NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TX 77058

COST REIMBURSABLE INDEFINITE-DELIVERY
INDEFINITE-QUANTITY (IDIQ) TASK ORDER
Texas Engineering Experiment Station
NNJ05HB41B

Task Order Number	*Amendment Number*	*Purchase Request Number*
40	Revision 2	Funded at Contract Level
SOW WBS	*Fiscal Year*	*Technical Monitor/Division/Extension*
	FY09	COTR: EC/Ralph Marak, 39144 / EC5/Lindsay Aitchison

Task Order Title

SOFT SHOULDER DESIGN, FABRICATION, AND TEST

Description/Purpose

Revision 2 to DO 40 is issued to extend the completion date to March 20, 2009 at no additional cost to the Government. All other terms and conditions of the DO remain unchanged.

Recapitulation of the DO Value:

Summary	Current Value
Cost	b4
Fee	b4
TOTAL	$ 190,215.55

THE CONTRACTOR IS NOT AUTHORIZED TO EXCEED THE TASK ORDER VALUE SPECIFIED HEREIN. THIS IS A COST PLUS FIXED FEE TASK ORDER.

NASA Approval

Contracting Officer	*Signature*	*Date*
Ronald Johnson	Ronald Johnson	2/17/09

CREW, ROBOTICS AND VEHICLE EQUIPMENT (CRAVE) CONTRACT
DELIVERY ORDER #: CRAVE-EC5-040

PROPOSAL INSTRUCTIONS: ____ DRAFT -- COMMENTS DUE BY: 10-JUL-2008
_X_ FINAL -- PROPOSAL DUE BY: 31-JUL-2008

DO TITLE: Soft Shoulder Design, Fabrication , and Test

DO Type: _X_ CPFF ___ FFP

DO Contact Information in Addition to the CRAVE Contract Specialist or CO:

TMR: Joe Gensler	Phone: (281) 483-0025
DO Manager: Name/Mail Code	Phone: (281) ###-#####
DO Mgr. Alternate: Name	Phone: (281) ###-#####

Concurrences:

Lindsay Aitchison Name DO Manager	Terry Hill Name DO Mgr. Management	_____ Joe Gensler COTR
_____ Name Division TMR	_____ Steve Miller S & MA	_____ Name

Task Contains Flight Hardware, Flight Software or GSE? ___ Yes _X_ No

Program Supported: __Shuttle __ISS _X_EVA _X_Advanced _____

WBS: _X_ 1.0 EVA __ 2.0 FCE __ 3.0 EVR __ ECLSS __ 5.0 ATCS __ 6.0 CHeCS

For purposes of complying with FAR 52.232-22, Limitation of Funds, the total amount allotted by the Government to contract is specified in clause B.6, Contract Funding. The funding listed in B.6 is the amount allotted for all Delivery Orders on the contract combined.

All terms and conditions of the contract apply to this Deltvery Order. In the event of a conflict between the contract and this Delivery Order, the contract shall prevail.

WBS reporting shall be done in accordance with applicable WBS reporting categories, as shown above and in the contract within Section C, Table 1.

