for the Lunar Simulation mode. The value of thrust/weight is continuously updated based on the integration of an assumed jet fuel flow rate, and the integration of the electronic rocket firing signals performed by the rocket fuel consumption detector circuitry (includes lift rocket fuel consumption). The two integrated signals are subtracted from the initial weight potentiometer signal (ground adjustable). This signal is then combined with one lift rocket pressure transducer signal (measure of lift rocket thrust) to obtain an instantaneous value of thrust/weight.

2-5-3-2 Automatic Jet Throttle.- The automatic jet throttle continuously controls jet engine thrust so that the local vertical component of force equals five-sixths of the instanteous vehicle weight plus or minus the vertical drag force. Figure 1-F(a)-13 is a block diagram of the Automatic Jet Throttle Control System. The throttle control loop, which employs a linear acceleration feedback is capable of adjusting the jet engine main fuel control angle at the rate of 6 deg/sec. The same automatic jet throttle serves as the emergency system for the primary hydraulic throttle. When used as the emergency throttle, a synchro feedback is used for jet engine fuel control.

WARNING

If an auto throttle malfunction occurs, the pilot should not select the emergency electric throttle.

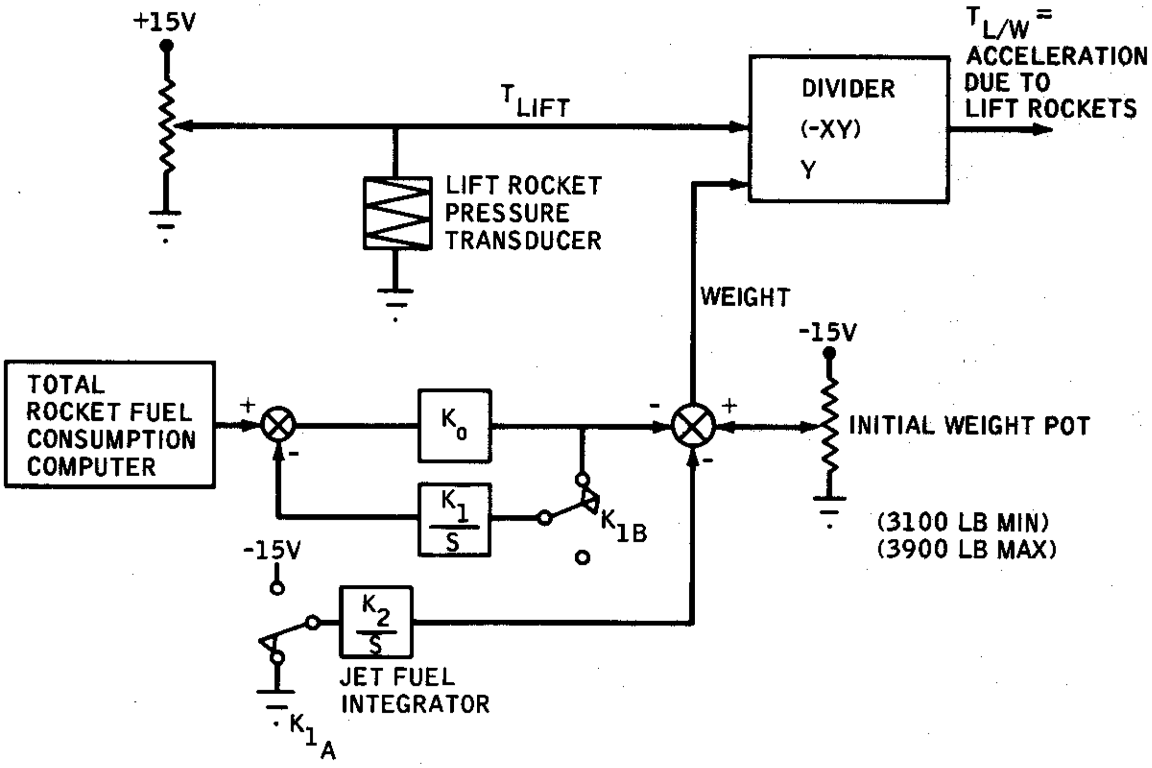


Figure 1-F(a)-14. - Thrust/weight computer.

Figure 1-F(a)-14.- Thrust Weight Computer

TABLE 1-F(a)-II.- JET ENGINE MODES OF OPERATION

Title	Conditions of Use
EMERGENCY GIMBALS LOCKED	1. Avionics will automatically select this mode if the engine angle exceeds 15 degrees from local vertical for greater than 0.5 seconds, nominally. Indication to the pilot is illumination of the Emer. Gimbals Locked red warning light. 2. Low primary hydraulic system pressure (1350 ± 50 psig) sensed by the hydraulic pressure switch will open the emergency solenoid valve allowing accumulator pressure to flow to the gimbal actuators, thus centering the engine. Indication to the pilot is illumination of the red Emer. Gimbals Locked warning light. 3. Primary AC failure will cause avionics to switch to Rate Backup and switch engine attitude control to this mode. Indication to the pilot will be illumination of the AC Failure Auto Pilot Back Up, and Emer. Gimbals Locked indicators 4. Primary DC failure will cause the avionics to switch to Rate Backup and switch engine attitude control to this mode. Pilot indications will be illumination of the DC Failure, Auto Pilot Back Up, and Emer. Gimbals Locked indicators. CAUTION If actuated, this mode should only be released on the ground.

TABLE 1-F(a)-II.- JET ENGINE MODES OF OPERATION - Continued

Title	Conditions of Use
GIMBAL LOCK	This mode overrides all other modes. It may be activated under any of the following conditions: 1. Pilot may select Gimbal Lock mode using the Gimbal Lock switch (fig. 1-F(a)-6) on 3-axis hand controller; this illuminates the Gimbal Lock Mode green status light. This mode is normally used for takeoff. It locks the gimbal actuators hydraulically, aligning the jet engine with the Z axis. To disengage the pilot will place the Gimbal Lock switch to OFF.
LOCAL VERTICAL	This mode is activated when any of the following conditions occur: 1. The pilot turns the LOCAL VERTICAL switch ON and Manual or Emergency Gimbal Lock is not selected. 2. Any of the 4 leg microswitches register greater than 1/2 inch compression and manual or emergency Gimbal Lock not selected. 3. The jet engine angle is greater than 15° from the local vertical while in engine centered or lunar simulation mode. To disengage this mode: 1. If manually selected the pilot must place Local Vertical switch OFF and depress Local Vertical Release button. 2. If automatically selected (conditions 2 or 3 above), the pilot will momentarily depress the Local Vertical Release button.

TABLE 1-F(a)-II.- JET ENGINE MODES OF OPERATION - Continued

Title	Conditions of Use
LUNAR SIMULATION (Jet Stabilization)	Characteristics of this mode are: a. Jet engine auto throttle supports 5/6th vehicle weight. b. Jet engine automatically gimballed to provide equal and opposite force to counteract horizontal vehicle drag. c. Lift rockets are used to control altitude and horizontal translations. Active when all of the following occur: 1. Lunar Simulation switch is placed at LUNAR SIM: 2. Lift Rocket T-handle is raised to command a firing where chamber pressure is greater than 100 psia. 3. Gimbal Lock and Local Vertical switches are OFF. 4. Jet engine angle is less than 16 degrees from local vertical. Deactivated Normally By: 1. Depressing SIM REL button on Jet Throttle. 2. Advancing Jet Throttle. 3. Placing Lift Rocket T-handle down to OFF. 4. Placing Gimbal Lock switch to ON.
ENGINE CENTERED	This mode is in operation when no other mode has been selected and the vehicle is airborne.

Section 1-F(a)-2

Control Van

To monitor vehicle systems performance and to communicate with the pilot, a control van, shown in figure 1-F(a)-15, is required during all flights and ground runs. The van interior (fig. 1-F(a)-16) contains two telemetry receivers, telemetry processing and recording equipment, and display instruments. A glassed enclosure at the end of the van contains a control booth from which the flight is directed. The van is staffed for each flight by a team of four engineers who are familiar with systems operations and flight operations. An operations engineer (Flight Director) heads this team and is responsible for coordinating all operations in the van and communications with the pilot and with other ground personnel. A jet engine engineer monitors the turbofan engine performance and maintains a log of jet (turbofan engine) fuel remaining throughout the flight. An attitude control systems engineer monitors the attitude control system operation by observing pitch and roll attitude rocket firings, rate gyro outputs, and side arm controller activity (fig. 1-F(a)-17). These attitude parameters are recorded and displayed in real time on Sanborn strip recorders. In addition to these data displays, 25 warning/status lights are displayed for the simultaneous use by the attitude control systems engineer and a rocket systems engineer.

The rocket systems engineer monitors the operation of the helium pressurant system and the hydrogen peroxide propellant system by observing six meters that display helium source and hydrogen peroxide tank pressures and lift rocket chamber pressures.

Figure 1-F(a)-15.- LLTV Control Van, Exterior View.

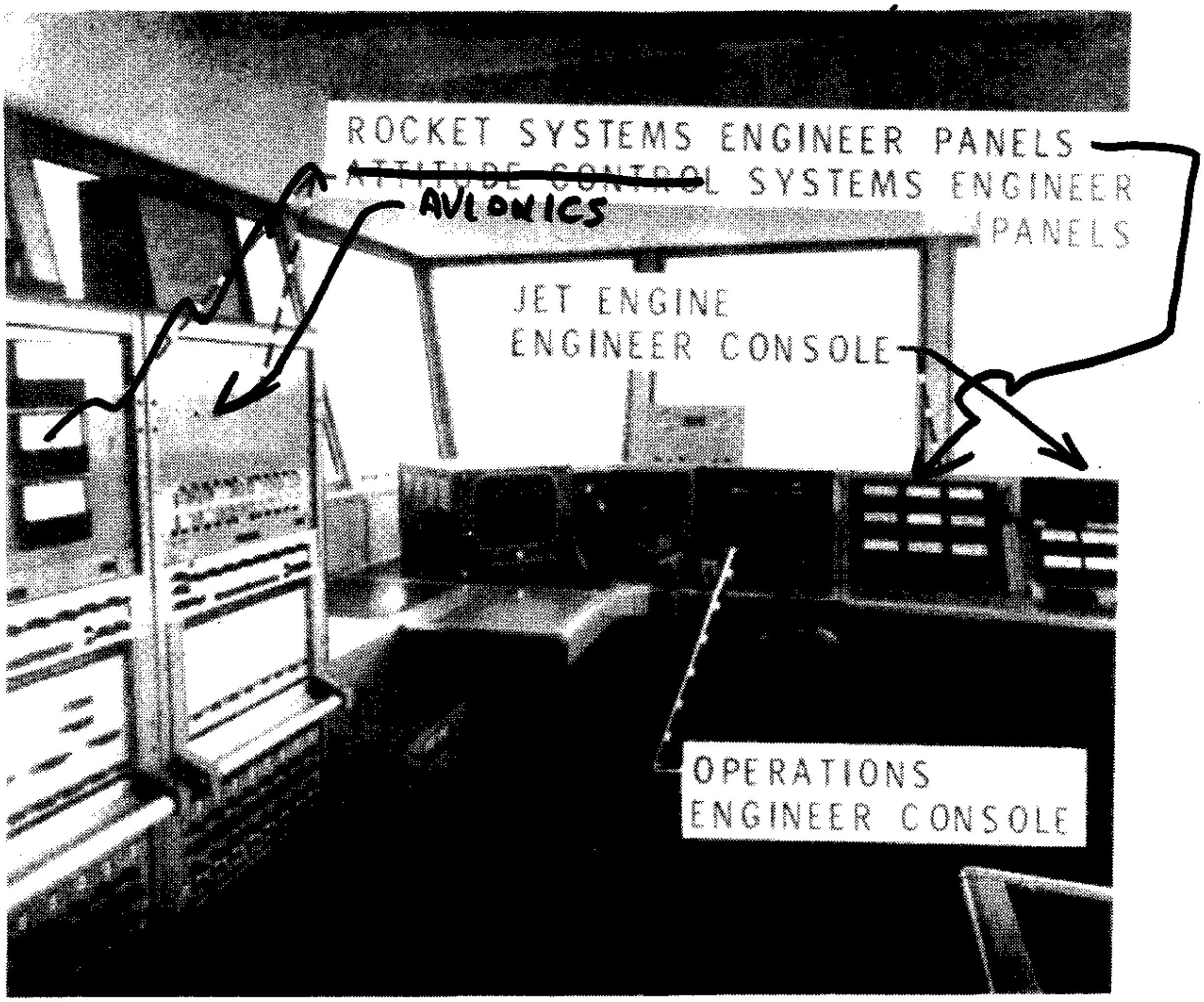


Figure 1-F(a)-16.- LLTV Control Van, Van Interior.

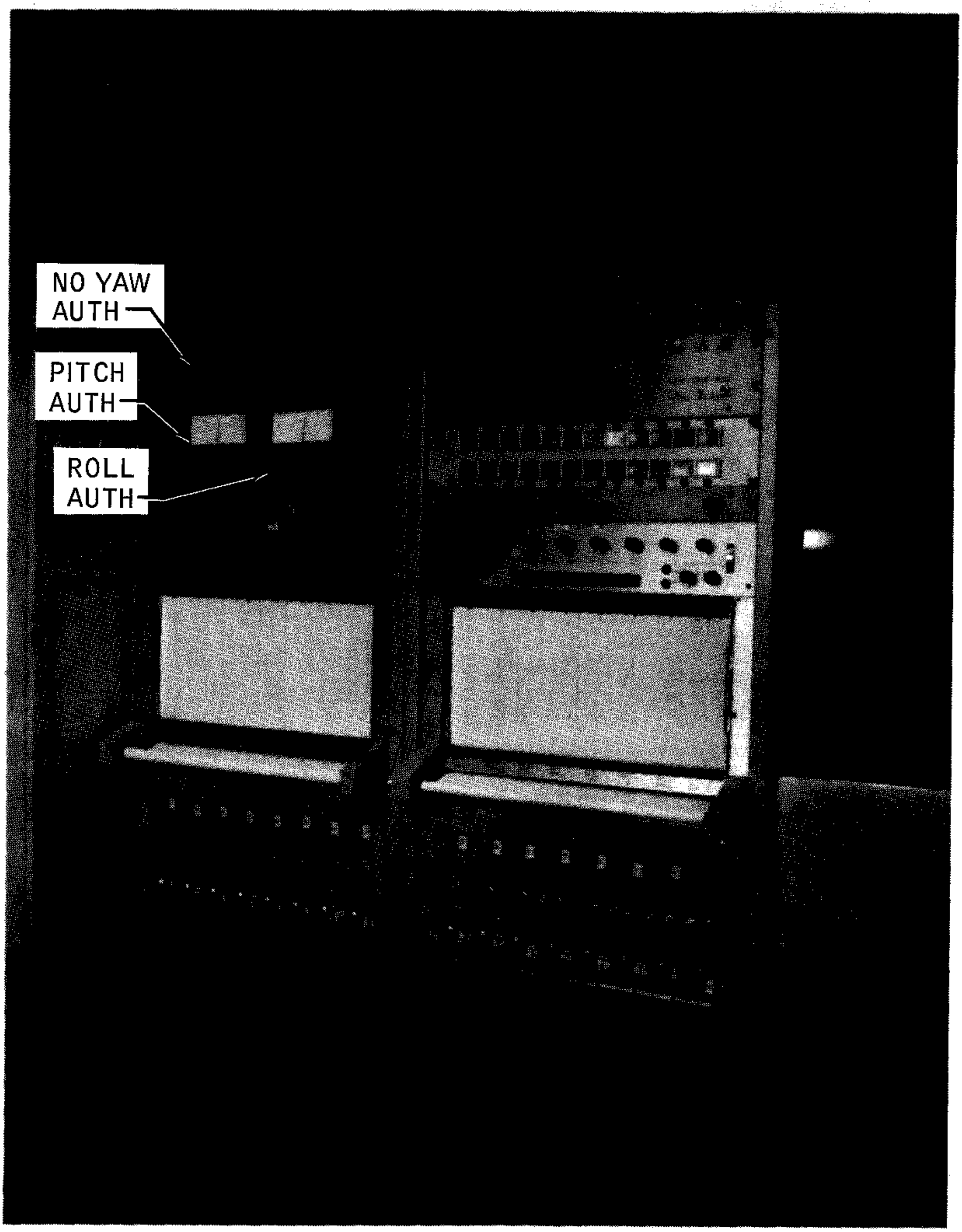


Figure 1-F(a)-17.- RCS Panel

All members of the team advise the Flight Director of the status of their systems prior to, during, and after each flight. In essence, the Flight Director operates as copilot and flight engineer. The control van team continuously monitor a large number of vehicle parameters in addition to those displayed to the pilot. This operational procedure was worked out prior to and during the research operations at the Flight Research Center.

The following is a report of the van configuration at the time of the accident.

LLTV TELEMETRY (TM) VANS

This report briefly describes the LLTV telemetry ground support vans, lists the operational equipment, and describes the difference in configuration between TM Van No. 1 and TM Van No. 2. TM Van No. 1 was manned for Flight 15.

The purpose of the TM van is to provide the ground support team communication with the pilot, visual real time displays of vehicle systems data, and permanent data records. Table 1-F(a)-III lists the display capability of the four operational positions and the major components of the data system and voice communications system. Table 1-F(a)-IV lists the LLTV telemetered data and location of each parameter on the display consoles. A sketch of each display panel and block diagram of the data system is shown on figures 1-F(a)-18 through 1-F(a)-22. All van operators talk on intercom and the conversation is recorded on magnetic tape. The operations engineer transmits on UHF.

The configuration of TM Van No. 1 deviates from TM Van No. 2 as follows:

TM No. 1	TM No. 2	
40	60	D.A.C. - Decom analog outputs
36	27	Decom event outputs (warning light drivers)
2	3	Strip chart recorder (8 Ch.)
0	1	Event recorder (30 Ch.)
6	9	*Avionics display meters (ACS)
0	1	TV monitor
0	1	**Time code generator
0	1	H_2O_2 flow computer

*Only 2 meters are used on TM No. 1 avionics panel at this time. (No yaw authority meter)

**Timing is routed from TM No. 2 to TM No. 1.

One strip chart recorder in TM No. 1 has a switch for each channel which allows selection of an alternate data input. The parameters which are patched to the switches are listed in Table 1-F(a)-III.

Jet engine throttle position and yaw thruster activity is not displayed in TM No. 1 due to limitation to 40 analog decom outputs.

The event recorder is used for postflight evaluation only. This record can be produced from tape playback.

The LLTV No. 1 was recently modified to expand the event format from 3 digital words of 9 bits each to 4 digital words of 9 bits each. The present data format utilizes 28 of the 36 bits. TM Van No. 1 was modified to enable processing of 4 digital words. This modification is not presently installed in TM Van No. 2; therefore, it is limited to 3 digital words or 27 events.

This vehicle modification, which was associated with CCA-8, provided additional event data and changed the function of some existing data bits. TM Van No. 2 is presently configured for the event format which existed prior to the vehicle modification (for support of LLTV No. 2). The event monitor panel layout for TM Van No. 2 is included for reference. The additional event functions which were made available by the vehicle modification are: Emergency Gimbal Lock, Pitch/Roll Rate Backup, Pitch Direct Latch, Yaw Direct Latch, Emergency AC Power, Yaw Rate Backup, and Roll Direct Latch.

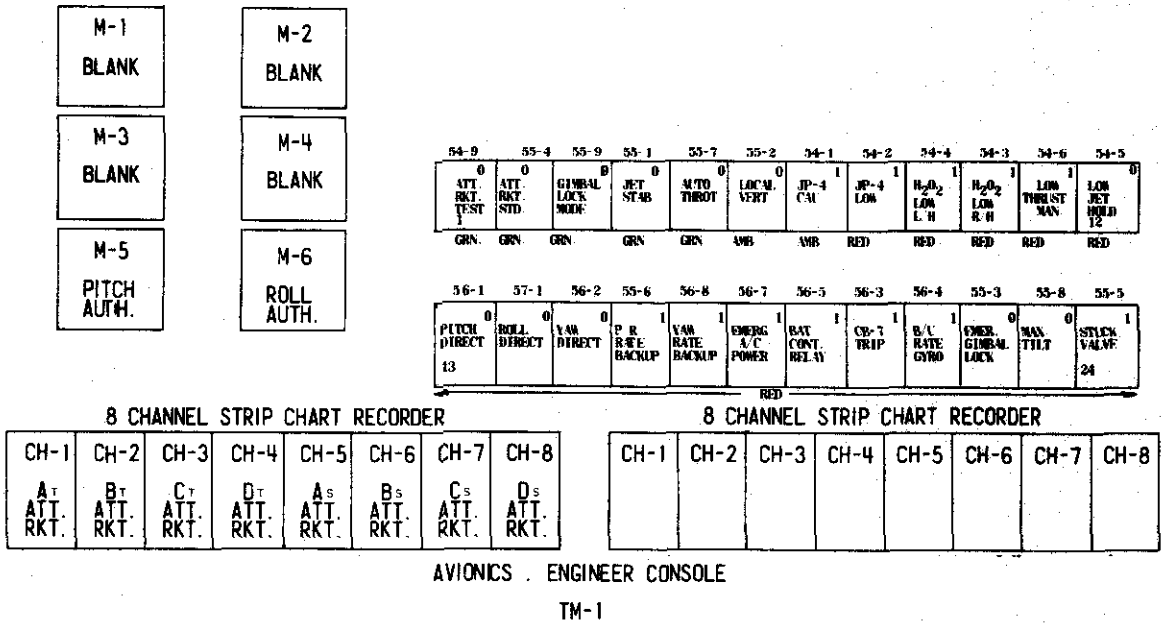
TABLE 1-F(a)-III.- DATA AND VOICE COMMUNICATIONS SYSTEM

Van No. 1	Van No. 2	
Quantity		
		Communication System — ARC 27/AIC 10
2	2	UHF Antenna
2	2	RT-178 Transceiver
2	2	Control Unit C-1904
5	5	Control Unit C-824/AIC 10
1	1	P. A. Amplifier - AM 944 AIC 13 or McIntosh
		Emergency Communication System
1	1	UHF Antenna
1	1	Cubic TR-31 Transceiver
1	1	MIC/Headset
1	1	Battery/LLRV - Gould National #230095
		Telemetry
2	2	UHF Antenna
		TM Receivers
2	1	A. Nems-Clarke 1401
1	2	B. Defense Elect - TMR-2
1	1	PCM Decom - Dynatronics UDS/715 including
40	60	A. Analog outputs
36	27	B. Event outputs
		Recorders
1	1	Magnetic Tape - Ampex FR-1814H - Direct
2	2	Direct Writing - Sanborn 7708A - 8 Ch.*
	1	Direct Writing - Brush Mark 200 - 8 Ch.*
	1	Event Recorder Brush 30 Ch.
		*Also listed as avionics display
		Avionics Console
*6	9	A. Analog meters (Thruster duty cycle)
24	36	B. Event lights
16	24	C. Analog strip chart channel
	1	D. H_2O_2 remaining readout
46		

* Six holes in panel but only two being used for pitch and roll, no yaw meters.

TABLE 1-F(a)-III.- DATA AND VOICE COMMUNICATIONS SYSTEM - Concluded

Van No. 1	Van No. 2	
Quantity		
		Operations Engineer Console
	1	A. TV monitor
36	36	B. Event lights
1	1	C. Engine timer
1	1	D. Flight timer
38		
		Rockets Engineer Console
9	9	A. Analog meters
12	12	B. Event lights
21		
		Engine Console
9	9	A. Analog meters
12	12	B. Event lights
1	1	C. Digital clock
22		
		Timing
	1	A. Time code generator IRIG A-B-C-D, 1 pps
1	1	B. Timing buffer
		Miscellaneous
	1	A. H_2O_2 fuel flow computer (prototype)
1	1	B. Attitude authority control unit
		C. Power supplies
		Test Equipment
2	2	A. Oscilloscope
1	1	B. Counter
2	2	C. DVM
1	1	D. Oscillator
1	1	E. V.O.M.
1	1	F. PCM signal simulator
1	1	G. Signal generator



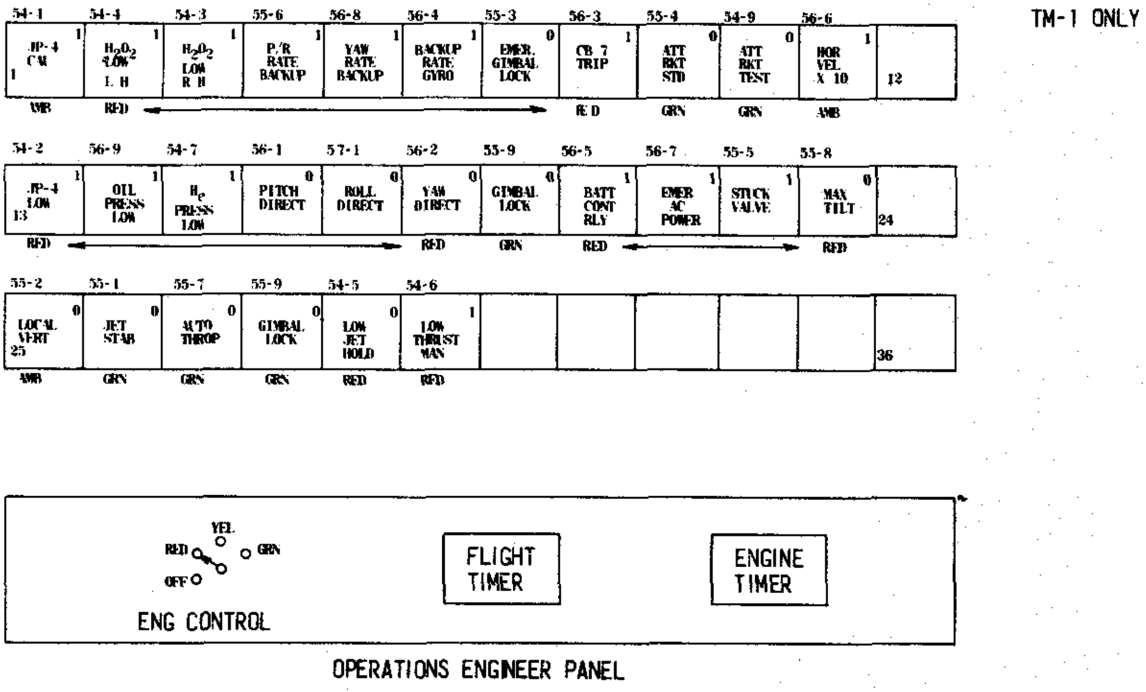
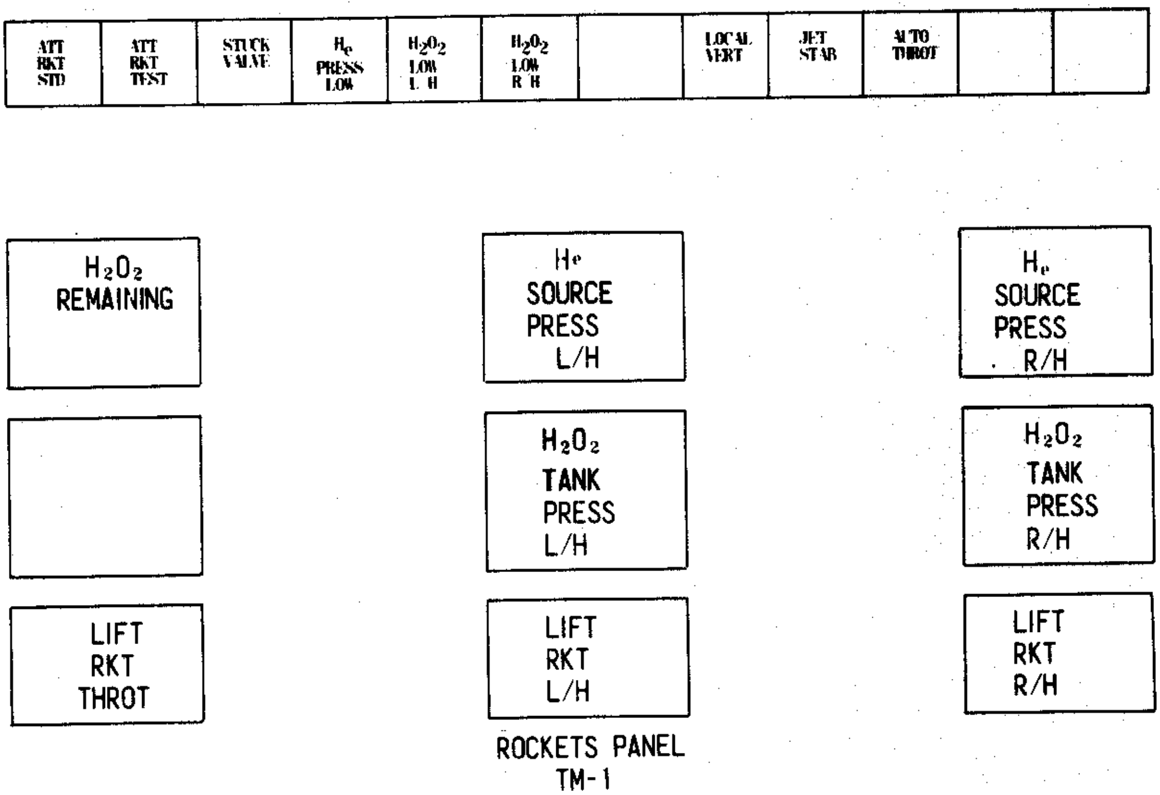


Figure 1-F(a)-18.- Avionics Engineer Console
Figure 1-F(a)-19.- Operations Engineer Console



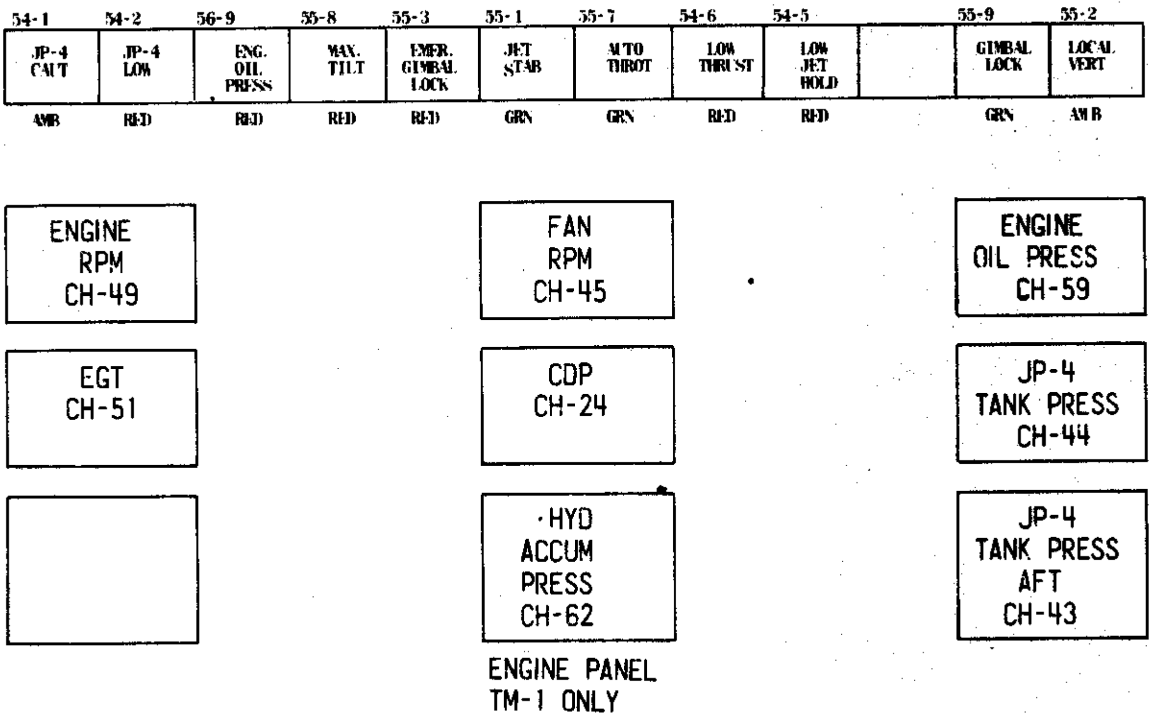


Figure 1-F(a)-20.- Rockets Panel
Figure 1-F(a)-21.- Engine Panel

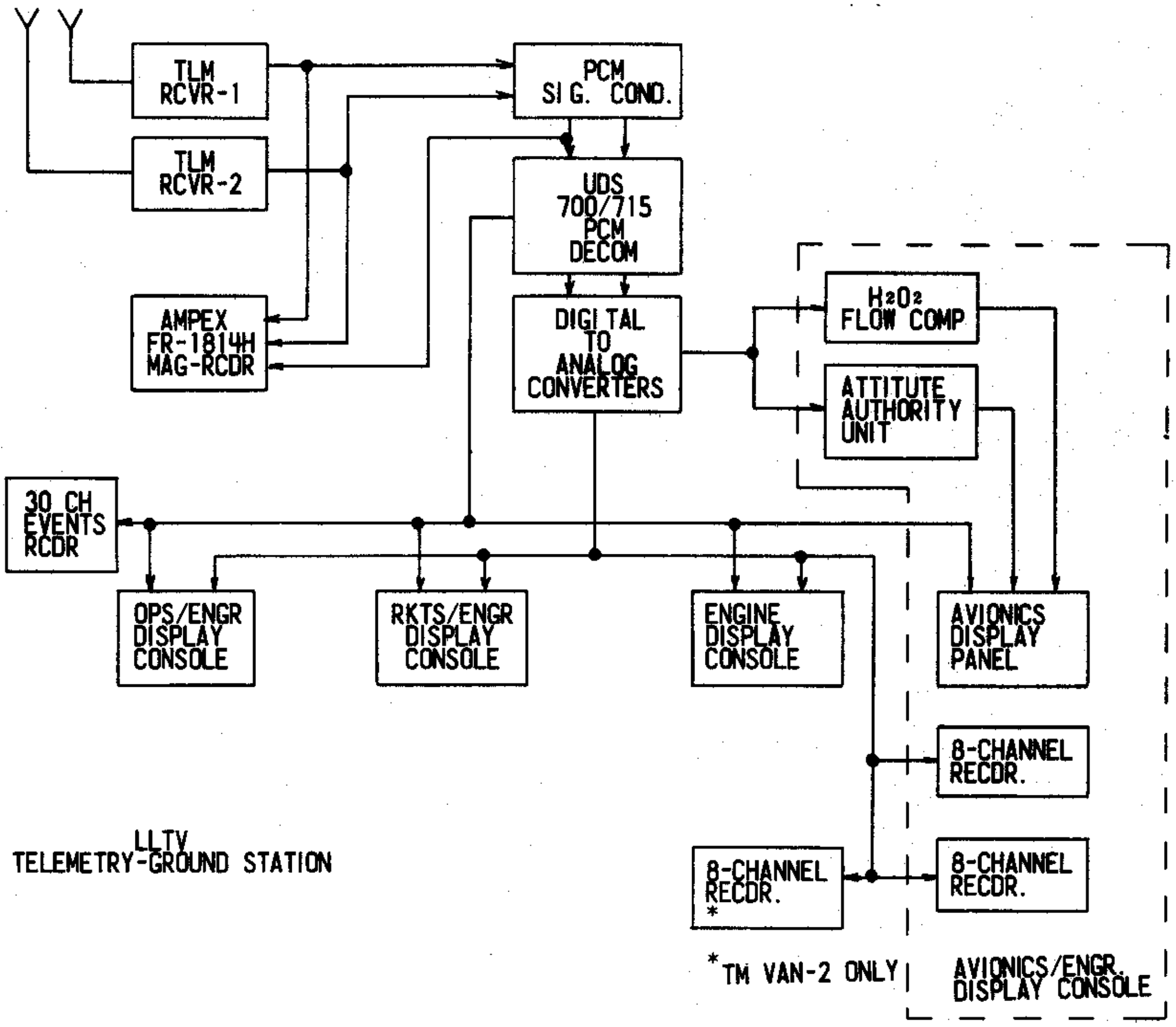


Figure 1-F(a)-22.- LLTV Telemetry Ground Station

TABLE 1-F(a)-IV.- TELEMETRY DATA

CHANNEL NUMBER	PARAMETER TM-1	DAC	AVIONICS	OPS	ROCKETS	ENGINE	INPUT 1 RCDR-2 PRE-FLIGHT	RCDR-1	INPUT 2 RCDR-2 FLIGHT	RCDR-4 30-CH	H_2O_2 COMP ATT AUTH
1	Veh Pitch Att	3							3		
2	Veh Roll Att	6							6		
3	Veh Yaw Att										
4	Veh Pitch Vel	1							1		
5	Veh Roll Vel	4							4		
6	Veh Yaw Vel	7							7		
7	AX Six Error										
8	He Source Press L/H	10			M-2						
9	He Source Press R/H	11			M-3						
10	Jet Eng Pitch Att										
11	Jet Eng Roll Att										
12	AX										
13	AY										
14	AZ										
15	Altitude										
16	Vertical Vel										
17	Drift Vel										
18	Horiz Vel										
19	Lift Rkt Throt	14			M-7						
20	Rate Com Pitch	2							2		
21	Rate Com Roll	5							5		
22	Rate Com Yaw	8									
23	Jet Eng Throt										
24	C D P	19				M-5					
25	Lift Rkt Cham Press L/H	37			M-8				8		
26	Lift Rkt Cham Press R/H	38			M-9						
27	Att Rkt Press BS	26						6			6
28	Att Rkt Press FS	34					6				14
29	Att Rkt Press BT	22						2			2
30	Att Rkt Press FT	30					2				10
31	Att Rkt Press GS	35					7				15
32	Att Rkt Press CT	23						3			3
33	Att Rkt Press CS	27						7			7
34	Att Rkt Press GT	31					3				11
35	Att Rkt Press AS	25						5			5
36	Att Rkt Press ES	33					5				13
37	Att Rkt Press ET	29					1				9
38	Att Rkt Press AT	21						1			1
39	Att Rkt Press DT	24						4			4
40	Att Rkt Press HT	32					4				12
41	Att Rkt Press DS	28						8			8
42	Att Rkt Press HS	36					8				16
43	JP-4 Tank Press Aft	40				M-9					
44	JP-4 Tank Press Fwd	20				M-6					
45	Fan RPM	16				M-2					
46	T/W Comp out										
47	+5V Cal										
48	-5V Cal										
49	Gas Gen RPM	15				M-1					
50	H_2O_2 Tank Press L/H	12			M-5						
51	E G T	18				M-4					
52	H_2O_2 Tank Press R/H	13			M-6						

