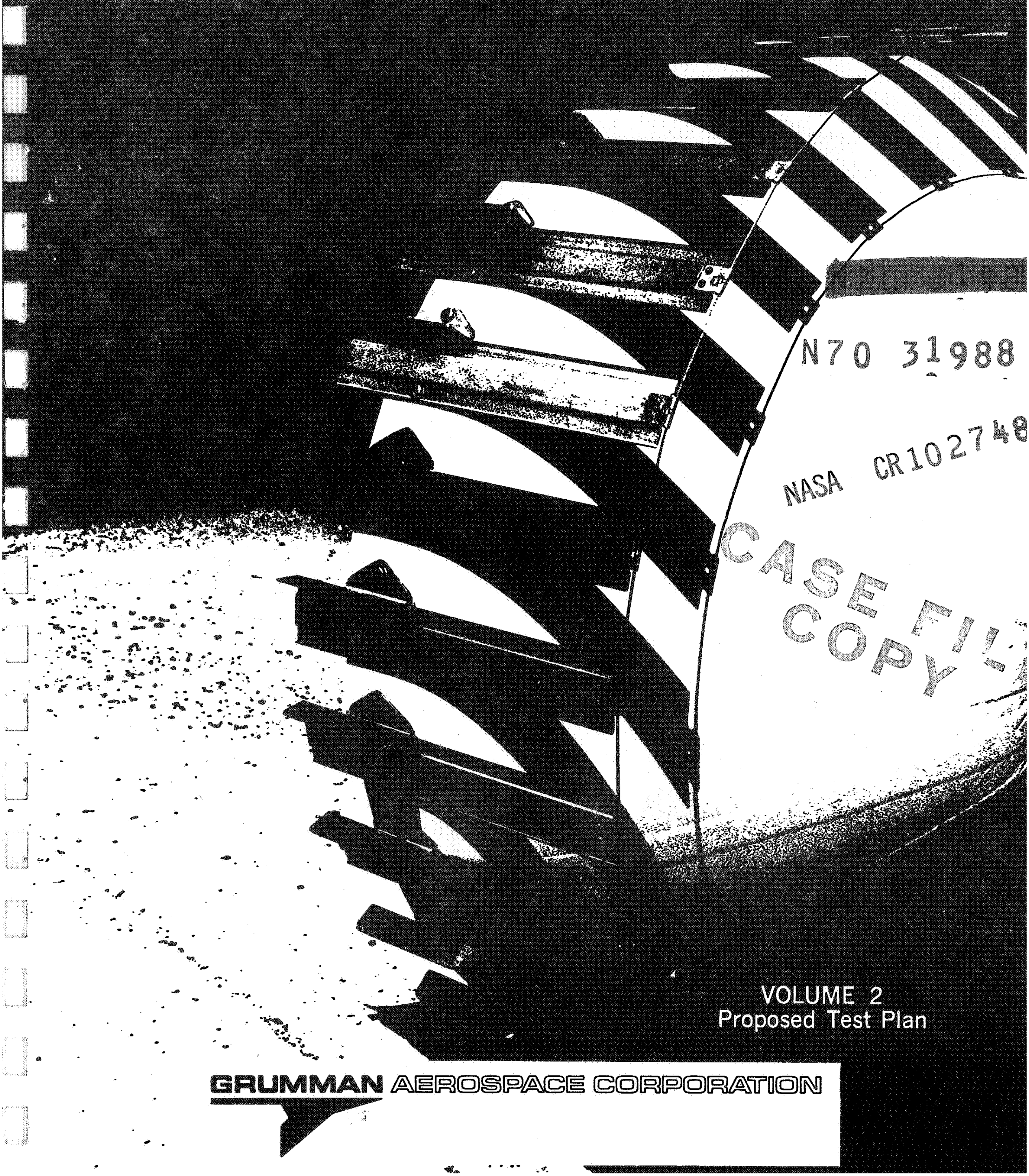
DESIGN AND FABRICATION OF WHEELS FOR A LUNAR SURFACE VEHICLE



VOLUME 2
Proposed Test Plan

GRUMMAN AEROSPACE CORPORATION

FINAL REPORT
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DESIGN AND FABRICATION OF WHEELS FOR A LUNAR SURFACE VEHICLE