Narrative Task Description

Background / Problem Description:
In the early days of manned spaceflight, pressurized space suit mobility wasn't a large suit design driver. Suits used in the Mercury and early Gemini programs were pressurizable, but only served as a backup to spacecraft Environment Control and Life Support Systems (ECLSS). Because suit pressurization was an unlikely and contingent event, un-pressurized comfort and mobility were the prime design objectives. As the Gemini program evolved and NASA began to experiment with micro-gravity Extra Vehicular Activity (EVA), suit capabilities were expanded to include a nominal pressurized operational role as well as its original launch and entry function. This was a difficult task for early designers of both the Gemini and Apollo suits as the very hardware, such as bearings in the arms and shoulders, that could provide enhanced pressurized mobility also tended to detract from the ability of the suit to protect crewmembers during launch and entry. The inclusion of scye bearings (aka shoulder bearings), for example, would have either required accepting the risk of launch and re-entry with a hard bearing between the shoulder of the crewmember and the spacecraft seat back, or innovative seat design that would provide both protection from an off nominal landing to the crewmember and lack of interference with the bearings. For 'one suit does it all' capability, these early designers chose to go with a 'soft-shoulder' approach that would eliminate the use of a scye bearing. In some cases, both arm and scye bearings were eliminated from the intra-vehicular configurations of suits for the crewmembers that would not be using their suits for planned EVA. While this decision limited pressurized shoulder mobility to the point that aids were often required to accomplish EVA tasks, crew safety was enhanced during the launch and landing phases of the mission. When NASA moved from Apollo to the Shuttle program a two suit system evolved so that both enhanced EVA mobility and launch/landing safety criteria could be met. The Advanced Crew Escape Suit (ACES), currently used by Shuttle astronauts for launch and landing, is very similar to the high altitude flight suit used by Air Force pilots today. Like the early suits, however, the ACES would provide little shoulder mobility if it were pressurized in the event of an emergency. Since the time Apollo ended in the early 70s, little research has been done in the area of soft shoulder design.

Purpose of Current Effort:
NASA is seeking a soft shoulder concept that enhances the pressurized mobility of the wearer beyond that which has been achieved by previous concepts. This concept shall be examined for use in both nominal micro-gravity EVA operations, as well as nominal and off-nominal launch/landing scenarios. Comfort during both pressurized and un-pressurized operations is, therefore, an important part of this task.

For this task, the contractor will develop soft shoulder design concepts to meet the design requirements of this DO from the brainstorming phase through concept fabrication and testing phases. The contractor will present their findings to NASA in the form of a concept review and a final report and presentation to NASA.

Kick-off Meeting:

The contractor shall participate in a kick-off meeting at NASA Johnson Space Center (JSC) no later than one week after this CRAVE DO ATP; at least one contractor team member shall be physically present at JSC for the meeting. The purpose of the kick-off meeting is two fold: [1] ensure common understanding of requirements, deliverables, and expectations and [2] provide hands-on interaction with NASA's D-suit prototype. The contractor shall prepare a presentation for the kick-off meeting that reviews all of the tasks within the scope of the DO and documents any areas in which the contractor desires more clarity (requirements, deliverables, etc.), and their go-forward project plan. At the conclusion of the kick-off meeting, the contractor and NASA will have reached consensus on the meaning of any ambiguous items; it is the contractor's responsibility to bring up topics for discussion. NASA will conclude that any requirements/tasks/deliverables not brought forward for discussion are clear in their intent and meaning. The contractor shall provide NASA with a memo noting agreements reached during the kick-off no later than 3 business days following the kick-off meeting.

To accomplish the second objective of the kick-off meeting, the contractor shall meet with the NASA space suit engineers in the JSC Advanced Space Suit Lab to review the D-suit soft shoulder design and receive a demonstration of the suit's performance capabilities.

Detailed Task Description:

1] Generate Conceptual Designs

After achieving a thorough understanding of the design requirements set forth in this DO and having conducted sufficient research of past and current soft shoulder designs for pressure garments, the contractor shall generate a minimum of five (5) soft shoulder conceptual designs. The contractor may elect to use their preferred brainstorming methodology for this phase of the task. Creativity is encouraged at this step in the process, thus it is not required that the precise details of each design be known prior to moving to the next step. However, each proposed concept must have sufficient depth to be ranked against the other concepts in terms of expected performance.

2] Concept Evaluation and Downselect

The contractor shall create a matrix that conceptually trades the proposed designs to a baseline design, the D-suit soft shoulder, with respect to the factors of merit (FOM) listed in Table 1.

