Enclosure (1) to
Letter #69MA625

ONE-MAN LUNAR FLYING VEHICLE PROGRAM STUDY OUTLINE

(CONTRACT NAS 9-9045)

NASA CR 102182

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STUDY APPROACH

The overall approach to this study is illustrated in the logic diagram shown in Figure 1. The study will be conducted in two phases: a three-month parametric phase and a three-month preliminary design phase. Parametric studies will concentrate on resolving the major remaining LFV issues so that a configuration may be selected for a preliminary design and specification study. Vehicle-oriented trade-off studies will be conducted at both the subsystem and overall system integration level as appropriate. The overall system matrix will be reduced by conducting most of the trade-off studies at the subsystem level. Additionally, parametric data will be generated in the program resources and mission analysis areas to assess the influence of the alternative approaches on cost and schedule and to define system operational requirements.

Data developed during the parametric phase will then be evaluated and a system approach will be selected. The selected system will be studied during the final three months of the contract to produce a preliminary design and system specification. A resources plan and a training plan will also be developed during the second three months and will be based upon the selected concept.

STUDY SCHEDULE

The study schedule presented in Figure 2 shows the individual task schedules and milestones for the study. The parametric systems analysis will be

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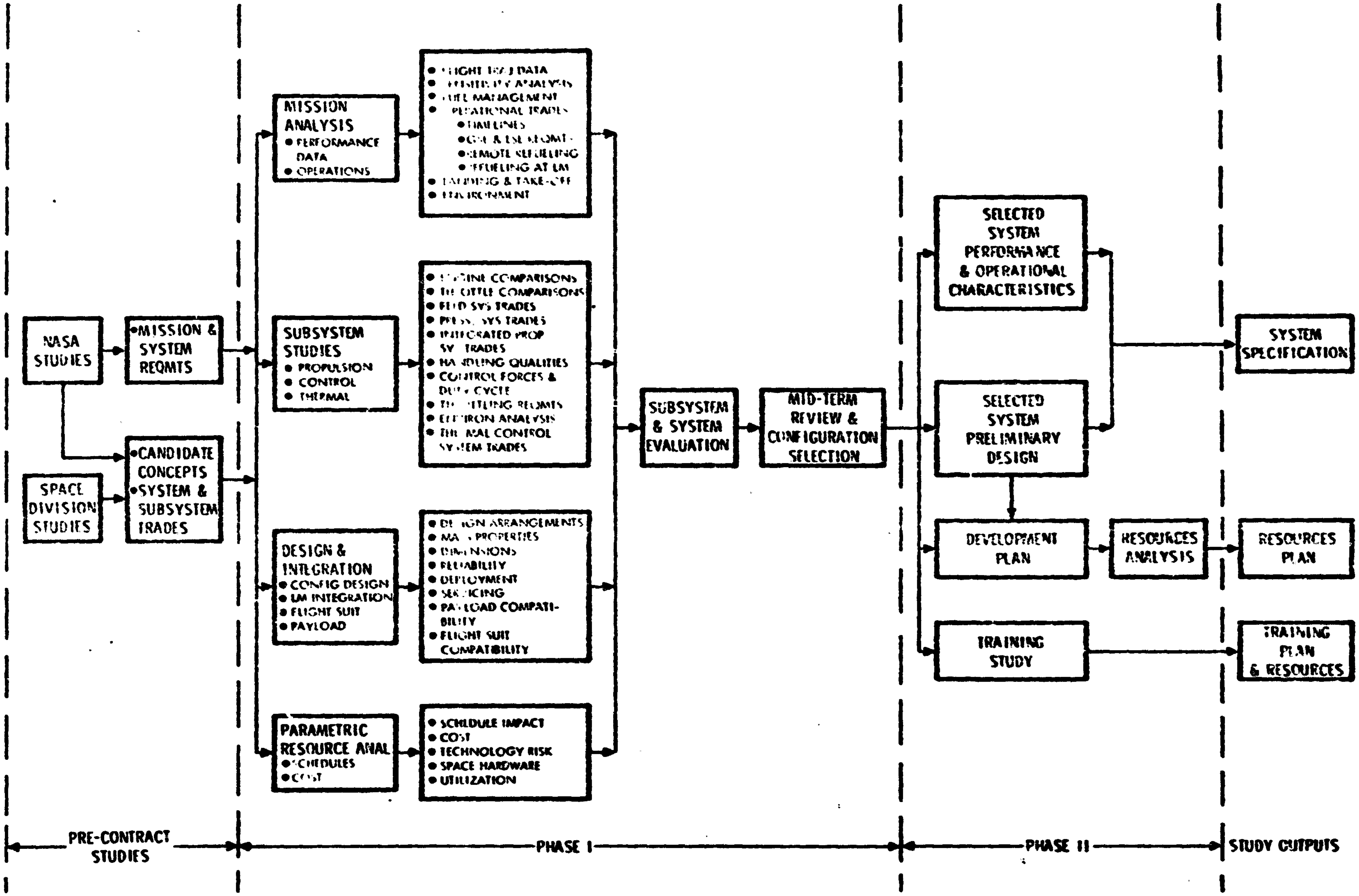
FIGURE 1. **OVERALL STUDY LOGIC**