VOLUME 2
Proposed Test Plan

Prepared for

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VOLUME 2

TEST PLAN

1.0 PURPOSE

The purpose of this test plan is to outline a comprehensive test program designed to qualify a wheel drive assembly (WDA) for use on the lunar surface. The plan is designed specifically for the Grumman Aerospace Corporation (GAC) conical fiberglass wheel concept, however, the test philosophies, requirements, and proposed procedures could be adapted to any WDA. The NASA sponsored Dual Mode Lunar Roving Vehicle (DLRV) study recently completed by the GAC was used as a primary reference to establish basic test requirements, and is referenced frequently herein. The plan is based on the availability of three WDA's, and encompasses static testing, mobility performance, and endurance tests under various environmental conditions. The minimum supporting instrumentation and test fixture requirements are also noted. It has been assumed that all tests would be run by NASA using various government facilities.

2.0 DESCRIPTION OF TEST ARTICLE

As part of this contract three elastic conical wheels, designed and manufactured by Grumman will be delivered to NASA for evaluation and qualification. The primary wheel structure is a laminated high temperature resistant fiberglass/epoxy system (F161/7581), coated with a polyurethane coating to resist abrasion and ultraviolet radiation, and fitted with titanium (6AL-4V) cleats interconnected by a continuous cable. The wheel hub configuration and bolt pattern utilized conforms to Grumman's DLRV design, but is easily adaptable to the other DLRV designs being considered. The cleated wheel has an overall diameter of 38 inches and a depth of 17 inches. The fiberglass varies in thickness from .190 at the hub section to .050 along the cone. Figure 2-1 shows the detail wheel design.

3.0 TEST CONDITIONS

Two basic test conditions are required to define the operating characteristics of any wheel drive assembly.

3.1 STATIC TESTS

Static testing should define the basic wheel spring rate, stress distribution and response characteristics to various loadings and obstacle shapes. The motor gear box would not normally be required for this test as long as the hub stiffness is properly simulated when the wheel is mounted for testing. The wheel should be mounted in a soil box designed to accomodate simulated lunar soils, and of sufficient size to eliminate any possible "wall effects". Normal wheel loadings from .5 to design maximum (5.5g) should be tested. Side loads up to 2.4g, and drag loads up to the stall torque output of the motor gear box must also be checked.

3.2 DYNAMIC TESTS

Dynamic testing should define the traffic mobility, endurance, and thermal vacuum (T/V) induced characteristics of the wheel drive assembly. For these tests the "selected" motor gear box should be used as the wheel drive. To satisfy the noted objectives three separate tests are defined below, assuming three test wheels and motor gear box assemblies are available.

- o <u>Traffic mobility</u>: Wheel No. 1 shall evaluate soft soil performance under ambient environment conditions at facilities located at Waterways Experimental Station.
- o <u>Endurance testing</u>: Wheel No. 2 will evaluate endurance on a road bed with simulated lunar soil under partial vacuum and high temperature environment conditions. The objective here is to assess the thermal contribution of a scuffing, slipping wheel, and a dust covered motor gear box to the endurance of the WDA, and also to further define the abrasion characteristics of the wheel and cleats. In addition to evaluating the wheel cycle life and motor drive failure modes, this test should determine if there is any possible resonent conditions which might be excited within the anticipated speed environment.
- o <u>Thermal/Vacuum testing</u>: Wheel No. 3 shall be evaluated in a manner similar to Wheel No. 2 above, except with no soil contaminent required, but under vacuum of the 10^{-6} Torr range and between temperature extremes of -250°F - +300°F, exposed to ultra violet radiation. This test will evaluate the effects of lunar night driving and the impact of long duration UV impingement on the fiberglass shell.

3.2.1 Traffic Mobility

Wheel number 1 should be evaluated to determine its performance characteristics. The selected motor gear box should be used to insure that the proper drive loads and speeds are applied, and to establish the operating "system" characteristics. The following items are a minimum listing of the performance measurement requirements.

- normal and axial loadings
- sinkage/footprint profile
- motor gear box input and output characteristics (voltage, current, temperature)
- wheel RPM, torque, % slip, drawbar pull and rolling resistance
- wear characteristics - wheel, cleat, hub attachment, motor gear box

These tests should be accomplished under ambient conditions using a simulated lunar soil. Should these tests be done at NASA, the soil bin test facilities at Waterways Experiment Station should be seriously considered.