Table 1: Figures of Merit with Corresponding Measure

FOM	Measure
Joint Range of Motion	Degrees
Joint Torque	Perceived Exertion
Ability to withstand limit load	Factor of Safety
Interference with seat lateral supports	Cooper-Harper rating
Interference with seat shoulder harness	Cooper-Harper rating
Occurrence of point loading	Cooper-Harper rating
Joint Volume	Change in pressurized volume during joint cycling

For this evaluation, it is assumed that all of the concepts can meet the requirements of this DO. The designs shall be ranked against the baseline on their expected performance with respect to the FOM in Table 1 using the following scale:

The contractor shall provide NASA with twice monthly status briefs (topics and scope to be provided by DO manager) detailing the current status of work, benchmarks accomplished, and what work is planned for the next two week period. Any encountered issues, problems, or risks are to be identified along with a mitigation plan – this is to include any issues, be it technical, cost or schedule. These reports are intended to be informal and may be submitted to the DO manager via email, but will be treated as official documentation.

Final Report:
The contractor shall deliver a report that provides a general description of all concepts generated during the brainstorming process, detailed description of the FOM evaluation process and rationale concept downselect, detailed description of the shoulder designs fabricated, overview of the testing completed on the shoulder designs, results of injury criteria analysis, discussion of each shoulder design performance as compared to requirements and recommendations for forward work. The raw data from testing and concept design drawings shall be included in an appendix to the report.

Final Report Presentation:
The contractor shall present their final report to NASA at JSC detailing the results of the trade studies, analyses, concept generation, test results, and concept down selection.

Definitions:
The following paragraphs provide further definitions on terms used throughout this DO. The definitions listed here are the ones to be used in completion of the tasks for this DO.

Soft Shoulder
A soft shoulder is a space suit shoulder configuration that does not include scye bearings to provide shoulder mobility. The soft shoulder joint is composed primarily of soft goods but may require additional hardware outside of the pressure envelope to achieve its mobility. An upper arm bearing may or may not be incorporated depending on the concept design. The Apollo A7LB and David Clark 'D' suits shown in Figure 1 are examples of suits that use soft shoulder designs. Both concepts use cables and pulleys, in addition to upper arm bearings, to achieve their shoulder mobility.

Figure 1: Apollo A7LB (Left) and David Clark 'D-Suit' (Right) Soft Shoulder Concepts

Shoulder Mobility
Shoulder Mobility is the combination of the shoulder joint's range of motion and the torque required to operate it. For example, a highly mobile joint is one that not only has a large range of motion, but also requires a low torque to operate it throughout that range. Range of motion is generally measured in terms of degrees through which a test subject and move a joint. Quantitative measures of joint torque can be obtained by several different devices such as a digital fish scale or the Primus RS; joint torque can be evaluated subjectively using ratings of perceived exertion.

Shoulder Range of Motion
Shoulder range of motion (ROM) is defined around the foundation established by the standard body planes of motion shown in Figure 2.