TABLE 1-F(a)-IV.- TELEMETRY DATA - Concluded

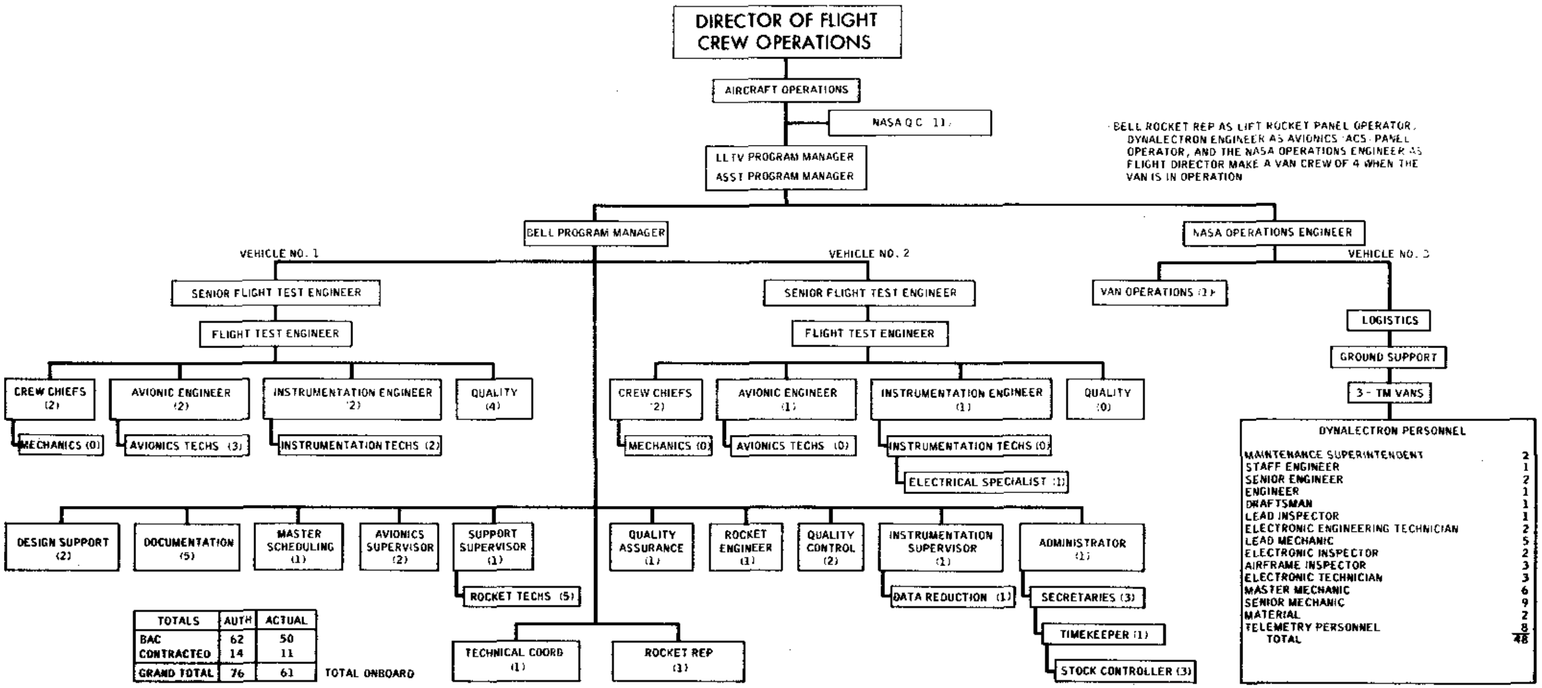
CHANNEL NUMBER	PARAMETER TM-1	DAC	AVIONICS	OPS	ROCKETS	ENGINE	INPUT 1 RCDR-2 PRE-FLIGHT	RCDR-1	INPUT 2 RCDR-2 FLIGHT	RCDR-4 30-CH	H_2O_2 COMP ATT AUTH
53	AY Error Sig										
54	Binary-Events										
55	Binary-Events										
56	Binary-Events										
57	Binary-Events										
58	H_2O_2 Lbs Remaining				M-1						
59	Jet Oil Press	17				M-3					
60	Airflow Vel (Anemometer)										
61	Airflow Direction (Yaw Vane)										
62	Hyd Accum Press	39				M-8					
63	AZ Error Sig										
NA	Att Auth Pitch	-	M-5								
NA	Att Auth Roll	-	M-6								

CHANNEL NUMBER	PARAMETER	COLOR	AVIONICS	OPERATIONS	ROCKETS	ENGINE	RCDR-4 30-CH
54-1	JP-4 Caut (1)	Amb	7	1		1	
-2	JP-4 Low (1)	Red	8	13		2	
-3	H_2O_2 R/H (1)	Red	10	3	6		
-4	H_2O_2 L/H (1)	Red	9	2	5		
-5	Low Jet Hold (0)	Red	12	29		9	
-6	Low Thrust Man (1)	Red	11	30		8	
-7	He Press Low (1)	Red		15	4		
-8	Doppler (0)	Amb					
-9	Att Rkt Test (0)	Grn	1	10	2		
55-1	Jet Stab (0)	Grn	4	26	9	6	
-2	Local Vert (0)	Amb	6	25	8	12	
-3	Em. Gimbal Lock (0)	Red	22	7		5	
-4	Att Rkt Std (0)	Grn	2	9	1		
-5	Stuck Valve (1)	Red	24	22	3		
-6	P/R Rate B/U (1)	Red	16	4			
-7	Auto Throt (0)	Grn	5	27	10	7	
-8	Max Tilt (0)	Red	23	23		4	
-9	Gimbal Lock (0)	Grn	3	19 & 28		11	
56-1	Pitch Direct (0)	Red	13	16			
-2	Yaw Direct (0)	Red	15	18			
-3	CB-7 Trip (1)	Red	20	8			
-4	B/U Rate Gyro (1)	Red	21	6			
-5	Batt Cont Relay (1)	Red	19	20			
-6	Hor Vel X 10 (1)	Amb		11			
-7	Emer. AC Power (1)	Red	18	21			
-8	Yaw Rate B/U (1)	Red	17	5			
-9	Oil Press Low (1)	Red		14		3	
57-1	Roll Direct (0)	Red	14	17			

Section 1-F(a)-3

Personnel

Figure 1-F(a)-23 is an organizational chart of the LLTV program personnel functions from the Director of Flight Crew Operations down, including contractor personnel directly involved or under the control of the program manager. The number of personnel available (as of Dec 8, 1968) to perform each function are indicated by (x).



*BELL ROCKET REP AS LIFT ROCKET PANEL OPERATOR, DYNALECTRON ENGINEER AS AVIONICS (ACS) PANEL OPERATOR, AND THE NASA OPERATIONS ENGINEER AS FLIGHT DIRECTOR MAKE A VAN CREW OF 4 WHEN THE VAN IS IN OPERATION

TOTALS	AUTH	ACTUAL
BAC	62	50
CONTRACTED	14	11
GRAND TOTAL	76	61

TOTAL ONBOARD

DYNALECTRON PERSONNEL	
MAINTENANCE SUPERINTENDENT	2
STAFF ENGINEER	1
SENIOR ENGINEER	2
ENGINEER	1
DRAFTSMAN	1
LEAD INSPECTOR	1
ELECTRONIC ENGINEERING TECHNICIAN	2
LEAD MECHANIC	5
ELECTRONIC INSPECTOR	2
AIRFRAME INSPECTOR	3
ELECTRONIC TECHNICIAN	3
MASTER MECHANIC	6
SENIOR MECHANIC	9
MATERIAL	2
TELEMETRY PERSONNEL	8
TOTAL	48

Figure 1-F(a)-23.- LLTV Personnel Organization Chart

Section 1-F(a)-4

MISSION RULES

The LLTV is flown at Ellington AFB, Texas, within the area indicated in the airfield diagram in Figure 1-F(a)-24. A typical flight profile over runway 17L/35R is shown in figure 1-F(a)-25. This profile could also be over runway 22R/4L. Both of these runways have been deactivated for regular airplane traffic. Figure 1-F(a)-26 is an early morning photograph showing the LLTV complex as it would have looked during Flight #15.

Extracts from the LLTV Mission Rules are included next. As in the case of the Flight Manual, certain sections have been marked for emphasis.

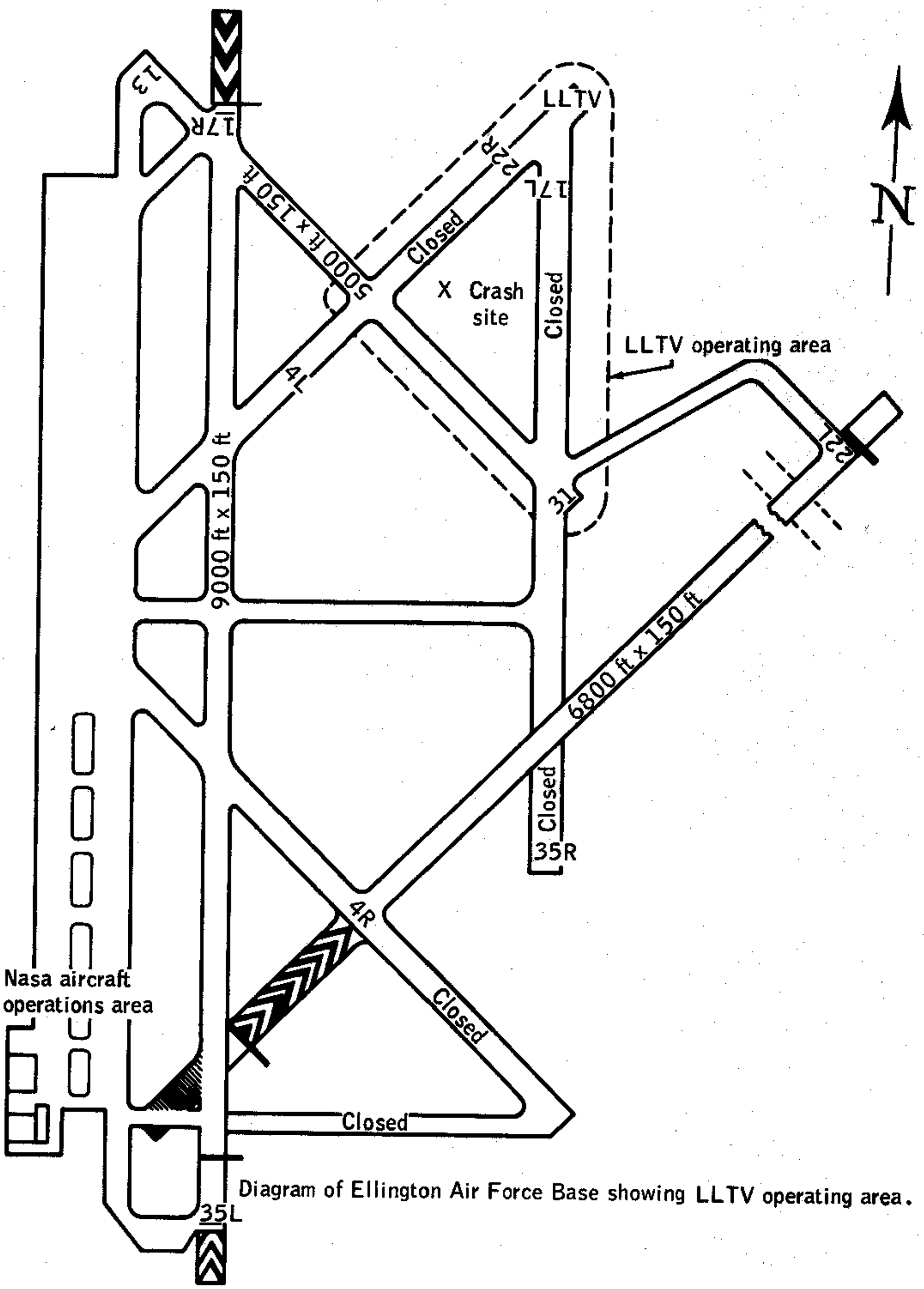


Diagram of Ellington Air Force Base showing LLTV operating area.

Figure 1-F(a)-24.- Ellington AFB

TYPICAL LLTV FLIGHT SHOWING SEQUENCE OF EVENTS

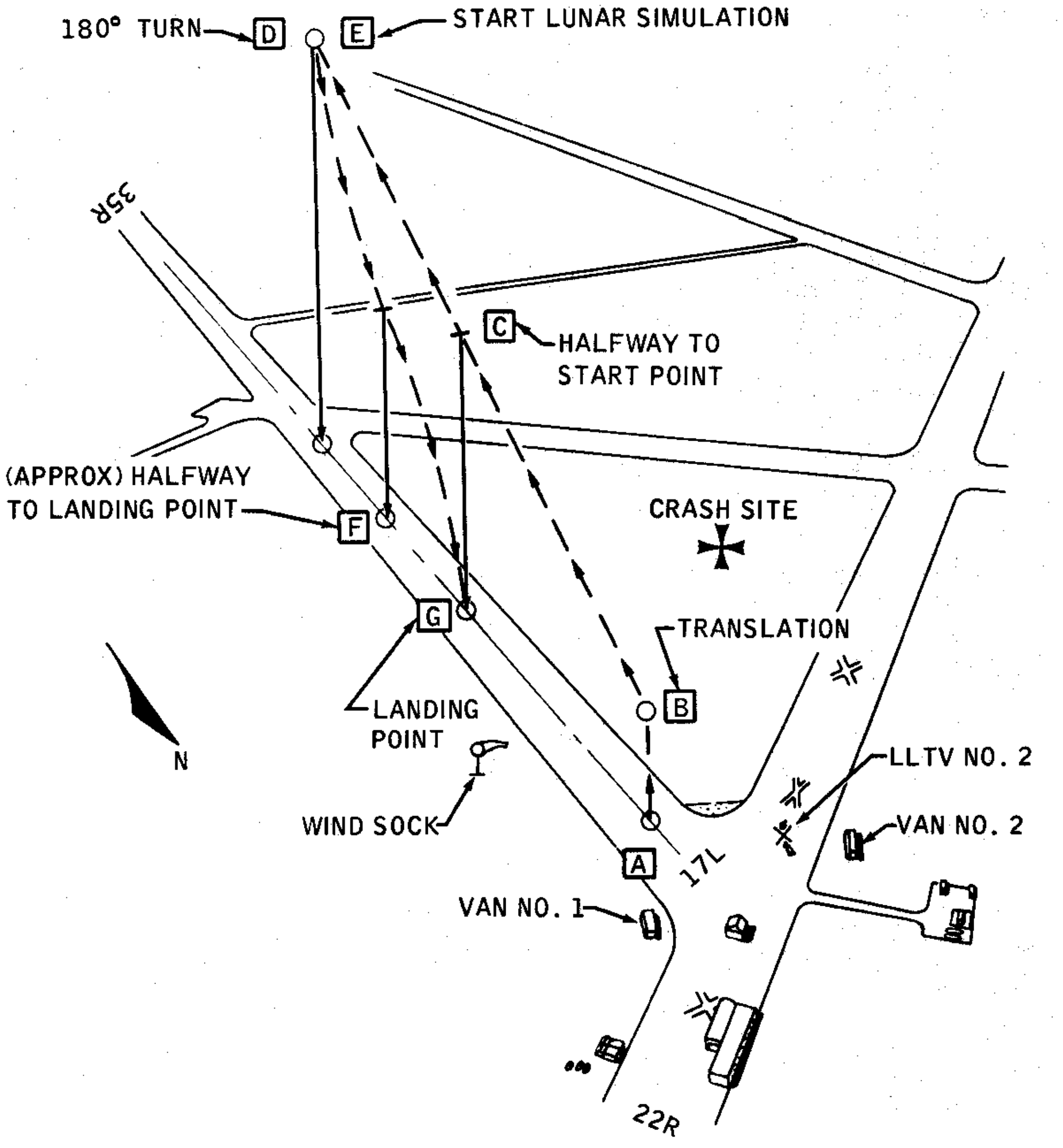


Figure 1-F(a)-25.- Typical Flight Profile

NASA
68-50849

Figure 1-F(a)-26.- LLTV Complex

1-F(a)-70

LUNAR LANDING TRAINING VEHICLE

MISSION RULES

SEPTEMBER 1968

Approved: Ronald K. Blilie
Ronald K. Blilie
LLTV Operations Manager

Approved: Dean F. Grimm 11-12-68
Dean F. Grimm
LLTV Program Manager

Approved: Joseph S. Algranti
Joseph S. Algranti
Chief, Aircraft Operations Office

2-5-3-2-1 Manual Override.- The manual jet throttle is hydraulically coupled to the main jet engine fuel control (refer to Paragraph 2-2-3), such that the pilot can manually override the automatic throttle system through the range of 70 to 100 percent rpm without exceeding force limits at the throttle gradient.

2-5-3-2-2 Disengage Capability.- A SIM REL pushbutton switch located on the jet throttle allows disengagement of the automatic throttle at any time to permit hydraulic throttle control.

2-5-3-2-4 Lift Rocket Thrust Control.- A closed loop position system connects the lift rocket control (T-handle, fig. 1-F(a)-7) with the lift rocket throttle valve. Thrust is linearly proportional to stick deflection.

2-5-3-2-6 Lunar Simulation Instrumentation.- A cockpit and ground monitored thrust-to-weight indicator displays normal acceleration in lunar g's. The thrust/weight computer output signals are also telemetered for ground station monitoring. A cockpit Auto Throttle green status light indicates when the automatic throttle has been engaged (light ON) and when the auto-throttle has been disengaged by the low auto-throttle clutch disengage switch (light extinguished).

Additional telemetry data recorded by the ground station include jet engine throttle position (potentiometer output) and low auto-throttle signal cutoff.

LLTV MISSION RULES

MISSION RULES

1. Introduction

This document contains mission rules to be used in conjunction with the operation of the Lunar Landing Training Vehicle (LLTV). In the event of conflict between this document and any other documentation, this document will govern.

Purpose

The purpose of this document is to establish rules for the operation and flight of the Lunar Landing Training Vehicles. Any deviation from these rules will require approval by program management.

Applicability

The operational rules set forth in this document shall be complied with for all LLTV flight operations. All LLTV pilots, operations van, and maintenance personnel involved in LLTV flight operations will know, understand, and comply with the contents of this document.

2. Flight Operations

a. Responsibilities

The LLTV Operations will be under the direction of the MSC LLTV Operations Manager. It will be his responsibility to make the final determination of the flight readiness of any LLTV.

The NASA instructor pilot will be responsible for insuring that the astronaut has been properly briefed and is ready for the proposed flight. He will monitor the flight from the operations van and will act in an advisory capacity to the flight controller. The instructor pilot does have the authority to direct the termination of the mission if in his judgment the mission cannot be safely continued.

The flight controller will have total responsibility from the operations van during the flight phase. He will insure that system status is reported to him, and as necessary, will advise the LLTV pilot of any necessary action required to comply with the flight plan, or to insure safe recovery of the pilot and/or the vehicle.

b. Operations Van Requirements

In preparation for a flight, the vehicle and operations van telemetry equipment shall meet the requirements of the operations van checklist. Any deviation shall require the approval of the MSC LLTV flight controller. The MSC LLTV flight controller may waive the requirement for operational equipment in the operations van other than the following minimum equipment:

(1) Telemetry receivers, processing equipment, and recorders.

(2) Communications

  (a) At least one primary UHF transmitter-receiver and an emergency UHF transmitter-receiver.

  (b) UHF communications with the fire truck.

  (c) Intercommunications between flight controller and vehicle crew chief.

  (d) Communication with Ellington Air Force Base control tower.

(3) The flight controller's control station shall be complete as described in the LLTV Operations Manual

shall be completely functional except that the flight controller may waive the Flight and Jet Engine timers.

NOTE: If Flight and/or Jet Engine timers are not functional, the flight time shall be maintained by the rockets system monitor and the engine time will be maintained by the jet engine monitor by use of manual stop watches.

(4) Rocket system monitor station shall be complete as described in the LLTV Operations Manual and shall be completely functional, except that the flight controller may waive the Local Vertical light, Jet Stabilization light, and the Auto Throttle light.

(5) Jet engine monitor station shall be complete as described in the LLTV Operations Manual and shall be completely functional except that the flight controller may waive the Compressor Discharge Pressure indicator and the Jet Throttle Position indicator.

(6) Avionics system monitor station shall be complete as described in the LLTV Operations Manual and shall be completely functional except that the flight controller may waive the third strip chart recorder. This recorder may be inoperative if yaw rockets are displayed on the #2 Sanborn recorder during the pilot's preflight.

c. Operations Van Staff Requirements

The operations van will be staffed with certified operators at each primary control station for all LLTV flights. A certified operator is one who has completed the prescribed course of training as outlined in the LLTV Flight Control Training Manual. The primary control stations are the flight controller's station, rocket systems station, jet engine station, and the avionics station. An operator trainee will be permitted to man one of the four stations, under the supervision of a certified operator, with the following restrictions:

(1) The trainee must have completed the prescribed course of training as outlined in the LLTV Flight Control Training Manual, except for the on-the-job training (OJT) phase.

(2) A trainee will not man a station during the pilot's first three checkout flights.

(3) A trainee will not man a station during a functional check flight (FCF).

(4) A trainee will not man a station during a test flight in which vehicle performance limits will be explored.

(5) A maximum of one trainee may be in training (OJT) during any flight.

3. NASA Astronaut Qualifications and Training

a. LLTV Transition

A pilot, who has previously completed the LLRV pilot checkout syllabus and was completely qualified in the LLRV, will, in addition to being qualified and current in helicopters, accomplish the following to become qualified in the LLTV:

(1) Complete the LLTV systems ground school.

(2) Complete the applicable simulator program of about five hours in the LLTV fixed-base simulator.

(3) Complete a tie-down combined systems run.

(4) Complete an LLTV C.G. fixture run.

(5) Complete a five-flight transition syllabus under the supervision of a staff instructor pilot.

(6) At the completion of the above program, the pilot will be considered LLTV qualified and will enter the proficiency phase of training, which consists of approximately 12 flights. Successful completion of the above will serve as pilot certification and will be accomplished by USAF Form 8B.

b. Initial Pilot Qualification and Training

Prior to the first flight in the LLTV, a pilot will have met the following minimum requirements:

(1) He will have completed a minimum of 100 hours total helicopter time, and 5 hours in the 30 days preceding first flight.

(2) He will have completed a checkout and familiarization in the Langley Lunar Research Facility Vehicle.

(3) He will have completed the LLTV simulator syllabus of approximately 10 hours.

(4) He will have attended the LLTV systems ground school.

(5) He will have had an ejection seat swing at Weber Aircraft Company facilities, Burbank, California.

(6) He will have completed a live firing of the attitude control system with the LLTV mounted on the C.G. fixture.

(7) He will have completed a combined systems run with the LLTV tied down.

(8) After completion of the above, a pilot will complete a 13-flight syllabus as described in the LLTV Flight Checkout Syllabus under staff instructor pilot supervision.

(9) At the completion of the above program, a pilot will be considered LLTV qualified and will enter the proficiency phase of training, which consists of approxmately 12 flights. Successful completion of the above will serve as pilot certification and will be accomplished by USAF Form 8B.

c. Currency Requirements

After completion of the proficiency phase, a pilot will maintain currency in the LLTV by flying a minimum of two full lunar simulations per 30-day period (preferably bi-weekly).

d. Recurrency Requirements

If a pilot, qualified in the LLTV, becomes uncurrent, he shall accomplish the following to reestablish currency:

(1) He shall be helicopter current.

(2) He shall complete applicable simulator program of about two hours in the LLTV fixed-base simulator.

(3) He shall complete a minimum of two flights in the LLTV, the first of which will be with the engine gimbals locked.

4. Minimum Support Requirements

The following support services and equipment are as indicated for flight operations:

a. A qualified medical doctor will be in attendance prior to flight (mandatory).

b. A qualified medical attendant/ambulance driver will be in attendance prior to flight (mandatory).

c. An ambulance will be stationed near the flight pad prior to flight (mandatory).

d. A fire truck (O-11A or equivalent) and four qualified firemen will be stationed near the flight pad prior to flight. The fire truck must be equipped with an operational two-way UHF radio with appropriate frequencies for communication with the operations van (mandatory).

e. Television equipment will be operational and capable of recording UHF audio and visual events of the entire flight. Color movie film will be used to record flight events. Both television and color movies are highly desirable; however, it is mandatory that either television or color movies record flight events for every flight.

f. Equipment identified in paragraph II of the "LLTV Emergency Procedures" (MSC Form 1982), dated November 1968, will be inspected, operational, and in position prior to flight (mandatory).

g. Personnel requirements and assignments and equipment positioning will conform to the requirements of the "LLTV Emergency Procedures" (mandatory).

5. Minimum Environmental Conditions

a. Surface Winds

Unless lower winds are specified in the LLTV Flight Checkout Syllabus, LLTV flights will not be permitted if the surface wind exceeds 15 mph.

b. Precipitation

The LLTV will not be operated, on the ground or in flight, during periods of falling rain unless adequate protection is provided to prevent the vehicle's sensitive components from becoming wet.

c. Hours of Operation

The LLTV will be flown only during the hours of daylight when the pilot is able to maintain visual reference with the ground.

7. Flight Restrictions and Limits

a. During LLTV flights, pilot initiated use of both sets of attitude rockets at the same time is not permitted in order to accomplish mission objectives. Both sets (standard and test) will only be used for added control in contingency cases. Exception: During some phases of the pilot training syllabus, the use of both is allowed to acquaint the pilot with the feel of the added control authority.

b. There will be no inflight system troubleshooting. The pilot will land if a system malfunction occurs.

c. Due to jet engine restrictions, an altitude of 1,000 feet MSL will not be exceeded.

d. All routine flights will be conducted over paved surfaces. All landings will be made on prepared surfaces. The only exception to the above will be in case of an emergency in which case a pilot will choose the most suitable site for the situation.

e. An operations van controller will not instruct a pilot to eject during an emergency. The pilot will be kept thoroughly informed of the vehicle status, but only he will determine if the requirement to eject exists.

f. The pilot will inform the flight controller of all switch changes. When possible, he will inform the flight controller of his intent to change a switch position before he takes action.

g. If communications between vehicle and control van are lost, the pilot will terminate the mission and land. Complete loss of TM van indications will be cause for mission termination and landing.

h. A pilot will not intentionally fly over any facility building or ground support equipment.

i. If the avionics back-up channel is activated during a landing, the pilot will not attempt to reset that channel until the flight controller determines that it is permissible to reset and to continue the mission.

1-F(b)

HISTORY OF FLIGHT

HISTORY OF FLIGHT

Section 1-F(b)

General

For ease of analysis and cross-reference, the flight has been divided into nine phases. This division is arbitrary to some extent because all parameters do not necessarily divide or crossover at exactly the same time. The phases are:

Phase I – Takeoff
Phase II – Climb
Phase III – Hover
Phase IV – Initial acceleration to set up a trajectory for lunar sim. Systems armed for lunar sim.
Phase V – Acceleration continues and lift rockets were activated.
Phase VI – Velocity stabilizes and yaw thrusters saturate.
Phase VII – Full lunar simulation is initiated by unlocking the gimbals. Attitude control is lost.
Phase VIII – Gimbals relocked
Phase IX – Vehicle not recoverable.

NARRATIVE HISTORY OF FLIGHT

Phase I - Takeoff to 07:25:53

Flight 15 completed a routine preflight checkout on the morning of December 8, 1968, and lifted off at 07:25:23 CST (local time). A gradual ascent to 50 feet altitude was accomplished in approximately 30 seconds while the LLTV was over the checkout area. During this time, the pilot was informed by the van, "We're showing you slightly left side heavy." During this period, the wind (derived from recorded data) was about 10 ft/sec and varying within ±20° of 360° (about 20° R relative to the vehicle).

Phase II - 07:25:53 to :27:10

At 07:25:55, a yaw right was initiated and continued until :27:10. At this time the heading[1] was about 110°. The vehicle continued to climb and passed through 500 feet of altitude at :27:10. During this climb, the derived wind increased to 40 ft/sec, and the direction shifted unsteadily to 040°. The airflow relative to the vehicle increased to approximately 25 ft/sec from a direction that varied sharply from 0° L to 65° L relative and back to approximately zero. During this period, the vehicle translated 1,500 feet on a track of approximately 180° at a peak ground speed of 37 ft/sec (predominately a right drift over the ground with respect to body axis, figs. 1-F(b)-1 and -2). The airflow during this period was predominantly from the right, but the direction was not constant. TM van communication informed the pilot

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[1] The pilot zeroed his heading indicator before takeoff (approximately aligned with true north).

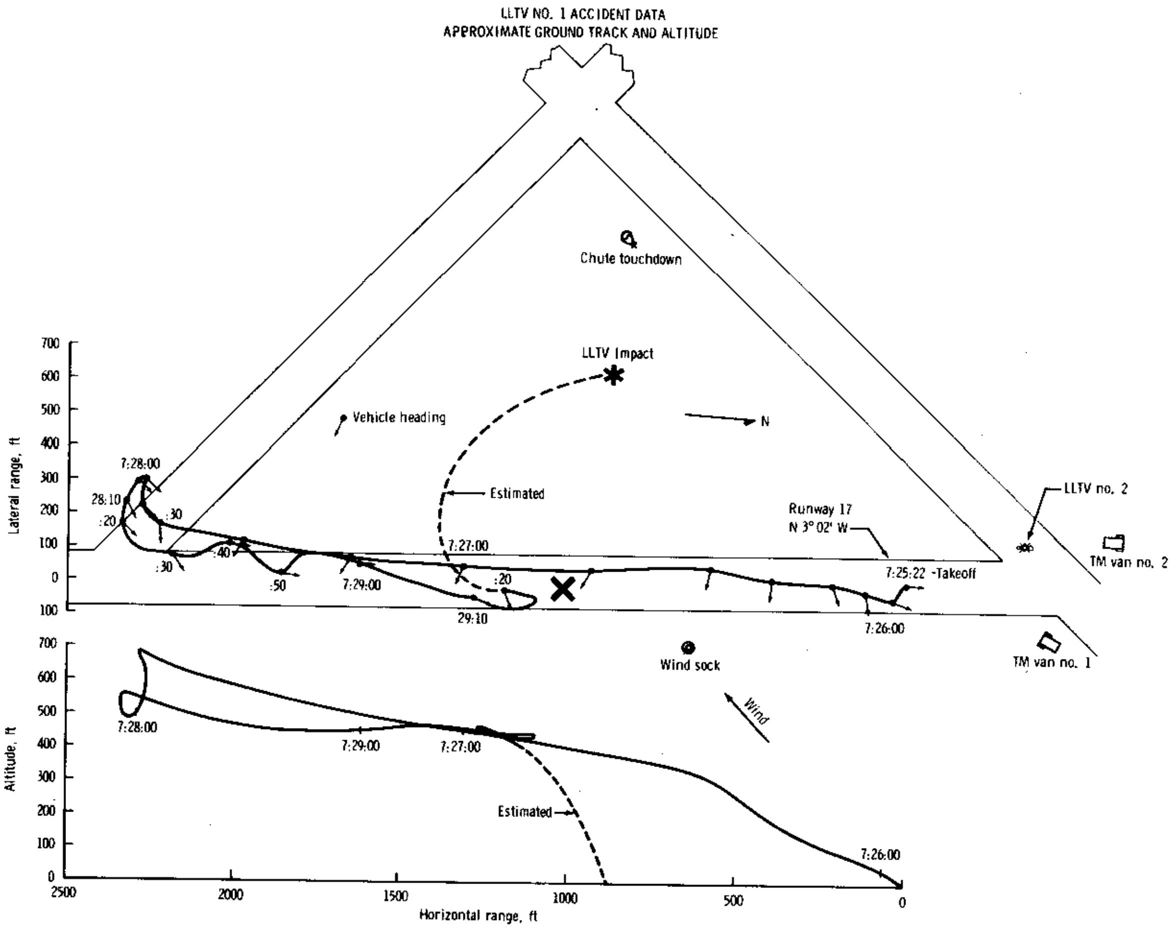

Figure 1-F(b)-1.- Ground Track and Profile Schematic

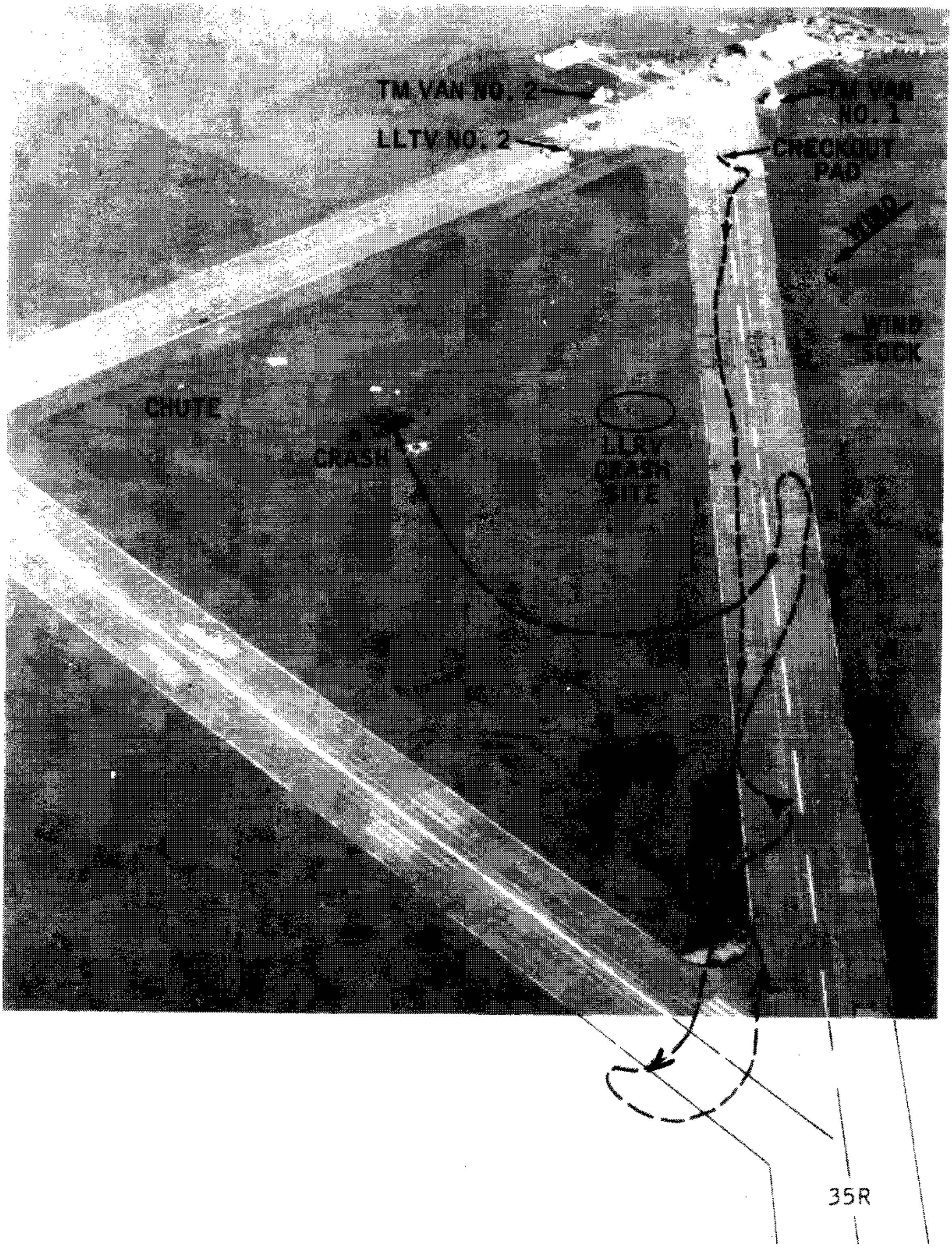

Figure 1-F(b)-2.- Ground Track and Profile Photograph

that the roll rockets were still firing as if the vehicle were left side heavy (consistent with an airflow from the right).