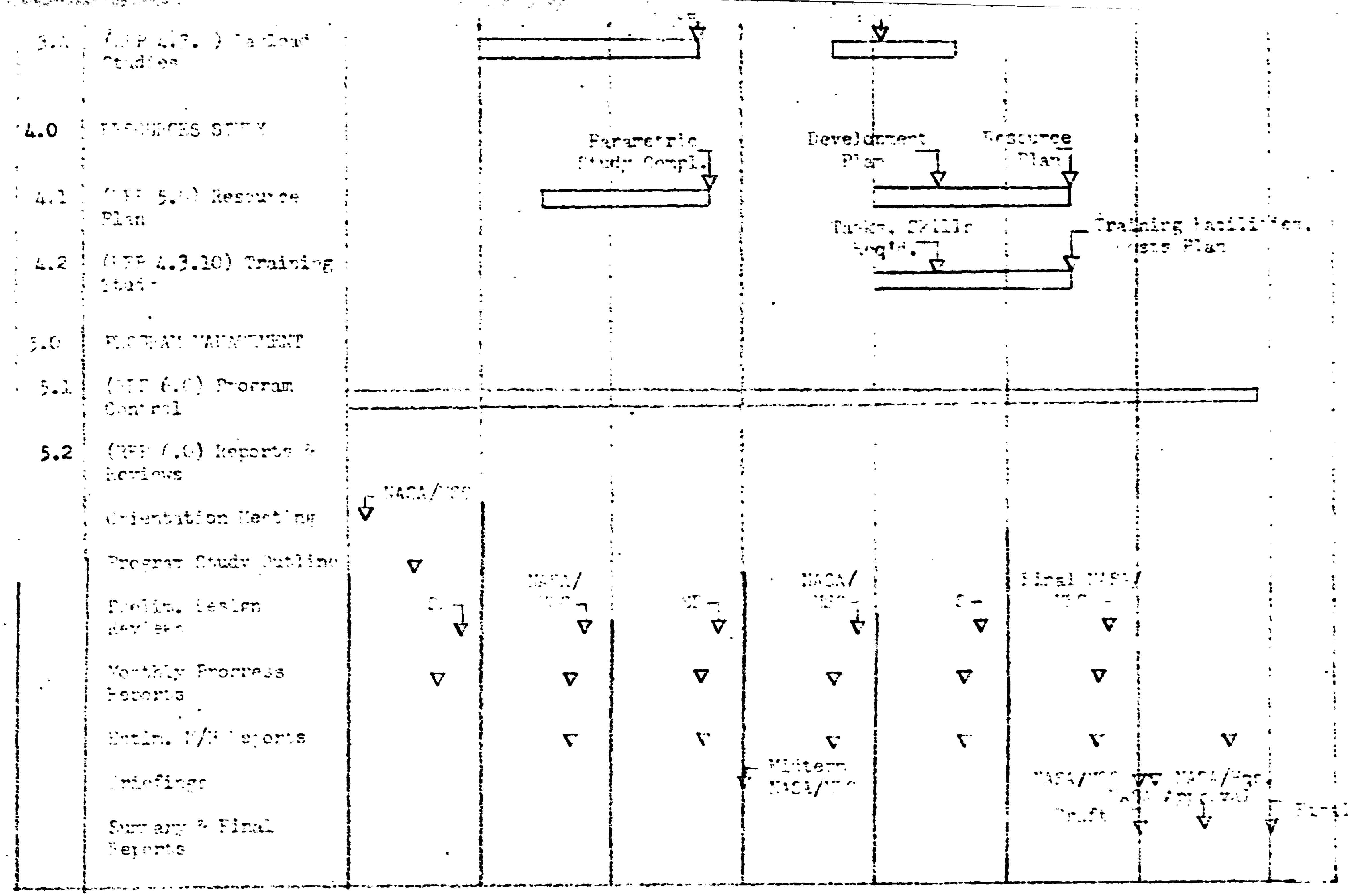


SPACE DIVISION OF NORTH AMERICAN ROCKWELL CORPORATION

FIGURE 2

PROGRAM SCHEDULE

WBS TASK	RFP TASK DESCRIPTION	1 JAN	2 FEB	3 MAR	4 APR	5 MAY	6 JUN	7 JUL
1.0	MISSION ANALYSIS							
1.1	(RFP 4.3.7) Vehicle Performance Data	Prelim. Trajectory Data	Flt Prog. Data	Parametric Study Compl	Simulation Comparison		Selected Concept Comparison	
1.2	(RFP 4.3.6) Operations Study	Basic Timeline	Soil Erosion Study CSM, LSE	Parametric Study Compl		Prelim Specs CSM, LSE	Operational Timeline	
2.0	SUBSYSTEMS STUDIES							
2.1	(RFP 4.3.2) Propulsion Studies		Issue Letters to Eng. Subs	Parametric Study Compl; Concept Selection		Design Refined	Subsystem Optimized	
2.2	(RFP 4.3.3) Control System Studies		Equations Cont. Config; Initiate Simulation	Parametric Study Compl; Concept Selected		Subsystem Optimized		
2.3	(RFP 4.3.4) Thermal Studies		Temp. Reqts	Parametric Study Compl; Concept Selected			Subsystem Optimized	
3.0	DESIGN & INTEGRATION							
3.1	(RFP 4.3.1) Configuration Design Study	Control Config.	Gear, Structure Concepts	Parametric Study Compl; Concept Selected			Escape Mission Adaptation, Night/Day Environ. Effects; Prelim. Design & System Spec.	
3.2	(RFP 4.3.8) LM Integration		Envelope Avail.	Mounting Determined		Interface Spec		
3.3	(RFP 4.3.9) Flight Suit Studies			Crew Tasks, Reqts.			Crew Restraints, Metabol. Reqts; Crew-Suit Integration	
3.4	[illegible]			Integration Concepts	Rescue Suit Reqts.			



FOLDOUT FRAME 2

completed prior to midterm briefing, at which time a configuration will be selected for the preliminary design phase of the study. The total duration of the study is seven months, including one month for final report approval and briefings at NASA/MSC and NASA/Headquarters.

STUDY TASKS

The following outline describes the tasks to be accomplished during this contract. These represent an expansion upon the study tasks described in the Contract Statement of Work.

TASK 1. CONFIGURATION DESIGN STUDY (3,660 Hours)

Objectives

Prepare design of LFV and support equipment, integrate and optimize system related results of subsystem and mission tasks, evaluate reliability and mass properties characteristics, and provide support to subsystem, mission, and resources tasks. Develop configuration conceptual designs in Phase 1 and preliminary designs and system specification in Phase 2.