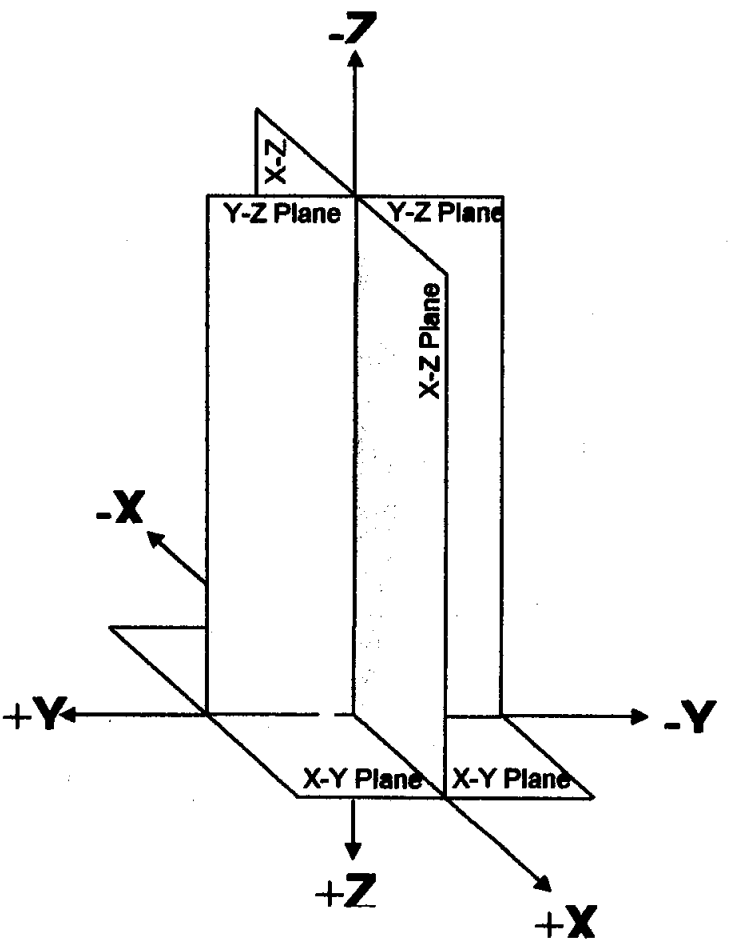

Figure 2: Human Body Planes of Motion

The suit shoulder ROM represents the total amount of motion the suit is capable of yielding provided the human's shoulder ROM is at least as large a range. The typical shoulder motions performed for shoulder ROM are, as shown in Figure 3, flexion/extension, lateral/medial, and abduction/adduction. The complete range of motion for any movements is the range between the extremes of the joint position. The maximum range of these movements, taken collectively, determines the overall shoulder range of motion provided by the joint concept. The range of motion in both pressurized and un-pressurized states are important to this effort.