3.2.2 Ambient Endurance Test

Prior to evaluating the wheel drive life cycle characteristics this WDA should be used to determine if any resonant conditions exist which might be excited within the anticipated vehicle speed range. A simple "shaker" system could be used for this test. The amplitude and frequency spectrum is defined in the DLRV specifications volume. Primarily wheel number two should evaluate mobility system endurance. In order to truly assess endurance as related to the lunar environment the contaminant effect of the lunar soil must be introduced into this test. To accomplish this all testing should be accomplished under partial vacuum conditions, and high temperature thermal simulation. It is recognized that a contaminate in the vacuum chamber creates a formidable problem, however, two possible solutions are suggested. First, only a partial vacuum of 10^{-2} - 10^{-3} is required to evaluate the thermal problem. Second the chamber may be run cyclically and out of phase with the running requirements for the wheel drive. The DLRV mission profile as developed in Volume II of Grummans DLRV phase B report indicated approximately a 20 minute drive cycle followed by a 30 minute stop for science activity.

3.2.3 Thermal/Vacuum Endurance Testing

Wheel No. 3 shall be evaluated in a manner similar to B above but under vacuum in the 10^{-6} Torr range and between temperature extremes of -250°F through +300°F, exposed to ultra violet radiation. The requirement for a soil contaminent for this test could be eliminated, however the test wheel should have abrasion characteristics as developed on wheels 1 and 2. Velocity cycles and wheel loading should reflect the mission condition being simulated, and be held constant for all dynamic endurance type tests. Loading shall consist of a nominal vehicle load (55#/Wheel for 1 Lunar g) and velocity equivalent to an average travel rate of 1.5 KM/Hr. for approximately 92% of test time and 7.5 KM/Hr. for the remainder.

4.0 TEST FIXTURES

4.1 WHEEL SUSPENSION

This must be viewed as the single most important consideration in this plan. The vehicle/wheel interface must be identical to the suspension system (limited torque bar) utilized on the vehicle. Component parts for this suspension should be fabricated and the final system assembled per Grumman DLRV final report. Loading methods are extremely critical if a realistic evaluation of the wheel is to be accomplished. Identical loading systems must be used for testing each wheel. Control parameters for the loading fixture design are the thermal/vacuum limitations imposed which direct the design towards an adjustable mechanical loading system as the simplest to make reliable at vacuum extremes. It must be a three degree of freedom arrangement with each degree restrained to simulate proper loading. To rigidly restrain the wheel in any direction would result in extreme concentrated loads, not representative of what the wheel will actually see in operation. A recommended loading system is illustrated in Figure 4-1.

4.2 ROAD BED

Identical road beds should be used for both endurance and thermal vacuum tests. This test road bed should be a continuous belt with suitable obstacles mounted at random per definition of NASA. Road bed design must specify a circumference that is not a multiple of wheel circumference to preclude the possibility of repetitive obstacle loading rather than random. The road bed should have a smooth surface parallel to the obstacles simulating running on the smooth mare. The test road bed should be constructed such that a simulated lunar soil could be overlaid on the smooth portion of the test surface for use in the partial vacuum tests. If this was considered unsatisfactory a separate soil test bed would have to be provided. For either case the road bed should be free wheeling rather than powered to eliminate the requirement for additional drive units in the chamber. A braking system on the road bed is required to induce wheel drag loads. The NASA selected motor gear box should be used to power the wheel,