Subtask Descriptions

1.1 Phase 1 Configuration Design

1.1.1 Prepare vehicle design drawings at the conceptual/outline configuration level that represent study alternatives. Develop concepts which optimize the configuration characteristics and make the best combination of alternative solutions of structure, landing gear, subsystem requirements. Prepare evaluation criteria and assessment reports documenting information resulting from this design effort to be utilized in Task 1.2.4.

1.1.2 Prepare preliminary drawings of subsystem, payload installation alternatives, and major subassemblies.

1.1.3 Prepare conceptual design drawings of lunar support equipment alternatives: propellant servicing, checkout, LFV assembly, deployment/transport, and others as required.

1.2 Phase 1 System Integration

1.2.1 Issue and maintain data records defining major mission, performance, operational physical/configurational and functional characteristics of the current LFV system standard to be used as the control configuration for parametric (Phase 1) studies.

1.2.2 Conduct LFV system optimization studies and support related subsystem activity by providing system/configuration impact trade data as required.

1.2.3 Evaluate reliability of system alternatives and provide subsystem alternatives reliability data support.

1.2.4 Develop evaluation criteria and assessment data for system/configuration alternatives. Incorporate and integrate evaluation results of related tasks. Prepare report of Phase 1 configuration selection describing basis and selections.

1.3 Phase 1 Structural Design Studies

1.3.1 Support Task 1.1 in the selection and application of structural methods, configuration and materials. Provide necessary preliminary stress analysis for purposes of sizing and developing structure mass properties. Establish preliminary loads and design margin criteria for all LFV mission phases.

1.3.2 Develop requirements and alternative concepts for landing gear and attenuators. Perform preliminary landing dynamics analysis to assess performance capability of candidate gear concepts. Perform conceptual design and parametric analyses of candidate attenuator concepts.