Phase III - 07:27:10 to :28:05

During this period, the altitude peaked at 680 feet before leveling off at about 500 feet. The southerly translation continued to a point approximately 2,300 feet south of the checkout pad area. During this time, the translation velocities gradually decreased until the vehicle was in a hover ($\dot{X}$ and $\dot{Y}$ both less than 5 ft/sec) at :28:05. During this period, the heading was changed to the left to 050°. Wind velocities during this period were 30 to 35 ft/sec from approximately 030°. At :27:33 the pilot was informed that "roll balance looks good." At :27:56 and 550 ft, the pilot reported hovering into a wind of 30 ft/sec. The JP-4 caution light was reported on at :28:02 by the TM van.

Phase IV - 07:28:05 to :28:50 (See Table 1-F(b)-I.)

During this period, the LLTV initiated a northerly translation starting from a position just off the western edge of Runway 35 and 2,300 feet from the checkout pad area. The heading was changed by yawing left from 050°, reaching 010° at :28:40 and holding steady at that heading. Ground track velocities were increased to about 25 ft/sec (predominantly $\dot{X}$); and the wind held generally 030° at 30 ft/sec. During this period the pilot armed Lunar Simulation (jet stabilization on) and verified Moment Compensation on. All of these events were verified by status lights and recordings. The altitude stabilized at approximately 450 feet at the end of this period.

Phase V - 07:28:50 to :28:55

At :28:50 the vehicle was holding a steady heading of 010° at an altitude of 450 feet. Ground velocity was about 20 ft/sec (predominantly $\dot{X}$) and increasing. Vehicle attitude was essentially level except for 4° pitchdown. At :28:53 the pilot raised the T-handle (increased throttle of simulated LM descent engine) to activate the lift rockets. From :28:50 to :28:55 the yaw thruster duty cycle[1] increased from about 30 percent to 50 percent (yaw left) without any yaw commands by pilot. Pitch duty cycle averaged about 25 percent (pitch down) with several small pitchdown commands. Roll duty cycle averaged about 25 percent (roll right) with several small roll right commands. The airflow relative to the vehicle during this period was about 45 ft/sec from 10° R.

Phase VI - 07:28:55 to :29:07 (See fig. 1-F(b)-4 and Table 1-F(b)-I.)

A further pitchdown maneuver from 4° to 8° was completed at :28:57. The forward ground speed was increased to 44 ft/sec at :29:07 (airflow velocity increased to 60 ft/sec from directly off the nose (X-axis)). Control commands were essentially limited to pitch. Thruster duty cycle gradually increased to 100 percent L in yaw and 40 percent down in pitch at :29:06.5.

Roll duty cycle reduced to approximately zero. At :28:58, the pilot confirmed that the auto throttle was working.

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[1] Thruster duty cycle information will tend to lag in time (by 1 to 2 seconds) the actual duty cycle used because of the averaging characteristics of the electronic circuits.

Phase VII - 07:29:07 to :29:15

At :29:08.5, the gimbal lock light went off indicating the initiation of a full lunar simulation. Almost coincident with this event, the yaw attitude began a very gradual divergence to the right with no pilot yaw commands inputs but with 100 percent yaw left duty cycle as called for by the attitude (heading) hold function of the ACS. At :29:09.5, a pitchup command was given (momentary peak at 12 deg/sec) of a 1-second duration and then was followed by a second of 10 deg/sec for 1/2 second. The vehicle pitchup rate increased to 9 deg/sec and held constant at this rate until :29:11.7. While this pitch command sequence was occurring the yaw divergence was accelerating at 4 deg/sec to the right (yaw duty cycle 100 percent left). The yaw change of attitude caused the airflow direction in the vehicle's x-y plane to change from 0° relative to 45° L by :29:12.5 and was continuing in that direction. By :29:14 the pitch thruster duty cycle meter and the roll thruster duty cycle meter had stabilized at 50 percent, indicating a 100 percent (saturated) single jet (C_T) duty cycle (pitchdown/roll left). At :29:14 (fig. 1-F(b)-3), the vehicle was diverging in attitude about all three axis (12 deg/sec yaw R, 8 deg/sec pitchup and 6 deg/sec roll R) although the maximum available torque from the Test Rocket System was being applied to oppose the divergence. At about :29:14, the pilot moved the hand controller to call for maximum roll left rate in addition to maximum pitchdown rate. At this time, the pitch rate began to decrease but was still in a direction opposite to the command (roll rate continued to increase in a direction opposite to the command).

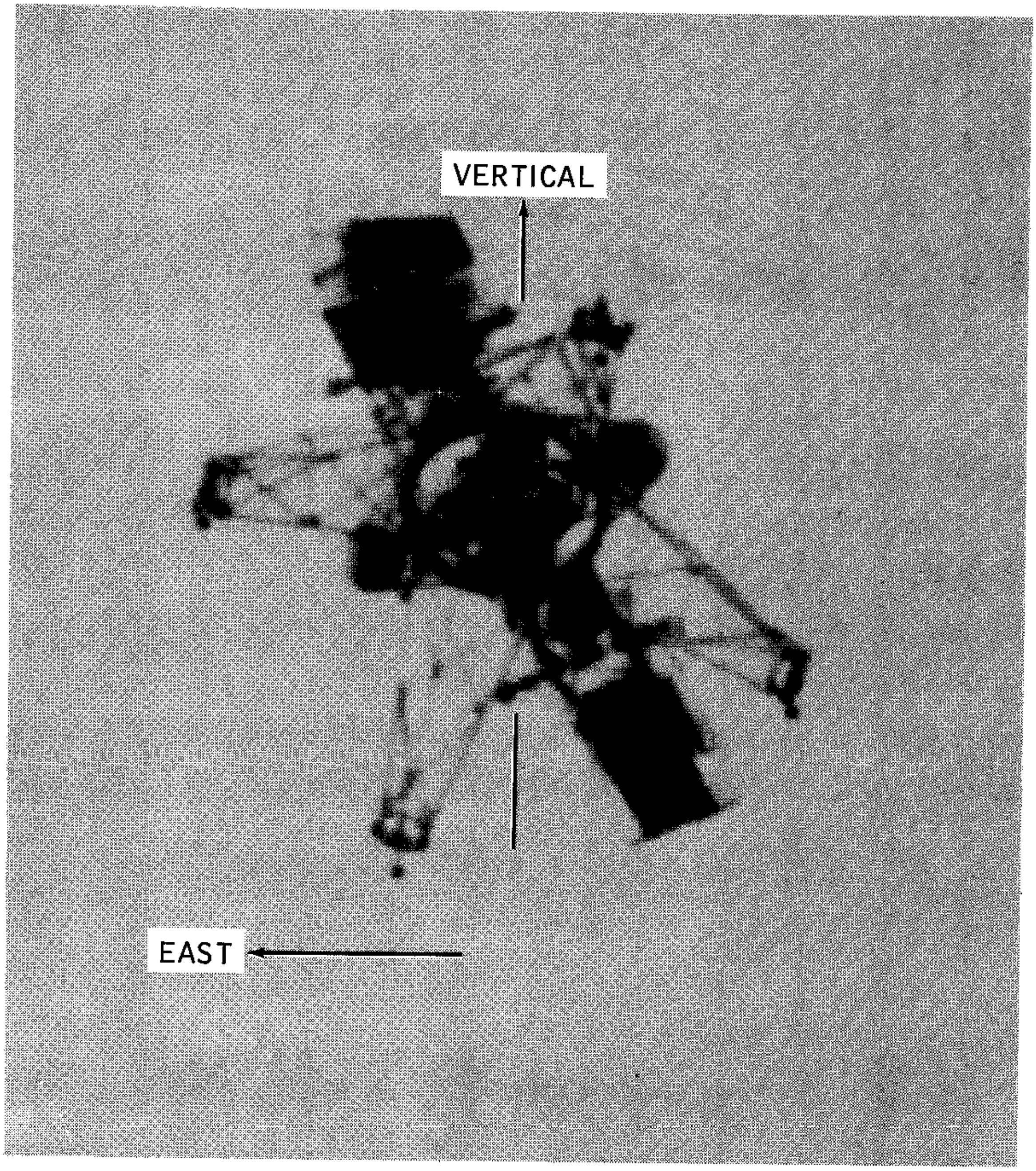


Figure 1-F(b)-3.- Initial Pitchup and Roll Right Photograph
(LLTV #1 @ 07:29:14 c.s.t.)

Phase VIII - 07:29:15 to :29:20

At approximately :29:15 the pilot released lunar simulation and the gimbal actuators started the engine toward the engine centered position. Almost immediately, the gimbal lock light indicated that the engine was being returned to the gimbal lock position. With the jet engine in the gimbal locked position (VTOL mode) and the vehicle pitched up and rolled right, the lateral and forward velocities changed magnitude rapidly. The translation velocities are seen in figure 1-F(b)-5 to pass through zero at :29:17 as the forward velocity reversed, and the lateral velocity changed direction from left to right. Attitude rate command of full pitchdown and full roll left was maintained until about :29:18.7, by which time the vehicle had obtained a pitch rate of about 20 deg/sec down and a roll rate in excess of 22 deg/sec left. The roll rate command was reversed and the pitch rate command zeroed (.2-.3 sec) before the vehicle passed through level attitude at :29:19.

Phase IX - 07:29:20 to :29:27

At :29:21.4, the doppler warning light illuminated, indicating nonreliable data. The radar altitude data also becomes unreliable at or before this time. Assuming conditions of 450 feet and altitude rate equal zero at :29:19, a derivation of vertical acceleration from that point to impact provided the curves of altitude and altitude rate to impact shown on figure 1-F(b)-6. At :29:22.5, a maximum bank angle of 102° was reached; and the pitch angle was 28° down. The pitch and roll rates reversed to pitchup roll right at this time and increased to

22 deg/sec or greater at 07:29:24. During the period after the jet engine (see fig. 1-F(b)-7) was returned to the gimbal lock position, the vehicle (and consequently the engine) attitudes in pitch and roll were mostly greater than that at which the combined vertical component of the jet and lift rocket thrust could counteract gravity. As a result, the vehicle began descending rapidly. The loss of telemetry at :29:26 is probably the time of ejection. The ejection seat rocket blasted the telemetry system and probably interferred with its transmission. The derived attitude at :29:26 comes close to agreeing with that observed from the film record at ejection. The best guess trajectory has ejection occurring at :29:26 at 100 feet and at a descent rate of 95 ft/sec. Vehicle impact probably occurred at :29:27, and pilot on-the-chute touchdown occurred at :29:41.

TABLE 1-F(b)-I.- A TABLE OF SIGNIFICANT EVENTS IN SEQUENCE

	Local Time	Vehicle Attitude Degrees(1)			Yaw Vane(3) Degrees	Anemometer Reading Ft/Sec (4)	Significant Event	Comment
		Pitch	Bank	Hdg(2)				
PHASE IV	07:28:36	0	0	0	9R	37	Aligned with 35R for sim run.	
	:38	0	4R		10R	35	Pilot pitched down further to accel to sim velocity.	
	:39	4D	4R		12R	35	Second time pilot moved hand controller to a stop.	R-L-R roll command to correct back to runway centerline.
V	:53.3	4	0		0	45	T-handle started up.	Wind shifting to left.
PHASE VI	:56.2	6	2R		0	48	Lift rockets on.	
	:58.2	7	2R		2L	48	Auto throttle (5/6 g).	
	:29:05.5	8	0		2L	60	IAS (anemometer) peak at 60 fps.	
	:06.5	8	0		2L	56	Yaw left thrusters firing 100% yaw left.	No pilot yaw commands.

(1) Pitch and bank angles measured relative to the horizon and the vehicle's X and Y axes, respectively.

(2) Heading is the horizontal angle between the vehicle's +x axis and an earth local vertical plane that passed through the x axis at the beginning of this control problem (07:28:07.2), i.e., heading reference rotated 10°R for this chart.

(3) Local airflow direction as measured by the yaw vane (sometimes called wind vane) in the vehicle's x-y plane. The vane is located on the top, right-hand corner of the cab (about 5 feet above the x-axis which induces an error when the vehicle is rolling rapidly about the x axis).

(4) This is the local airflow velocity in the vehicle's x-y (yaw) plane.

TABLE 1-F(b)-I.- A TABLE OF SIGNIFICANT EVENTS IN SEQUENCE - Continued

	Local Time	Vehicle Attitude Degrees			Yaw Vane Degrees	Anemometer Reading Ft/Sec	Significant Event	Comment
		Pitch	Bank	Hdg				
PHASE VII	:29:07.2	7D	0	0	6L	58	Vehicle heading starts drifting R.	Yaw (heading) control is lost.
	:08.5	6		1R	8	58	Lunar sim started.	Gimbal locks released.
	:09.0	6		2	9	58	Engine pitches down 6° for lunar sim.	Wind has shifted about 17°L.
	:10.0	6		3	14	62	IAS starts up from 60 fps.	Wind gust. Pilot commands pitch up.
	:11.0	2U		11	19	70	IAS up to 70 fps.	Wind gust still building.
	:11.5	6		14	25	75	Pitch control lost.	No pilot inputs, attitude hold is firing full pitch dn, but vehicle continues up @ 10°/sec.
	:11.9	12	1R	16	35	75	Third saturated pilot command (pitch down). Roll control is lost.	
	:12.5	17	3	21	54	80	IAS peaks @ 80 fps.	Wind gust of 20 fps and a 40° shift to the left.
	:12.6	18	3	23	60	80	Single rocket (C_T) logic starts (pitch dn, roll left).	
	:12.7	19	4	25	66	80	T-handle full up.	
	:13.3	25	7	34	95	75	Heading rate max @ 13°/sec R.	
	:14.8	31	23	47	130	53	Pilot punched out of lunar sim (engine starts to center).	Note large increase in bank angle.

TABLE 1-F(b)-I.- A TABLE OF SIGNIFICANT EVENTS IN SEQUENCE - Continued

	Local Time	Vehicle Attitude Degrees			Yaw Vane Degrees	Anemometer Reading Ft/Sec	Significant Event	Comment
		Pitch	Bank	Hdg				
PHASE VIII	:29:15.0	31U	30R	48R	130L	51	Emer. gimbal lock starts.	
	:15.2	31	33	49	120	50	Fourth saturated command (roll left)	
	:15.4	31	38	49	120	50	Max engine tilt light.	
	:15.5	31	39	49	120	48	Pilot starts up with jet throttle.	
	:15.6	31	40	50	118	47	Heading rate stops (50°R of starting point). (F_T and H_T yaw left rockets stop firing for first time.	Roll rate max at 17°/sec R, pitch rate 0 at 7°/sec^2 dn.
	:16.2	30	50	52 (4)	93	37	Engine completes gimbal lock up.	
	:17.0	26	54	50	43	20	Roll right stops.	Relative airflow drops to 20 fps and reverses direction.
	:17.5	23	48	48	82R	20	Relative wind 82°R and increasing.	Translating and vertical velocities relative to ground about zero.
	:17.8	20	42	44	90	22	Single rocket logic stops (pitch down only, for 5 sec) but vehicle continues to <u>accelerate</u>, rolling left at 22°/sec^2.	Intermittent yaw R thruster firing.
	:18.3	13	28	40	90	34	Roll R rockets only, for 2½ sec (roll rate 25°/sec L).	Max pitch rate at 20°/sec dn.
	:18.7	6	14	39	90	44	Single rocket logic, pitch up roll right (roll rate 28°/sec L).	

(4) Heading by itself becomes unusable in calculating wind after this point. For a complete and accurate analysis of wind and the vehicle's dynamic and aerodynamic flight after this point, additional data reduction would be required by comparing doppler velocities of the vehicle relative to the ground and of the vehicle's attitudes.

TABLE 1-F(b)-I.- A TABLE OF SIGNIFICANT EVENTS IN SEQUENCE - Concluded

	Local Time	Vehicle Attitude Degrees			Yaw Vane Degrees	Anemometer Reading Ft/Sec	Significant Event	Comment
		Pitch	Bank	Hdg				
PHASE VIII	:29:19.1	1D	2R	38R	82R	51	Vehicle level in pitch and roll, flying backwards and to the right.	Roll rate max at 30°/sec L. Pitching down at 15°/sec.
PHASE IX	:20.0	10	27L	40	0	43	Relative airflow reverses to left still at 50 fps.	Vehicle angular and descent rates so high now that crash is inevitable.
	:21.2	20	85	87 (5)	76L	22	Relative airflow drops to 20 fps 90° from L.	Descent vector involved here.
	:21.7	28	95	90	90	28	Roll R only ACS firing.	
	:21.9	32	100	90+	92	35	Pitch rate stops.	
	:22.1	35	100	90+	95	40	Pitch down-roll R ACS firing.	Yaw R thruster saturated again.
	:22.5	35	100	90+	97	58	Roll left stops.	
	(6) :22.7	34	100	90+	98	68	Roll R only ACS firing.	
	:23.2	25	90	90+	98	97	Pitch down-roll R ACS.	
	:23.5	22	85	90	95	113	Pitch down-roll L ACS.	
	:24.0	0	75	52	90	120+ (est 135)	Hand controller released.	
	:25.5	15U	10	14L	72R	120+ (est 135)		
	:26.0	25	0	18L	210	50	TM data stops.	Ejection
	:27.0	35	80R	NW			Vehicle impact.	Vehicle translating northwest rapidly.

(5) Heading is not very reliable when vehicle attitude is greater than about 85° in either pitch or bank.

(6) Attitude TM data unreliable past this point. Color movies used to estimate attitude.

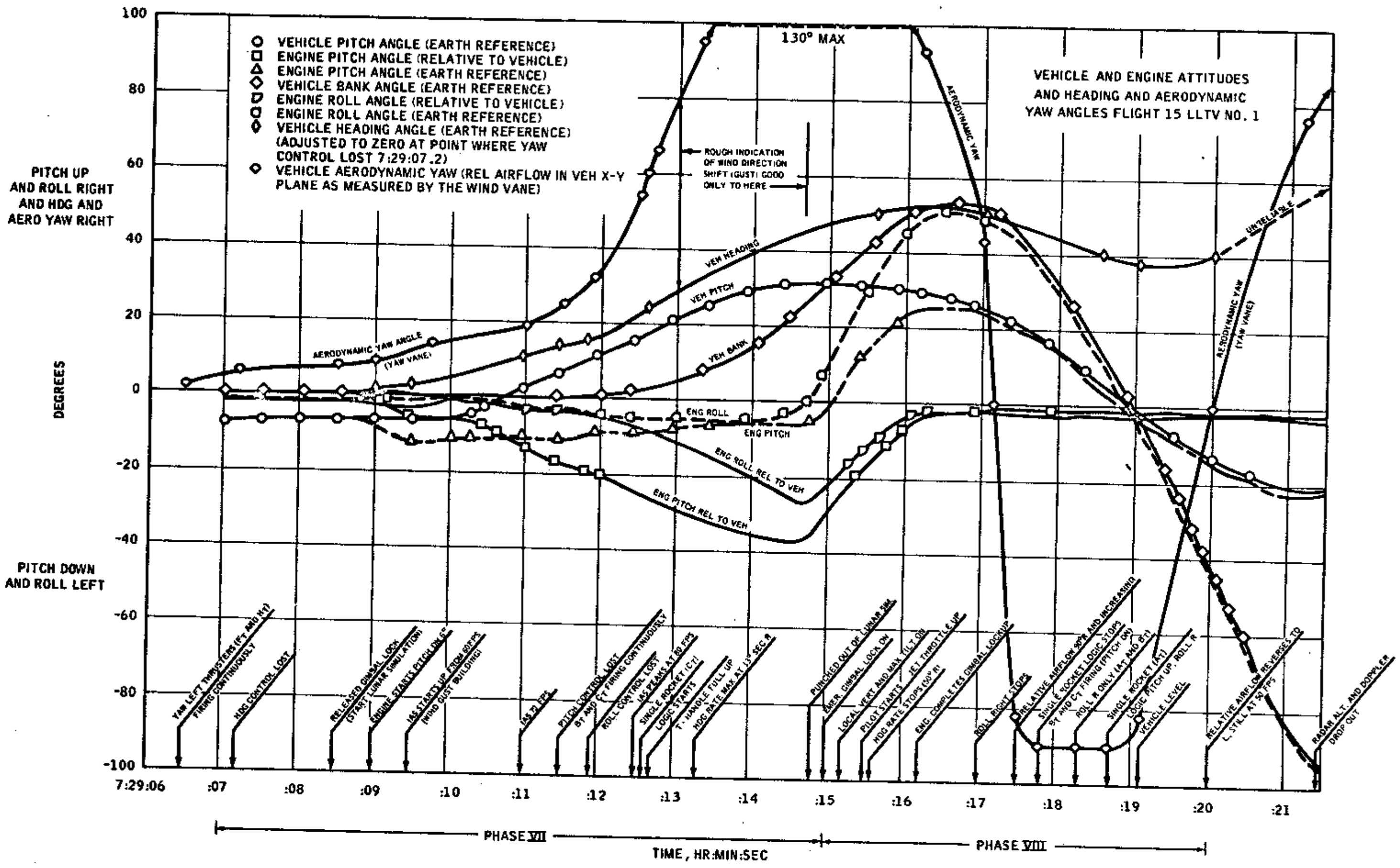


Figure 1-F(b)-4.- Vehicle and Engine Attitudes and Heading and Aerodynamic Yaw Angles

LLTV NO.1 - ACCIDENT DATA

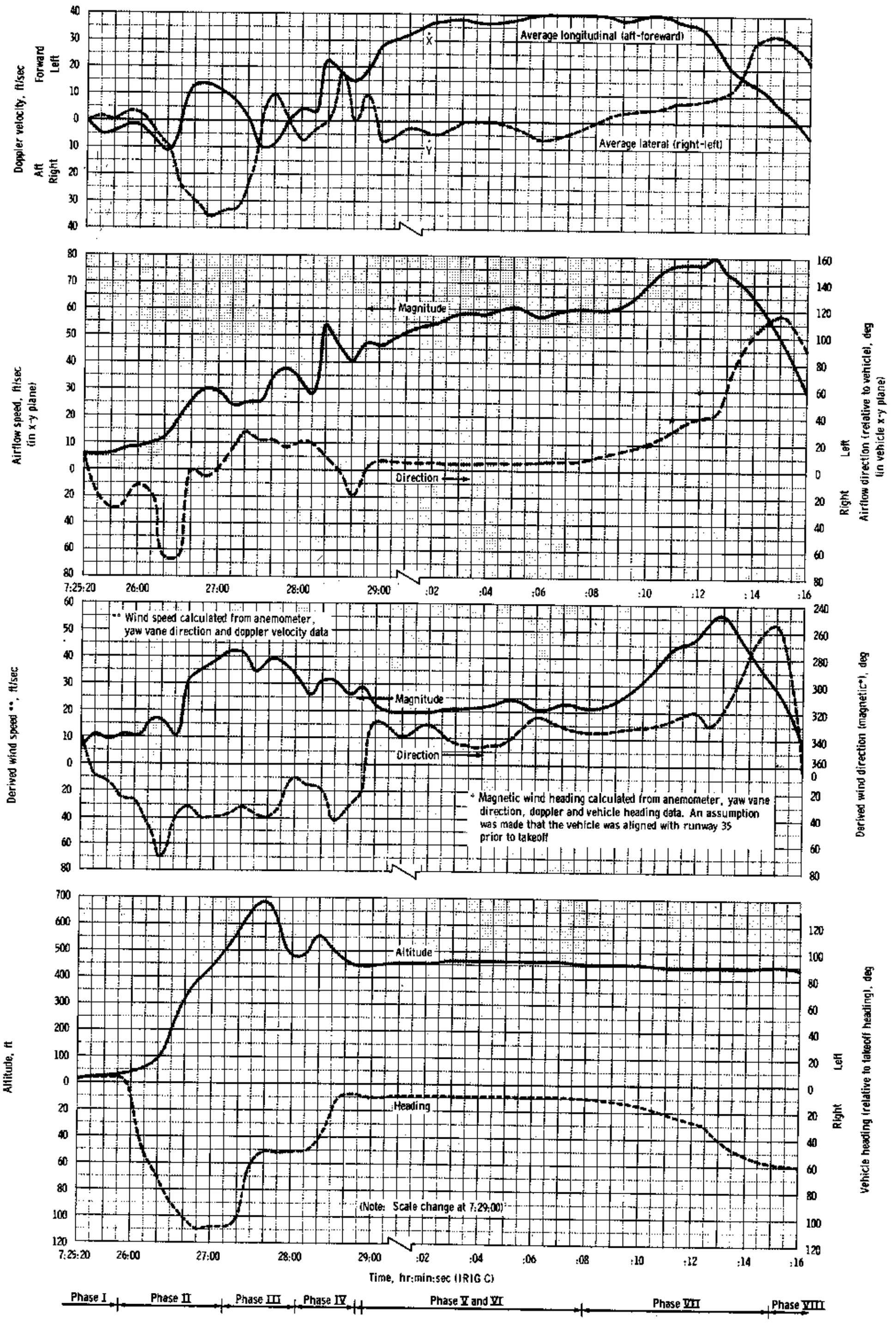


Figure 1-F(b)-5.- Doppler, Airflow, Derived Wind, Altitude and Heading

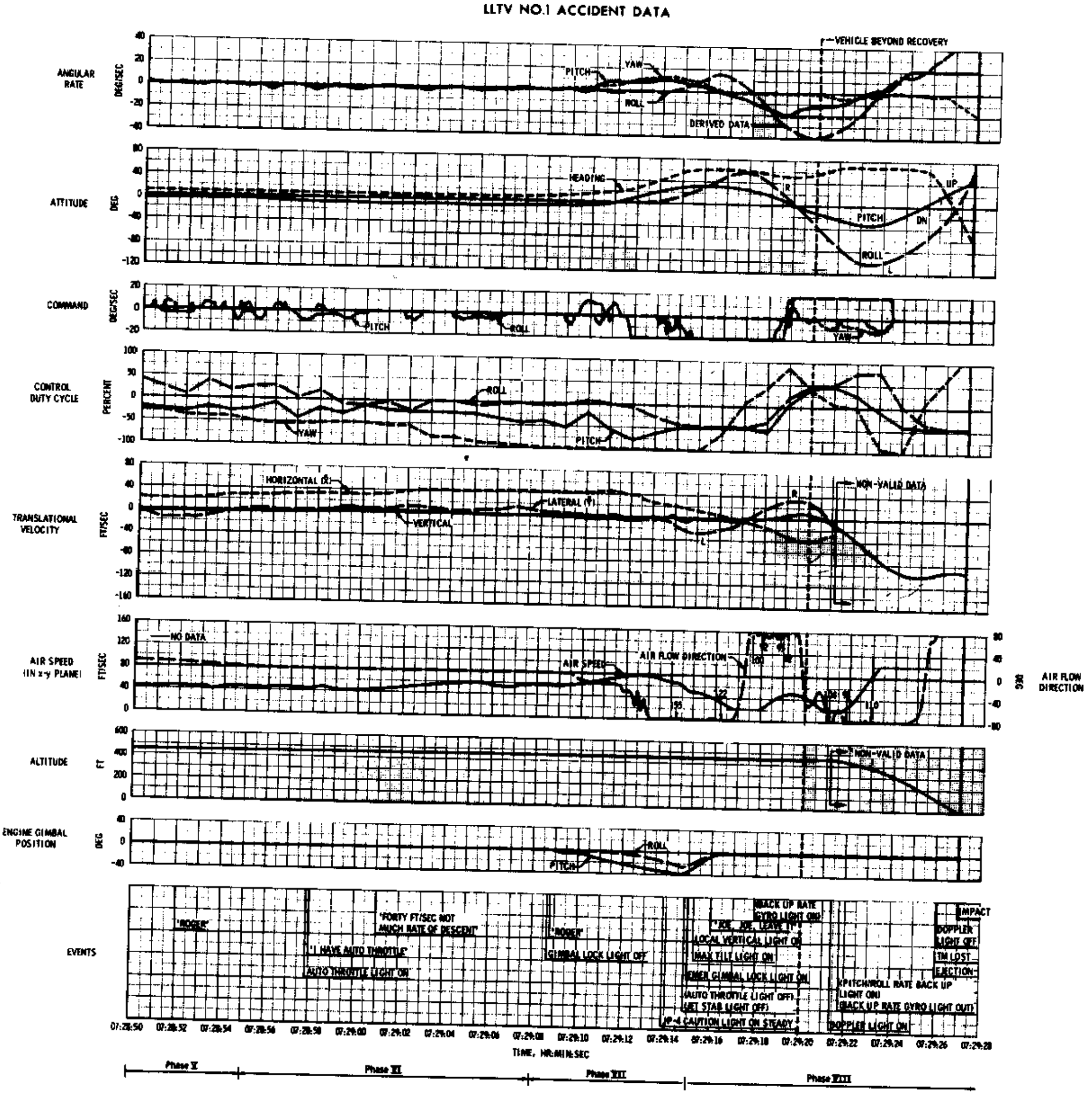


Figure 1-F(b)-6.- Angular Rate, Attitude, Communications, Duty Cycle, etc.

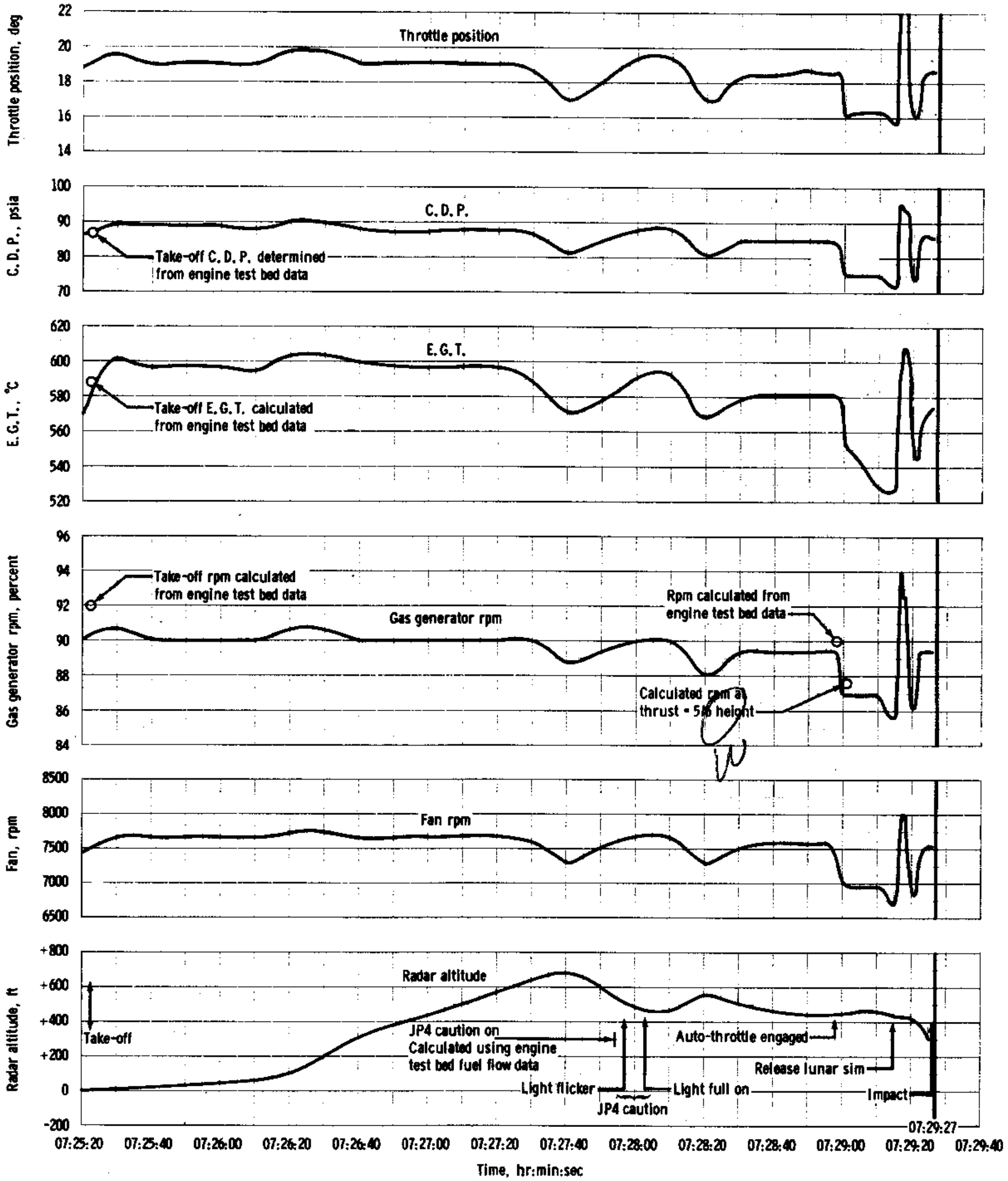


Figure 1-F(b)-7.- Fan Jet Engine Parameters

1-G

FLIGHT & OPERATIONS PLAN

1-G-1

MILITARY FLIGHT PLAN

AIRCRAFT UNIT OF ASSIGNMENT/HOME STATION: NASA MSC EFD

AIRCRAFT SERIAL NO.: LLTV-1

TYPE OF FLIGHT PLAN: ☐ IFR ☐ DVFR ☒ VFR ☐ FVFR

RADIO CALL: TM1 VAW

AIRCRAFT DESIGNATION/TO CODE: LLTV-1

ESTIMATED TRUE AIRSPEED: —

DEPARTURE TIME (Z): PROPOSED 1330Z ACTUAL

INITIAL CRUISING ALTITUDE: —

POINT OF DEPARTURE: EFD

STANDARD INSTRUMENT DEPARTURE

NAME AND NUMBER: — TO

IFR	VFR	ROUTE OF FLIGHT	TO	ETE
	X	LOCAL	—	0+10

REMARKS —

RANK/HONOR CODE —

PSGR/CARGO CODE —

HOURS FUEL ON BOARD	DIST TO DESTN	ALTERNATE AIR FIELD	ETE TO ALTN	NOTAMS	DD FORM 365F (*Wt. and Bal.*)	WEATHER	REQUEST CLEARANCE AFTER
0+30	—	—					—

INST RATING	SIGNATURE OF PILOT IN COMMAND	SIGNATURE OF APPROVING AUTHORITY	DATE
—	—	Harold E. Ream	12/8/68

CREW/PASSENGER LIST – ☐ *Attached* ☐ *See Passenger Manifest*

DUTY	NAME AND INITIALS	GRADE	SERVICE NO.	ORGANIZATION AND LOCATION
PILOT IN COMMAND	ALGRANTI JS	CIV	—	NASA MSC EFD

PREVIOUS EDITION OF THIS FORM WILL BE USED UNTIL STOCK IS EXHAUSTED.

☆ U.S. GOVERNMENT PRINTING OFFICE : 1966 0—221-375

0-38305

Model 7260 Date 26 September 1968	**BELL AEROSYSTEMS** A COMPANY	Page 1 of 3 Report 7260-931014

LLTV MISSION PLAN

1. Pilot J. S. Algranti Oper. No: T1-15-162F Date: 12-6-68

2. Weight and Balance

(a) Clearance (Form 3-1) LLTV No. 1 Issue No. 4 Dated 10-14-68

(b) Leg Ballast

	Fwd Lt.	Fwd. Rt.	Aft. Lt.	Aft. Rt.
Leg Ballast	6.5#	4.2#		

(c) Aft Rack Position
X (Datum Full Fwd) 1 hole aft
Y (Datum Centre) 3 holes left
Z (Datum Full Down) 1 hole up

(d) Centre of Gravity

O.W.E. Plus Ballast --
X - Body Station BS 200.00
Y - Buttock Line BL 200.00

O.W.E. Plus Ballast minus gimballed equipment - Z - Waterline WL 199.78

(e) Fully Serviced Weight 4178 lbs.

3. Objectives:

Primary (a) Verification flight after completing CCA #8 changes.
(b) Full LUNAR SIM checkout.

Secondary

Pilot: J. S. Algranti Oper No: T1-15-162F Date: 12-6-68

4. Mission Checklist

a. Take-Off: PRIMARY RATE COMMAND/GIMBAL LOCKED.

b. Release LOCAL VERTICAL

c. Translate away from TM Van and climb to Lunar Sim entry position at approximately 500 feet altitude.

d. Establish hover. (Call wind speed and direction.)

e. Select MOMENT COMP. ON.

f. Select LUNAR SIM ON.

g. Pitch down 10 degrees and commence acceleration and descent. (Call H_2O_2 remaining and He source pressure.)

h. At approximately 30 fps (5 to 7 seconds) raise T-handle. (Verify auto throttle.)

i. At approximately 45 fps (2 seconds later) select GIMBAL LOCK OFF.

j. Fly to a landing: PRIMARY RATE COMMAND with MODEL/LUNAR SIM.

Model 7260 Date 26 September 1968	**BELL AEROSYSTEMS** A textron COMPANY	Page 3 of 3 Report 7260-931014

Pilot: J. S. Algranti Oper No: T1-15-162F Date: 12-6-68

5. Changes Since Last Flight:

Avionics System

a. Auto throttle relocated to drive fuel control through Cam assembly.

b. Override force checked at 28#.

c. Emergency throttle realigned and checked out satisfactory on engine run.

Electrical and Data System

a. Rate gyro and accelerometer running time meters installed (CCA #8).

b. Avionics Backup light functions wired to TM (CCA #8).

c. Emergency inverter power loss function wired to TM (CCA #8).

d. Master warning control box replaced (diode protection for transistorized switch - DC warning light - added.)

e. Anemometers - voltage doubler circuit removed -
cockpit instrument recalibrated
- underreads by about 6 fps below 30 fps
- accurate above 30 fps.