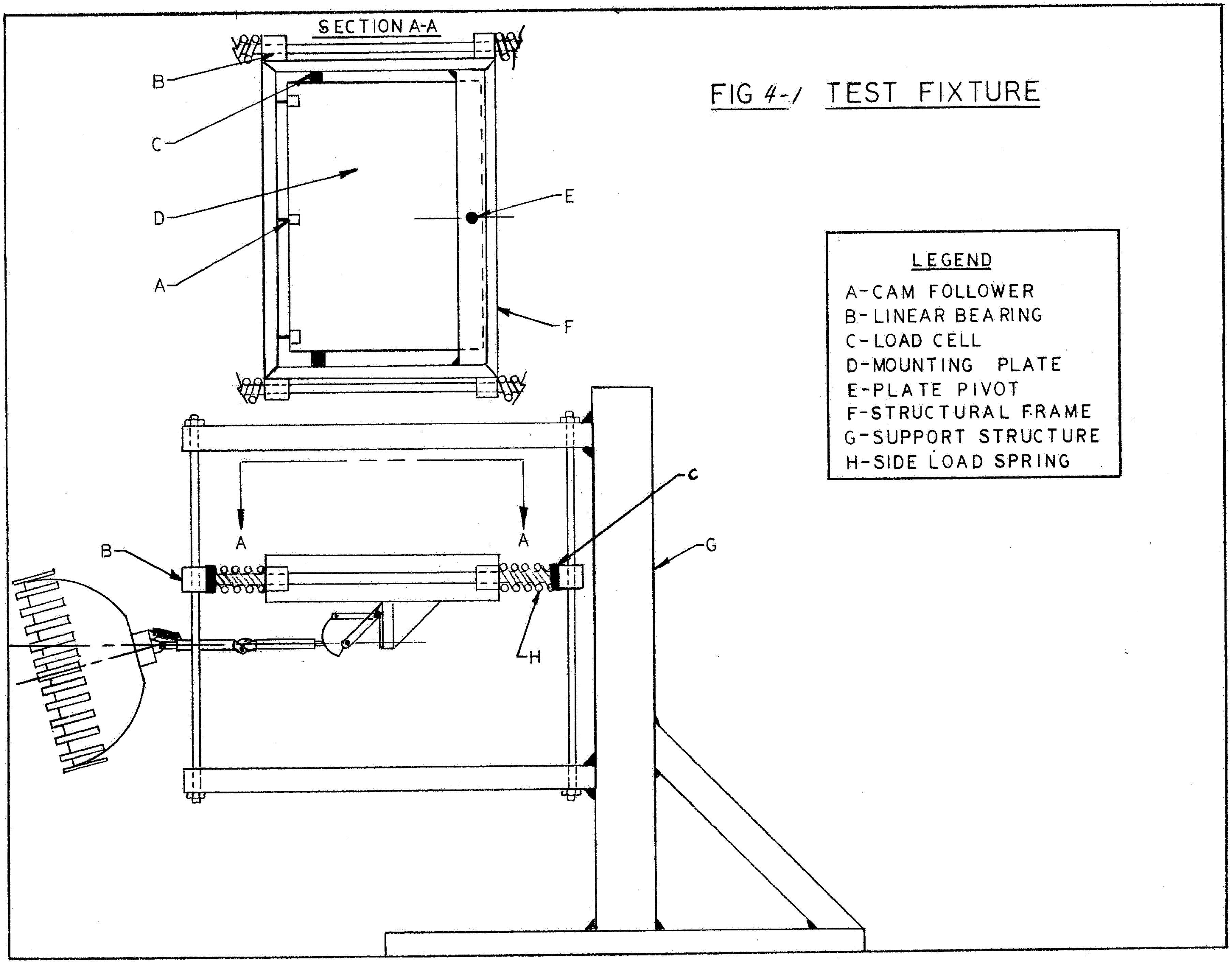


FIG 4-1 TEST FIXTURE

thereby providing an additional data feedback.

The mission profile must be considered in the design and operation of the road bed. A specific percentage of mission life shall find the wheel operating on a soft soil surface and another percentage of operation in a rubble strewn environment. In order to simulate this shared duty condition, the road bed is visualized as two parallel tracks, one studded with obstacles and the other surface smooth. To preclude a concentrated line loading condition on the wheel cleats, which is unrealistic while operating in soft soil, the smooth surface should be padded with a resilient, spongy material selected to approximate the spring and damping characteristics of the soil expected to be encountered. A recommended road bed arrangement is illustrated in Figure 4-2.

The same basic set-up can be utilized with a power unit added to drive the road bed if a fine control of drag loading is deemed necessary and the expense of providing a unit capable of being operated under the Thermal/Vacuum conditions can be justified.