1.4 Configuration Control

1.4.1 Establish and maintain records on mass properties of candidate configuration and major subassemblies. Conduct trade-off analysis of major weight/inertia sensitive configuration design alternatives. Support other task areas in the preparation of subsidiary trade studies.

1.5 Phase 2 Configuration Preliminary Design

1.5.1 Prepare preliminary design drawings of the selected LFV configuration. Optimize the configuration characteristics with respect to space utilization, primary and secondary structure, thermal insulation and dust, plume, meteoroid protection.

1.5.2 Prepare preliminary design drawings of payload, subsystem and major subassembly installation.

1.5.3 Prepare preliminary design drawings and system specifications data on LFV lunar support equipment: propellant servicing, LFV assembly, checkout, and deployment/transport.

1.6 Phase 2 System Integration

1.6.1 Continue the control configuration data effort from Phase 1 (Task 1.2.1) through Phase 2 on the selected configuration.

1.6.2 Prepare top-level reliability functional diagrams, make reliability assessment, and specify preliminary reliability allocations for the selected configuration.

1.6.3 Prepare a preliminary system requirements specification which incorporates the results of all Phase 2 design tasks and represents a definition of LFV system operation and performance requirements; configuration, subsystem and component requirements; LM, Flight Suit, Lunar Support Equipment, Payload, LFV interface requirements.

1.7 Phase 2 Structural Design

1.7.1 Support Task 1.5 in the optimization of structural methods, configuration, and materials for the selected configuration. Prepare preliminary stress analysis on optimized LFV preliminary design.

1.7.2 Develop optimized landing gear preliminary design. Prepare preliminary design of selected attenuators subassembly and components. Perform dynamic analysis of selected landing gear design and define envelope of acceptable landing initial conditions reflecting the capability of the design. Prepare landing gear and attenuator development plan giving outline requirements for testing, special facilities, and identifying long-lead and critical-development areas.

1.8 Establish and maintain records on mass properties of the LFV system. Support other task areas in the optimization of design elements of the selected configuration.

1.9 In Phase 2, prepare configuration design drawings and study report on an LFV modified for escape to lunar orbit.

1.10 In Phase 2, prepare configuration design drawings and study report on LFV modification and/or design changes necessary to accommodate earth-shine operations.

TASK 2. PROPULSION STUDIES (1,580 Hours)

Objectives

(Phase 1)

1. To obtain required engine feed system and component data.
2. To define the optimum LFV propulsion subsystem design criteria by conducting the parametric study considering the specified range of variables and alternatives at major component, subassembly, and subsystem levels.

(Phase 2)

1. To select the optimum propulsion subsystem baseline preliminary design. To prepare a detailed schematic and formulate nominal baseline performance, weight, and operational characteristics. To evaluate and select a servicing concept, define control system interfaces, and the engine exhaust plume.
2. To evaluate and select propulsion subsystem components through the trade-off analysis of their respective design and operational characteristics.
3. To determine the characteristics of the selected propulsion subsystem through the range of operating requirements and environment.

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Subtask Descriptions

2.1 Parametric Data Requirements Definition

Survey and evaluate NR/SD, NASA, and rocket engine component contractor LFV propulsion system data for applicability of such data to the present study. Formulate a detailed plan for producing the complete scope of parametric data. Prepare parametric engine design data including engine performance, geometry, and weight as a function of P_c and throttle setting for various design thrust levels and nozzle area ratios.

2.2 Propulsion Subsystem Parametric Study

Perform parametric studies to estimate propulsion system weights, performance, and geometry throughout the range of design parameters.

The parametric study shall consider the following design alternatives:

Engine	-	type, throttling method, number P_c, area ratio
Feed System	-	tank type, number of tanks, parallel or series, pressurization
Flight Duty Cycle	-	nominal and alternate trajectories

Prepare parametric curves illustrating the variation of major component and subsystem weight and performance for the foregoing alternatives. Prepare a subsystem schematic for each major design alternative which has a significant variation.

Define required supporting interface data requirements from system configuration and control studies.

Combine the propulsion subsystem parametric data with overall system weight sensitivities. Define the optimum propulsion system design point on the basis of minimum system weight for a specific mission. Select the optimum propulsion system concept or baseline design for further analysis, considering number of tanks, engines, engine criteria, throttle range.

2.3 Baseline Propulsion Subsystem Preliminary Design

Prepare a preliminary design and schematics of the baseline propulsion subsystem concept, including pressure schedules, propellant quantities, residuals, performance, and weights.

Formulate and evaluate various propellant transfer concepts and LFV fueling procedures.

Define propulsion/control subsystem interfaces and engine throttling and TVC actuation force requirements.

Define the engine exhaust plume characteristics.