Compiled By: Alan O. King 12/6/68
A. O. King

Approved by: 8 Dec 68
R. Blilie

Approved By: J S Algranti
J. S. Algranti

Approved By: J S Algranti
PILOT

Distribution:
Pilot (1)
TM Van Crew (6)
File (1)
S. Nassiff (3)

1-H

MAINTENANCE & INSPECTION RECORDS

MAINTENANCE AND INSPECTION REPORT

A. Vehicle Historical Data

1. Vehicle Identification: Lunar Landing Training Vehicle Serial Number 1
2. Acceptance Date: October 1967
3. Total Flight Hours: 02:08:38
4. Unit was received new and has had no overhauls.
5. Dates and type of last inspection attached.

B. Engine Historical Data

1. Engine Model and Series: CF-700-2CV
2. Engine Serial Number: 239-007
3. Total Engine Hours: 22:22:00
4. Engine received new from General Electric and has no overhaul history.
5. Date installed in vehicle: 7 June 1968
6. Time Accrued Since Installation: 22:14:00
7. Date of Last Inspection: Not Applicable
8. Type of Last Inspection: Pressurization Runs and Installation Only
9. Type of Fuel Utilized: JP-4

C. Miscellaneous Chemical Explosion Data

1. Explosion of propellants occurred upon ground impact during vehicle break-up.

D. Systems Status After Crash

1. There were numerous laboratory analysis and functional tests accomplished on components, gases, and fluids from the various systems which verified the vehicle operations to have been in accordance with the specifications under the circumstances at the time of the vehicle crash.

INSPECTION CRITERIA FOR LLTV #1

	Last Completed	Due Date
30-Day Items		
Landing Gear Struts Serviced	11-22-68	
Rocket System Functional	11-17-68	
Stuck Valve Check (Ramp)	11-18-68	
Visual Inspection of Structure Welds		11-25-68
Lunar Sim. Alignment	11-11-68	Suggested 12-19-68
ACS Alignment	11-11-68	Suggested 12-04-68
60-Day Items		
Avionics Test Cart Verification	9-30-68	Suggested 1-01-69
Battery Change (Capacity Check)	11-04-68	
90-Day Items		
H_2O_2 High Pressure Relief Valve Check	11-15-68	
TM Calibrations Including Rate and Attitude Gyros and Accelerometer Cals.	9-30-68	Suggested 1-02-69
Seat Inspection	11-15-68	
Filters - Changed or Cleaned		
JP-4 Tanks (2) Fuel Control (2)	11-04-68	
JP-4 Pressurization (1)	11-04-68	
Hyd. Pump (1)	11-04-68	
Helium (2)	11-15-68	
Engine Oil (1)	11-06-68	

INSPECTION CRITERIA FOR LLTV #1

	Last Completed	Due Date
90-Day Items (Continued)		
Hyd. System Press. Relief Valve	11-22-68	
Hyd. System Sample & Particle Count	11-22-68	
120-Day Items		
Doppler Radar Check	11-21-68	
Radar Altimeter Check	11-21-68	
Autothrottle Actuator High Speed Gears Checked and Lubricated	11-23-68	
180-Day Items		
Eng. Inspection & Functional Test	6-13-68	
Eng. Oil Change	11-14-68	
O_2 Bottle & Reg. Checked (Purge)	10-01-68	
Dye Penetrant Check of All Weld Areas		Suggested 4-03-69
Electrical Plug & Wire Inspection	9-07-68	
360-Day Items		
Proof Load H_e and H_2O_2 Tanks		Suggested 10-03-69
Check Max. Thrust of Lift Rockets	10-01-68	
X-Ray and Zyglo Gimbal Ring		Suggested 10-03-69
X-Ray Trunnions		Suggested 10-03-69
JP-4 System Functional Check	Approx. 9-30-68	

1-I

COM, RECORDINGS, TRANSCRIPT

TIME HISTORY OF EVENTS AND AUDIO RECORD
FLIGHT T1-15-162F, DECEMBER 8, 1968

Source Code:		
	Event	- From Telemetry Data
	UHF	- Air-Ground Radio
	IC	- TM Van Intercommunications

Time	Source	Audio or Event
07:25:23	Event	Liftoff
:23.5	Event	Doppler light out (doppler operative)
:30.8	Pilot - UHF	Local vertical release
:34	Blilie - IC	Balance - Tom?
:35	Pierson - IC	Left side heavy
:38	Blilie - UHF	We're showing you slightly left side heavy
:39	Pilot - UHF	O.K. The wind is slightly off my right
:42	Blilie - UHF	Roger
:48	Pilot - UHF	It's a nice cool day. I'm hovering at 92 percent. I'll do a 180 and start translating down the runway.
:56	Blilie - UHF	Roger
:58	Pierson - IC	Still left side heavy
:59	Blilie - IC	He's turning around now. Should be cross wind.
:26:04	Pilot - UHF	Radar altimeter appears to be working O.K.
:08	Blilie - UHF	Roger
:10	Reisert - IC	Two minutes to caution
:12	Blilie - IC	O.K.
:32	Pierson - IC	Still showing left side heavy

Time	Source	Audio or Event
07:26:34	Blilie - IC	Still showing left side heavy?
:37	Pierson - IC	25 percent
:38	Blilie - IC	Yea, that's it
:40	Blilie - IC	25 percent? O.K.
:42	Pilot - UHF	I'm letting the wind blow me. It looks like I've got a fairly good wind up here. I'm indicating 400 feet now.
:48	Blilie - UHF	Roger
:51	Pilot - UHF	My time to caution please?
:54	Blilie - UHF	Show you one and a half minutes to caution
:58	Pilot - UHF	O.K.
:27:03	Pilot - UHF	I've got a car that's just about coming up under my operating area. I have him in sight. Don't worry about him.
:12	Blilie - UHF	O.K. He'll be crossing. I believe he's G.C.A. man.
:17	Reisert - IC	One minute to JP-4 caution
:20	Blilie - UHF	One minute to JP-4 caution
:22	Pilot - UHF	O.K.
:28	Pierson - IC	Balance looks better
:33	Blilie - UHF	Your balance looks good
:39	Reisert - IC	30 seconds to caution
:42	Blilie - UHF	You're drifting off the runway Joe. You've got 30 seconds to caution.

Time	Source	Audio or Event
07:27:48	Pilot - UHF	O.K. I'm reading 30 feet per second at 500/.....
:52	Blilie - UHF	Say again -- you cut out
:56	Pilot - UHF	30 feet per second, 550 feet. I'm hovering into the wind - now I've a little wind off my right.
:28:02	Blilie - UHF	I show you with a JP-4 caution light
:05	Pilot - UHF	Hovering set up, moment comp is on, and lunar sim is on
:05	Pilot - UHF	Lunar sim is on
:10.7	Event	Jet stab on
:10	Blilie - UHF	Your jet stab on. Verify moment comp on.
:14	Pilot - UHF	I said the moment comp is on
:46	Pilot - UHF	I've got about 25 feet per second. T-handle coming up now.
:52	Blilie - UHF	Roger
:57.8	Event	Auto throttle on
:58	Pilot - UHF	I have auto throttle
:29:01	Pilot - UHF	I have 40 feet per second, not much rate of descent.
:08	Pilot - UHF	Gimbal lock is off
:08	Blilie - UHF	Roger
:10.8	Event	Pilot initiates nose-up

Time	Source	Audio or Event
07:29:13.9	Event	JP-4 caution on steady
:14.8	Event	Auto throttle off - Jet stab off
:14.9	Event	Emergency gimbal lock on
:15.2	Event	Max tilt on
:15.3	Event	Local vertical on
:16	Blilie - UHF	Joe, Joe, leave
:17.9	Event	Backup rate gyro light on
:21.4	Event	Doppler light on
:21.7	Event	Pitch/roll rate backup. Backup rate gyro light out.
:23	Pierson - IC	Joe, get out!
:26	Event	Doppler light off
:26.1	Event	Doppler light on. End of data.
:27	Event	Vehicle Impact
:29	Blilie - UHF	Ellington Tower Emergency in the LLTV area
:34	Tower - UHF	Roger, the crash trucks are on the way now

1-J

LIST OF DAMAGED PARTS

DAMAGED PARTS

The complete vehicle and all components were a total loss. No segment of the LLTV No. 1 could be used as flight hardware again.

1-K

PARTS TEARDOWN REPORTS

PARTS TEARDOWN AND LABORATORY REPORTS

All teardown and laboratory reports are in the Accident Board files and available if required.

They are not included at this point because they do not contribute anything to this report. All systems were functional as stated in the Maintenance Section of this report.

1-L

LAB REPORTS

LABORATORY REPORTS

All laboratory reports are in the files of the Accident Board and are available if they are required.

The laboratory reports are not included in this report because they contribute nothing; all systems were functional.

1.0

MEDICAL REPORT

TO : Chairman, LLTV Accident Investigation Board

FROM : G. F. Humbert, M.D.

SUBJECT: Statement concerning the Lunar Landing Training Vehicle (LLTV) accident of 8 December 1968

At approximately 0700 on 8 December 1968, I was on duty at the Lunar Landing Training Vehicle (LLTV) site (Ellington AFB) as support Medical Officer for a LLTV flight. The pilot of the craft was Mr. Joe Algranti. The morning was "clear and crisp" with little surface wind. I noted that the steam from reaction control jets on the LLTV was unusually and persistently visible. The preparatory events were not remarkable as far as I could observe. Engine "light off" and preflight events were not unlike more successful flights. I did note, in retrospect, that after lift-off more thruster activity was evident than is usual. Ascent to approximately 500 feet was unremarkable.

Shortly after maximum height attainment, at approximately 0730, the craft appeared unstable. This became markedly evident when a large pitchup attitude was noted. Increased evidence of control instability followed with the craft making unusual changes in roll and pitch. Concurrently, the craft lost altitude. It appeared that the pilot ejected very close to the last possible moment consistent with survival. That ejection occurred at a time when the seat/man trajectory was approximately 45° - 55° from the vertical. Seat separation and chute deployment were nominal. The chute was completely full at pilot touchdown, well away from the burning wreckage. He performed a roll landing maneuver without injury. His chute collapsed without dragging him.

I arrived at the pilot's side approximately two minutes after touchdown. The pilot was on his back. He was conscious but minimally stunned. He was coherent and able to relate that he was not injured. Cursory examination confirmed this to be true. The pilot related how sorry he was "to have to leave the bird." After the pilot rested a few moments, I assisted him to the ambulance. Together we returned to the LLTV site trailer for a more complete examination. No remarkable findings were noted.

After he debriefed the accident with the rest of the flight team, he proceeded to the MSC site dispensary for a complete examination. See the enclosed narrative summary.

G F Humbert M.D
G. F. Humbert, M.D.

Enclosure

1-0-2

Standard Form 502
Rev. August 1954
Bureau of the Budget
Circular A-32

CLINICAL RECORD	NARRATIVE SUMMARY	
DATE OF ADMISSION 12-8-68	DATE OF DISCHARGE NA	NUMBER OF DAYS HOSPITALIZED NA

(Sign and date at end of narrative)

POST-ACCIDENT PHYSICAL EXAMINATION

HISTORY:

On 8 December 1968 during a qualification flight of a Lunar Landing Training Vehicle (LLTV), Mr. Algranti was forced to eject at approximately 100 - 150 feet because of severe attitude control difficulties and concurrent loss of altitude. The ejection was initiated very late in the accident sequences. The system worked very well, resulting in a fully deployed and open chute at pilot touchdown. The only positive finding at the crash site was pain in the left hamstring muscle.

REVIEW OF SYSTEMS:

CNS: Not remarkable

MUS-SKEL: Post ejection pain in both posterior thighs

OTHER SYSTEMS: Not remarkable

PHYSICAL EXAMINATION:

GENERAL: Well developed white male in minimal acute distress with diffuse pain in both posterior thighs, greater on the left. Mental alertness not compromised

T= 98 BP= 140/85 P= 105 R= 18

HEAD: Normocephalic

EYES: Pupils - round regular and equal
Light reflex - equal
E.O.M. - intact
Funduscopic exam - negative

EARS: Not remarkable

NOSE: Not remarkable

THROAT: Not remarkable

(Use additional sheets of this form (Standard Form 502) if more space is required)

SIGNATURE OF PHYSICIAN D F. [illegible] MD	DATE 14 FEB 69	IDENTIFICATION NO.	ORGANIZATION
PATIENT'S IDENTIFICATION *(For typed or written entries give: Name--last, first, middle; grade; date; hospital or medical facility)*		REGISTER NO.	WARD NO.

Algranti, Joseph S.

Standard Form 502
Rev. August 1954
Bureau of the Budget
Circular A-32

CLINICAL RECORD NARRATIVE SUMMARY

DATE OF ADMISSION: 12-8-68

DATE OF DISCHARGE: NA

NUMBER OF DAYS HOSPITALIZED: NA

(Sign and date at end of narrative)

PHYSICAL EXAMINATION (Continued)

NECK: Supple, no tenderness

CHEST: Clear to A&P; N.S.R.; no murmurs; A_2 is greater than P_2

ABD: Not remarkable

BACK: Not remarkable, no spinal tenderness noted

EXTREMITIES: No deformity noted, R.O.M. not compromised. Minimal contusions, abrasions, and ecchymosis noted to involve both posterior thighs. Mild tenderness and hyperemia noted.

NEURO: Not remarkable

LAB:

Blood carbon monoxide = None
Blood sugar = 89 mgm% (Actual)
Blood ethyl alcohol = None
Blood urea nitrogen = 18.5 mgm%
Blood HEB. = 15.5 Grams
Blood HCT. = 45.5%

IMPRESSION:

1. Post-ejection trauma to both thighs (greater on left)
2. Normal adult male

RX:

1. Ice packs PRN
2. Darvon Compound 65 4h PRN

12 DECEMBER 1968:

Because of moderate ecchynosis, edema and pain of posterior left thigh, the

(Use additional sheets of this form (Standard Form 502) if more space is required)

SIGNATURE OF PHYSICIAN

DATE: 14 FEB 69

IDENTIFICATION NO.

ORGANIZATION

PATIENT'S IDENTIFICATION *(For typed or written entries give: Name—last, first, middle; grade; date; hospital or medical facility)*

REGISTER NO.

WARD NO.

Algranti, Joseph S.

1-0-4

Standard Form 502
Rev. August 1954
Bureau of the Budget
Circular A-32

CLINICAL RECORD	NARRATIVE SUMMARY	
DATE OF ADMISSION 12-8-68	DATE OF DISCHARGE NA	NUMBER OF DAYS HOSPITALIZED NA

(Sign and date at end of narrative)

12 DECEMBER 1968 (Continued):

patient placed on oral emzyme (ORACYME) therapy for four days. Rest with leg elevation indicated.

19 DECEMBER 1968:

Almost complete resolution of soft tissue injury--full duty status.

(Use additional sheets of this form (Standard Form 502) if more space is required)

SIGNATURE OF PHYSICIAN J.F. [illegible], Jr MD	DATE 14 FEB 69	IDENTIFICATION NO.	ORGANIZATION

PATIENT'S IDENTIFICATION *(For typed or written entries give: Name—last, first, middle; grade; date; hospital or medical facility)*

REGISTER NO.

WARD NO.

Algranti, Joseph S.

NARRATIVE SUMMARY
Standard Form 502
502-108-03

1-0-5

LIFE SCIENCES REPORT OF AN INDIVIDUAL INVOLVED IN AN AF ACCIDENT/INCIDENT
SECTION A. AIRCRAFT ACCIDENT/INCIDENT

1 GENERAL

a. Name, Grade, Serial No. Algranti, Joseph S. (Civilian)
b. Assigned Base and Command MSC - Houston
c. Aircraft Type, Model, Series (as applicable) LLTV # 1
d. Primary AFSC NA
e. Duty Assignment NASA Pilot
f. Current Rating NA
g. Age 44
h. Height 70½
i. Weight 178
j. Years of Educ. 17
k. Activity at time of Accident/Incident Test Flight

2 Chief, Aircraft Operations MEDICAL DATA

a. Degree of Injury: None ___ Minor X Major ___ Fatal ___ Missing ___
b. Days Hospitalized -0-
c. Days in Quarters 2½
d. Total Days to be Lost 2½
e. Waiver NA Yes ___ No ___ Specify ___
f. If Fatal: Was Autopsy Form Submitted to AFIP? Yes ___ No ___ NA
Were Specimens Submitted to AFIP? Yes ___ No ___ Frozen ___ Fixed ___
g. Diagnosis: Describe Fatalities, Injuries and Causes (Use Basic Diagnostic Nomenclature, AFR 160-13). Specify Primary Injury in non-fatal or primary cause of death in fatal.

Contusions, compression trauma, abrasions posterior, both lower extremities.

3 PHYSIOLOGICAL INCIDENT (Complete Items 1, 2, 3, 4, 5, 6, 7, and 10 as applicable)

a. Type Mission Test
b. Duration of Flight 3.5 minutes
c. Single Ship ☒ Formation ☐
d. Ind. Alt at time of inc. 500'
e. Cabin Alt at time of inc. 500'
f. Time at Alt. NA hrs. Aircraft Pressurization ground checked on NA
g. Did you use O₂ Preflight? Check: Yes ☒ No ☐
h. Regulator Setting 100% Last Check on NA
Type Regulator Used Scott System
i. Oxygen System Pressure at takeoff: 1800
at time of incdt 1500 Capacity 1800
j. Last Check of O₂ System on Takeoff
k. Type of Mask MBU-5/P Adequate Fit: Yes ☒ No ☐
Checked within 15 days ☒ 30 days ☐ Over 30 ☐
l. Time Lapse between incident and examination Approximately 2 minutes
m. Specify Tests (Specify Type and Results):
CO - None
Blood Sugar - 89 mgm %
Ethyl Alcohol - None
~~XXXXX~~ BUN 18.5 mgm %
~~XXX~~ Hb=15.5 Hct=45.5

tach a diagram of the flight profile involved, use additional sheet(s)

4 PSYCHOPHYSIOLOGICAL FACTORS

Check only factors present. Explain the basis for your determination in Item 10. Cite all clinical and lab evidence

FACTOR	Not Sig	CONTRIBUTED TO ACCIDENT			FACTOR	Not Sig	CONTRIBUTED TO ACCIDENT		
		Definite	Probable	Possible			Definite	Probable	Possible
Aging					Preoccupation/Channelized Attention				
Alcohol					Other				
Air Sickness					Fatigue				
Auditory Interference					G-Forces				
Body Build					Hyperventilation				
Boredom					Hypoxia				
Cardiovascular					Illness				
Discipline					Language Barrier				
Distraction					Missed Meals				
Drugs and/or Self-Medication					Motivation/Morale				
Dysbarism (Specify)					Spatial Disorientation				
Emotional Disturbances					Task Over-saturation				
Anxiety					Unconsciousness				
Fear					Vertigo				
Get-Homeitis					Visual Restriction				
Irrational Behavior					Other Related Factors (Explain)				
Over Confidence					No Factors Present X		▨	▨	▨
Panic									

5 ENVIRONMENTAL FACTORS

(Check only factors present. Explain the basis for your determination in Item 10. Cite all clinical and lab evidence)

FACTOR	Not Sig	CONTRIBUTED TO ACCIDENT			FACTOR	Not Sig	CONTRIBUTED TO ACCIDENT		
		Definite	Probable	Possible			Definite	Probable	Possible
essure, i.e. Rapid mpression, Pressure Loss, Etc., Specify					Smoke, fumes				
Cold					Vibration				
Deceleration Forces					Weather			X	
Heat					Windblast				
Light Intensity					Other Related Factors, Specify				
Noise					No Factors Present		▨	▨	▨

6 TRAINING RELATED TO THIS ACCIDENT/INCIDENT (Give Dates Accomplished)

a. Ejection Seat Training: Seat Simulator July 1968 Ejection Seat Tower 1963 Previous Ejection None
Lectures/Demonstrations July 1968 Other (Explain) ___

HOURS
Total Flying Time 11,500 hr
This model LLTV = 1 hr
LLRV = 2 hr

b. Survival Training: July 1968
USAF School: Ground x Water ___ Arctic ___ Jungle ___ Lectures/Demonstrations July 1968 Other ___
c. Parachute Training:
Jump School: No Nr. Previous Jumps -0- Lectures/Demonstrations July 1968 Other Parasail 1963 - 1968
d. Physiological Training Date April 1966 Place Randolph AFB
e. Last Chamber Flight Date April 1966 Place Randolph AFB
f. Type Flight NA

g. AFSC or Other Training	h. Name of Course or OJT	i. Dates Attended	j. Aptitude Scores Applicable
NA			

7

PERSONAL, PROTECTIVE AND SURVIVAL EQUIPMENT

Specify all applicable items of equipment on appropriate line and specifically indicate all types of clothing worn and any other equipment that influenced operation.

ITEM	EXAMPLE	TYPE	NOT AVAILABLE	AVAILABLE: Not Used	AVAILABLE: Used: Functioned	AVAILABLE: Used: Failed
Head Protection	P-4B, HGU-2/P, HGU-6/P	Protect, Inc. Molded Helmet			X	
Eye Protection	Visor, Glasses	Visor			X	
Ear Protection	Ear Plugs, Muff	Helmet			X	
Oxygen Mask	MBU-5/P MBU-3/P	MBU-5/P				
Clothing Worn	K-2B, A/P-22S-2	Beta-cloth Flying Suit				
Clothing, Survival	Sleeping Bag, Down-Filled Suit		X			
Gloves	B-3A, MG-1	Standard			X	
Footgear	Alert Boots, Combat Boots	Denher Custom Boots			X	
Body Restraints	Seat Belt, Shoulder Harness	Navy Integrated			X	
Life Vest	LPU-2/P		X			
Life Raft	PK-2, E-2B		X			
Survival Kit, Container	Global, MD-1		X			
Communications	URC-11, SARAH		X			
Other Signaling Devices	Flares, Mirrors, Whistle		X			
Rations	Food/Water, Provided/Forged		X			
Survival Equipment	Rifle, Fishing Gear		X			
Seat	Fwd/Rear Facing, Side, Fixed, Etc.	Weber LLTV Ejection			X	
r Equipment	Flashlight, etc. (Specify)		X			

8

ESCAPE

a. General: (Check or fill in as appropriate)

Ejection ☒ Bailout ☐ Landing Surface: Ground ☒ Flat X Mtns ____ Ice/Snow ____ Hilly ____ Desert ____ Wooded ____ Swamp ____ Other (Exp) Grassy

Water ☐ Calm, Shallow ____ Deep ____ Rough, Shallow ____ Deep ____ Unknown ☐

b. Surface Winds, Knots Calm (estimate if unk) Dragged: Yes ☐ No ☒ Difficulty releasing Chute Canopy: Yes ☐ No ☒

c. Reason for Jump (if more than one indicate):
Fuel Exhaustion ____ Fire ____ Engine Failure ____ Mid-Air Collision ____ Loss of Control X Other (Exp) ____

d. Attitude of Aircraft:
Level ____ Inverted ____ Dive ____ Bank ____ Spin ____ Spiral ____ Climb ____ Other (Exp) Pitch up & roll rt. - 45° Escape Trajectory

e. Altitude above Surface 500' IAS 30 Km (if not known, approx.) Seat Catapult: Ballistic ____ Rocket X

f. Difficulties Initiating Escape: Minimal, posterior lower extremities
Centrifugal Force ____ Canopy/Hatch Failure ____ Injury X Actuating Controls (Specify) ____ Other (Exp) ____

g. Difficulties During and After Escape:
Clothing/Equipment Interference ____ Seat entangled in Shroud Lines ____ Legs/Arms entangled in Shroud Lines ____ Automatic Lap Belt Malfunction ____
Held onto Seat Actuating Controls ____ Did not Separate ____ No Dif X Other (Exp) ____

h. Seat Separation Device Installed: Yes X No ____ Functioned Properly: Yes X No ____
Failed: Webbing ____ Initiator ____ Other (Exp) ____

i. Type Parachute: Seat X Back ____
Canopy release: Single ☐ Double ☐ None
Canopy: 28' X 30' ____

Parachute equipped with Zero Delay Lanyard: Yes ____ No X

Connected to D-ring: Yes ____ No X

Automatic Lanyard Connected: Yes ____ No X

NOTE: A narrative statement will be prepared by each ejectee and/or survivor to include all information pertinent to escape and survival. The statement will be attached to this form. In the event of a fatality, the statement will be prepared by the Flight Surgeon. Pilot's Official Statement

9

RESCUE AND/OR SURVIVAL

a. Survival involved (Survival implies any water landing and anytime over 1 hour before rescue on land) Yes ____ No X

b. Distance nearest Rescue (military base) 0 NM

Time before Rescue 2 mins.xx

Transmitted distress signal: Yes X No ____
Transmitted position fix: Yes ____ No X

c. Effects of Exposure: Frostbite Immersion Sea Sickness Insect Bites Sunburn Dehydration Other (Explain) NA

d. Primary Factor in Rescue: Radio/Beacon (Specify) Visual Flares ____ Mirror ____ Flashlight ____
Sea Marker Dye ____ Position Fix ____ Chaff ____ Local Population ____ Other (Specify) ____

e. Type Rescue: None Required ____ Ground Party, Military ____ Local Population ____ Helicopter/other Aircraft (Specify) ____
Boat ____ Self Rescue (Walked Out) ____ Other (Specify) Ambulance and crash crew on duty

10

MEDICAL OFFICER'S RATIONALE, COMMENTS

This section is to include comment on medical, personal, social, family, industrial hygiene and allied factors in incident causation, and a description and analysis of the factors in injury causation. Injuries should be correlated with the operations of personal equipment, malfunctions and failures of structures, systems, etc. Pertinent contributing factors in Items 3 through 9 should be commented upon. Include X-ray and laboratory findings. Pertinent recommendations are encouraged.

Personal interview has revealed no significant physiological factors involved in this accident. It is the impression of this Observer that the LLTV was being flown outside of its inherent air velocity envelope and that altitude control was lost resulting in the crash. The ejection occurred at nearly the last possible moment for pilot survival. The injuries received were consistent with ejection starting when the pilot was not in firm contact with the seat pan. See attached clinical record.

RECOMMENDATIONS: It is recommended that each pilot be custom fitted to the ejection seat with respect to leg height to decrease posterior leg injury during ejection.

Date	Typed Name, Grade and Title of Medical Officer	Signature
15 Jan. 1969	G.F. Humbert M.D. G. F. Humbert, M.D.	G.F. Humbert MD

FORM DEC 64 711g

1-P

BOARD PROCEEDINGS

BOARD PROCEEDINGS

December 8, 1968

The accident occurred at 0730 c.s.t. Sunday morning. By 1130 hours a tentative board had been selected. The Flight Safety Office made a telephonic report to NASA Headquarters. The Director of Flight Crew Operations gave the initial briefing to the tentative board, who then reviewed the TV tape. LLTV #2 was impounded by the board. A 16mm color film was reviewed. A news release was also made.

December 9, 1968

Mr. Calvin Jarvis, Research Division, Flight Research Center, Edwards, California, was assigned to the board as the systems engineering representative. The Program Manager and Bell Aerosystems engineers were assigned the task of reducing data from TM Van #1. Lapse rate charts from Lake Charles and Victoria were requested from the Houston Weather Bureau and were to be mailed to MSC.

December 10, 1968

Written orders confirming the Board of Investigation were published. Data reduction was being continued. Storage space was prepared for the wreckage. Written statements were received from the pilot, inspectors, mechanics, eyewitnesses, etc. Most of these statements were written the day of the accident or the following day.

December 11, 1968

All members were present for the first formal board meeting. The board members were brought up to date on LLRV/LLTV history. The Program Manager presented differences between LLTV #1 and #2 with the aim of

December 11, 1968 (continued)

having the board release #2 for modification to latest configuration, thereby continuing the program. The board agreed unanimously to release LLTV #2 for these EO's and TP's as presented. The Flight Plan and movie were reviewed. The battery modification on LLTV #2 was approved. After lunch, the board reconvened for its first closed session. Exhibit 7.1 (color print - 16mm) was given to a NASA Headquarters representative. A discussion concerning the time table and work distribution ensued. Mr. Roberts was given the responsibility of obtaining a secretary and Mr. Lucas was to obtain the vehicle status.

December 12, 1968

Informal meeting attended by Messrs. Jarvis, Cheatham, Lucas, Roberts and Ream. An LLTV systems briefing was given by Bell Aerosystems and NASA LLTV Operations.

December 13, 1968

Ground school for the board. Miss Carol J. Dykes assigned to the board as secretary.

December 14, 1968

Board interviewed the pilot. The pilot noted a lack of roll authority upon unlocking the gimbal. The board decided to test the vehicle in a wind tunnel.

December 16, 1968

Further discussion on wind tunnel test--board unanimously agreed wind tunnel test necessary. Board released Mr. Jarvis to return to FRC, Edwards, California.

December 17, 1968

Board drafted a letter to the MSC Director from the Board Chairman, concerning preliminary board findings and recommendations to date. The letter was subsequently finalized and handcarried to the Director by Mr. Ream, who briefed him on its content.

December 18, 1968

An informal discussion of report format was held. Board viewed flight film. Mr. Richard U. Lea of the Legal Office staff assigned to support board activities. The "Lundin Report" was discussed. A TWX to NASA Headquarters was drafted.

December 19-22, 1968

Board did not convene.

December 23, 1968

Captain Schirra read the constitution of the board. Status of wind tunnel test was given by the LLTV Program Manager. Presentations were given by Bell Aerosystems. Comments and progress thus far on the five preliminary board recommendations were made by the Program Manager.

December 24-26, 1968

Board did not convene. (Meeting with the MSC Director.)

December 27, 1968

Board convened at 1330 hours and discussed the meeting with the MSC Director. Then a general discussion took place.

December 28-29, 1968

Board did not convene.

December 30, 1968

Board convened at 1330 hours. TM Van visited by board to witness rerun of Flight #15 in TM Van #1. Board requested a thirty-day extension of the report due date.

December 31, 1968

Board did not convene. Data reduction and analysis continued.

January 13, 1969

Received thirty-day extension of report due date. Received NASA Headquarters clarification on report format (Draft of NASA Safety Manual, Part IX, to be used.)

January 28, 1969

Board convened to exchange information.

January 29-February 17, 1969

Data reduction and analysis continued.

February 18, 1969

Mr. Roberts presented the current status of the LLTV #1 Accident Board Investigation to the NASA Headquarters LLTV #1 Review Board. The major portion of the briefing covered the "Flight History" and the reasons why the vehicle performed as it did. Since there were no official board findings or recommendations as of February 18, 1969, the Review Board was referred to the Accident Board's preliminary findings, dated December 17, 1968. Mr. Roberts also stated that, in his opinion, the investigation had not uncovered any significantly new information that

February 18, 1969 (continued)

would change the preliminary findings and recommendations. The investigation since December 17, 1968, has only confirmed and expanded this preliminary report.

February 19, 1969

Sections of the report being prepared in final draft form.

February 24, 1969

Another extension of the report due date requested (March 14, 1969).

February 25, 1969

The board convened at 1330 and discussed the analysis section which is essentially complete. Mr. Roberts was directed to make a draft of the Findings and Recommendations and submit these to the individual members for review prior to the next meeting (0900, March 3, 1969).

February 28, 1969

Messrs. Ream, Cheatham, and Roberts briefed Dr. Gilruth on the current status of the investigation. The briefing was essentially the same as that given to the Hq. Review Board on February 18, 1969.

March 3, 1969

Request for extension of Report due date received. New date: March 14, 1969.

March 5, 1969

Full Board meeting. Findings, Conclusions, and Recommendations finalized. Report released for printing.

1-Q

DIRECTIVES APPOINTING BOARD

1-Q-1

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA GEN. REG. NO. 27

5010-107

UNITED STATES GOVERNMENT

Memorandum

TO : WHOM IT MAY CONCERN

DATE: DEC 10 1968

FROM : AA/Director

SUBJECT: Appointment of a Board of Investigation

In accordance with MSCM 1700 dated October 1965, a Board of Investigation is appointed to determine the cause and circumstances surrounding an accident which resulted in loss of Lunar Landing Training Vehicle No. 1. The accident occurred at Ellington Air Force Base, Texas, on December 8, 1968, at approximately 7:30 a.m., CST. The Chairman of the Board of Investigation is authorized to take all action necessary to:

a. Investigate the facts.

b. Determine the probable cause of the accident.

c. Accomplish or recommend corrective or remedial measures.

d. Within 30 days, prepare original and seven copies of completed report of findings and recommendations with photographs and statements attached. Forward original and one copy for approval by the Director through the Legal Office and Safety Office, in turn. Forward remaining copies direct to the Safety Officer.

The members of the Board are:

Chairman - Captain Walter M. Schirra, Jr., Astronaut.

Qualified Pilot - Mr. Harold E. Ream, Aircraft Operations.

Aircraft Investigation Officer - Mr. Conway H. Roberts, Aircraft Operations.

Aircraft Maintenance - Mr. Dick M. Lucas, Aircraft Quality Assurance.

Safety - Mr. John C. French, Flight Safety Office.

Systems Engineering - Mr. Donald C. Cheatham, Guidance and Control.

Systems Engineering - Mr. Calvin Jarvis, Research Division, Flight Research Center, Edwards, California.

In addition, the MSC Chief Counsel, the MSC Safety Officer, and any other MSC element as deemed necessary by the Board Chairman, will act as consultants to the Investigating Board.

Robert R. Gilruth

CA:DTGregory:gbn

1-R

WEATHER

WEATHER

The following is the weather as received from the Ellington AFB Weather Station:

08 DEC 1968

TIME	SKY CONDITION	VIS	TEMP	DWPT	WIND TRUE DRCTN	WIND SPEED (KNOTS)	ALSTG.
0656	/Φ	15	32	25	04	02	050
* 0730	/Φ	15	34	25	04	03	051
0756	/Φ	15	38	26	05	05	052

2-A

NARRATIVE DESCRIPTION (ANALYSIS)

DEFINITIONS

The LLTV is neither an airplane nor a spacecraft but an aircraft designed to simulate a spacecraft while it (the LLTV) is operating in the earth's atmosphere and subject to the earth's gravitational field. Therefore, its mode of operation is rather unique and discussing its operation becomes difficult if certain terminology is not well defined. Although most of the following terms are basically standard aerodynamic terms, there are some slight differences and/or restricted meanings. As is customary, all directions are relative to the pilot unless otherwise stated. Also, some definitions have been expanded to explain peculiar LLTV system operations relative to the term being defined.

LIST OF DEFINITIONS

1. Engine Centerline
2. Vehicle C.G.
3. Vehicle Axis (X, Y, and Z)
4. Attitude (Pitch, Roll, and Heading)
5. Wind
6. Airflow
7. Measured Airflow
8. a. Aerodynamic Pitch
   b. Aerodynamic Roll
   c. Aerodynamic Yaw
9. Inertial Flight Path Velocity and Attitude
   a. Inertial Flight Path
   b. Inertial Velocity
   c. Inertial Attitude (Pitch, Yaw, and Roll)
10. Aerodynamic Flight Envelope
11. ACS
12. Thruster Duty Cycle
13. Control Authority
14. IAS
15. Limit Cycling
16. Aerodynamic Instability
17. Single Rocket Logic (See Paragraph 2-5-1-2-4 of Tab 1-F(a)-1

DEFINITIONS AND SYSTEMS EXPLANATIONS

1. Engine Centerline

The axis which the fan-jet engine's fan, compressor and turbine rotate about (the engine is mounted in the LLTV pointed up so that its thrust counteracts gravity). (Figure 2-A-1) The thrust line is coincident with the engine's centerline. The engine is gimbaled so that the engine centerline can be tilted about the vehicle's C.G. within certain limits.

2. Vehicle C.G.

The vehicle has a design center of gravity that is on the engine's thrustline and at waterplane 200. The actual vehicle C.G. varies a little, but only a very little because of severe restrictions caused by the limited amount of attitude control forces available. In other words, if the actual C.G. is much displaced from the engine's thrustline, the resulting moment will exceed the moment generating capability of the Attitude Control System (ACS). The pilot sits in the vehicle with the C.G. behind him and slightly below him.

3. Vehicle Axes

The vehicle has conventional aircraft axes (X, Y, and Z) that pass through the design C.G. (Figure 2-A-1).

a. X-Axis - The vehicle's X-Axis is the fore and aft axis relative to the pilot; +X forward, -X aft (also called the roll axis).