4.3 INSTRUMENTATION

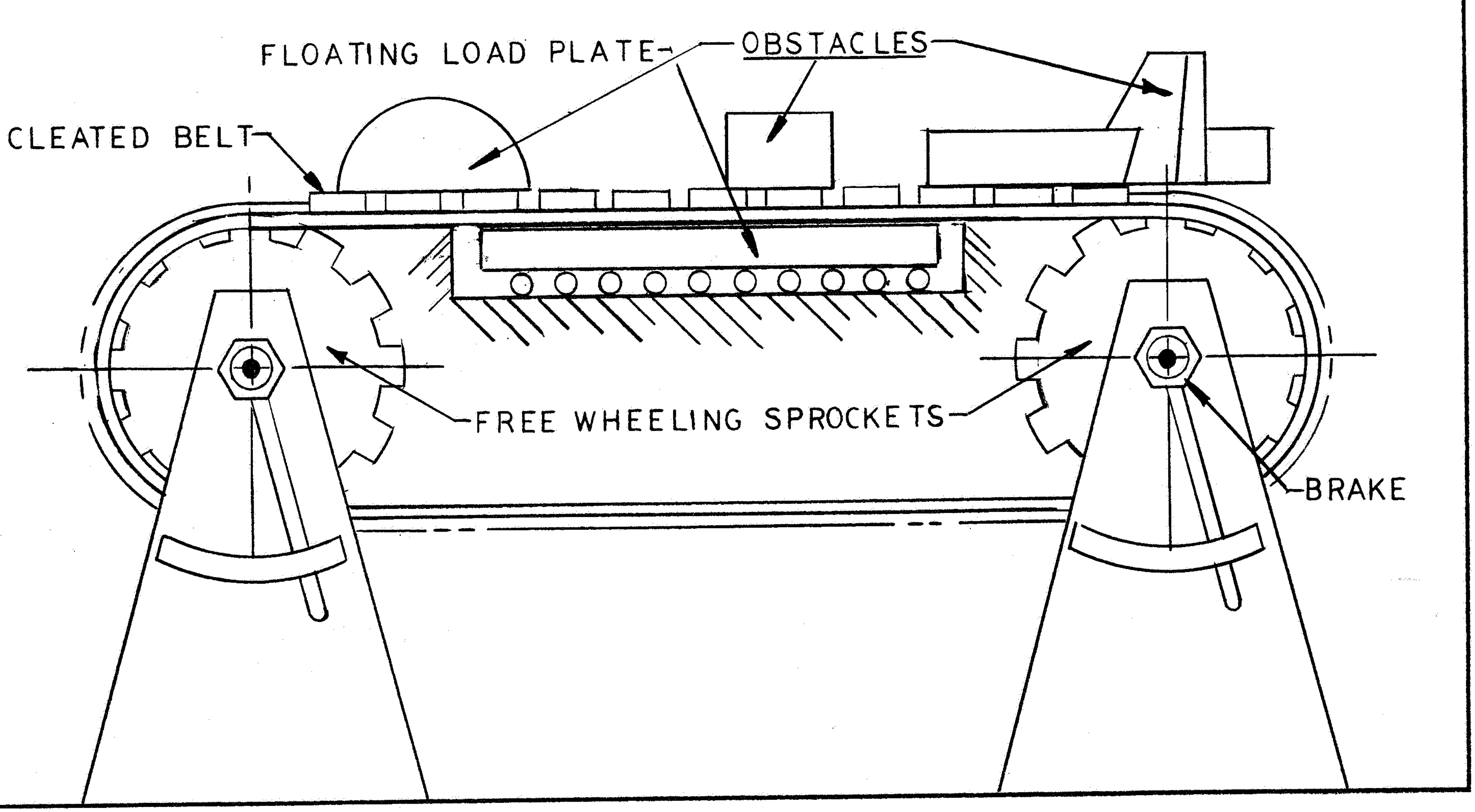
4.3.1 Static Testing (wheel)

Instrumentation for the static tests shall be designed to evaluate spring rate and wheel deformation under static loading for both level terrain as well as specified obstacles. The wheel shall be indexed to insure measurements are taken at the same wheel position and strain gaging designed to cover deflections in all critical areas of the wheel cone. Gages shall be permanently bonded to the interior wheel surface and shall be capable of being easily disconnected for dynamic wheel testing sequences. All normal, axial and drag loads should be recorded.