2.4 Baseline Propulsion Subsystem Design Tradeoffs

Prepare a list of applicable tanks, components, design criteria, physical characteristics and weight.

Formulate candidate designs employing bladders, bellows, screens, and/or baffles. Develop equations for in-tank propellant dynamic behavior for the LFV.

Evaluate the alternative engine design concepts including throttling technique and thrust chamber concept. Compare valve, injector and T/C concepts including gimballing, jet vanes, and jetavators. Evaluate the desirability of variable, non-in-flight mixture ratio control.

Based on trade-off studies and comparative development status and costing data, recommend the most desired overall propulsion subsystem concept.

2.5 Propulsion Subsystem Design Analysis

Conduct design analysis of the selected propulsion subsystem. Determine performance over the range of expected operating conditions and environments.

Prepare a CEI Part I specification for the LFV propulsion subsystem and the propulsion subsystems section of the final study report.

TASK 3. CONTROL SYSTEM STUDIES (1,570 Hours)

Objective

To provide parametric data on control system characteristics, handling qualities and vehicle performance for a number of design concepts. To further define the control subsystem characteristics and requirements for the selected system.

Subtask Descriptions

3.1 Set requirements and limits on control parameters. Determine the basic mass properties limits set by LM requirements. Determine the control limits for maximum and minimum angular acceleration, hand control throw range, throttle throw range and thrust-to-weight ratio range, and engine gimbal angles and rates.

3.2 Derive the Equations of Motion for all control configurations. Derive the six-degree-of-freedom equations of motion for a general vehicle configuration so that they may be used for all control configurations. Linearize the equations of motion and separate control planes. Solve transfer function for β/δ , the ratio of pilot lean angle from vertical to pilot control angle from the thrust vector.

3.3 Define control configurations. Define preliminary and failure control modes for pitch and roll on each vehicle concept. Determine the range of moment of inertia and center of gravity appropriate for each vehicle concept. Synthesize yaw primary and failure control modes.

3.4 Conduct handling qualities studies of each vehicle concept. Using existing literature, select an appropriate pilot transfer function. From a knowledge of the typical LFV flight profile, select a pilot task to be used as a constraint in the pilot performance. Conduct a root locus analysis of the two-loop system with variable vehicle moment-of-inertia for each axis of each vehicle concept. Assumptions will be made for vehicle masses and pendulum lengths where necessary. Assess handling qualities ratings for each vehicle concept.

3.5 Conduct performance analysis. Estimate the pilot workload associated with operating each of the vehicle concepts by considering data from the root locus analysis, the visual simulation, and the tethered flight vehicle. Estimate the minimum landing velocity expected for each vehicle configuration based on limit cycle amplitude and frequency data from the root locus analysis, the visual simulators, and the tethered flight vehicle. Describe the expected vehicle attitude and attitude rate at impact. Define specific failure mode operational procedures for the major effects of failure and give evidence of operational feasibility in terms of data where possible. Estimate the maximum round trip, straight-line flight range based on all available data for each vehicle concept. Compare measures of control power between the concepts requiring engine gimbaling.

3.6 Conduct throttle control and linkage analysis for selected concept. Determine the total throw based on thrust-to-weight range requirements, and estimate the resulting hand force required. Set requirements for nonlinear characteristics based on pilot comments. Define the throttle control linkage mechanism for primary and failure mode operation. Describe the system operational characteristics, including sink rate control if required.

3.7 Conduct attitude controller and linkage analysis for selected concept. Determine the hand force necessary to move the rotational controller based on throw distance requirements. Set requirements for nonlinear stick characteristics. Define the rotational controller linkage mechanism for primary and failure mode operation. Set requirements for gimbal servo actuator and power if necessary. Describe the system operational characteristics, including feedback systems if required.

3.8 Set requirements for displays. Set requirements for both vehicle status and flight variable displays based on data from literature, visual simulation, and tethered vehicle. Estimate range versus display weight tradeoffs where applicable.

3.9 Prepare a controls subsystem description. Prepare functional and schematic drawings of the subsystems. Compile weight, cost, power and availability data for controls off-the-shelf hardware. Prepare final report covering entire control system study and assist in the preparation of a subsystem specification.

TASK 4. THERMAL STUDIES (1,260 Hours)

Objectives

To develop and implement reliable thermal control concepts and structure and component thermal designs which will fulfill the mission requirements for lunar day, lunar night (earth-shine) and combined missions, and to demonstrate the thermal design adequacy by analytical evaluations which include all mission phases and components.

4.1 Temperature Criteria. Establish mission and component level temperature requirements and external boundary conditions. Establish thermal design criteria.