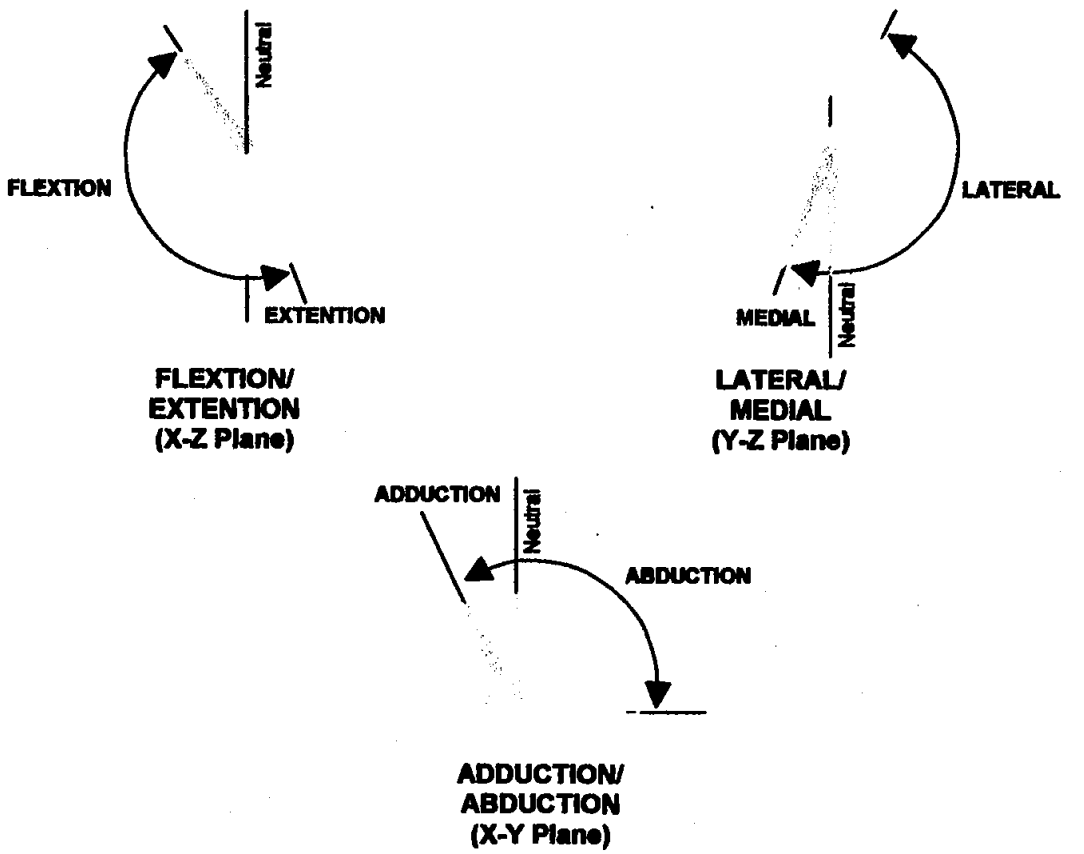

Figure 3: Range of Motion Definitions

As a reference, for each of the three movements from Figure 3, Table 2 lists a Nude Reference Value (NRV), the range of motion of the Apollo A7LB suit pressurized to 3.7 psid and the range of motion of the David Clark 'D-Suit' soft shoulder concept pressurized to 4.3 psid.

Table 2: Apollo A7LB and D-Suit Shoulder Range of Motion

	Nude Reference Value	Apollo A7LB (3.7 psid)	D-Suit (3.75 psid)
Adduction/Abduction	48/134	120*	18/73
Flexion/Extension	168/61	135/30**	110/30
Lateral/Medial	207*	135/30**	113/5

* Total Range of Motion; Data taken from Apollo SSA Design and Performance Specification MSC-CSD-A-017
**Data taken from Grumman LSP-340-6, Space Suit Assembly Performance and Interface Specification

Comfort
Comfort is a subjective measure and shall be evaluated as the absence of discomfort caused by a particular design concept. The term 'discomfort' includes pressure points, 'hot spots,' and slight abrasion or blisters. Discomfort is not to be confused with 'injury,' which, for the purpose of this DO, is defined to be sustained extreme discomfort that persists after the test/objective is complete. Any concept resulting in or with high potential to cause injury will be disqualified for human evaluation.

A common way to measure human physical discomfort is the Corlett-Bishop Discomfort Scale. This scale is meant to provide user feedback at regular intervals over a period of time to track how discomfort increases and where it is located. The rankings used for the Bedford scale are shown in Figure 4. Appropriately measuring 'comfort' will assume a subject that is well fit into a prototype garment. Again, comfort in both pressurized and un-pressurized states is considered an important attribute to the soft-shoulder design.

Discomfort Scale	
0	Nothing at All
0.5	Extremely Low Discomfort
1	Very Low Discomfort
2	Low Discomfort
3	Moderate Discomfort
4	
5	High Discomfort
6	
7	Very High Discomfort
8	
9	
10	Extremely High Discomfort

Figure 4: Corlett-Bishop Discomfort Scale

Perceived Exertion
The perceived level of exertion is based on the degree to which mobility is hampered such that the shoulder design accelerates the user's level of fatigue while performing movements. The Borg Rating of Perceived Exertion (RPE) scale shown in Figure 5 is a widely used scale to

subjectively rate a user's perceived level of exertion required to accomplish a task. The scale, shown in Figure 5, is set up such that it increases linearly with physiological measures such as heart rate and the volume of oxygen in the lungs as the level of exercise also increases.

Borg RPE Scale	
6	No Exertion at All
7	Extremely Light
8	
9	Very Light
10	
11	Light
12	
13	Somewhat Hard
14	
15	Hard
16	
17	Very Hard
18	
19	Extremely Hard
20	Maximal Exertion

Figure 5: Borg Rating of Perceived Exertion Scale

Suit/Seat Interface

The suited crewmember is anticipated to be securely restrained in a conformal seat. The conformal seat differs from most prior spaceflight seat applications (e.g., Shuttle and Apollo) in that it will provide significant lateral restraint capability. An example of a generic seat which possesses such lateral support features is depicted in Figure 6. Note the use of bolsters in the shoulder and head regions to provide lateral support.