4.3.2 Mobility Testing

In general the instrumentation must define the wheel loading, RPM, thrust output and surface soil conditions. The following specific items should be noted.

FIG. 4-2 TEST ROAD BED



- Drawbar Pull
- Torque Input
- Wheel Speed
- Carriage Speed
- All Soil Strength Parameters
- Radial & Axial Wheel Load
- Wheel Sinkage

4.3.3 Dynamic Endurance Testing (wheel)

Instrumentation shall be designed to provide a permanent, continuous record of load cell readings for drag loads, axial loads, and normal loads during endurance and thermal vacuum environment tests. A wheel revolution counter and tachometer should be utilized with the recorder to provide a permanent, continuous record of load cell readings which could be correlated with the wheels cycle life. The applicability of measuring wheel rim temperatures should be considered.

4.3.4 Static Testing (drive unit)

No special instrumentation is anticipated for initial testing of the drive unit. It is assumed that the candidate unit chosen has been completely inspected upon receipt to applicable specifications and such information is available for comparative purposes during testing.

4.3.5 Dynamic Testing (drive unit)

Instrumentation required shall consist of the ability to continuously monitor power input and pre-selected critical temperatures during the test and have these plotted versus time for comparison to related parameters.

The test sequence and instrumentation requirements noted above are advanced as the simplest most economical arrangement to qualify the WDA for use on the lunar surface. If desired,additional strain gage data could be obtained during the endurance testing. A more sophisticated approach requiring use of a slip ring assembly could be used to monitor wheel stress while rotating. In addition, it would be necessary to plot this data against a profile of the road bed to indicate the conditions being encountered as the wheel is driven over the various obstacles.

The most convenient arrangement would be to mount a shaft to the center of the wheel drive unit and extend it outboard where the slip ring pickup housing can be more easily supported and restrained.

5.0 TEST PROCEDURES

The procedures outlined are considered the minimum effort required to obtain reliable data. They were designed as the simplest, most economical approach to fully evaluate wheel capability. Where applicable, more sophisticated alternate approaches are noted for information and consideration.

5.1 ESTABLISHMENT OF INITIAL TEST CONDITIONS

5.1.1

With wheel freely suspended from the test fixture and subject to no load, the diameter shall be measured using three point measuring techniques at a minimum of four specific locations indexed so that measurement can be duplicated for comparison purposes at specified test intervals. End purpose of measurements is to establish the capability of checking wheel for permanent set. Each individual wheel should be so defined.

5.1.2

Wheel shall be positioned using indexing called out in Paragraph 4.3.1 with wheel touching but not loaded against a soil box free to float in the horizontal plane. Radial loads shall be applied in 20 lb. increments from 0 through 300 lb. with wheel deformation and stress distribution recorded for each load increment.

5.1.3

The above step shall be repeated for each radial obstacle defined except that the specified obstacles shall be rigidly mounted to a non-deflecting plate capable of floating in the horizontal plane.

5.1.4

With plate restrained fore and aft and working against load cells in the axial direction, increase the axial load until a maximum equivalent to a 2.4 g side load is achieved. Load increments of 20 lbs. should be used, with the wheel bearing against the defined obstacle for side loading. Strain readings, axial load, and radial loads shall be recorded.

5.1.5

Paragraph 5.1.1 shall be repeated and recorded and a close visual inspection given to all surfaces and observations recorded. In particular cleats and adjacent areas subject to abrasion and hub and bolt pattern areas should be inspected.

5.2 MOBILITY TESTING

5.2.1

A common Wheel suspension system or an identical system (See Figure 4-1) must be used to support the Wheel during soilbin testing. The mounted wheel must be checked for vertical and lateral excentricity prior to testing.

5.2.2

Soil utilized in testing should be the NASA lunar soil model. While it is realized that a true 1/6 g test is extremely difficult, correlation factors can be applied from current NASA small scale tests and limited to 1/6 g tests to provide adequate prediction of lunar performance.

5.2.3

Data required from soilbin testing shall consist of:

a) Draw bar force generated vs. load and % slip
b) Foot print size and shape vs. load (photographic record)
c) Steering force required vs. Load and Speed (speeds required 7.5 KM/Hr. and 1.5 KM/Hr.)
d) Depth of Wheel penetration vs. Load
e) Observation of cleat clogging or jamming tendencies supported by photographs
f) Observations as to effects of dust generated on operation of drive system.