4.2 Parametric Design. Perform parametric studies for candidate designs and design concepts for all mission phases, components, and for lunar day and lunar night (earth-shine) conditions; establish design requirements and select suitable component level thermal designs.

4.3 Thermal Design Analysis. Evaluate the selected design concepts and the selected LFV configuration design to demonstrate design adequacy under all conditions of operation.

4.4 Development Requirements. Establish preliminary thermal test requirements and their influence on resource requirements considering development time, relative costs, reliability, manufacturing ease.

TASK 5. PAYLOAD STUDIES (320 Hours)

Objectives

Investigate the characteristics of expected payloads and their effect on LFV design and operations. Establish requirements for LFV design provisions necessary to accommodate the payloads. Establish the acceptable range of payload characteristics and any constraints.

Subtask Descriptions

5.1 Payload Characteristics Definition

5.1.1 Utilizing existing human factors data and LFV mission/operational requirements, define the range of astronaut physical characteristics and mobility condition expected to be a requirement for rescue operations.

5.1.2 With the assistance of MSC and utilizing the groundrule data of the RFP, investigate the nature of mission objectives and supporting scientific equipment and establish the range of physical characteristics and relevant functional characteristics of planned and desired hardware payloads.

5.2 In conjunction with flight suit and Configuration Design Study Tasks, develop requirements and corresponding design concepts for support, restraint, and protection of rescued astronauts for both: (1) LFV design provisions; and (2) flight suit design provisions (if any). Evaluate requirements and concepts and select the most appropriate for incorporation in design.

5.3 In conjunction with the configuration design study task, develop design requirements and concepts for accommodation of hardware payloads on the LFV. Consider functional requirements, assessibility, impact on LFV c.g. trim, separability of hardware components, bulk and shape limitations, and environmental (natural and LFV induced) protection. Evaluate and select the most appropriate design concepts and the maximum acceptable range of payload characteristics.

5.4 In Phase 2, update the results of conceptual Subtask 5.2 and develop preliminary design requirements for LFV provisions to load and transport a rescued astronaut. Preliminary design of these provisions is to be performed under Task 1.

5.5 In Phase 2, update the results of conceptual Subtask 5.2 and develop preliminary design requirements (if any) for flight suit design changes necessary to provide adequate support and restraint of an LFV-rescued astronaut.

5.6 In Phase 2, evaluate the results of LFV preliminary design and prepare a definition of hardware payload physical, functional and operational characteristics range that reflects the capability of the selected LFV configuration.

TASK 6. OPERATIONS STUDY (815 Hours)

<u>Objective</u>

The objective of this task is to conduct analyses of lunar operations that bear on the LFV design and its use so as to establish the operational requirements that must be met by the LFV system.

6.1 <u>Timeline Generation</u>

Generate basic timelines identifying periods of spacesuit and shirtsleeve activity; periods of spacesuited housekeeping activity; periods of local spacesuited scientific activity; and periods of spacesuited LFV-oriented activity.

Generate detailed timelines which analyze operations associated with the LFV, including timelines for LFV assembly, checkout, fueling, flight, etc. for normal operations. Also develop modified timelines for rescue operations.

Generate detailed operational timelines which analyze LFV system designs, and develop specific detailed operational timelines to verify concept feasibility.

6.2 Soil Erosion Studies

Estimate effects of lunar soil erosion caused by LFV rocket plume and identify and evaluate alternative approaches to overcoming potential hazards to the astronaut(s), LFV, and LM from soil erosion caused by LFV rocket plume.

6.3 GSE and LSE Studies

Perform GSE and LSE studies analyzing environmental conditions and astronaut capabilities in spacesuits; generate trade-offs associated with alternative modes of unloading, assembly and checkout of the LFV. Prepare preliminary specifications for GSE and LSE by analyzing LFV system designs; generate GSE and LSE specifications essential for safe and efficient operation of the LFV system.

TASK 7. VEHICLE PERFORMANCE DATA (450 Hours)

Objectives:

Establish parametric trade-offs of altitude, range, and velocity as a function of engine performance and flight profiles based on analytical analyses. Define baseline trajectory profiles for constant altitude and semi-ballistic modes for ranges of ½, 2, 6 and 8 miles, based on digital program results. Evaluate sensitivity of range to errors in thrust, attitude, and pitch rate errors. Compare digital results with simulation data for selected profiles, and establish performance data for final selected concept.

Subtask Descriptions

7.1 Develop and document analytical approach and resulting parametric data based on flat moon, constant lunar gravity, and constant T/W and pitch angles.