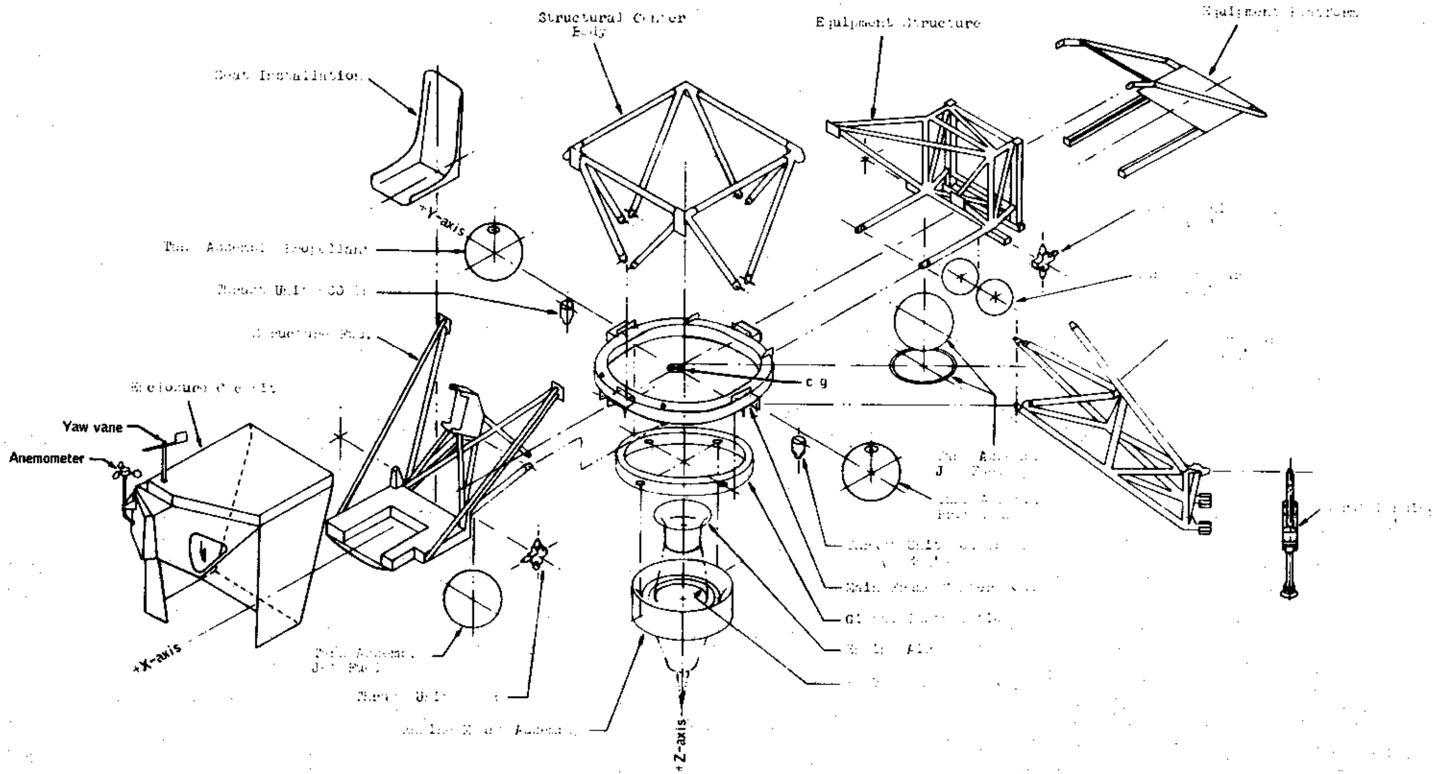


Figure 2-A-1.- X, Y, Z Axes, C.G., and Engine

b. Y-Axis - The vehicle's Y-Axis is the lateral axis, +Y is to the pilot's right and -Y is to his left (also called the pitch axis).

c. Z-Axis - The vehicle's Z-Axis is its vertical axis relative to the pilot, +Z is down relative to the pilot (also called the yaw axis).

4. Attitude

The attitude of the vehicle relative to the earth's local surface. These are the parameters recorded by TM. These parameters are only directly useful for analyzing aerodynamic effects when the vehicle is moving horizontally and to the north, and the wind is either zero or out of the north and horizontal. Otherwise, the "inertial" pitch and roll should be used. But these parameters were not calculated except for spot checks. Therefore, aerodynamic analysis of pitch and roll effects are estimates made from spot calculations and are limited by the flight path being horizontal and to the north. Aerodynamic yaw effects are easier to analyze since the aerodynamic yaw angle was measured by a yaw vane, and the airflow velocity was measured in the yaw (X-Y) plane by the anemometer.

a. Pitch-Attitude* - That angle between the +X axis and the horizon (+ is nose up).

b. Roll-Attitude* - That angle between the +Y axis and the horizon (+ is roll right) (also called bank).

---

* Note the hyphen because there is a distinct difference between pitch-attitude and aerodynamic pitch angle and between roll-attitude and aerodynamic roll angle.

c. Heading - The vehicle's heading is measured in the horizontal plane. It is that horizontal angle between the +X-axis and a vertical plane that passed through the vehicle's X-axis when the pilot set the directional gyro to zero before takeoff. On this flight (No. 15), the LLTV #1 was parked pointed approximately north down the runway (358 degrees true or 350 degrees magnetic). For simplicity, this report measures heading left or right of the takeoff heading and assumes this was true north.

NOTE: Do not confuse heading with inertial yaw or aerodynamic yaw.

5. Wind

The magnitude and direction of the flow of the local air mass relative to earth. The direction is generally horizontal but can have a vertical component, particularly when there is turbulence. The horizontal component of the wind for this flight was measured by an anemometer and wind vane on top of TM Van #1. The vehicle also measured horizontal wind while it was sitting on the ground or while in a hover. There was also a wind sock nearby. Except for the one hover reading at 500 feet, all direct wind information during this flight was surface wind. The pilot had to rely on mental calculations for wind at all other times (estimated from doppler and anemometer readings).

6. Airflow

The free stream velocity and direction of the airflow relative to the vehicle. The airflow has not been calculated for this report, but the airflow can be assumed approximately equal to the "measured airflow" as long as the aerodynamic pitch and roll angles are small (less than about 15 degrees).

7. Measured Airflow

The airflow in the vehicle's X-Y (yaw) plane as measured by the anemometer (magnitude) and the yaw vane (direction). Direction is measured left or right of the +X axis (the anemometer and wind vane can only rotate in the X-Y plane). In addition to local effects of the cab, there is another error induced here because these instruments are located about five feet from the X-axis and roll rates have an effect.

8. a. Aerodynamic Pitch

The angle between the airflow and the X-axis as measured in the X-Z plane.

b. Aerodynamic Yaw

The angle between the airflow and the X-axis as measured in the X-Y plane (as recorded by the yaw vane).

c. Aerodynamic Roll

There is no aerodynamic roll angle when both aerodynamic pitch and yaw are zero. However, if either has a finite magnitude, then some of this is transferred to roll. The aerodynamic roll angle is measured between the airflow and the Y-axis in the Y-Z plane.

9. Inertial Flight Path Velocity and Attitude

These terms would not be necessary for an aerodynamic analysis if the aerodynamic pitch, roll, and yaw angles had been measured and there had been no wind gusts. However, since only the aerodynamic yaw angle was measured and the airflow velocity was only measured in the yaw (X-Y) plane and there was considerable turbulence; these terms must be used if the doppler velocities and radar altitude are to be used to determine aerodynamic pitch, roll, and yaw.

For simplicity, this report neglects the earth's motion. With this assumption then, the vehicle's inertial flight path is relative to earth and was measured by doppler radar for translation and a radar altimeter for vertical displacement.

Except for wind, the inertial flight path would be equal and opposite to the airflow. The inertial flight path has not been accurately calculated; therefore, a detailed aerodynamic study is difficult, except for the period of time when the vehicle was moving north and horizontal, and the wind was out of the north so that attitude as recorded can be equated to aerodynamic pitch, roll, and yaw.

a. Inertial Flight Path - The direction of motion of the vehicle C.G. relative to the earth's local surface.

b. Inertial Velocity - The velocity of the vehicle C.G. along the inertial flight path.

c. Inertial Attitude - The attitude of the vehicle relative to the inertial flight path.

(1) Pitch - The vehicle's "inertial" pitch is that angle between the (inertial) flight path and the +X axis measured in the X-Z plane.

(2) Yaw - The vehicle's "inertial" yaw is that angle between the flight path and the +X axis measured in the X-Y plane.

(3) Roll - There is no "inertial" roll angle unless the X-axis is displaced from the inertial flight path. If it is, then the roll angle is measured between the flight path and Y axis in the Y-Z plane.

10. Static Aerodynamic Flight Envelope

That three-dimensional, imaginary "volume" generated by the aerodynamic flight vector in any direction wherein control of the vehicle can be maintained. This is a "static" envelope in that the vehicle is assumed to have zero rotation. Also, unless otherwise stated, this assumes only one system of attitude thrusters are used. If "both" sets are used, then the magnitude of the envelope in any direction is increased accordingly. Also, the thrust setting of the ACS thrusters must be stated.

11. ACS

Attitude Control System (see Section 1-F(a)-1).

12. Thruster (ACS Rockets) Duty Cycle

The average firing time of the ACS thruster(s) in question (yaw, pitch, or roll) over the last two minutes.

13. Control Authority

Quite often used synonymously with thruster duty cycle (No. 12 above). The average (in percent) ACS control capability used during the last two minutes. One hundred percent yaw authority means the ACS thruster(s) in question is firing continuously; therefore, there is no additional control authority available from that thruster(s).

14. IAS

Indicated air speed. The vehicle anemometer reading is the "indicated air speed."

15. Limit Cycling

Limit cycling is the phenomenon where the control authority is so high that the system does not dampen out the reaction of the vehicle to the ACS thrusters. This means that the vehicle will continuously oscillate in the ACS deadband areas and use excessive fuel.

16. Static Aerodynamic Instability

As used in this report, static aerodynamic instability for the conditions in question means that the aerodynamic moments do not tend to return the vehicle to its original position, but tend to rotate it about one or more of its major axes.

17. Single Rocket Logic

See paragraph 2-5-1-2-4 of Tab 1-F(a)-1.

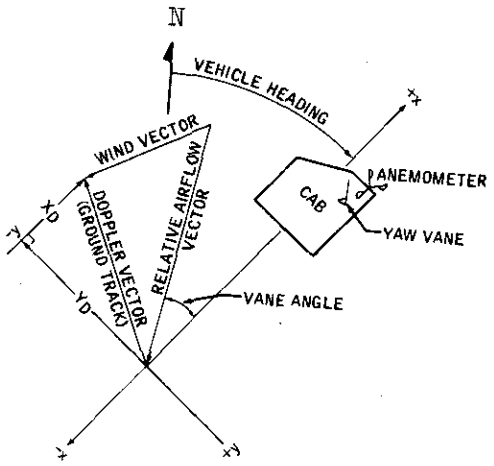


Figure 2-A-2.- Vector Diagram

Yaw vane angle is the angle measured by the airflow vane on top of the cab. (It rotates in the vehicle's x-y plane.)

Relative Airflow Direction (in x-y plane) = yaw vane angle.

(-) is airflow from left.

(+) is airflow from right.

Anemometer (reading) = Relative Airflow Magnitude (in the vehicle's x-y plane).

Relative Airflow Vector (in x-y plane) = Relative Airflow Direction and Anemometer reading.

If the vehicle is level and moving level relative to the earth's surface and the wind has no vertical component, then:

Wind Vector (relative to vehicle) = Relative Airflow Vector + Doppler Vector

Wind Vector (relative to earth) = Wind Vector (relative to vehicle) + Vehicle Heading.

NOTE: To calculate the airflow in other than the vehicle's x-y plane: The altitude rate vector must be added to the doppler vector (this gives the inertial vector), and the wind vector must be assumed or extrapolated.

ANALYSIS

General

The investigation was centered about Phases VII and VIII because the flight was basically normal up to Phase VII, and the accident was inevitable after Phase VIII.

Phase I

The preflight (Tab 2-D) and takeoff were routine. However, there are two factors that should be discussed here. First, although it was not unusual to be making a flight at seven o'clock Sunday morning (because this program has been operating on a high priority basis for some time), it does indicate the program urgency. Early morning flights have been an operational necessity to avoid high wind conditions. Close investigation failed to reveal any personnel fatigue problems that could have contributed directly to the accident. For instance, the pilot had a good night's rest, etc. The second factor is weather (Tab 1-R). Ellington AFB was in an area dominated by a large high-pressure system. At this time of the morning (about sunrise), there was a very strong temperature inversion (34° F at the surface and approximately 40°F at 1,000 feet). Coincident with this inversion was a very strong surface wind shear, i.e., the surface winds were relatively calm; but somewhere between 200 and 500 feet, the wind increased to about 30 to 35 f.p.s. out of the northeast. A strong wind shear creates very sharp wind gusts or turbulence. Also, the LLTV had never been flown when the temperature was this low. The "slightly left side heavy" mentioned right after liftoff was attributed to the right crosswind developing a tendency to roll left or appear left side heavy. This tendency is counteracted by the appropriate thruster firing and is indicated to the van crew by the roll authority meter.

Phase II

Phase II consisted primarily of the climbout and positioning downwind for the lunar simulation. The usual procedure is to make the sim run downwind; but due to the position of LLTV #2 on the other runway and the lack of wind information above the surface, runway 35R was selected. The calm surface wind was misleading. The large increase of wind velocity with altitude did not become apparent until climbout and hover.

Phase III

Phase III appeared normal except that a good wind check in the hover showed a stronger and a more northerly wind than was expected (northeast at 30 to 35 f.p.s.). In retrospect, this could have been the first clue that a problem could develop. Normally, the vehicle would be flown downwind during the lunar simulation portion of the flight to decrease the aerodynamic effects on the vehicle; but the LLTV #2 was being prepared on the other runway for an 0830 flight (Tab 2-D-2 and Figure 1-F(a)-25), and one of the mission rules is <u>not</u> to fly over anything except concrete (Section 1-F(a)-4). At this point the pilot had only two choices: continue the profile as planned but at a reduced velocity or abort the mission because he did not have the fuel to reposition himself for a run in any other direction. The pilot made a mental calculation (Tab 2-D-1) of the effective headwind component (21 to 15 f.p.s.) and made the decision to continue with the flight profile as planned, except for shooting for 35 f.p.s. ground speed instead of 45 f.p.s. (Tab 2-D-1) (this headwind component, when added to the desired doppler ground speed of 35 f.p.s., gives a true airspeed of 56 to 60 f.p.s.). However, the TM data indicates that the ground velocity did in fact reach 40 to 45 f.p.s.

At this point in the program, no one thought 60 f.p.s. was out of the flight envelope of the vehicle in forward flight. The design specification does not limit the use of both sets of ACS thrusters simultaneously, and the thrusters are designed for ~~90~~ 120 pounds. ~~In this configuration, 80 f.p.s. IAS along the X axis is probably possible.~~ FRC investigated flight characteristics with 90 pound settings. However, this much control authority generated "limit cycling" problems in the past. This problem is the main reason the thrusters were set at 60 pounds. The use of both sets of thrusters has not been standard practice in the past because of the "limit cycling" problem. Also, it was felt that the second set of ACS thrusters should only be used as a backup system and selected only when needed. Roll control problems had been experienced in the past with large lateral relative airflow components, but the pilot had no intention of yawing the vehicle drastically while at a high airspeed.

Phase IV

During this phase, the pilot attempted to establish a trajectory matching the trajectory planned for the LM at 500 feet above the moon's surface on its landing approach. Since the velocities to be matched are ground velocities (not airspeed), the pilot must devote most of his attention to the doppler ground speed, vertical velocity, and acceleration instruments. In this case, the pilot did not pay much attention to the indicated airspeed or yaw vane indicator (aerodynamic yaw angle) after this point for several reasons. First, he was busy trying to establish the trajectory, using the doppler and radar altimeter instruments as well as arming the systems for lunar sim. Second, he did not have confidence in the anemometer (indicated airspeed) due to its past unreliability. Ironically ~~through~~ though, for the first time this system worked reasonably well on this flight within its limited capabilities. Third, the cockpit anemometer indicator is a 0 to 60 f.p.s. meter, so it is ~~not uncommon~~ possible to have it saturated during the entry into the lunar sim trajectory. Fourth, these cockpit displays (particularly the yaw vane display) are not in the field of view where the pilot has his attention devoted at this time. Fifth, the pilot was not concerned with vehicle heading once it was aligned with the runway because the AFCS holds the vehicle heading constant unless a pilot command is received. (It is not necessary to change the vehicle heading to effect a lateral acceleration.)

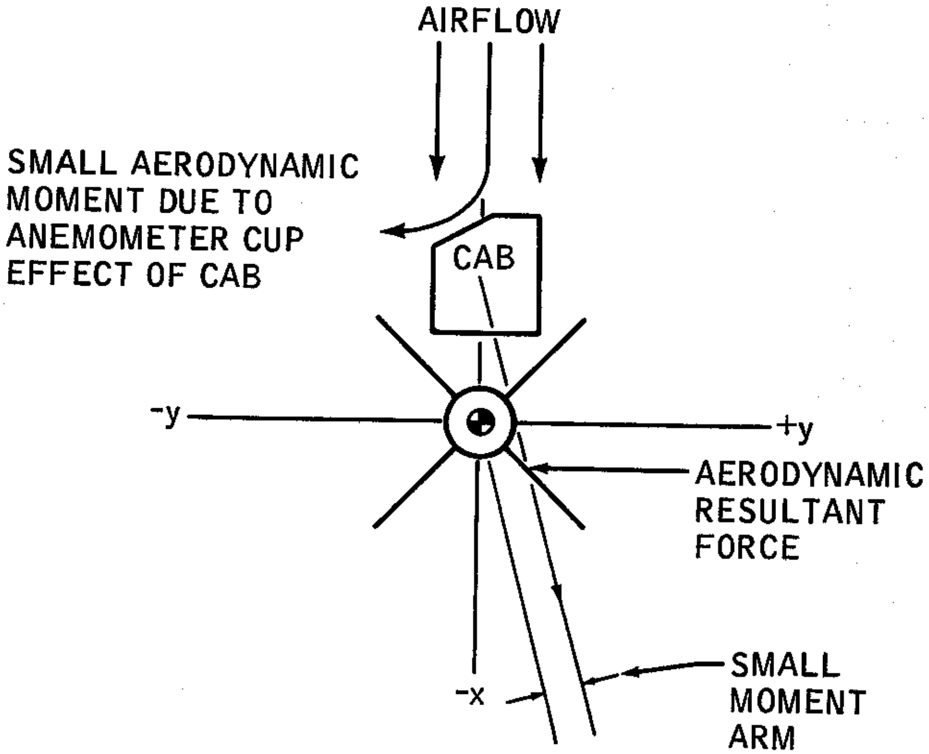
Phase V

As the indicated airspeed increased to about 45 feet/second (and relative air flow 10°R), the yaw thruster duty cycle increased from 30 percent to 50 percent. (AFCS was holding the vehicle heading constant by firing the yaw left thrusters to counteract the aerodynamic torque to the right.) This is in retrospect because neither the pilot nor the ground crew had any real time instrumentation or any other way of knowing what the yaw thruster duty cycle was. This information was recorded, however, and was usable in the postflight analysis. Pitch and roll parameters were nominal during this phase. These aerodynamic moments are evidently generated by the relatively large surfaces of the pilot's cab which is located well in front of and above the vehicle's center of gravity. The vehicle is inherently aerodynamically unstable. As aerodynamic forces increase, the resulting moments must be counterbalanced by the attitude thrusters. If these aerodynamic moments and other moments exceed the counterbalancing thruster moments, control of the vehicle is lost. In the case of forward flight, the cab is not symmetrical about the X-Z plane. The front opening is canted about 30° left. This means the vehicle has an appreciable yaw right aerodynamic moment on it in forward flight (X-Axis aligned with airflow). In fact, the data indicates that the relative airflow must be about 20°R before the aerodynamic yawing moment is zero. Also, once the vehicle starts rotating from the balanced (but unstable) forward flight condition, these aerodynamic torques increase rapidly because the effective moment arm of the cab increases. (Reference Figure 2-A-3).

The pilot activated the two lift rockets by raising the "T" handle at 07:28:53. This was all normal, and as far as the pilot and van crew could determine, everything was go and only the engine gimbals needed to be unlocked to complete entry into lunar sim.

Phase VI

As the pilot continued his forward acceleration, the yaw thruster duty cycle increased to 100 percent at 7:29:06.5 and the pitch duty cycle increased to about 50 percent at :29:08. There was still no practical way available to the pilot to detect the situation, and the TM Van had not detected and reported the increase in pitch thruster duty cycle. The TM Van did not have the IAS (anemometer) or yaw vane parameters displayed in real



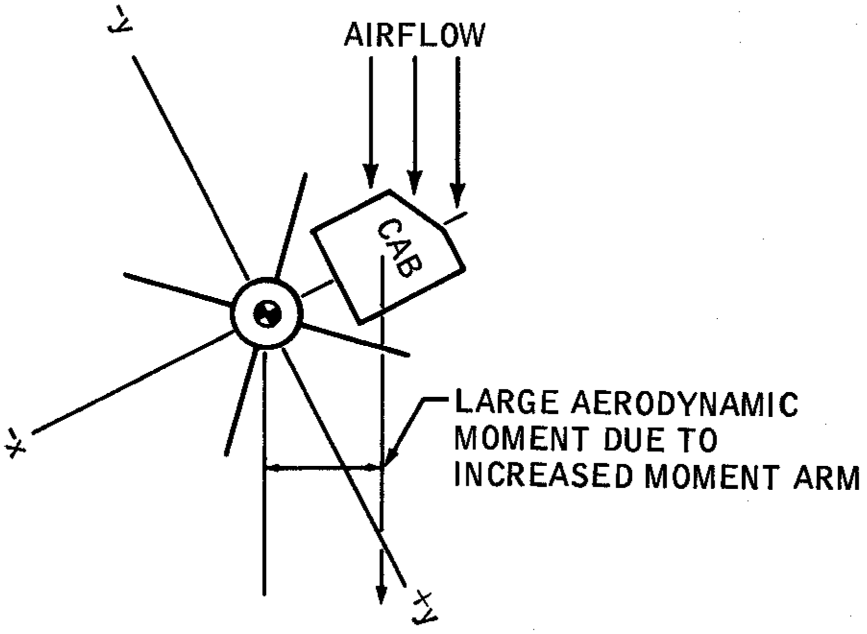


Figure 2-A-3.- Cockpit Cab Moment Arm

time, so they did not know how much the airspeed was increasing.

Phase VII

Almost coincidental to the pilot unlocking the gimbal (:29:08.7) to start a full lunar simulation, the aerodynamic moments exceeded the yaw compensation capability of the Test Rocket System and the vehicle began to yaw right, causing an increasing left sideslip angle. There is no indication in the recordings or in the pilot's statement that this yaw divergence was detected. When the pilot called for pitch up (at :29:09.5) to start flying the desired landing approach, the vehicle responded normally; i.e., it satisfied the pilot command as would be limited by an acceleration capability of 8 feet/second^2 (model). When the pilot reversed the command to stop the pitch up (:29:11.5), the aerodynamic moment in pitch essentially equaled the control moment in pitch and the pitch rate did not change significantly. This loss of pitch control was the result of an increase in the airflow which increased the aerodynamic pitch up moment. The divergence in yaw created a sideslip angle which in turn caused a considerable roll moment to the right. The combined pitch and roll accelerations resulted in a single ACS thruster (C_T) being fired for both pitch and roll control. The resulting control torque in pitch was able to keep the pitch rate from further increasing, but the control torque in roll was less than the disturbance and the roll rate increased to about

18 degrees/second at :29:15.5. During this period, the aerodynamic yaw angle had continued to diverge, further aggravating the roll control deficiency. (Reference Table 1-F-(b)-1)

Phase VIII

The pilot released lunar simulation at about the time (:29:15) that some measure of control was returning in pitch and yaw (the rates were then changing to the direction of command). The pitch and roll attitudes had, however, reached rather extreme values (32 degrees in pitch and 53 degrees in roll), and the pilot held constant maximum roll left and pitch down command rates until :29:18.5. The airflow during this time was changing rapidly in both speed and direction such that the aerodynamic moment was suddenly (at :29:17) in the same direction as the roll command, and the roll rate rapidly reached and then exceeded 20 degrees/second left. (Figure 1-F(b)-3) (Figure 2-A-14). Although the pilot reversed his command before the roll and pitch angles passed through zero, the high angular rates coupled with aerodynamic moments in roll in the same direction caused the roll attitude to increase to about 100 degrees left. The vehicle was well beyond recovery after 07:29:19.

The use of "both" attitude control thruster systems (Standard plus Test) prior to developing a control authority problem would have provided adequate control and the attitude divergences would not have started. It is also clear that the selection of both at some later point (after about :29:18 or :29:19) would not have allowed recovery because the vertical descent could not have been halted prior to ground contact (Figure 2-A-4). Of interest, and of importance in understanding how rapidly the problem developed, is the latest time at which switching to "both" would have allowed recovery. A rough analysis indicates that use of "both" after about 19 seconds would have delayed the impact but would not have prevented it. Figure 2-A-4 shows the dead man boundaries applicable to the LLTV recoverability from combinations of altitude, altitude rate and vehicle attitude. (The roll rate was only 28°/second left at :29:18, but although the vehicle was level at :29:19, the roll rate was 38°/second left (Figure 2-A-14). ~~The moment compensation limit of 8°/second^2 would mean about 8 seconds would be required to stop this roll rate and return to level if the only moments generated were from the ACS thrusters).~~ Switching to "both" at :29:18 would have led to a rather exciting trajectory, but possible recovery. It is significant that there was only 3 to 5 seconds after the pilot released lunar simulation that the flight was recoverable.

Phase IX

Other than a transmission of "Joe, Joe, leave it!" (Tab 1-I-4) about one second after the pilot released lunar simulation, there were no communications during the critical period. This transmission probably had no influence upon the pilot decision and timing of the ejection. However, since the pilot indicated a reliance (post-accident interview) upon the van to inform him of control authority status, the absence of this status information coupled with the transmission that was made could have strengthened the pilot's belief (although wrong) that the problem source was not the control system, but rather something of the nature of a runaway jet engine gimbal.

SUPPLEMENTAL ANALYSIS

This supplemental analysis information was separated from the preceeding section to improve the presentation. The following subjects are covered:

1. LLTV Deadman's Curve
2. Aerodynamic Moments About the Three Major Vehicle Axes
3. Conversion of Aerodynamic Moments into LLTV Operating Limits
4. Determination of Ejection and Impact Times and Ejection Seat Performance
5. Pilot Survival (Crash/Rescue)

LLTV DEADMAN'S CURVE

Figure 2-A-4 depicts the deadman boundaries caused by altitude and sink rate versus available thrust from the fan-jet engine only or from the fan-jet engine plus the two lift rockets. Assumptions are:

1. Vehicle weight = 3,800 pounds
2. Maximum fan-jet thrust - 4,400 pounds
3. Maximum left rocket thrust = 1,000 pounds
4. Vehicle attitude remains constant

Flight No. 15 is plotted on the chart, showing the resultant (pitch and roll) attitude (angle between the Z axis and local vertical) at one-second intervals from 07:29:11 to impact at 07:29:27. This depiction is slightly misleading because it does not account for high pitch and/or roll rates that require time to control. This aggravates the situation. However, assumption No. 4 above is conservative if the vehicle could be returned to level; so they offset each other to some extent.

LLTV DEAD MAN'S CURVE

FAN-JET IN GIMBAL LOCK OR CENTERED MODE

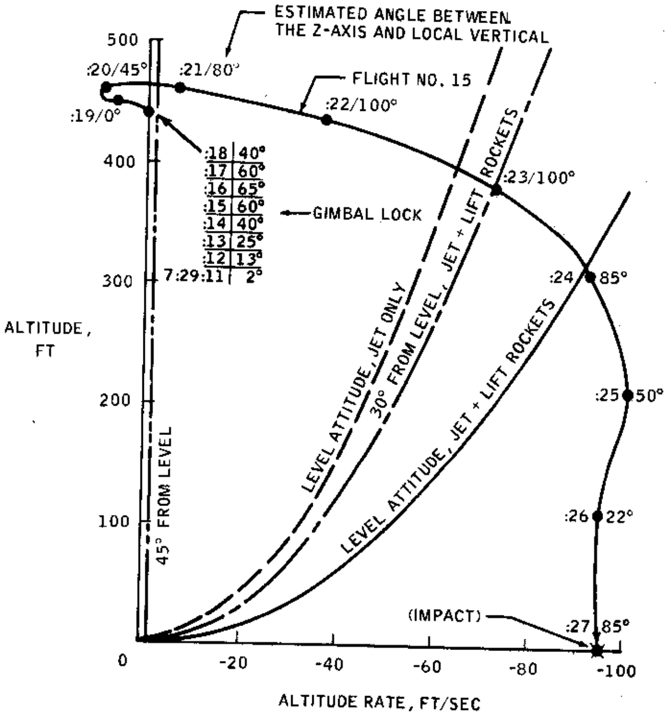


Figure 2-A-4.- LLTV Deadman's Curve

AERODYNAMIC MOMENTS ABOUT THE THREE MAJOR VEHICLE AXES

Figures 2-A-5, 6, and 7 depict the aerodynamic moments about the three major axes as indicated by data from Flight Nos. 13 and 15. Of particular interest is the moment generated by the airflow through the engine. This is broken out only in the pitching moment chart, but it is also a big portion of the rolling moment. The engine effect on yawing moment is probably quite small since the engine gimbal limits are relatively restrictive.

The large scatter of the data points is due primarily to the poor aerodynamic instrumentation of the LLTV. Another factor is the aerodynamic complexity of the vehicle. A third factor is the low velocities flown. This allows wind distrubances to have a major influence.

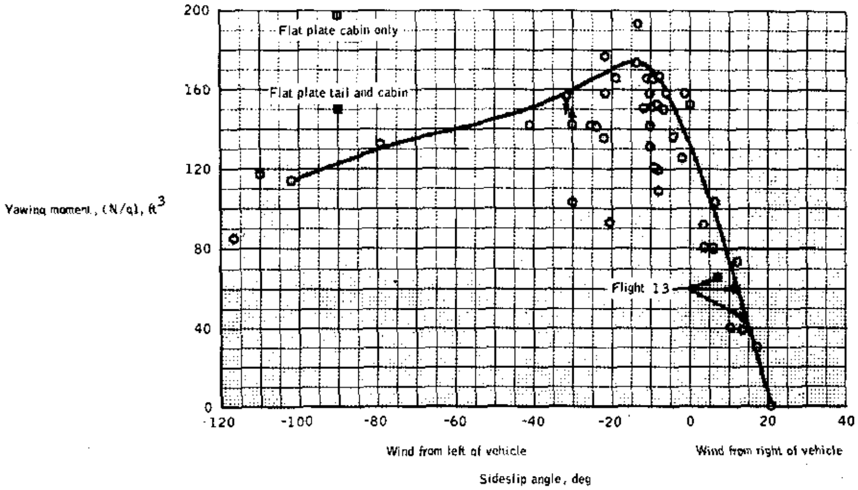


Figure 2-A-5.- Yaw Moment Versus Sideslip Angle

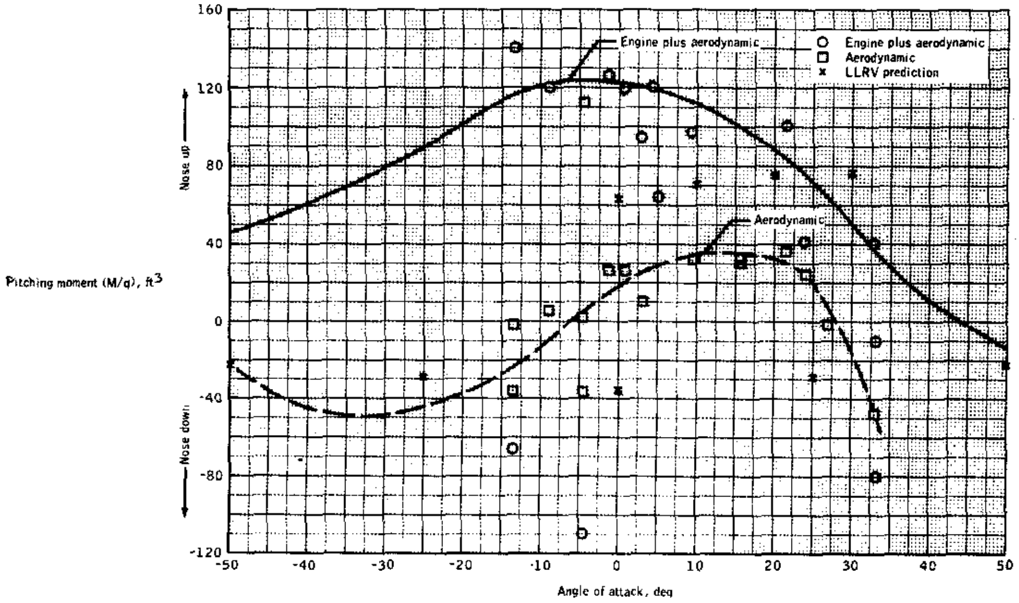


Figure 2-A-6.- Pitching Moment Versus Angle of Attack

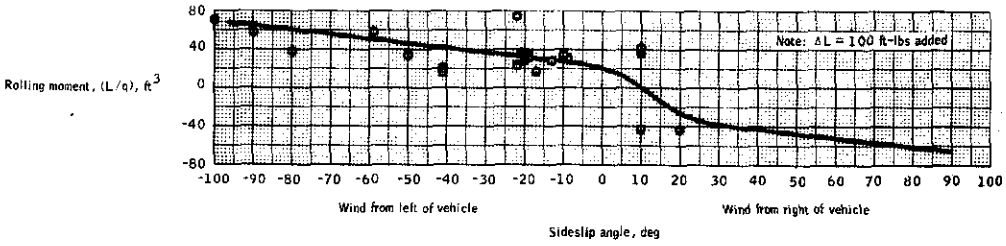


Figure 2-A-7.- Rolling Moment Versus Sideslip Angle

CONVERSION OF AERODYNAMIC MOMENTS INTO LLTV OPERATING LIMITS (AERODYNAMIC FLIGHT ENVELOPE)

The following section is a limited study made to determine the nature of the LLTV Aerodynamic Flight Envelope as it existed on this flight (No. 15). There have been many assumptions, extrapolations, estimations, etc., made in order to define the nature of this Flight Envelope. The Board feels confident that the nature of the envelope is fairly accurate, but the magnitudes may have large errors. Also, the envelope that is presented in the following pages is not the complete envelope, but only a two-dimensional presentation of a more complex three-dimensional envelope.

Figure 2-A-8 is a polar plot in the vehicle's X-Y (yaw) plane. The relative airflow as measured by the anemometer and yaw vane during Flight No. 15 is plotted on this figure at one-second intervals. The recorded yaw vane reading establishes the radial and the anemometer reading determines the magnitude. Therefore, if a line is drawn from this plotted point to the center of the chart, it represents the local airflow vector as sensed at that time by the yaw vane and anemometer which are located on the top, right hand corner of the cab (Figure 1-F(a)-2). Except for local cab effects, this is a fair estimate of the airflow in the vehicle's X-Y plane. During the time period from 07:29:17 until the airflow plot goes off the chart, the vehicle was rolling left. The roll left rate was particularly high between :29:18 and 29:21.5. Figure 2-A-9 has the Roll Authority Limits

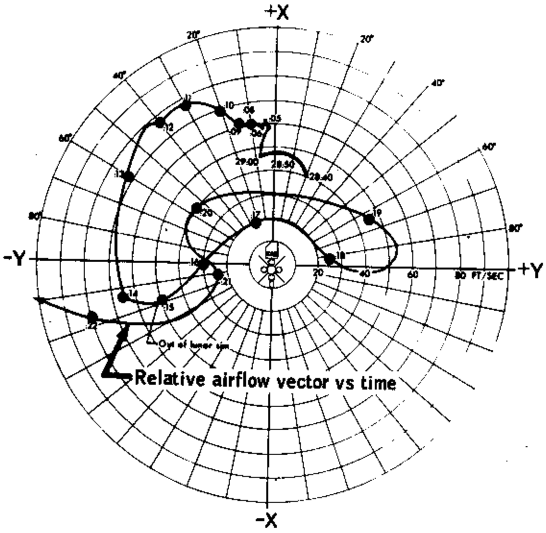


Figure 2-A-8.- Relative Airflow in X-Y Plane

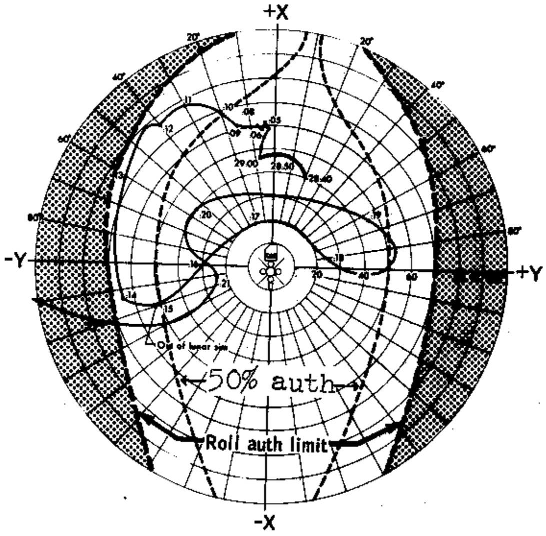


Figure 2-A-9.- Roll Authority ~~Angle~~ Limits

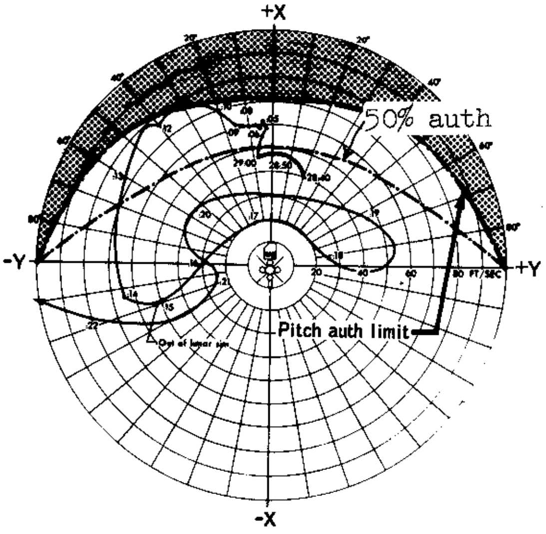


Figure 2-A-10.- Pitch Authority Limits

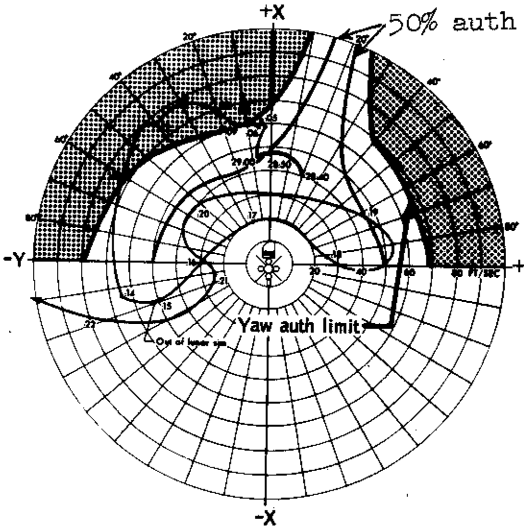


Figure 2-A-11.- Yaw Authority Limits

plotted over Figure 2-A-8. The 100 Percent Authority Limit means that if one set (2) roll thrusters are firing 100 percent of the time, then this roll moment (360 feet/pounds for 60-pound thrusters) is just balancing the aerodynamic rolling moment at this point. The 50 percent line represents one thruster firing continuously or two thrusters firing 50 percent of the time. The 100 percent line is only 1.414 or $\sqrt{2}$ greater than the 50 percent line because of the squared velocity factor of the aerodynamic moment equation.