5.2.4

Upon completion of soilbin testing the wheel drive unit shall be disassembled to compare its condition to initial conditions established upon wheel drive acceptance from vendor. Particular note should be taken of the following areas:

a) Condition of gears and bearings

b) Electrical characteristics of the motor

c) Condition of lubricant and determination of loss

d) Condition and effectiveness of seals

5.3 ENDURANCE TESTING (PARTIAL VACUUM CONDITIONS)

5.3.1

After static testing to establish the initial wheel characteristics has been completed, Wheel No. 2 shall be mounted on the suspension/loading fixture (Figure 4-1), dead weight loaded to normal load requirements and driven through the candidate drive system, over the test road bed (Figure 4-2), for an equivalent of 1,400 KM at an average speed of 1.5 KM/Hr. and 120 KM at an average speed of 7.5 KM/Hr.

In order to introduce actual vehicle inertia at 1/6 G into the test, the dead weight load utilized shall be six (6) times the load required with 5/6 of it counter balanced to insure proper mass representation.

5.3.2

The test should be broken into segments such that failures can be quickly detected and their cause more easily determined. A suggested examination cycle is shown below.

AVERAGE VELOCITY	DISTANCE TRAVERSED	NORMAL LOAD
7.5 KM/Hr	60 KM	55 lbs.
7.5 KM/Hr	120 KM	55 lbs.
1.5 KM/Hr	350 KM	35 lbs.
1.5 KM/Hr	700 KM	35 lbs.
1.5 KM/Hr	1050 KM	35 lbs.
1.5 KM/Hr	1400 KM	35 lbs.

Also shown above is the nominal radial load required for each test segment. The reduced load noted for the low speed tests represents the worst case anticipated unmanned loading schedule noted in the DLRV Mass Properties Paragraph 3.2.2 Volume II Book 1 of the DLRV Final Report.

In addition to establishing the average velocity and distance to be covered, a specific velocity profile, and consistent with that a terrain roughness profile must be established based on a selected site and the corresponding mission profile. This profile should, for example define the frequency of occurence of a 5 inch rock at 15 KM/Hr, and the percentage of time spent on lunar night driving.

5.3.3
At the completion of each phase, the test shall be halted, and the wheel statically tested in accordance with Paragraph 5.1.1 above. Results shall be recorded and compared with initial parameters to determine degree of deterioration. Complete compliance with Paragraph 5.1 is not considered necessary as an abbreviated version should clearly indicate if problems exist.

5.3.4
Wheel loading, speed and number of revolutions shall be continually recorded during all dynamic testing together with power input and temperature rise of drive unit.

5.3.5
Testing shall be continued until all six (6) phases are completed or catastrophic or near catastrophic failure occurs.

5.3.6
At the completion of testing the wheel drive unit shall be examined as in 5.2.4 above.

NOTE:
Minor failures (e.g. cracks, permanent set, etc.) shall not constitute cause for discontinuation of the test. Time and defective condition shall be noted and testing continued to evaluate usable life after partial failure.

5.4 ENDURANCE TESTING (THERMAL/VACUUM CONDITIONS)

5.4.1
After static testing to establish initial test parameters has been completed, Wheel No. 3 shall be subjected to defined temperature/vacuum limits and exposed to ultra violet rays for dynamic testing.

-CAUTION-

THE GAC WHEEL HAS BEEN DESIGNED TO BE COMPATIBLE WITH THE GRUMMAN SELECTED DRIVE SYSTEM WHICH HAS AN UPPER TEMPERATURE LIMIT OF +350°F. CARE MUST BE EXERCISED IF OTHER DRIVE SYSTEMS ARE UTILIZED FOR TESTING, THAT WHEEL HUB TEMPERATURE DOES NOT EXCEED +350°F.

5.4.2

Test procedures shall be identical to those outlined in 5.3 above except that only three test phases shall be accomplished. See note below.

5.4.3

At completion of testing wheel drive unit shall be examined as per Paragraph 5.1.1 and 5.2.4

NOTE:

It is felt that with the partial vacuum and ambient results in hand, it will be possible to determine extent of additional deterioration due to environment extremes without incurring additional expense of completing a full time run in the chamber.