7.2 Develop digital program consisting of building-block segments for synthesizing specified flight modes. Generate trajectory and performance data for various types of flight profiles.

7.3 Perform sensitivity analysis by perturbing digital program inputs such as thrust, altitude, and attitude rate to examine the effect on trajectory variables, particularly range.

7.4 Generate trajectory and performance time histories for comparison with simulation results. Analyze simulation results and make a preliminary definition of flight performance instrumentation requirements.

7.5 Generate trajectory and performance data for selected flight profiles and the final selected configuration concept.

TASK 8. LM INTEGRATION (470 Hours)

Objectives

Establish requirements for LFV and support equipment design provisions that are necessary for their integration with the LM. Develop LM modification design concepts that are mandatory for LFV system utilization. Provide information for operations study (Task 6) on LFV/LM interface operations.

Subtask Descriptions

8.1 Obtain from Grumman/MSC LM structure and exterior surface design drawings.

8.2 Prepare drawings/reports defining available LFV mounting envelopes on the LM.

8.3 Prepare drawings/reports defining available LFV support equipment stowing envelopes on the LM.

8.4 Obtain from Grumman/MSC a definition of LMD propellant system including: (1) system schematic, dimensions, and location of components; (2) post-landing displays, controls and operations; (3) post-landing propellant quantity probabilistic model, including source, location, and availability for LFV utilization; and (4) post-landing propellant and ullage temperature and pressure timelines.

8.5 Obtain from Grumman/MSC a definition of LM exterior surface post-landing temperature timeline.

8.6 Conduct LFV mounting and removal concept design studies.

8.7 Conduct LFV propellant servicing-LM integration concept design studies.

8.8 Conduct LFV support equipment stowing and removal design studies.

8.9 Prepare preliminary LM-SLA-LFV interface specifications including: (1) LM attach points design requirements, location and design loads; (2) LFV mounting envelope; and (3) LFV removal provisions; (4) LFV support equipment stowing locations, envelope, attach points, and loads; and (5) LFV propellant servicing interface design requirements.

8.10 Prepare report recommending LM modification requirements (if any) for attachments, servicing connections, propellant system control.

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TASK 9. FLIGHT SUIT STUDIES (550 Hours)

Objectives

Investigate the astronaut/flight suit/LFV interfaces and establish design requirements to ensure compatibility of system design with crew operation and control capabilities.

Subtask Descriptions

9.1 Astronaut/Suit Requirements

Develop astronaut task outline for LFV deployment, checkout, flight and rescue operations, LFV platform ingress/egress; establish astronaut anthrpometric characteristics and recommend panel controller arrangements; and define visor characteristics and evaluate astronaut perceptual/control capabilities for earth-shine and sunshine conditions.

9.2 Suit Mobility

Analyze the interaction between the astronaut mobility and LFV handling qualities; investigate restraint design requirements and "G" tolerance effects to establish LFV design requirements for both pilot and rescued astronaut support and restraint.

9.3 Environmental Analysis

Establish metabolic expenditure and work capacity; determine thermal and physical/chemical effects on suit due to exhaust gas impingement and solar radiation; develop requirements for crew integration mockup tests and coordinate space suit studies with MSC. Evaluate LFV preliminary design suitability for astronaut/LFV operation interfaces.

TASK 10. TRAINING STUDY (350 Hours)

Objective

Prepare a preliminary LFV astronaut training plan to provide assessment of skills required, facilities, and costs involved with the operation of the selected LFV concept.

Subtask Descriptions

10.1 Crew Requirements

Analyze astronaut tasks in preparing, checkout and operating the LFV; identify unique astronaut skills associated with LFV use; and determine training techniques and procedures.

10.2 Facilities Requirements

Define requirements for equipment and facilities; investigate the availability and suitability of training facilities.

10.3 Training Plan

Analyze the costs of training and prepare an overall training plan.

TASK 11. RESOURCE PLAN (760 Hours)

Objective

Resource analyses will be made to assist in selecting the best design concept, in optimizing the design and subsystems for this concept, and in establishing the program schedules and costs for the optimum LFV system.

Subtask Descriptions

11.1 Preliminary Resource Studies

Establish preliminary development plans and costs and selected key cost/schedule tradeoffs for each alternate configuration examined in the first phase.

11.2 <u>Selected Configuration Resource Plans</u>

Establish for the selected configuration a more detailed development plan and cost estimates.

MANPOWER REQUIREMENTS

The manpower required to accomplish the tasks is given in Table 1 for each labor category.