The -X (or rearward flight) portion of these charts was not calculated. Therefore, the limits as shown in the lower half of the polar plots are only "eyeball" estimates put in to show that the vehicle has some kind of flight envelope when the airflow is from the rear.

Figures 2-A-10 and 2-A-11 are the same as Figure 2-A-9, except pitch and yaw authority limits are plotted. Note that the yaw limit pattern is not symmetrical about the X-axis. It is rotated about 20°R because of the canted door on the front of the cab. One set (2) of 60-pound pitch thrusters generate 700 feet/pounds of moment about the Y-axis, and the test set of yaw thrusters generate 700 feet/pounds of moment about the Z-axis. In Figures 2-A-9, 10, and 11 another set of limit lines could be drawn further out to show the limit when using both sets of attitude control thrusters.

Figure 2-A-12 is Figures 2-A-8, 9, and 10 combined. This figure depicts the combined moments about the X and Y axes. This figure

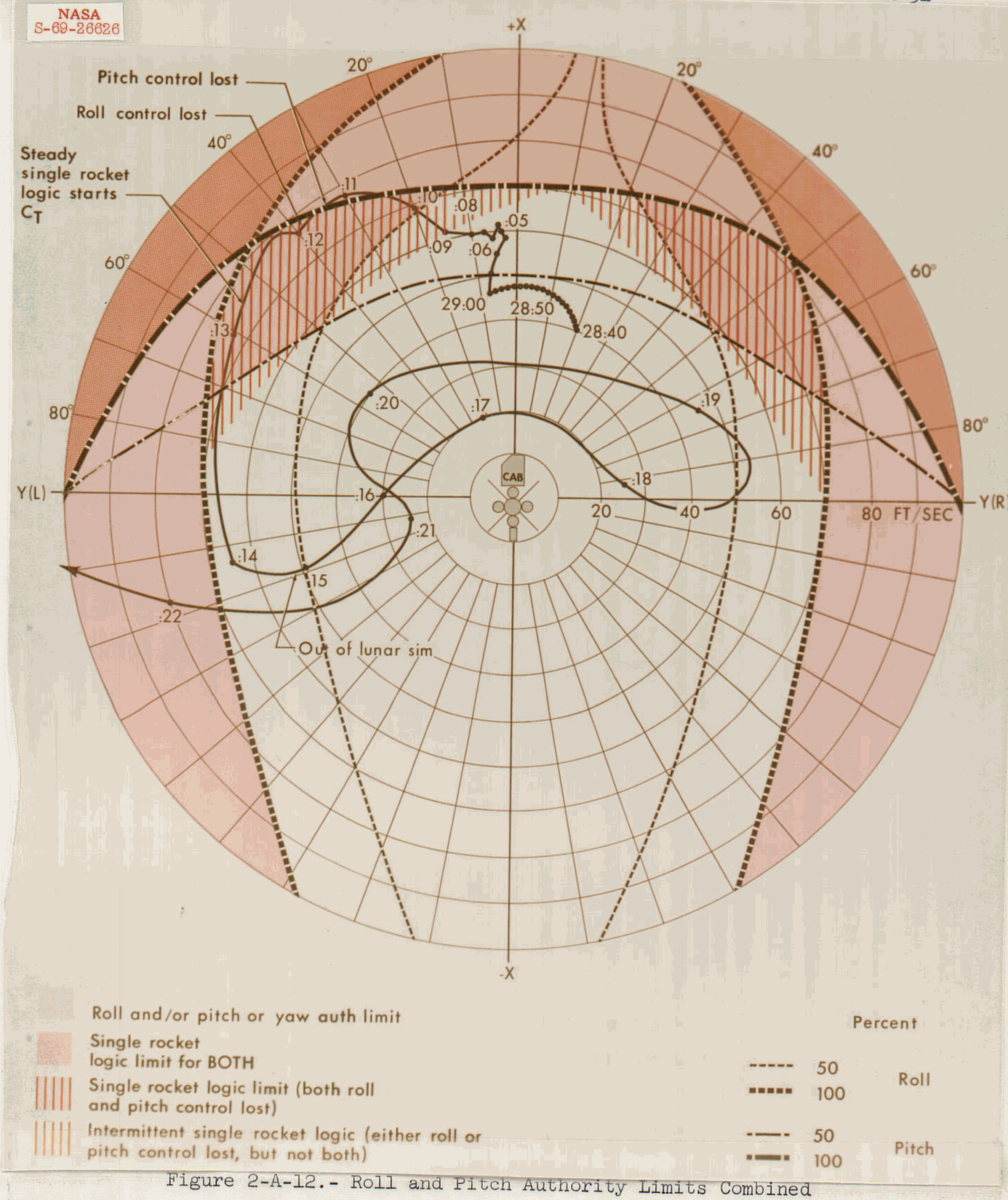


Figure 2-A-12.- Roll and Pitch Authority Limits Combined

graphically illustrates the effects of "single-rocket-logic." The attitude control thrusters are so designed that if a combined pitch and roll is commanded, two of these three rockets will be creating opposing moments and therefore ineffective. In order to save fuel, there is a "single-rocket-logic" function in the ACS that prevents opposing rockets from firing. This then means that when in "single-rocket-logic," the pitch and roll authority is reduced by 50 percent. The heavy shaded area outside both the pitch and roll 100 percent lines is a "single-rocket-logic" limit with both ACS thruster systems operating. Between the point where the two 100 percent lines cross and the two 50 percent lines cross is an area where one set of thrusters will not control the vehicle. Both of these "single-rocket-logic" areas extend to the X and Y axes. This extension represents areas where the ACS is switching back and forth between "single-rocket-logic" and just one set (either pitch or roll). When in this intermittent single-rocket-logic area, control is being lost about that axis which is closest to the area in question.

In summary then, if the "corners" are rounded off the flight envelope to simplify it, one could say that roughly, the LLTV flight envelope for one set of ACS 60-pound thrusters is a sphere with a radius equal to the point where the two 50 percent lines cross (about 60 f.p.s.). The Flight Envelope for both sets of ACS thrusters (set at equal levels of thrust) would be a sphere with a radius equal to the point where the two 100 percent lines cross (about 80 f.p.s.).

NOTE: The standard yaw thrusters do not have as much moment arm as the test set does.

Figure 2-A-13 is Figures 2-A-11 and 12 combined. The yaw thrusters are independent of pitch and roll and therefore are not subject to single-rocket-logic. As Figure 2-A-13 illustrates, the LLTV experiences control problems in pitch and roll before it runs out of yaw control authority, except for one small "window" located between 0 and 20° left at about 60 f.p.s. Evidently, Flight No. 15 was the first time the LLTV had been flown up against this window. In this case, the gust of wind was sufficient to put the vehicle through this window with the resulting divergence and loss of control about all three axes. In the past, the vehicle had been operated to the one-set control limit in pitch or roll and recovered either by selecting both sets of ACS thrusters by slowing down or maybe the limit was exceeded momentarily by a gust of wind and was therefore momentary. In any case, the existance of this yaw window was not known to anyone in the LLTV program at MSC. Everyone (LLTV) was of the opinion that the LLTV had roll and pitch control limits but that yaw control was not a problem because pitch or roll control would be lost first and yaw control limits were academic. This accounts in part for the Yaw Thruster Duty Cycle (Yaw Authority) meter not being in Van #1. The yaw authority meter was scheduled to be installed in Van #1, but it was felt that there were more important parameters to be monitored and other urgent problems were given priority over this installation.

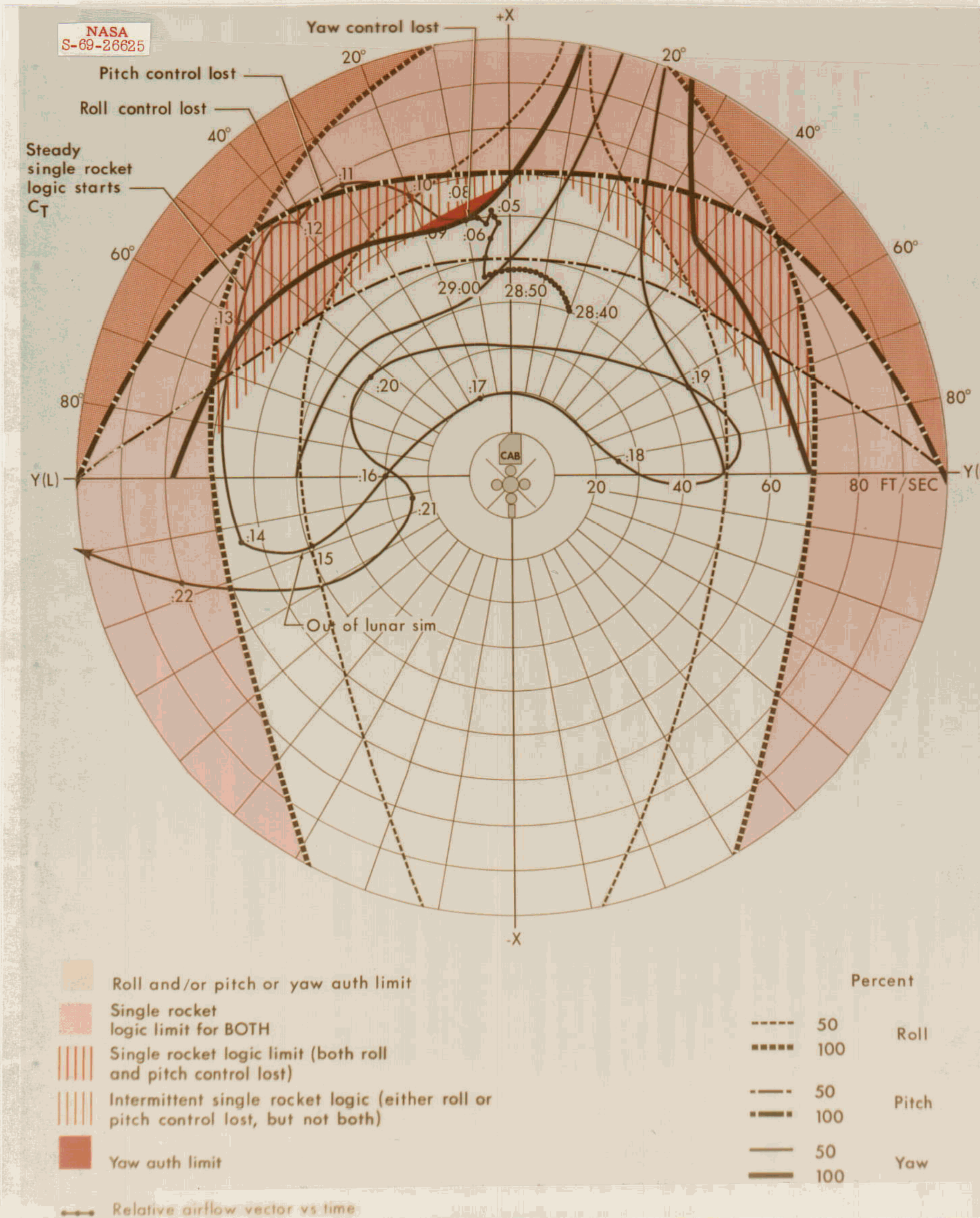


Figure 2-A-13.- Roll, Pitch and Yaw Authority Limits Combined

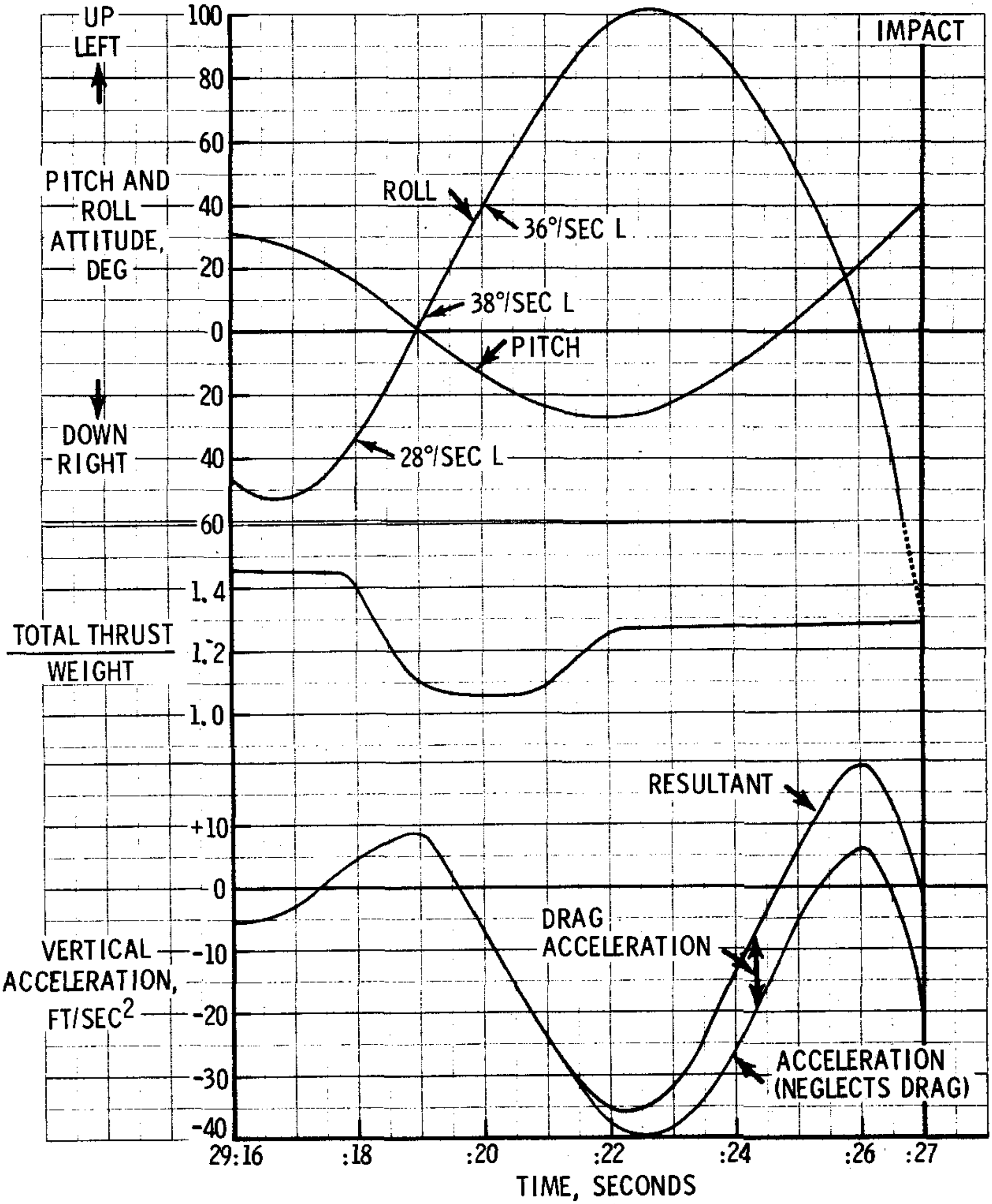
DETERMINATION OF EJECTION AND IMPACT TIME

Several TM parameters including altitude and altitude rate became unreliable prior to ejection due to the extreme vehicle attitudes. In order to investigate ejection seat performance, the ejection and impact times had to be determined accurately.

Correlation of the 16mm color film with the TM data showed that the TM did not stop at impact as was first thought. It stopped about one second prior to impact which was just about the time the ejection took place. It is surmised that the ejection seat rocket blast probably interferred with the TM transmission is some way. Correlation of the 16mm film with the TM data was made by using the engine gimbal lock-up and ACS thruster firings which were all quite easily detected in the film. (ACS thruster chamber pressure TM data was good until TM failure at 07:29:26.)

In summary then, loss of TM and ejection was at :29:26 and impact was at :29:27.

Figure 2-A-14 shows the derived time histories of the vehicle attitude, thrust/weight ratio and the vertical acceleration from :29:16 to :29:27 (impact). This information was needed before the altitude and altitude rate could be calculated and depicted in Figure 2-A-15. Note that the ejection was at about 100 feet above the ground with approximately 97 feet/second sink rate. The ejection seat reversed this sink rate to approximately 150 feet/second rate of climb. This then allowed the chute to deploy at about 200 feet above the ground. The pilot made three gentle oscillations in his chute before landing at 07:29:40.



CALCULATED TIME HISTORIES OF PITCH, ROLL, T/W AND VERTICAL ACCELERATION OF LLTV FLIGHT #15

Figure 2-A-14.- Time History of Accelerations

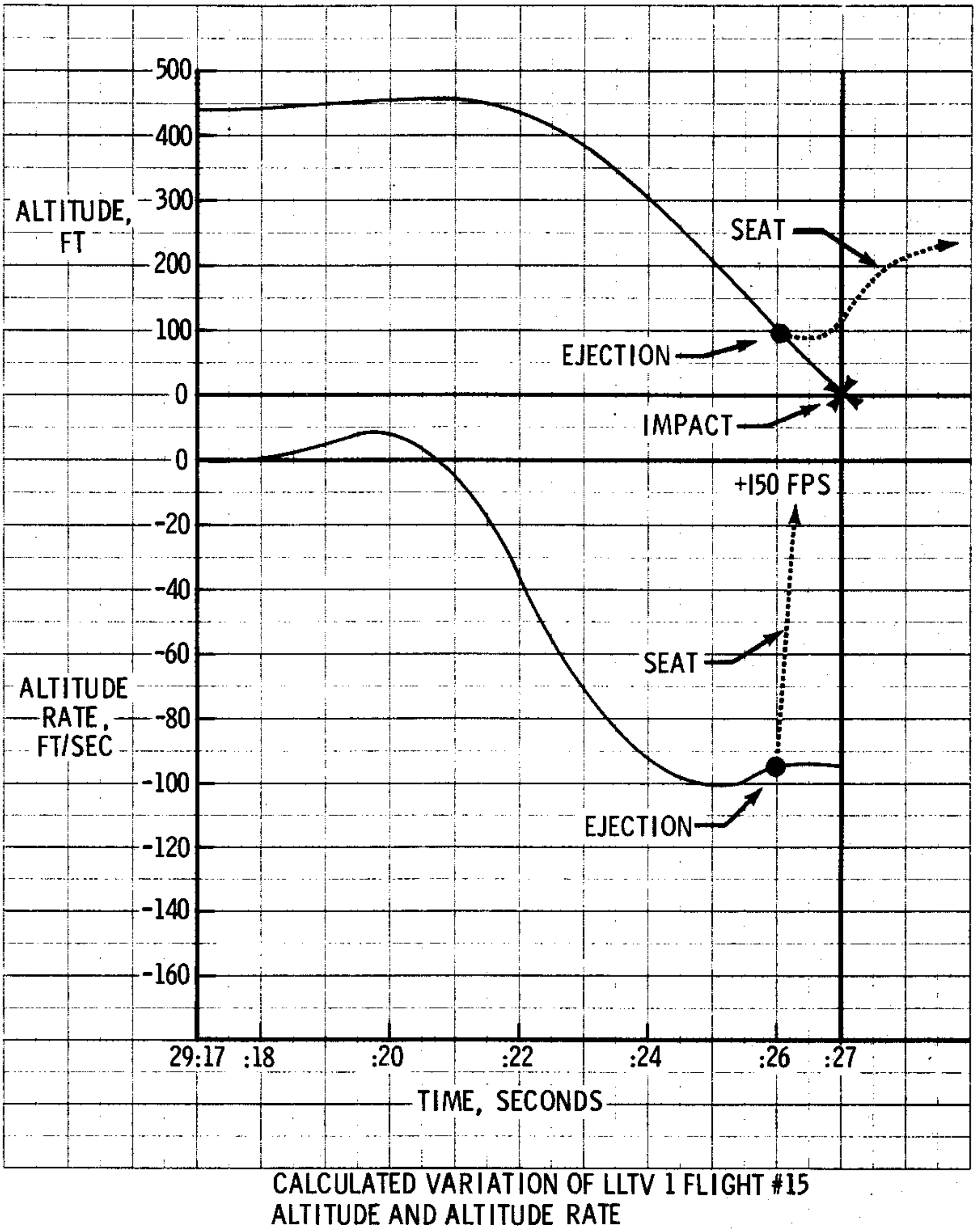


Figure 2-A-15.- Altitude and Altitude Rate

PILOT SURVIVAL

The egress system has worked extremely well in the two accidents that the LLRV/LLTV program has suffered. However, there is always the possibility that during some future emergency, the pilot may not eject either by his own choice or because the ejection seat failed. Such a possibility raises the question: Is there anything to be learned from these two crashes in this regard?

A cursory examination of both of these rather severe crashes has revealed surprisingly little fire and impact damage to the cockpit area relative to the condition of the rest of the vehicle (Figures 2-A-16 and 2-A-17). This is due in part because both vehicles contacted the ground in a tail-low attitude, and the structure of the vehicle is an excellent shock absorbing structure. There have been many survivors of aircraft crashes where the cockpit appeared in a much worse state. Considering the protective equipment worn by the pilot, it is conceivable that either or both of these pilots might have survived their initial crash impact and certainly a pilot would have a good chance of surviving a lesser crash.

A close study of the color movies from both of these crashes has shown an initial fireball after impact that lasted about one second. Due to the protection afforded by the cab and the protective clothing worn, a one-second flash fire would probably not burn the

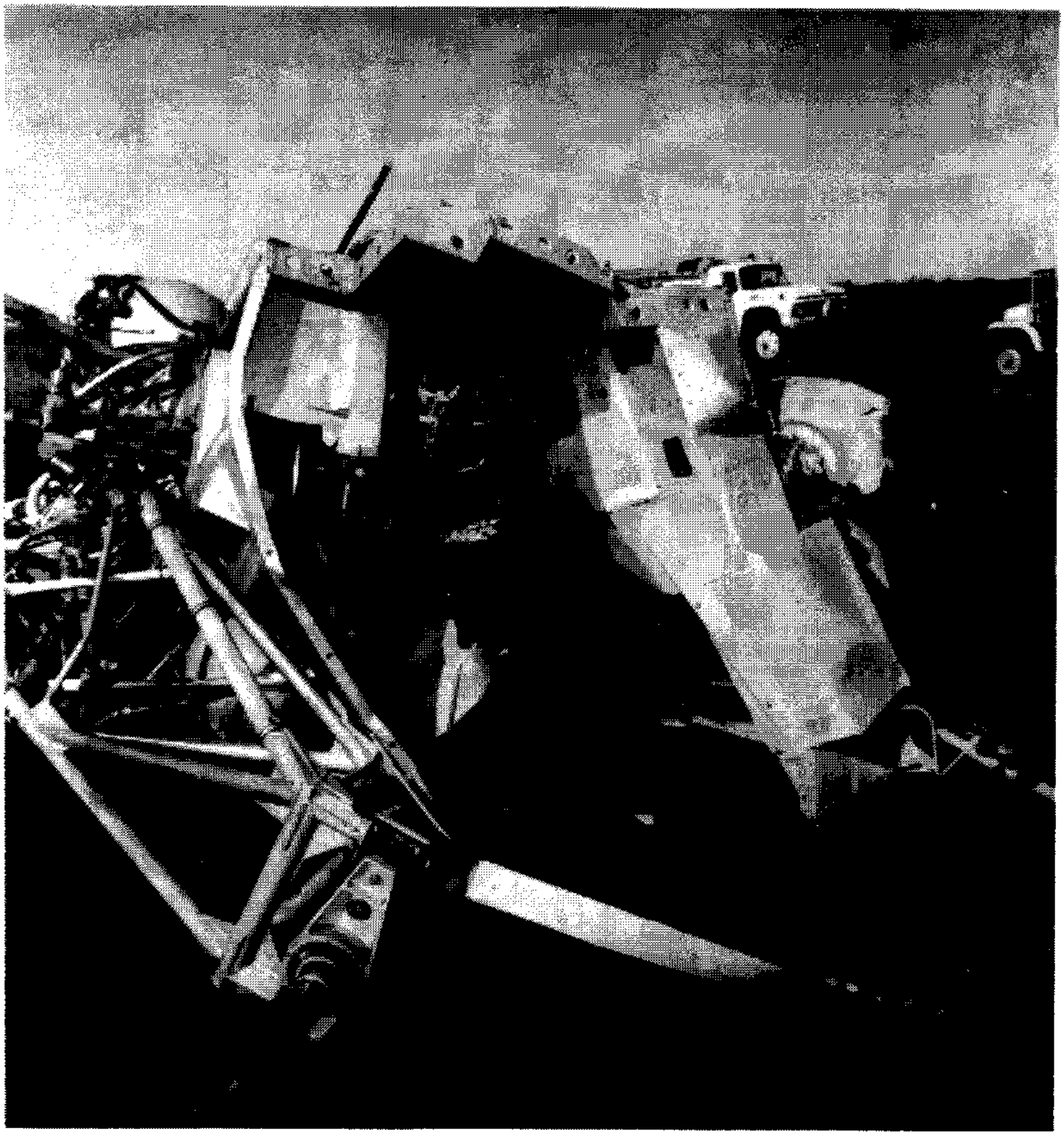


Figure 2-A-16.- Cockpit Crash Photograph

Figure 2-A-17.- Instrument Panel Crash Photograph

pilot too severely. However, in both cases there was residual burning after the initial fireball. This burning continued at a slowly decreasing rate until extinguished by the fire and rescue team.

The fire and rescue equipment consists of an O11-A crash truck (1,000 gallons water) (manned by three firemen), a 250 g.p.m. pumper (500 gallons water) (200 pounds dry chemical) (one fireman), and an ambulance with a flight surgeon and medic that are standing by during all flights. After both crashes, the heavy fire truck could only progress so far from the pavement before soft ground stopped it, although it had not rained in days in either case. Note the ruts and standing water in Figure 2-A-18.

When the pilot is still in the vehicle, very rapid extraction of the pilot from the burning wreckage could make the difference between life and death. The residual burning should not prevent two properly clothed firemen from extracting an unconscious pilot from the wreckage, but the speed of rescue appears to be of the utmost importance here. However, there is a hazard to rescue or firefighting personnel caused by the presence of both JP-4 and hydrogen peroxide, a very bad combination. In both crashes there was both JP-4 and hydrogen peroxide remaining in the vehicle after the fire was extinguished. In some cases these fluids were in a tank that had not ruptured on impact. If these tanks had ruptured due to heat and/or pressure during the firefighting period, the firemen could have been injured. In both of these crashes, extinguishing the fire did not accomplish much since the pilot was clear of the fire, the vehicle was a total loss due to impact, and the wreckage was not needed for investigation because of the availability of TM data.

Figure 2-A-18.- Fire Truck Ruts

2-B

FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

The following is a list of the casual factors as found by the Board. They are rated and listed in the order of their importance in the opinion of the Board. ~~In rating these factors, the Board has considered the practicality of management controlling the factor in the limited time available to prevent a future accident. Therefore, the rating of the findings and the recommendations should be considered together.~~

FINDINGS OF THE BOARD

A careful examination of all the telemetry recordings and other factual data has indicated that no LLTV systems anomalies existed during Flight No. 15. The flight operations followed an integrated-system approach, whereby the LLTV is supported by a TM Van with the monitoring stations manned by systems experts. This concept embodies the TM Van acting as the "flight director" to the extent that systems status are monitored and significant information regarding status is communicated to the pilot. This integrated system operation and the flight planning operation of Flight No. 15 was found to have a number of factors which contributed to the accident. These factors have been classified as main factors and then expanded to include subfactors. The five main factors are as follows:

1. There was a lack of knowledge of the aerodynamic operating limitations.

2. The Standard Rocket System was not utilized to supplement the control authority of the Test Rocket System when aerodynamic moments exceeded the capability of the Test Rocket System.

3. The operating environment included wind conditions for which normal operating margins did not accomodate.

4. Recommendations of the previous accident board for LLRV #1 were not totally implemented.

to be removed

5. Recommendations of the previous accident review board for LLRV #1 were not fully disseminated.

The first four main factors include additional subfactors and they are listed with comments as follows:

1. (a) There did not exist sufficient quantitative aerodynamic data from which the operating envelope of the LLTV could be defined and observed.

Comment: This is not a newly recognized factor, but one that had been previously accepted as a result of the demonstrated flight velocities of the LLRV.

(b) There was a lack of sufficient appreciation for the existing wind conditions.

Comment: Neither the TM Van nor the pilot recognized that the reported wind at operating altitude when added to the intended ground track velocities exceeded the previous maximum airspeed of LLTV #1 by over 10 feet/second.

(c) There was a lack of sufficient concern about yaw attitude during flight.

Comment: The pilot did not attempt to control yaw during the Flight No. 15 emergency, although it deviated by more than 50 degrees. Discussions indicated that yaw angle was not considered control critical prior to Flight No. 15, as evidenced by lack of a yaw thruster duty cycle display in the TM Van. It also appears that the pilot has a poor yaw visual reference from the cockpit unless the FDAI is monitored.

(d) There were inadequate displays and procedures in the TM Van.

<u>Comment</u>: Air flow velocity and direction were not displayed in the TM Van. Without these parameters displayed, the aerodynamic operating limits could not have been monitored had they been known. A yaw control authority meter was not installed. The overall arrangement of displayed parameters precluded a timely analysis by the systems observer of the control usage due to either disturbance torques or control commands.

2. (a) The pilot did not identify that a control problem existed that could be alleviated by the use of "both" systems because he misinterpreted the source of the control problem.

<u>Comment</u>: The coincidence of the first apparent loss of control authority with the start of lunar simulation led the pilot to the erroneous conclusion that he had an engine gimbal malfunction.

(b) The TM Van did not identify a control authority problem to the pilot.

<u>Comment</u>: This is due in part to the lack of a yaw authority display. No control authority status was communicated even through pitch and roll caused a "full on" thruster firing 12 seconds prior to impact.

3. (a) There is evidence (see derived wind data, Figure 1-F(b)-5) that coincident with the initial pitch-up maneuver the

wind gusted from 20 feet/second to 55 feet/second and shifted approximately 20 degrees left in about 3 seconds.

(b) The procedure of utilizing surface wind only for flight planning and obtaining an estimate of wind at a hover point in flight was insufficient to verify that the intended simulation flight plan was safe.

<u>Comment</u>: If an operating limit is to be observed, a wind profile should be available prior to flight.

4. (a) The Mission Rules as defined and approved for astronaut training were utilized as guidelines for test flights.

(b) Crash/rescue trucks became mired in soft ground when attempting to proceed to the crash site.

CONCLUSIONS

Based upon the foregoing findings, the following conclusions were made by the Board:

1. That the primary cause of the accident was that the vehicle entered a region of flight where aerodynamic moments overpowered the control system in use such that attitude control was lost. The source of the control problem was not identified by either the pilot or the TM Van in time to add ~~a~~ the second control system which could have restored control capability.

2. That the adverse region of flight was entered because:

(a) The aerodynamic limitations of the LLTV were not completely known by anyone.

(b) The existing wind conditions were insufficiently accounted for in preflight and real time flight planning.

(c) The configuration of displays in both the LLTV and the supporting TM Van inadequately defined the existing flight conditions.

3. That corrective actions should be taken relative to defining the aerodynamic characteristics of the LLTV and improving the LLTV and/or TM Van system operations before the LLTV is used for astronaut training.

RECOMMENDATIONS OF THE BOARD

As a result of the findings by the Board, the following recommendations are made:

1. Conduct wind tunnel tests to provide sufficient aerodynamic data from which the aerodynamic operating limits of the LLTV can be established. Verification of this data should be accomplished during flight tests.

2. Reconfigure control systems such that deflecting the attitude controller against the hard stops will cause the system to switch to "both" sets of attitude thrusters.

3. Provide the pilot with a cockpit display of (1) airflow speed and direction, and (2) control authority indications in all axes.

4. Reconfigure the TM Van monitor station locations and displays at each station to effectively implement the "flight director" concept. This should include the displays of yaw rocket authority and an X-Y plotter presentation of airspeed and direction.

5. Provide an effective yaw reference that is within the pilot's normal field of view while flying the LLTV.

6. Increase the thrust output of the attitude rocket systems as much as is feasible.

7. Revise the LLTV Operations Manual so that it provides specific descriptions of the flight profiles to be used. All profiles shall depict allowable wind conditions.

8. Implement a means of measuring the existing wind profile from the surface through an altitude of 700 feet.

9. Provide adequate crash/rescue protection.

10. Investigate means of alleviating leg injury on ejection.

11. Implement a system of data review to investigate detected or suspected anomalies.

2-D

STATEMENTS

STATEMENT OF JOSEPH S. ALGRANTI
CONCERNING LLTV #1 ACCIDENT ON 8 DECEMBER 1968

On December 8, 1968, I entered the cockpit of LLTV #1 at 0703 for a scheduled repeat of Test Flight No. 14 of the LLTV Flight Test Plan, which was to have been the final demonstration flight prior to NASA acceptance of the No. 1 vehicle. All preflight and engine checks were normal, except for a warning tone upon finally engaging the gimbal lock which was reported on radio. This has been an intermittent problem in the past and was of no particular significance.

Takeoff was at about the normal 15 minutes after jet engine start. It was a very cool day and liftoff was at 94 percent, the lowest we've seen so far; and I was hovering at only 92 percent at 50 feet shortly after takeoff. All control functions appeared normal, and I proceeded down runway 17 left to the intersection of the southeast runway, which was our briefed starting point. We had discussed using runway 22R if the wind appeared too high at 500 feet for a lunar simulation to the north. I let the wind translate me south while climbing and called out the wind at 550 feet as being 30 f.p.s. on the anemometer. This was on a northeast heading, so I figured that on a due north heading over the runway, the wind component should not be too high for a lunar simulation attempt. I got the call of JP-4 caution and this surprised me a little as I thought I still had a little time left. I confirmed the JP-4 caution, armed lunar sim, moment comp, and yawed the vehicle about 30 degrees to the left and assumed a pitch attitude of about 8 degrees nose down. I used the doppler indicator and called out 25 f.p.s. when I raised the "T" handle to begin the trajectory. I got what appeared to be normal auto-throttle and continued to hold 8 degrees nose down until I read 35 f.p.s. on the doppler. At this time, I unlocked the gimbal and the vehicle appeared to pitch up slightly and began a right roll. I felt almost level in pitch, but noticed at once that I appeared to have no roll authority. I have felt this before at times, but only for very short times while in strong crosswinds. Although I continued to hold full left roll, I rolled to an estimated right bank of about 30 to 40 degrees. Then I rapidly appeared to pitch down and roll left to an equally high, or maybe a little higher, left bank attitude. During the roll back to the left, I punched lunar sim release and advanced the jet throttle. The pitch and roll attitudes were so extreme that I decided to get out, as I figured I had lost control. I ejected on the third roll excursion when I thought I was going through an upright position. The seat sequence appeared mild and all systems worked exactly as advertised. I heard the firing of the seat, etc., but was not able to follow the seat motions; and in a very short time, I was on a good chute. I was only on the chute for about 7 to 10 seconds and made a very easy landing in the grass. I experienced no injury at all, except slight soreness in the back of the thighs where the seat edge caught my legs upon ejection. To the best of my remembrance, this was the sequence of events that preceded the accident.

Joseph S. Algranti

STATEMENT OF HAROLD E. REAM CONCERNING LLTV #1 ACCIDENT ON 8 DECEMBER 1968

The following is a statement of the events prior to, during and subsequent to the LLTV accident that occurred Sunday, 8 December 1968:

I reported to the Building 2000 area at approximately 0615 for the briefing prior to the scheduled LLTV flight. LLTV-1 and LLTV-2 were scheduled to fly in that order, and I was scheduled to fly test-flight number three on TV-2. Mr Algranti was scheduled to fly TV-1 on a repeat flight of test flight 14, a lunar sim in model. When I arrived, Joe (Mr. Algranti) had not arrived; so the briefing proceeded with the operating crew and myself for my flight. We discussed the flight plan and the component changes that had been made to TV-2 since the last flight. We had briefed my flight at an earlier date for the same flight plan; so it was a recap of the maintenance that had been performed in the interim. We had concluded the briefing for my flight when Joe arrived; so we immediately went into the brief for his flight. Since the flight was a repeat of a familiar flight plan, most discussion centered upon the changes that had been made to TV-1, the major change being the auto-throttle mechanization. The briefing was concluded to everyone's satisfaction, and we proceeded to the TM Van #1 preparatory to the flight. I filed two local flight plans by telephone with estimated takeoff time for TV-1 as 1330Z (0730 CST) and TV-2 as 1430Z (0830 CST). My position in the TM Van is advisory, observing the operation from a pilot's viewpoint, and manning the emergency UHF radio adjacent to the operation engineer's console position. With me in the van was Mr. Jere Cobb, who was observing the whole operation as orientation since he was scheduled to begin pilot transition when NASA accepted the vehicle. The pilot entry, communications check and pre-flight procedures were normal and with no anomalies. The surface wind at takeoff was essentially calm with an occasional ripple of the wind sock, which is located several hundred feet south of the TM Van #1. The takeoff and translation portion of the flight appeared normal in all respects with Joe commenting about a stronger wind at altitude drifting him down the runway. We expected this as the smoke from the stacks of the Webster power plant, about 8 miles south of EAFB, indicated that a good breeze from the east did exist about 100-150 feet. The wind shear was discussed as part of the pre-flight briefing, and Joe indicated he would look at the wind at altitude and decide which direction to proceed with the sim run. He did report the wind at about 500 feet as being 30 feet per second when he checked the velocity while in a hover. At this point the vehicle appeared to be drifting down wind off the immediate vicinity of the runway; so I asked Mr. Blilie to have him bring it back over the runway. This request was transmitted, and Joe did start back as well as taking the initial steps to set up for the lunar sim. The van radio receiver apparently was not too good since Mr. Blilie asked for repeats of switch position which I had heard clearly transmitted by Joe over my emergency radio receiver. The entry into the sim run appeared normal, with the vehicle essentially aligned with and over the runway heading north. Joe called out velocities as he picked up forward speed. I clearly heard 25 fps, and then I heard another transmission which sounded like either 30 or 40; it wasn't clear. Joe reported lift rockets and this was observed. Then he reported gimbal lock coming off. I believe Mr. Blilie verified this sequence. I was watching the vehicle; and from the time gimbal lock off was reported, the vehicle started a slow yaw to the right. This yaw continued and at about the same time, the vehicle started to pitch up and roll to the right. From my position in the van, it looked as though the yaw angle was about 30 or 40 degrees and the pitch about 20 or 25 degrees and the roll about 20 degrees when the roll started to reverse. When the roll left started, it continued at a fairly high rate and the vehicle started to rapidly translate. At this time the left roll continued until the vehicle attitude was at least 60 degrees. It was apparent that we were out of control; and I think I yelled to Mr. Blilie to get him out or some such phrase; but I think that we all felt that it was apparent to the pilot that he was in trouble and didn't need to be told. The vehicle came out of the roll in a left yaw pitch up motion but had, as a result of the large angles, developed a high sink rate and was descending rapidly. I observed the ejection when the vehicle was about level in the pitch up portion of the gyration. The ejection sequence looked good, and I saw the chute. Out of the corner of my eye, I had seen the vehicle impact; and it looked like the ejection occurred about one second before the vehicle hit the ground. The emergency equipment responded as they saw the crash with the ambulance and flight surgeon heading for the pilot and the crash truck and pumper heading for the burning wreckage. Mr. Blilie had immediately called EAFB tower at the time of crash, and additional fire equipment responded to help. As soon as I saw that all the emergency procedures were effected, I left the TM Van to go to the office to call Mr. Slayton's residence. I also attempted to get to the telecom office; but they were busy, apparently with the crash alert. I was unsuccessful in contacting anyone by telephone; so I went back out and greeted Joe, who had been driven back to the office area in the ambulance. After talking with Joe for a few minutes, I was able to confirm with telecommunications that our management had been advised of the accident. After the flight surgeon had examined Joe, we started to debrief on the accident.

This statement is a narrative of the events up to the debriefing as I best remember.

Harold E. Ream

Harold E. Ream

December 9, 1968

Statement of Ronald K. Blilie, flight controller during the flight and accident of the LLTV, vehicle #1, Joe Algranti pilot, flight #T1-15-162F, December 8, 1968.

The pilot (J. S. Algranti) was briefed to fly a full lunar simulation mission to check out a vehicle modification relocating the auto-throttle assembly. The pilot was briefed on the Mission Plan (Report 7260-931014 - Operation T1-15-162F - dated 12-6-68) by Mr. Alan King, BAC. The flight was to be flown over Runway 35R. Following the briefing, the pilot proceeded to the vehicle. I went to TM Van #1 and joined the flight control team to begin the pre-takeoff checkout. Pre-takeoff van checks by the control team were completed prior to the initial pilot communication check-in. Pre-takeoff checks by the pilot were completed without discrepancy. The jet engine was started at approximately 0724 c.s.t. Prior to takeoff, Don Reisert (jet engine monitor) confirmed adequate JP-4 tank pressure (greater than 5 psi) and hydraulic accumulator pressure (2200 psi). Tom Pierson (avionics system monitor) confirmed proper attitude control system operation but he reported that the C_t rocket appeared fuzzy. Attitude rocket thrust levels were normal and the fuzzy appearance of the rocket trace was not detrimental to system performance. Rocket system parameters were normal with 738 lb of H_2O_2 remaining and 3850 psi helium pressure at takeoff. The surface wind was noted on the van anemometer at less than 5 mph and this was relayed to the pilot. The pilot called the Low Thrust Manual light out at 75% engine rpm and called the JP-4 tank pressures "in the green." After takeoff the pilot called his takeoff rpm at 94%. Pierson indicated the vehicle was slightly left side heavy which was relayed to the pilot. The left side heaviness was attributed to the wind which was coming from the vehicle's right side. The pilot established a hover and reported engine rpm was 92% and that the radar altimeter appeared to be operating properly. During the translation south on Runway 35R at about 400 feet the pilot commented that the wind was drifting the vehicle and seemed to be strong. The pilot established a hover at about 550 feet and reported the vehicle was into the wind and the wind speed was 30 feet per second. I noted the H_2O_2 remaining to be approximately 630 lb. The pilot reported turning the Lunar Simulation switch "on." I noted the proper light (Jet Stab) come on in the van. Shortly thereafter the pilot called 25 fps, which I interpreted to mean doppler translational velocity, and that he was raising the T-handle. The Auto-throttle light came on in the van indicating the pilot was in the lunar simulation mode. The pilot hesitated for a few seconds before turning the Gimbal Lock switch off then called his velocity (again interpreted as doppler velocity) to be 40 fps and then switched gimbal lock off. I looked at the Gimbal Lock light in the van and noted the light was off. When I looked at the vehicle again it had begun a yaw to the right and appeared to be almost 90° to the runway heading. The vehicle pitched up to an excessive angle (estimated at greater than 30°) and began to roll right. I was unable to determine the amount of roll. At this time I involuntarily transmitted "Oh, Joe, leave it ...." The vehicle continued to change attitude to approximately a 90° roll left and began falling out of the sky. The pilot ejected at a very low altitude. I observed the chute blossom at what I would estimate to be 200-300 feet. I called Ellington AFB tower and declared an emergency. The crash truck and emergency equipment proceeded to the crash site and pilot. Communication was maintained with the crash truck on UHF radio. I left the van when I saw the pilot returning in the wagon.

Ronald K. Blilie

December 8, 1968
12:30 p.m.

Statement of Thomas E. Pierson, avionics monitor during the flight and accident of the LLTV, vehicle #1, Joe Algranti pilot, flight #T1-15-162F, December 8, 1968.

I reported to the LLTV operations site, Bldg. 2000, Ellington Air Force Base, at 0600, December 8, 1968.

Two operations were planned, a full simulation flight with Ship #1 and a gimbal-locked flight with Ship #2. Mr. J. Algranti was pilot for #1 and Mr. H. Ream was to be pilot on Ship #2. Both pilots were briefed between 0600 and 0700. I was in attendance at the pilot briefings.

Following the briefing, I moved to the operations control van #1 with the other members of the control van crew. I took my assigned position at the avionics monitor panel and completed the control van preflight checks. All checks were normal.

Mr. Algranti entered the cockpit of Ship #1, established communication with the van, and proceeded with the pilot's preflight checklists. All checks appeared normal. The only item of note was the fact that the chamber pressure trace of attitude rocket C_t had some high-frequency fluctuations, as displayed on the Sanborn strip recorder. The thrust level of the rocket was satisfactory and this type of "noise" is not unusual, however, it was commented upon during the control checks.

At lift-off I reported the vehicle balance as "left side heavy." This is a conventional phrase to indicate attitude rocket firings to oppose a roll left moment on the vehicle. Such a moment might be a result of weight unbalance, but is more commonly a result of a crosswind. The pilot confirmed a crosswind component from the right. This condition persisted as the vehicle translated down the runway to a position for entering lunar simulation.

As the vehicle came to a hover, and was brought into the wind, the rocket firings shifted to a "tail heavy" pattern as expected. The frequency of firings and duration of pulses indicated considerably more wind at altitude than was being indicated on the ground. Approximately one-half of the control authority available from one set of rockets was being used by the attitude control system at this time.

The entry to lunar simulation was normal with no transients on any parameters displayed at my panel. As usual, attitude rocket activity decreased, indicating a stable condition. The pilot commanded a pitch up as is normal to reduce forward velocity. My first indication of trouble was when the pitch command went to full nose down and remained there. At about this time I also heard Mr. Blilie's exclamation. From this point events occurred rapidly and my memory of the sequence may not be borne out by telemetered data, but I remember a hard-over roll command, a MAX-TILT light, an emergency gimbal lock light, and an autopilot rate backup light. I heard a comment of "he's out" or "get out" and all data ceased.

I had no real-time indications of a malfunction that could have accounted for the extreme attitudes of the vehicle.

Thomas E. Pierson

Thomas E. Pierson
Dynalectron Staff Engineer

December 11, 1968

Statement of Donald Reisert, jet engine monitor during the flight and accident of the LLTV, vehicle #1, Joe Algranti pilot, flight #T1-15-162F, December 8, 1968.

Prior to engine start accumulator pressures and JP-4 tank pressures were on the low end of the required pressures and this was probably due to the LLTV being on the pad a long time before flight. All jet engine panel lights were normal. Oil pressure low, emergency gimbal lock, max tilt, low thrust manual, pilot's gimbal lock and local vertical were illuminated. JP-4 caution, JP-4 low, jet stab, auto-throttle and low jet hold were out.

At 0715 c.s.t., the jet throttle was moved from fuel cut-off to the idle position and the start was normal with 500°C EGT at 46% RPM after 2 minutes stabilization.

The pre-takeoff check list was normal and flight time to JP-4 caution light was given as over 3 minutes when requested. At about 9 minutes and 40 seconds after engine start the pilot advanced the throttle to about 75% RPM to bring the JP-4 tank pressures up above 5 psi. At 10 minutes 38 seconds after engine start the throttle was further advanced and takeoff was at approximately 10 minutes 43 seconds after engine start.

After takeoff, all jet engine parameters appeared in the green and normal. Two minutes, 1 minute, and 30 seconds to JP-4 caution light were given and all parameters appeared normal. The JP-4 caution light blinked about ten times and stayed on at 13 minutes 20 seconds after engine start. The light came on approximately 6 seconds before the manual integration indicated (this is normal accuracy). The fuel curve was redrawn from the light fixed position. About this time the green jet stab light came on and at 14 minutes 14 seconds after jet engine start the auto-throttle green light came on. The gas generator RPM was noted to drop back to about 86% indicator equal to about 88% RPM. The fuel curve was redrawn at this time to about 30#/minute for the lunar simulation mode and all parameters were normal. At this time, the flight controller made statements abnormal to the situation and in looking up, I noted the max tilt and emergency gimbal lock red lights illuminate. A quick glance out the window showed the vehicle falling rapidly. The red lights were not called out due to others talking in the van and the obvious trouble was known to all present. I then checked the accumulator pressure and it had decreased to about 1600 psi verifying the engine in emergency gimbal lock, next

I scanned the jet engine RPM and this appeared to be about 90%. A glance out the window to see if the vertical velocity had decreased showed the ejection. The time of ejection was marked as 14 minutes 40 seconds after jet engine start.

Donald Reisert

Donald Reisert

December 8, 1968

Statement of Paul R. Belair, rocket panel monitor during the flight and accident of the LLTV, vehicle #1, Joe Algranti pilot, flight #T1-15-162F, December 8, 1968.

My panel displays from pilot entry to vehicle impact were normal. All consumables were well within the normal operating range for a lunar simulation flight. Beginning at vehicle lift-off, I maintained a close observation of all my displays. I became alerted to the problem when Ron Blilie, the NASA operations engineer and flight controller, said "Joe! Joe!", I looked up from my panel and saw that the vehicle was pitched up approximately 30 to 40 degrees and rolled approximately 10 to 15 degrees right. I then quickly scanned all my displays, but they were normal and there was no detectable lift rocket thrust unbalance. I looked up again and saw the vehicle then pitched down and rolled to the left. The roll left continued until the vehicle was almost 90 degrees and had a high descent rate. Just before impact the vehicle was rolling back to the right but still had a pitch down angle. At this point the pilot ejected from the vehicle which appeared to be approximately 50 to 75 feet above the ground. I was primarily watching the pilot and only saw the vehicle impact and burst into flames out of the corner of my eye.

Paul R. Belair

Paul R. Belair
Bell Aerosystems Company

STATEMENT OF MELVERD E. COPLIN CONCERNING LLTV #1 ACCIDENT ON 8 DECEMBER 1968

I was the NASA Quality Assurance Representative during the preflight inspection of LLTV #1 on 8 December 1968.

Power was applied to the vehicle and the avionics preflight was started at 0300 hours. All vehicle systems were normal in accordance with the applicable checklist.

Systems preflights were completed at 0650 hours, with pilot entry at 0700 hours. I was on ground communications during the engine start and throughout the pilot's power failure and rocket system tests. All systems were, to the best of my knowledge, normal.

I was located in front of TM Van #1, watching the vehicle. I observed a pitch-up maneuver; and the vehicle appeared to yaw and roll right, then roll left, remaining left side down and losing altitude at a high rate. At approximately fifty feet prior to ground inpact, the vehicle partially righted itself; and the pilot ejected successfully.

Melverd E Coplin
Melverd E. Coplin
LLTV Quality Assurance

STATEMENT OF ALAN O. KING CONCERNING LLTV #1 ACCIDENT ON 8 DECEMBER 1968

I was in the control area of TM Van #1 at the time of the accident. My station was in the center of the van behind the Controller, Rocket Engineer and Jet Engine Panel Monitor. My function was to monitor systems behavior and advise the controller if requested.

The pretake-off checks proceeded in a routine manner with no anomalies. The take-off was normal with lift-off occurring at about 92 percent RPM (consistent with the low ambient temperature of about 33°F). The wind at ground level was virtually negligable, but a wind shear was evident as the climb up to the lunar sim entry point progressed.

The pilot reported established in a hover into wind at 550 feet altitude and quoted the wind speed at 30 feet per second.

I observed the vehicle start a translation in the direction of the intended "sim" but with some right crab angle. I heard the pilot call moment compensation on over the radio. I observed the Jet Stab light on the controller's panel come on, indicating lunar sim had been selected. This panel looked normal at this time. The vehicle was yawed left to correct the crab angle. I observed the lift rockets fire and checked the controller's and engine panels for auto-throttle operation. The auto-throttle light was on and engine RPM was stable at about 86 percent. I observed the gimbal lock mode light go out on the controller's panel where the gimbals were released to set up the full lunar sim mode. At this point, all systems indications were satisfactory. Subsequent to this time, my attention was fixed on the vehicle until impact.

Alan O. King

Alan O. King
Senior Flight Test Engineer
Bell Aerosystems Company

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6

UNITED STATES GOVERNMENT

Memorandum

TO : Chairman, LLTV Accident Investigation Board **DATE:** January 6, 1969

FROM : CC/LLTV Quality Assurance

SUBJECT: Clarification of Item "I", Step 1, Page 10, of the LLTV Preflight Checklist 7260-931005, Revision "B", dated April 12, 1968

During the preflight of LLTV #1 the morning of December 8, 1968, the audio tone requirement and operation was verified by BAC contractor technician, BAC Quality Control Inspector, and myself for three separate functional checks.

The reasoning of the repeated tone check was the BAC Quality Control Inspector read the watch and timed the tone duration, his statement was that the time duration was 2.5 seconds on the first test.

Since a previous test indicated the tone time duration was 1.5 seconds, the test was repeated a second and third time to assure the time duration. The two watches were monitored by the BAC Quality Control Inspector and myself. The time duration of the audio tone both times was 1.5 seconds.

The audio level of sound was high enough during the above test that I could hear the tone while standing near the cockpit of the vehicle on the entrance ladder. I could listen at the same time as the BAC Quality Control Inspector actuated the test switch.

Melverd E. Coplin
Melverd E. Coplin
LLTV Quality Assurance Section

2-G

ADDITIONAL DATA
(WIND TUNNEL TESTS)

WIND TUNNEL TESTS

The analysis of the wind tunnel tests were not complete at the time this accident report was printed. The following memorandum and attached data are submitted with the report as preliminary information.

OPTIONAL FORM NO. 10
MAY 1962 EDITION
GSA FPMR (41 CFR) 101-11.6
UNITED STATES GOVERNMENT

Memorandum

TO : CF/Director, Flight Crew Operations

DATE: FEB 26 1969

MAR 3 1969

FROM : CF131/Project Support Office
James P. Bigham

In reply refer to:
CF131-9M-29

SUBJECT: LLTV wind tunnel test program

This is to summarize the principal results of tests conducted in the full scale tunnel at Langley Research Center (LaRC) to determine LLTV aerodynamic characteristics. Testing was performed in the period from January 7, 1969, to February 7, 1969.

Procedure

LLTV Number 3 was used. The vehicle was supported in the tunnel's 30 x 60 ft. test section by three struts. Two of these struts were attached to an auxiliary cross beam between the shock struts of the vehicle's two aft legs, and the third tunnel strut fastened to an A-frame between the shock struts of the two front legs.

General procedure was to set the vehicle at a particular angle of attack (α) and vary sideslip angle in the range from 0 to ± 45 degrees during each run at a constant tunnel velocity, usually 59 feet per second. Vehicle forces and moments were measured both with the engine operating and not operating at sideslip angles of 0, ± 5, ± 10, ± 15, ± 20, ± 30, ± 45 degrees. Vehicle structural and tunnel constraints limited the maximum α to + 15 degrees. These constraints also required that the engine be maintained in the vertical mode for all conditions, and that sideslip angles of ± 45 degrees not be exceeded at tunnel speeds greater than 40 feet per second. Data were obtained engine off at sideslip angles from 45 to 90 degrees at 39 feet per second.

Three basic vehicle configurations were evaluated:

a. Configuration as it was at the time of the LLTV No. 1 accident.

b. Configuration as above with cockpit top removed.

c. Configuration "a" with cockpit enclosure side window and aft curtain out.

In addition to the above, some data were taken for configuration "c" with the simulated LM window attached to evaluate its effects.

All force and moment data were reduced to coefficient form and plotted against sideslip angle for a given angle of attack. Moment data for configurations "a" and "c" for $\alpha = \pm 15$ degrees are given in enclosures 1 through 4. Similar data were obtained for configuration "b" and for configurations "a", "b", and "c" at $\alpha = 0, \pm 5$, and ± 10 degrees, but are not enclosed. A conventional body axis system is used with rolling moment (L), pitching moment (M), and yawing moment (N) positive roll right, pitch up, and yaw right respectively.

Both power (engine) off and on data are presented in enclosures 1 through 4. For ease of presentation, all moments have been divided by q. The vehicle torques due to engine operation are the difference between the power off and power on curves. Engine moments for a particular vehicle attitude are proportional not to q as are the power off data, but rather vary directly with airspeed for a given engine thrust and atmospheric density. Engine data presented in enclosures 1 through 4 are for an airspeed of 54 feet per second ($q = 3.45$). Separate engine moment data for configuration "c" as a function of velocity and sideslip angle are given in enclosure 5.

All engine data were obtained through strain gauges mounted on the engine pitch and roll actuators. For this reason, the power on data is not totally accurate since the effects of the induced airflow over the vehicle caused by engine operation are not included. However, these effects are probably of secondary importance.

Generally, the tunnel data confirmed the presence of large yaw right and pitch up moments at the lower angles of attack and sideslip as evidenced in the LLTV accident. Removal of the side window and aft curtain reduced the yawing moment and correspondingly affected rolling and pitching moments to a lesser extent. It also markedly improved the vehicle stability characteristics. Vehicle yawing and rolling moments are believed to be acceptable in configuration "c"; however, pitching moment appears to be higher than is desirable. If these results are confirmed by flight test, top off data indicates that the pitching moment can be reduced towards the trim point by venting of the cockpit roof.

Flight Envelopes

A preliminary limiting flight envelope for configurations "a" and "c" is given in enclosure 6. Maximum attitude thruster moments were taken as 180 and 270 ft. lbs. in roll, 350 and 525 ft. lbs. in pitch, and 700 and 1050 ft. lbs. in yaw for configurations "a" and "c" respectively. As is noted on enclosure 6, pitching moment determines the envelopes at sideslip angles from 0 to ± 45 degrees, and rolling moment controls beyond that point. Because of the possibility of single thruster operation in pitch and roll, yawing moment is not critical for either envelope. Both envelopes hold for all angles of attack from - 15 to + 15 degrees. For configuration "a", - 15 is the most critical. For configuration "b", the critical α varies with sideslip angle.

It should be noted that the envelopes represent vehicle disturbance torques equal to 100% of a single thruster output. A margin must, of course, be allowed for control, and the actual operational envelope would be correspondingly reduced from that shown.

Although configuration "c" offers some improvement over "a", an expansion of the envelope for sideslip angles in the range from - 45 to + 45 degrees may be possible. Pitching moment controls in this range, and the tests at LaRC indicated that pitching moment can, in turn, be controlled through changes to the cockpit enclosure roof. Enclosure 7 presents pitching moment as a function of angle of attack for configurations "a", "b", and "c". As can be seen, a complete removal of the top would result in excessive pitch down moment. However, if these numbers are confirmed by flight test, it should be possible to reduce the pitching moment to a value close to the trim point through limited venting of the roof. This is to be examined during the LLTV Number 2 flight test program.

Data Accuracy

Because the magnitude of LLTV aerodynamic moments in relation to those of an aircraft are small and are extremely difficult to measure accurately in the wind tunnel, the data should be taken with reservations. It is believed the general trends shown are correct. However, absolute magnitudes should be accepted with caution pending confirmation by flight test. The accuracy of the limiting airspeeds presented in enclosure 6, for example, is no better than ± 20%. For this reason, these envelopes must be considered preliminary, and a reasonably thorough flight test program should be conducted before a final operational envelope is defined. This should not be difficult because of the large amount of information telemetered from the vehicle and the fact that aerodynamic forces at higher airspeeds can be predicted from data taken at airspeeds of 40 feet per second or less.

Comparison with LLTV No. 1 Accident Data

A direct comparison of wind tunnel data with aerodynamic moment data obtained from the telemetry records of the LLTV accident is generally not feasible since the vehicle was not flown in a stabilized flight condition. However, three points were found where the angular accelerations were zero and which offer a check of tunnel roll, yaw, and pitch data.

At 7:26:25, the roll thrusters indicated a vehicle roll left disturbance torque of 180 feet lbs. (or 100% single thruster control authority). This occurred at an airspeed of 19 ft. per second and a sideslip angle of 75 degrees wind from the right. The envelope for configuration "a" in enclosure 6 checks this point.

At 7:29:06 the yaw left thrusters saturated at a sideslip angle of 5 degrees wind from the right, an angle of attack of - 15 degrees, and an airspeed of 60 feet per second (q - 4.3). Enclosure 1 shows an N/q of 165 per this condition or a moment of 710 ft. lbs. This is equivalent to the output (700 ft. lbs.) of the saturated thrusters.

At 7:29:08 the firing of the pitch thrusters indicated a pitch up moment of 300 ft. lbs. This occurred at a sideslip angle of 5 degrees wind from the right, an angle of attack of - 10 degrees, and an airspeed of 63 feet per second.

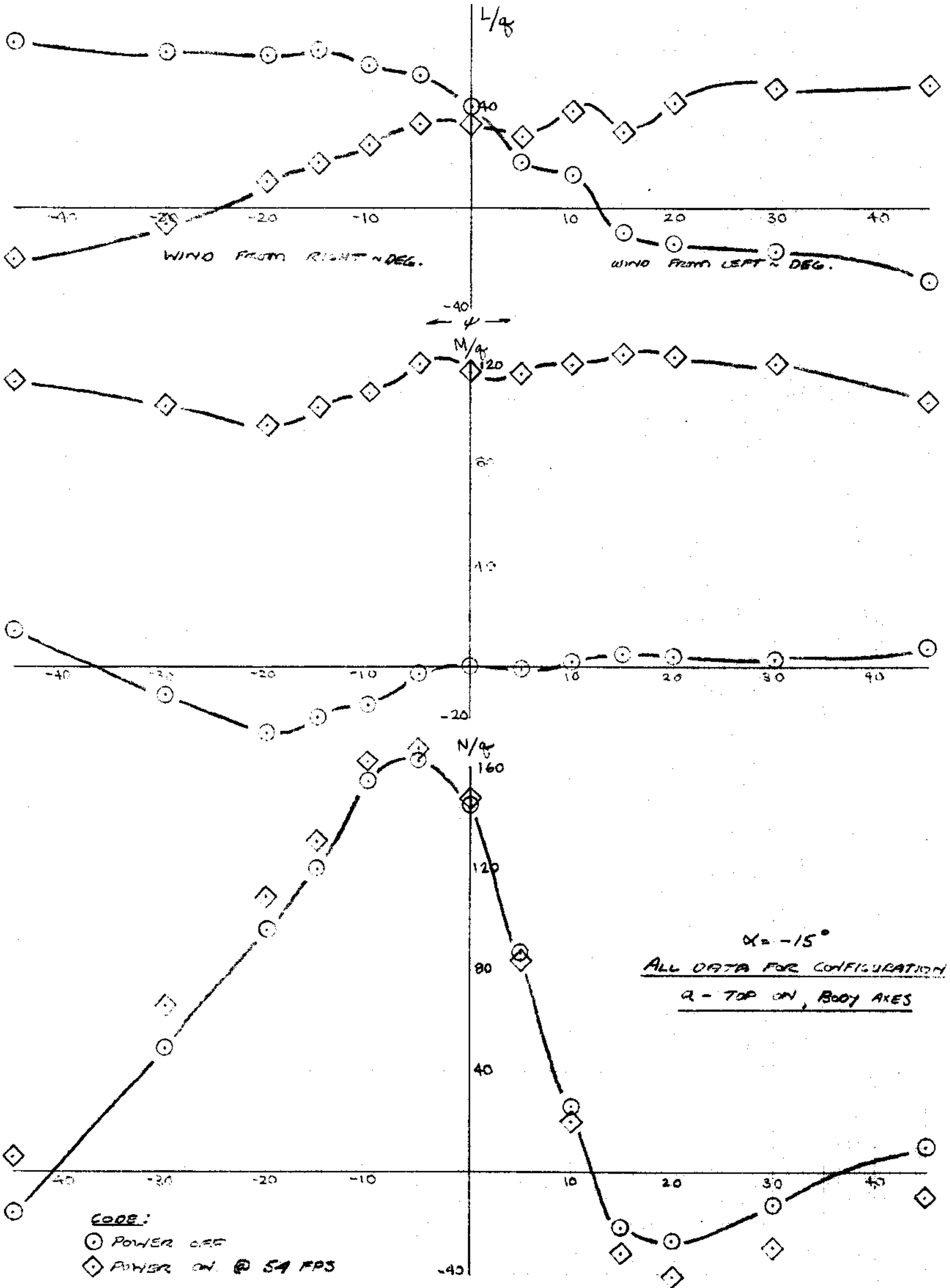
Enclosure 7 shows an M/q of approximately 80 at this condition. This is almost entirely engine moment and converts to a torque of 320 ft. lbs. at 63 feet per second which checks the flight point.

James P. Bigham, Jr.

Enclosure

cc:
CA/T. McElmurry
CC/R. Blilie
CF131/S. Nassiff
EG2/D. Cheatham
CC/J. Algranti
CC/H. Ream
CC/R. Glover
CC3/J. Cobb
CB/W. Schirra
CC/C. Roberts
SA/J. French
CC/D. Reisert

CF131:JBigham:pjg 2-25-69



$\alpha = -15°$

ALL DATA FOR CONFIGURATION

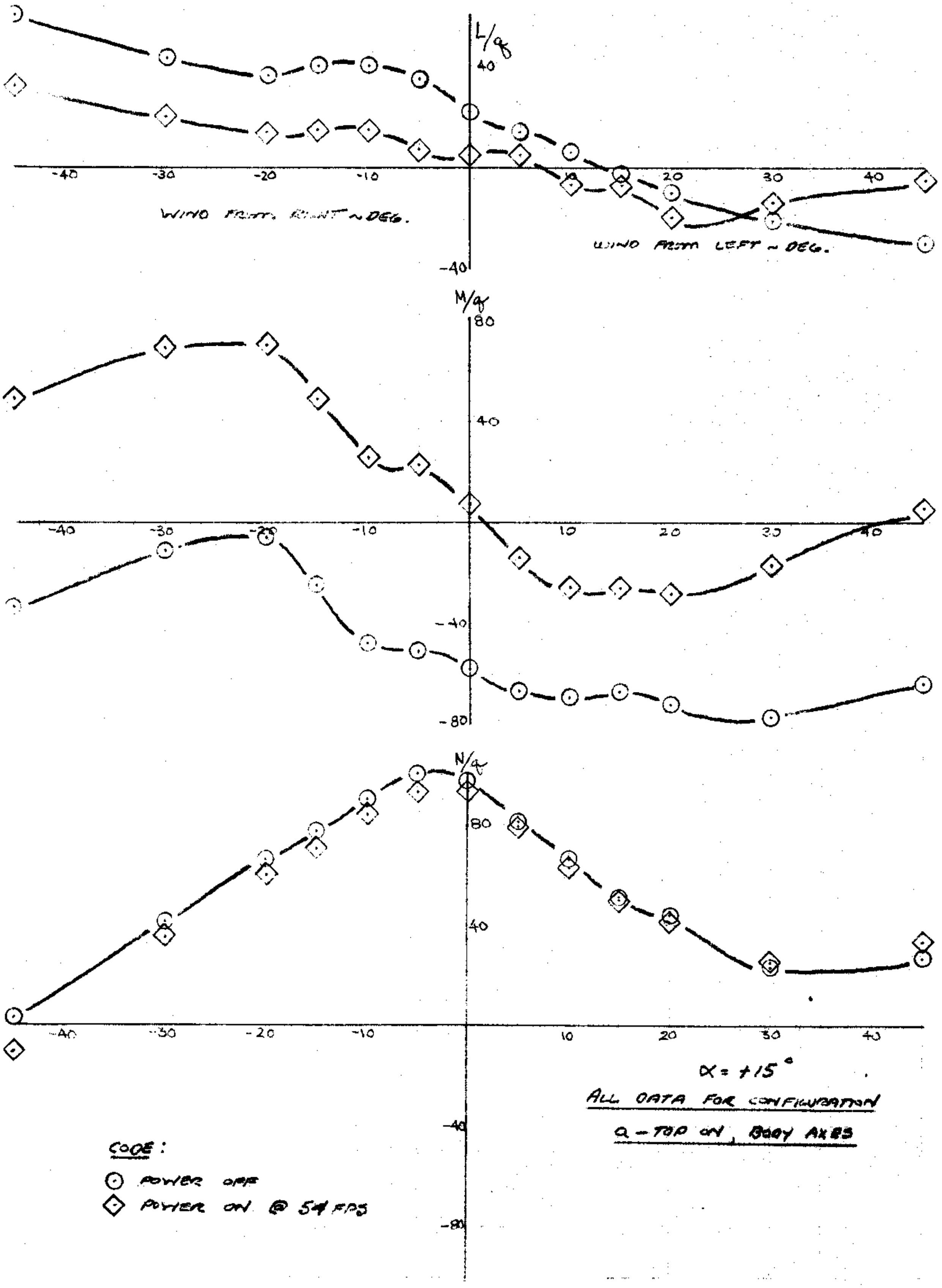
a - TOP ON, BODY AXES

CODE:

⊙ POWER OFF

◇ POWER ON @ 54 FPS

ENCLOSURE 1

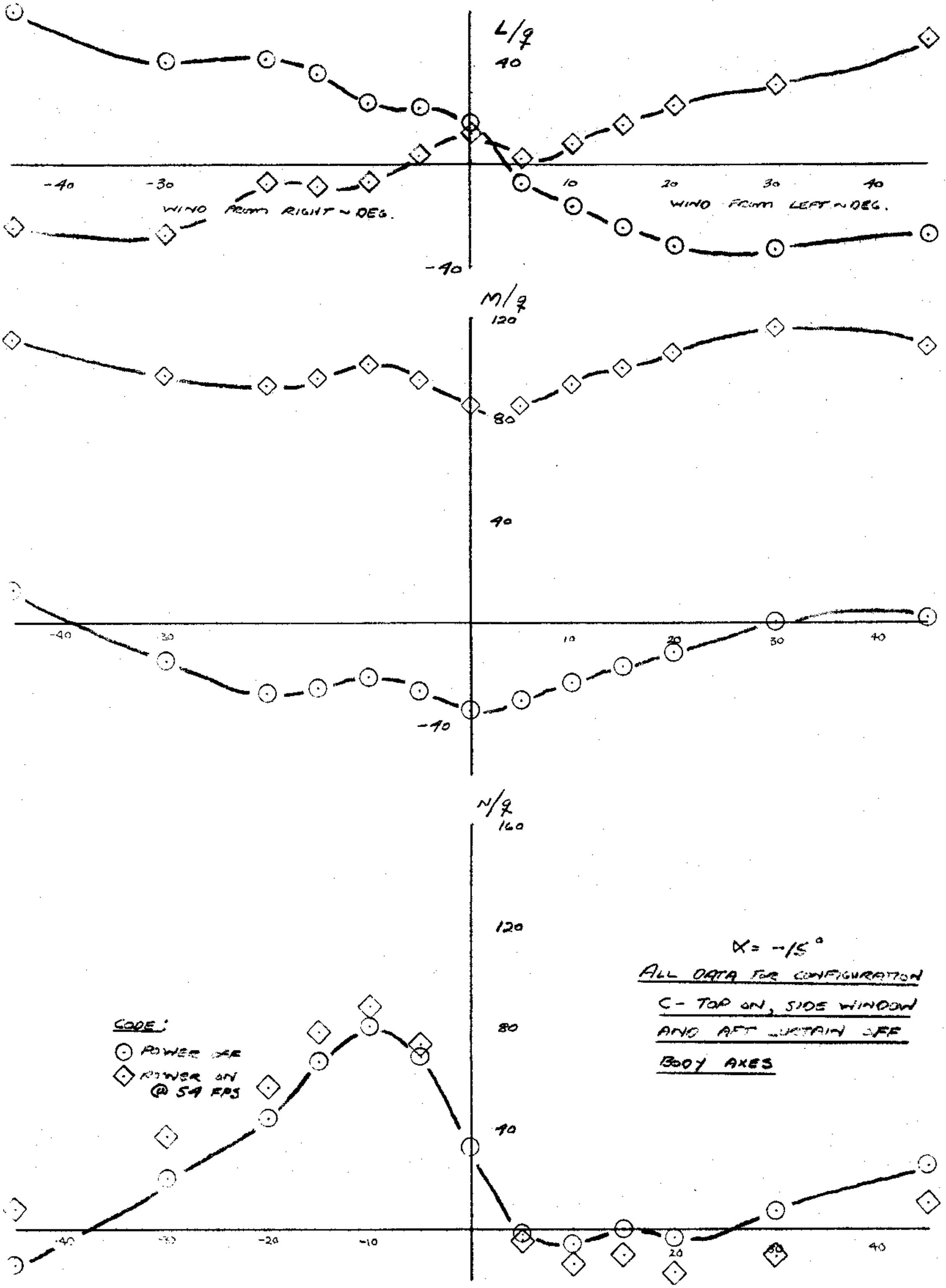


α = +15°

ALL DATA FOR CONFIGURATION

Q-TOP ON, BODY AXES

ENCLOSURE 2

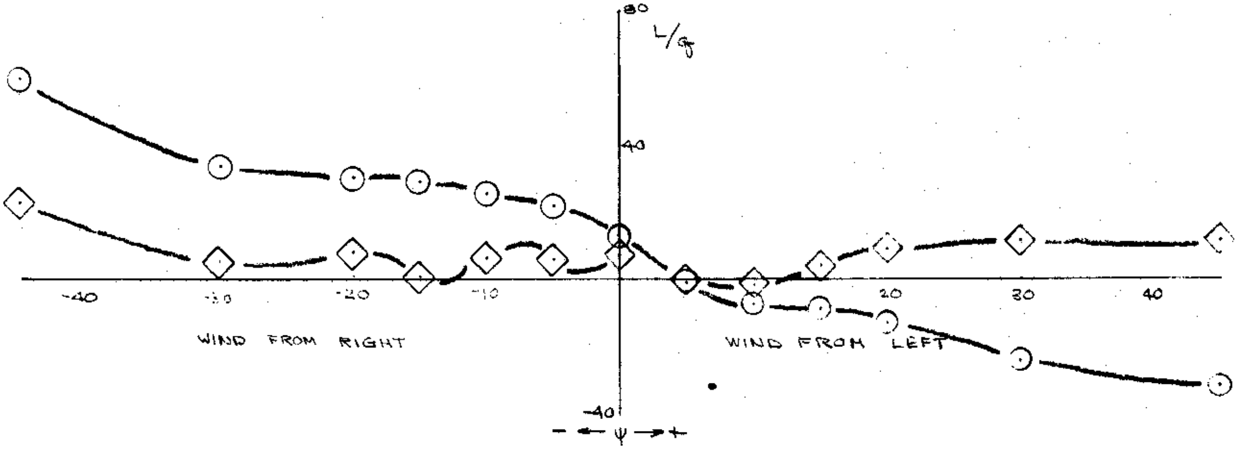


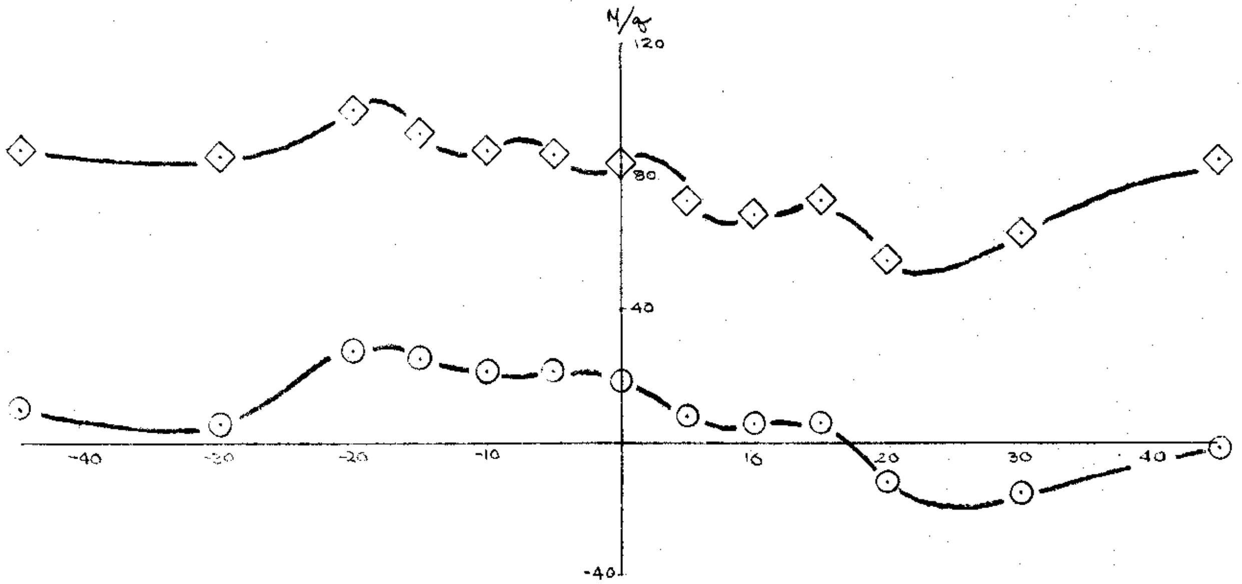
$\alpha = -15°$

ALL DATA FOR CONFIGURATION C - TOP ON, SIDE WINDOW AND AFT CURTAIN OFF

BODY AXES

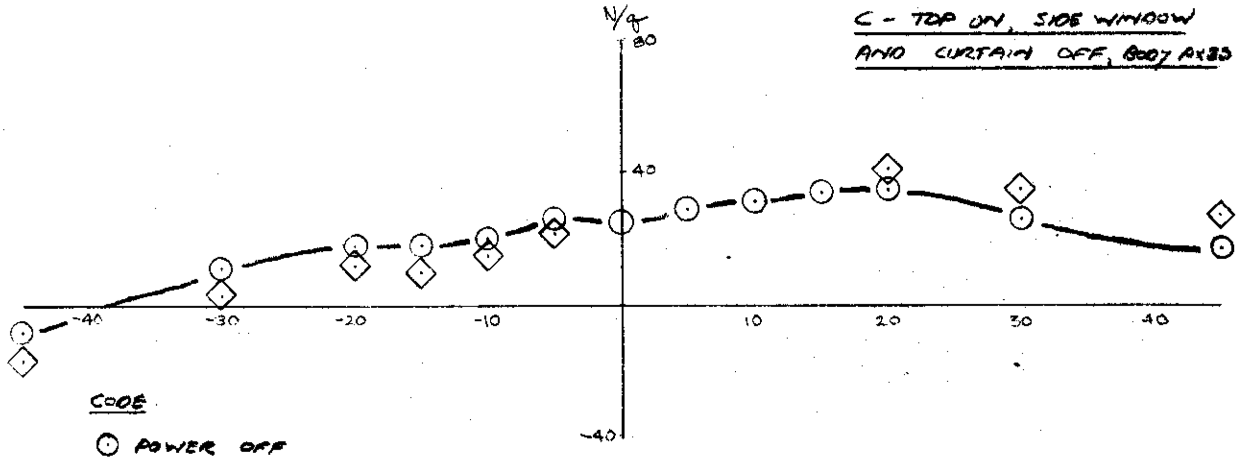
ENCLOSURE 3





α = +15°

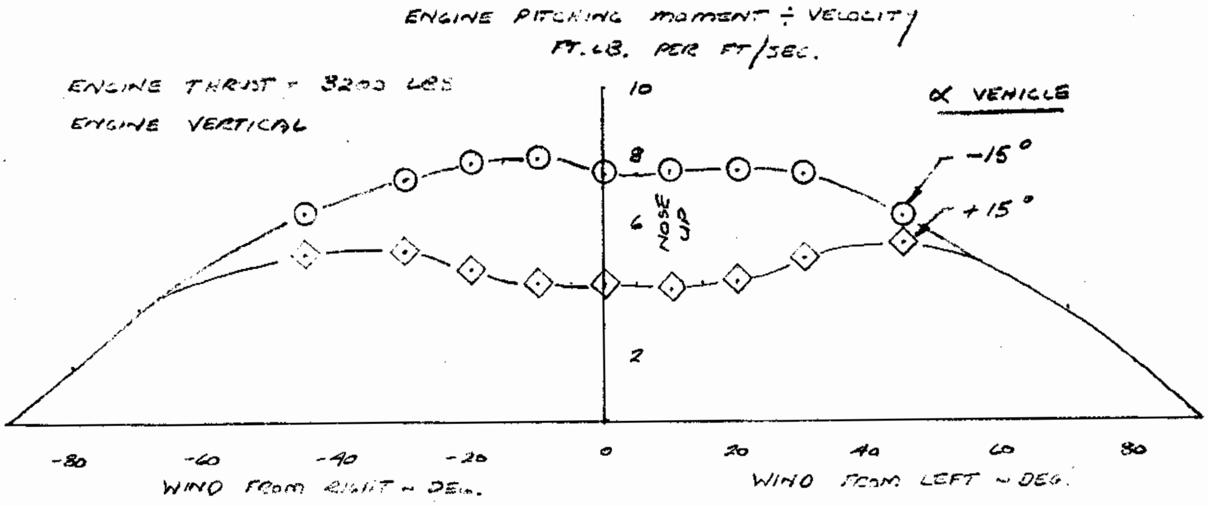
ALL DATA FOR CONFIGURATION
C - TOP ON, SIDE WINDOW
AND CURTAIN OFF, BODY AXES

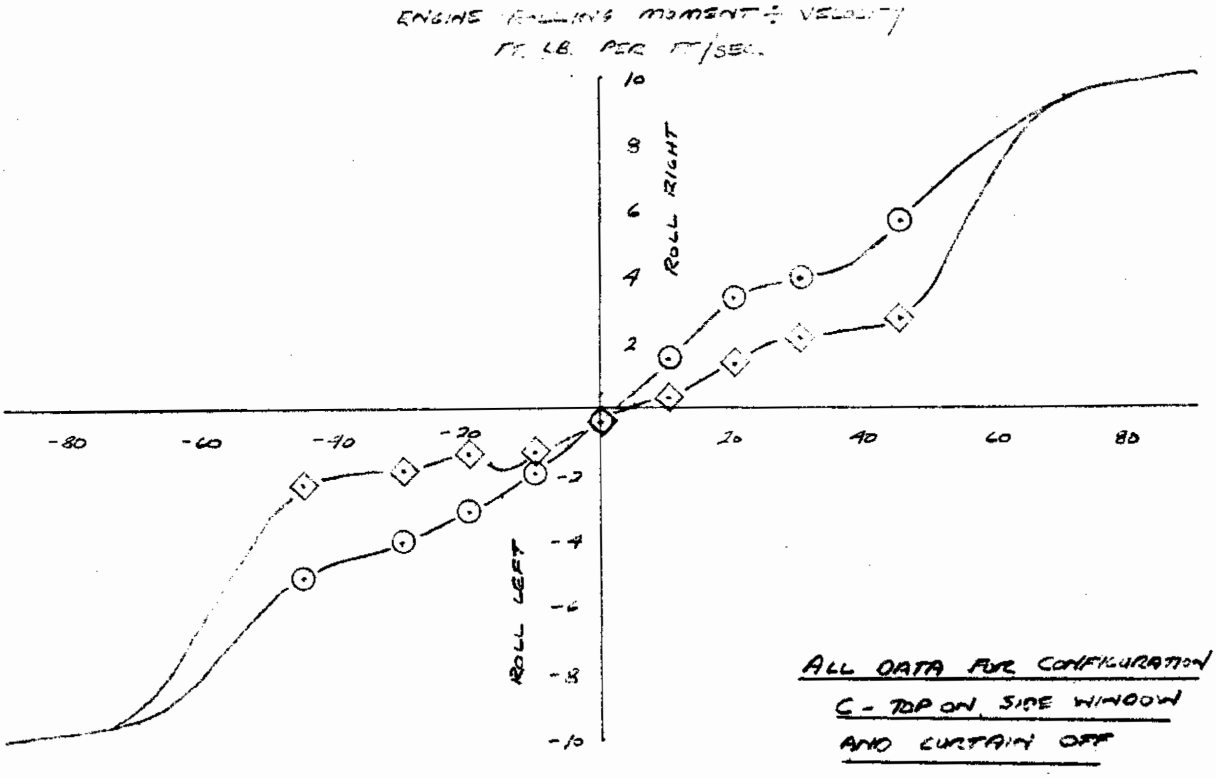


CODE

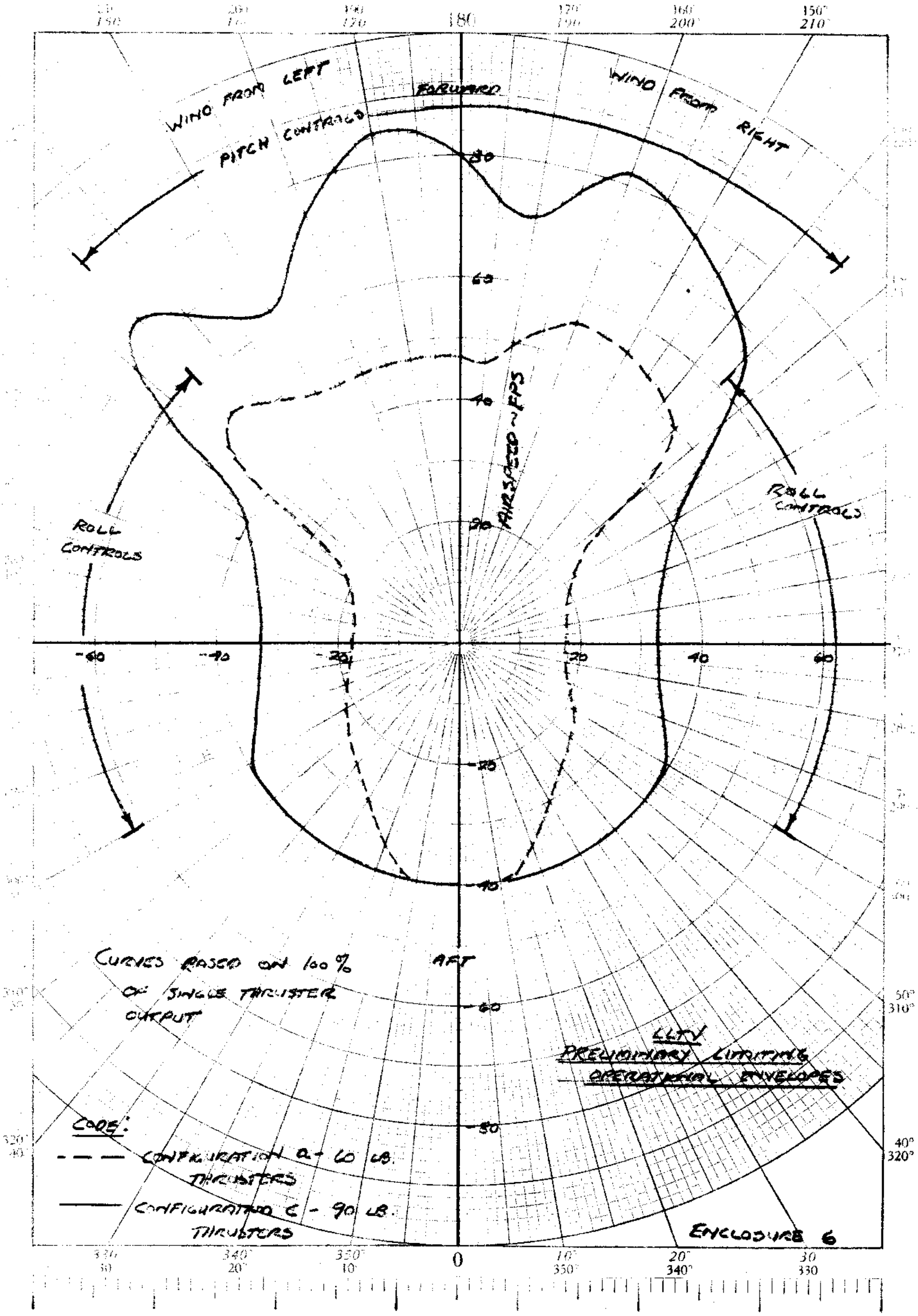
⊙ POWER OFF
◇ POWER ON @ 54 FPS

ENCLOSURE 4





ALL DATA FOR CONFIGURATION
C - TOP ON, SIDE WINDOW
AND CURTAIN OFF

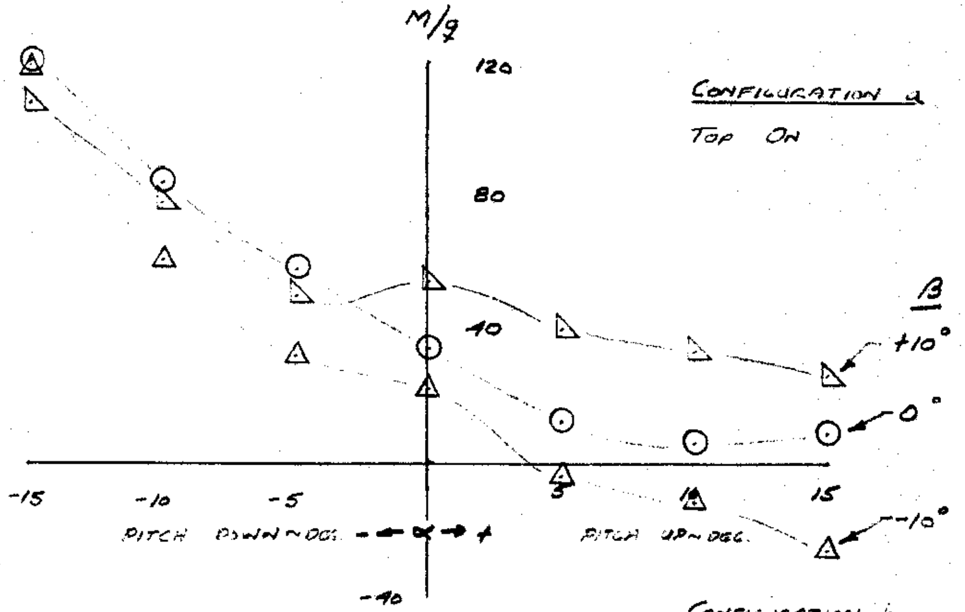


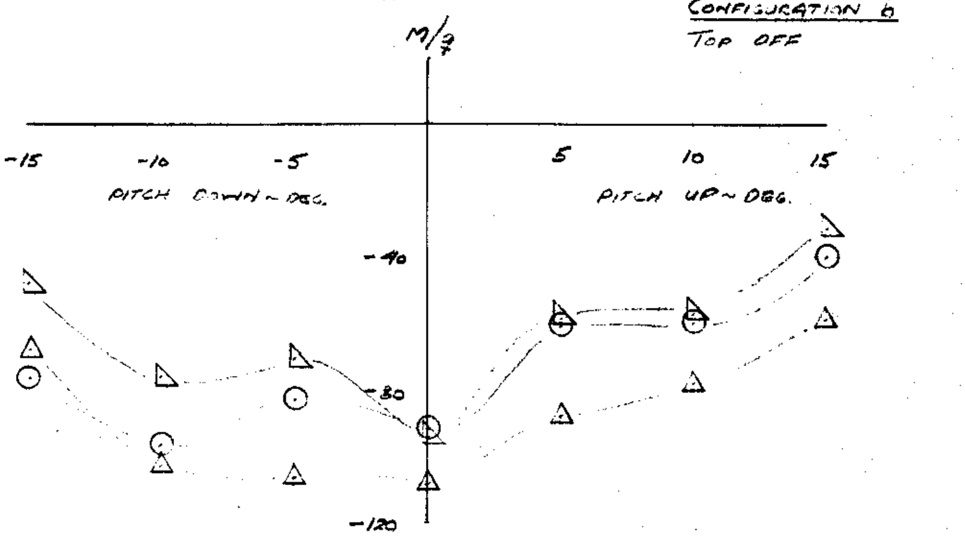
Curves based on 100% of single thruster output

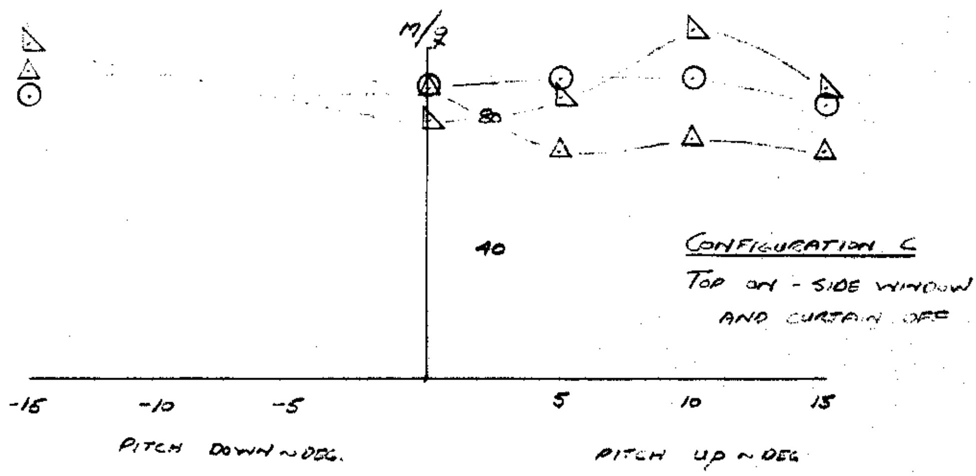
LLTV
PRELIMINARY LIMITING OPERATIONAL ENVELOPES

CODE:
– – – Configuration a – 60 lb. thrusters
——— Configuration c – 90 lb. thrusters

Enclosure 6


M/q
120
80
40
-40
CONFIGURATION a
TOP ON
β
+10°
0°
-10°
-15
-10
-5
5
10
15
PITCH DOWN ~ DEG. ← α → +
PITCH UP ~ DEG.


CONFIGURATION b
TOP OFF
M/q
-15
-10
-5
5
10
15
PITCH DOWN ~ DEG.
PITCH UP ~ DEG.
-40
-80
-120


M/q
80
40
CONFIGURATION C
TOP ON - SIDE WINDOW
AND CURTAIN OFF
-15
-10
-5
5
10
15
PITCH DOWN ~ DEG.
PITCH UP ~ DEG

INTERIM REPORT ON FLIGHT EVALUATIONS OF LUNAR LANDING VEHICLE ATTITUDE CONTROL SYSTEMS

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Abstract

An interim report is presented to summarize some of the results of a continuing flight-test investigation using the NASA Langley Research Center Lunar Landing Research Facility to study flight control problems of manned lunar landing vehicles. This report is concerned with the attitude control system only, and emphasis is placed on the pitch control system. The research vehicle employed in this investigation is designed so that many of the control system parameters can be varied over wide ranges of values which include those of the Apollo Lunar Module. About one hundred and fifty flights in simulated lunar gravity have been made to date by a group of ten research pilots including three astronauts and three pilots who also have had flight experience in the NASA Flight Research Center Lunar Landing Research Vehicle (LLRV). These flights were made using rate command and acceleration command type control systems and the primary variables were attitude control power, maximum command rate, and system dead band. The results, which are presented in terms of pilot ratings of the vehicle's handling qualities and related comments, show that there is a relatively large range of system control parameters which produce acceptable handling qualities when using a rate command system and indicate tentatively that optimum values for control power and maximum command rate are about 12.5 degrees per second per second and 12.5 degrees per second, respectively. Also, the results showed that acceptable handling qualities were not provided when using an acceleration command system for the range of parameters covered.

I. INTRODUCTION

For nearly the past 2 years, the Lunar Landing Research Facility located at NASA Langley Research Center, see figure 1, has been in operation; furthermore, for a similar period of time the Lunar Landing Research Vehicle, see figure 2, has been flying at NASA Flight Research Center. The purpose of both of these two related flight-test operations has been to evaluate the pilot handling qualities of lunar landing vehicles similar to the Apollo Lunar Module during the terminal approach and touchdown phase of the Apollo lunar mission. The intent of this paper is to disclose some hitherto unpublished results of the Langley research program pertaining to attitude control systems and to show the correlation of these data with information derived from the LLRV flight tests and also with information concerning related fixed-base simulator studies obtained from other sources. Inasmuch as the Langley data were obtained from the initial portions of a continuing program, these data are preliminary in nature and consequently are discussed only in terms of general trends in handling qualities produced by varying combinations of some of the control-system parameters. Emphasis is placed on a rate command type of control system although some comments are concerned with an acceleration-command system.

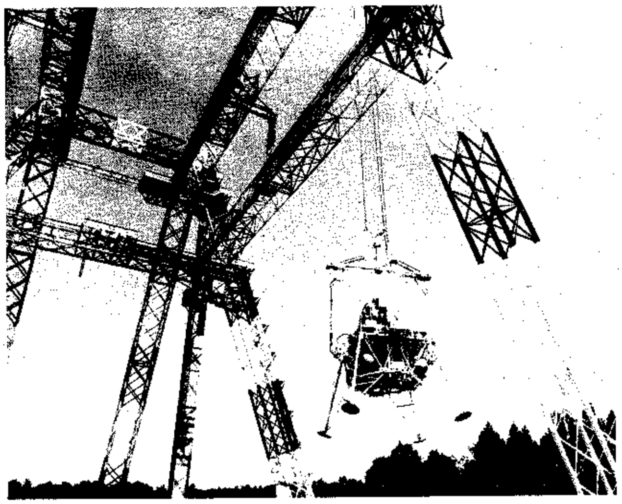

Figure 1.- Photograph of research vehicle flying in the Lunar Landing Research Facility at Langley Research Center.

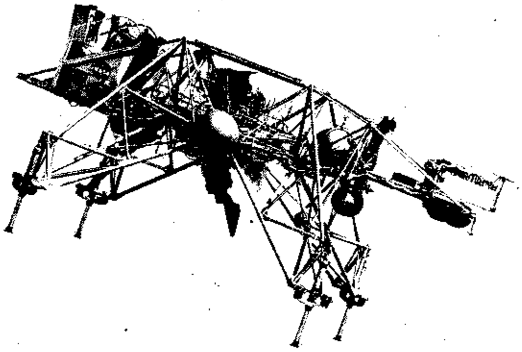

Figure 2.- Photograph of the Lunar Landing Research Vehicle at Flight Research Center.

In general, this discussion leads to establishing a tentative boundary for combinations of the basic system variables; "control power" and "maximum available rate," which yield acceptable handling qualities as determined by pilot ratings and subjective comments. Consideration of this boundary in conjunction with observations of the pilot's performance provides some insight relative to an optimum control system.

II. DISCUSSION OF LLRF RESEARCH PROGRAM

There has been general uncertainty relative to the pilot handling qualities of lunar landing vehicles, not necessarily concerning the pilot's ability to perform the landing, but more so with respect to the most appropriate combination of the test point symbol denote the rate dead-band values covered at each test point. (Note that the solid lines radiating from the origin represent the test parameter combinations which produce response times for maximum control inputs of 1/4, 1, and 4 seconds, respectively.) Inasmuch as this is merely a status report on a continuing program, the number of flights for each test point varies greatly; for some points only one flight has been made with one pilot, but for others several flights have been made with several pilots.

The results shown in figure 3 are in the form of averaged values of the pilot rating numbers (table I) assigned by each of the pilots after flying the vehicle with the specific test combinations. The numbers appearing above and below some of the symbols denote the highest and lowest of the rating values assigned to each particular combination of dead band, control power, and maximum command rate. The numbers appearing within the symbols represent either the rating assigned to a single flight or the average of all ratings assigned to the several flights for a particular test combination. Because of the incomplete status of this flight program these results do not represent a true sampling process, but are useful at this time to help denote some trends.

A brief survey of the test points in which multiple flights were made shows that the spread in pilot ratings for a given dead-band value was as large as 3.0. This is an unusually large variation of pilot ratings inasmuch as the pilot rating spread is customarily considered to be more in the order of 0.5 for more familiar flight investigations of aircraft. There are several factors, however, which may account for this unusual dispersion, the first being that the ratings for all flights including those assigned during the initial training period of each of the pilots have been included. Secondly, no distinction has been made in the test points for the differences in flight trajectories or for the changes made in the vehicle systems as previously mentioned. Consequently, some of this spread may be due to the rather crude approach taken here of lumping all the test points together. Obviously, the results of the subsequent test flights will help to clear up this point; however, it is believed some legitimate trends can be observed on the basis of the averaged data used in this review.

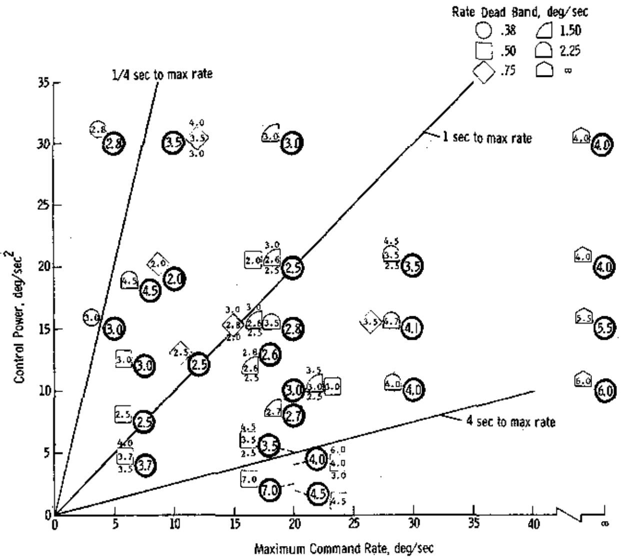

Figure 3.- Plot of pitch control system test points and pilot ratings for the Lunar Landing Research Facility Vehicle.

In the light of this significant spread, and the relatively few number of independent changes in rate dead band, there is little opportunity at this stage to evaluate the effects of rate dead

TABLE I.- COOPER PILOT-OPINION RATING SYSTEM

Operating conditions	Adjective rating	Numerical rating	Description	Primary mission accomplished	Can be landed
Normal operation	Satisfactory	1 2 3	Excellent, includes optimum Good, pleasant to fly Satisfactory, but with some mildly unpleasant characteristics	Yes Yes Yes	Yes Yes Yes
Emergency operation	Unsatisfactory	4 5 6	Acceptable, but with unpleasant characteristics Unacceptable for normal operation Acceptable for emergency condition only[1]	Yes Doubtful Doubtful	Yes Yes Yes
No operation	Unacceptable	7 8 9	Unacceptable even for emergency condition[1] Unacceptable - dangerous Unacceptable - uncontrollable	No No No	Doubtful No No
	Catastrophic	10	Motions possibly violent enough to prevent pilot escape	No	No

[1] Failure of a stability augmenter.

readily apparent on the basis of available information as to why flight-test and fixed-base simulation studies should differ in this respect.

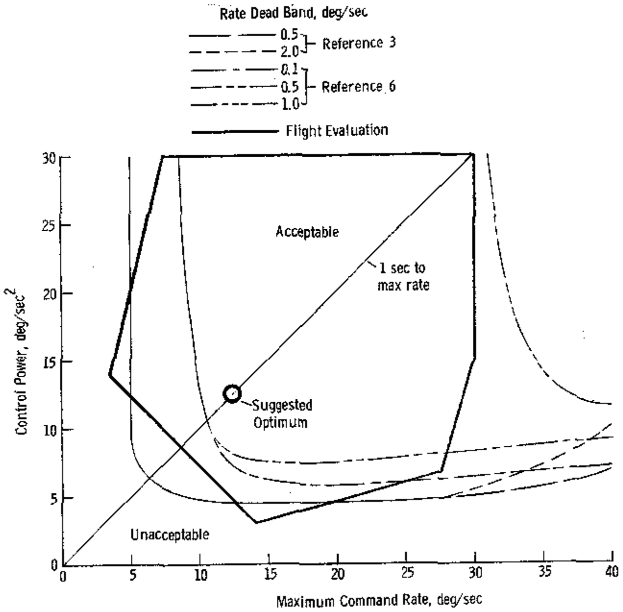

Figure 8.- Comparison of acceptable pilot rating boundaries established by use of the LLRF and the LLRV pitch control systems.

The results of a recent flight-test investigation using a variable stability helicopter to study the use of on-off or bang-bang type controls for V/STOL aircraft,[8] show a somewhat similar type of closed boundary as indicated in figure 11 of reference 8. This boundary has been replotted in figure 9 of this report by using the relationship

$$\text{Maximum control rate} = \frac{\text{Control power}}{\text{Angular velocity damping}} \qquad (1)$$

Inasmuch as the vehicle of reference 8 had linear damping rather than the nonlinear damping as provided by the lunar-landing-type vehicle, there is basic difference in the dynamics of the vehicle responses. Furthermore, the V/STOL test helicopter was flown, of course, in earth gravity where the horizontal response to angular displacement of the vehicle is much greater than for lunar gravity. These differences may account for the reduced area of the V/STOL boundary relative to the lunar-landing-vehicle boundary. The reduced area is primarily the result of a smaller range of acceptable control power values for the V/STOL condition. The boundaries are in close agreement for the upper and lower limits for maximum control rate and the optimum combination for control rate and control power discussed previously is enclosed within the V/STOL boundary.

On the basis of the comparison of the results of the Langley preliminary research program and various other studies of lunar-landing-vehicle attitude control systems, it is tentatively concluded that combinations of the following range of system parameters will generally provide acceptable handling qualities for performing a lunar landing task during the touchdown phase:

Control power, deg/sec^2	5 to 30
Maximum control rate, deg/sec	5 to 30
Rate dead band, deg/sec	0.5 to 2

An optimum combination of handling qualities appears to be obtained with a control power of 12.5 deg/sec^2 and maximum command rate of 12.5 deg/sec which provide a response time of 1 second to reach maximum rate.

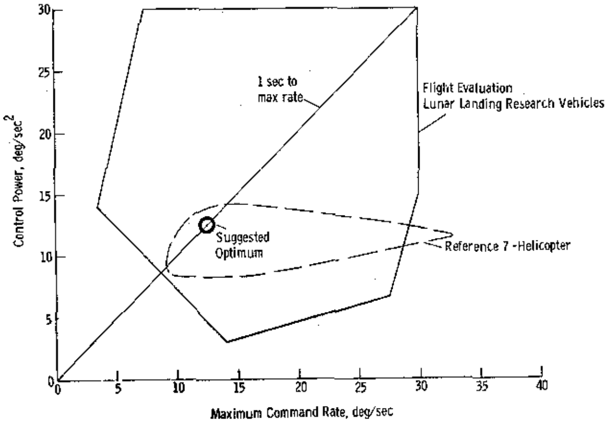

Figure 9.- Comparison of the acceptable pilot rating boundaries derived from flight evaluations of the lunar landing research vehicles and a helicopter using a bang-bang type control system.

VIII. ATTITUDE CONTROL MODES

Up to this point there has been no attempt to differentiate between the two basic modes of attitude control, namely, acceleration command and rate command, which were utilized in this investigation. The acceleration command mode has been treated as a rate command system with infinite maximum available rate and dead band. The form of acceleration control employed is, of course, an open-loop system in which only the direction of angular acceleration is commanded; the magnitude of acceleration is established by the relation of the fixed attitude rocket thrust level to the moment of inertia about the respective axis. Control power, therefore, is the primary system variable for the acceleration mode under consideration.

A review of figure 3 reveals that for the values of control power tested, no acceptable pilot ratings were obtained for the acceleration mode in contrast to the large range of control power values which resulted in acceptable ratings for the rate command mode. The primary objection to the acceleration mode expressed by the pilots is that their primary piloting workload was increased markedly by the lack of system damping and the need for the pilot to provide rate limiting. Although the pilots found objectionable characteristics with the acceleration mode, they expressed the view that flight control was not as difficult in this mode as they had expected. Furthermore, some pilots made the comment that they would consider this mode acceptable as long as the pilot's workload was concerned only with the flying task. From the observer's viewpoint, the basic difference between the two modes of control was evidenced by frequent small-scale motions of the vehicle when the acceleration mode was utilized.

Although not investigated in any detail, the attitude controller dead band and physical characteristics appear to be more significant factors for the acceleration mode than for the rate command mode. Several comments or complaints were made concerning the controller after the vehicle had been flown in acceleration mode even though many flights had previously been made in rate command mode by each of the pilots using the same controller. Concern was expressed about the controller position, actuation motion (that is, location of pivot point), and dead band. Generally, a wider dead band than that provided was requested so as to eliminate the inadvertent input about an axis other than the one being commanded. The controller dead band used for most of these flights was equivalent to ±1° out of a total ±10° stick travel. These problems seem to stem from the fact that the pilot work load was much greater in acceleration mode than rate mode. As a consequence, controller deficiencies which the pilot overlooked in rate command were more readily apparent in acceleration command because the deficiencies interfered with the pilot's ability to make more frequent and precise control inputs.

IX. CONCLUDING REMARKS

In closing it can be stated that a rather broad review of preliminary data from the LLRF research program and comparison with related data from other sources indicates some general trends which should prove useful in considerations of handling qualities of lunar landing vehicle. These trends imply that there is an optimum range of values for pitch attitute control power and maximum command rate in which acceptable handling qualities can be attained.

Results of the continuing research program will be required to define more clearly the boundary values for acceptable handling qualities and to establish effects of control system rate dead band on these values.

REFERENCES

1. O'Bryan, Thomas C.: Flight Tests of a Manned Rocket-Powered Vehicle Utilizing the Langley Lunar Landing Research Facility. Presented at AIAA Guidance and Control Specialists Conference, Seattle, Washington, August 15-17, 1966.

2. Brown, David A.: Langley Simulators Perform Lunar Tasks. Aviation Week and Space Technology, April 13, 1964.

3. Jarvis, Calvin R.: Rate Command System Requirements for Attitude Control of a Lunar Landing Research Vehicle. Proposed Technical Note. H-436.

4. Matranga, Gene J.; Mallick, Donald L; and Kluever, Emil E.: An Assessment of Ground and Flight Simulation for the Examination of Manned Lunar Landing. Presented at AIAA Flight Test Simulation and Support Conference, Cocoa Beach, Florida, February 6-8, 1967.

5. Mallick, Donald L; Kluever, Emil E.; and Matranga, Gene J.: Flight Results with a Non-Aerodynamic, Variable Stability, Flying Platform. Presented at the Society of Experimental Test Pilots 10th Annual Symposium, Beverly Hills, California, 1966.

6. Matranga, G. J.; Washington, H. P.; Chenoweth, P. L.; and Young, W. R.: Handling Qualities and Trajectory Requirements for Terminal Lunar Landing as Determined from Analog Simulation. NASA TN D-1921, August 1963.

7. Cheatham, D. C.; and Hackler, C. T.: Handling Qualities for Pilot Control of Apollo Lunar Landing Spacecraft. AIAA-NASA Third Annual Space Flight Meeting, Nov. 4-6, 1964.

8. Garren, John F., Jr.; DeCarlo, Daniel J.; and Driscoll, Norman R.: Flight Investigation of an On-Off Control for V/STOL Aircraft Under Visual Conditions. NASA TN D-3436, June 1966.