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TABLE 1. HOURLY TIME ESTIMATES BY TASK AND LABOR CLASS

WBS Tasks	RFP Tasks	Labor Classes								Total
		Engr Mgr	Proj Mgr	Proj Engr	MTS VI	MTS V	MTS IV	MTS III	MTS II	
1.1	4.3.7					450				450
1.2	4.3.6				415	400				815
2.1	4.3.2			350		630	600			1580
2.2	4.3.3			330		1240				1570
2.3	4.3.4			380					880	1260
3.1	4.3.1			200	1510	170	720	480	580	3660
3.2	4.3.8								470	470
3.3	4.3.9					550				550
3.4	4.3.5					320				320
4.1	5.0					330		430		760
4.2	4.3.10					350				350
5.1 + 5.2	6.0	*	35							35
	TOTALS	*	35	1260	1925	4440	1320	910	1930	11,820

* Indirect hours not included;

Table reflects engineering hours, does not include hours for Data Management (35) and Publications (531).

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PROGRAM ORGANIZATION

The program organization is shown in Figure 3. The full time Program Manager is G. M. Hanley. The relationship of the Company-sponsored simulation activities to the LFV program organization is also shown.

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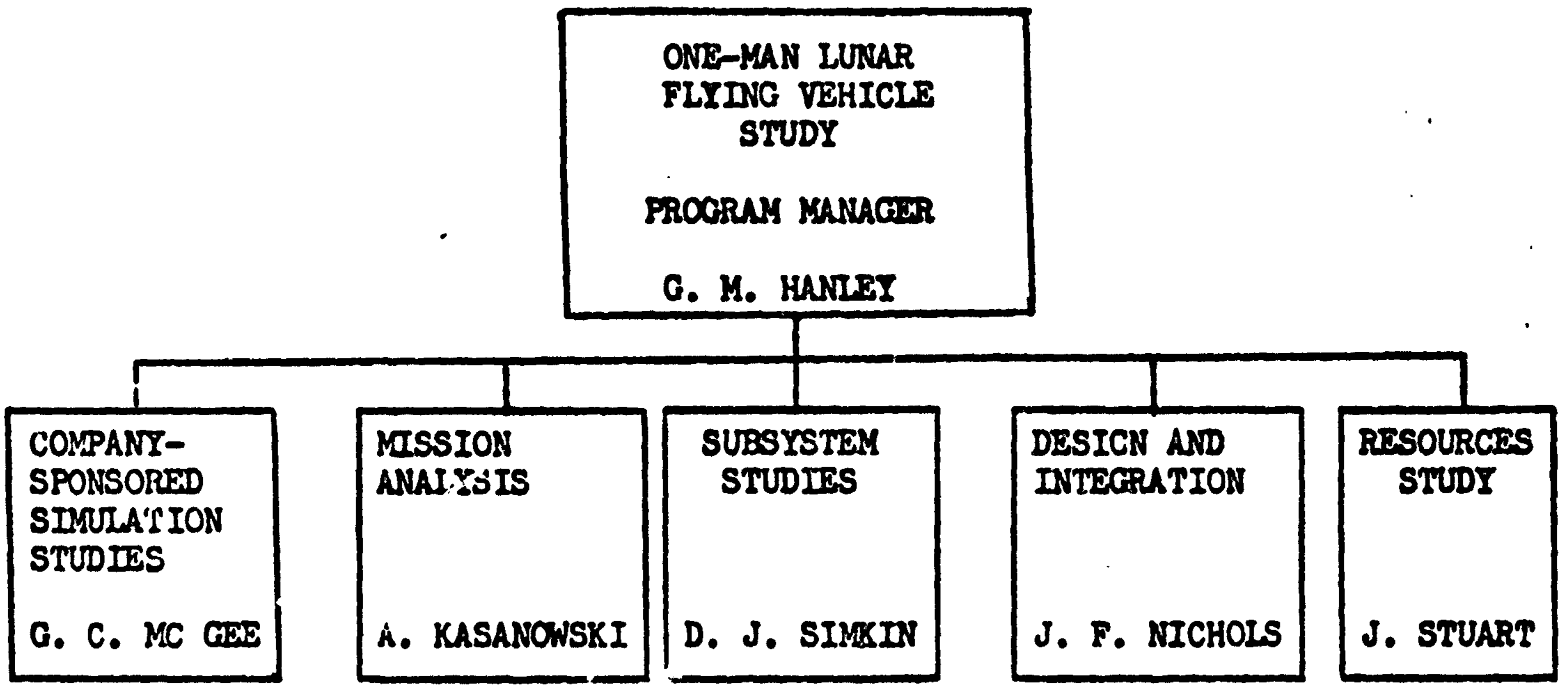

FIGURE 3. LFV PROGRAM ORGANIZATION