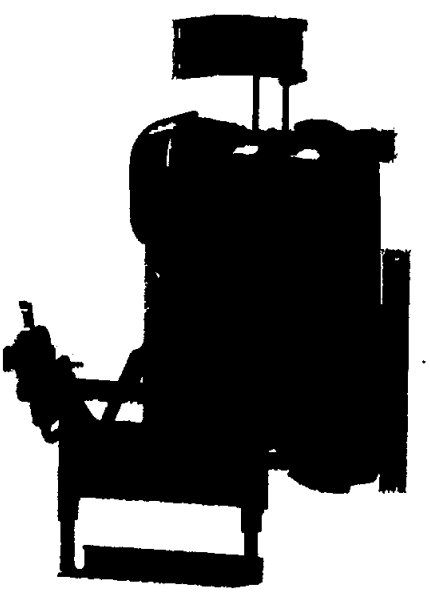

Figure 6: Generic Seat with Lateral Support Features

Lateral support for the entire system includes shoulder restraints (harnesses) as well as rigid shoulder and torso bolsters for lateral support. The seat will provide restraint in all primary coordinate axes (as depicted in Figure 2) for acceleration events.

Since traditional restraint and support systems provide protection all axes via a combination of shoulder harnesses, lap harnesses, crotch harnesses, rigid seat body bolsters, and the seat back itself, the soft shoulder design must be compatible with such systems. Potential areas for incompatibility between the shoulder design and the seat/restraint system include the following:

- Shoulder harness interface with shoulder anatomy: A shoulder harness must support the occupant's anatomical shoulder in an appropriate manner to be effective. Proper shoulder harness placement is superior (or over) to both the clavicle and the coracoid process of the scapula, and should also be lateral (outboard) to the root of the neck and medial (inboard) to the acromion process of the scapula. Injury could occur during acceleration events without proper interface of the shoulder with the harness due to the suit shoulder design.

- Point loading and poor load distribution for –x acceleration: To be effective, shoulder harnesses must distribute the loading of the harness uniformly across the body in the shoulder/chest and upper torso region. This is particularly important in a -x acceleration event as shown in Figure 8, but generally applies to acceleration events in all primary axes.

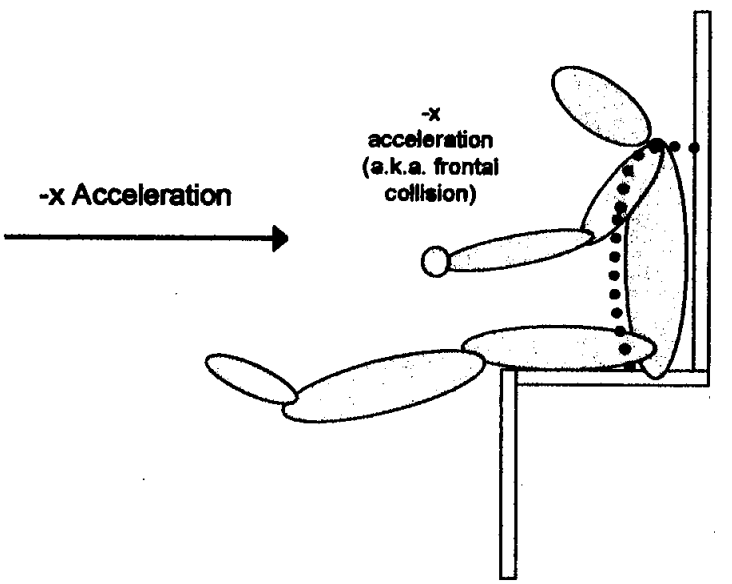

Figure 8: Acceleration in the Frontal (–x) Direction

- Point loading for lateral acceleration: The occupant's shoulders must be effectively supported in the lateral direction by the rigid seat bolster construction. Point loading from side supports in all primary acceleration directions must be minimized. For example, should joint design features in the areas depicted by the red boxes in Figure 9 will cause point loading to the anatomy of the seated occupant in the event of a lateral acceleration. The soft shoulder design, above and beyond the use of the arm bearings as provided, should preclude such point loading situations.

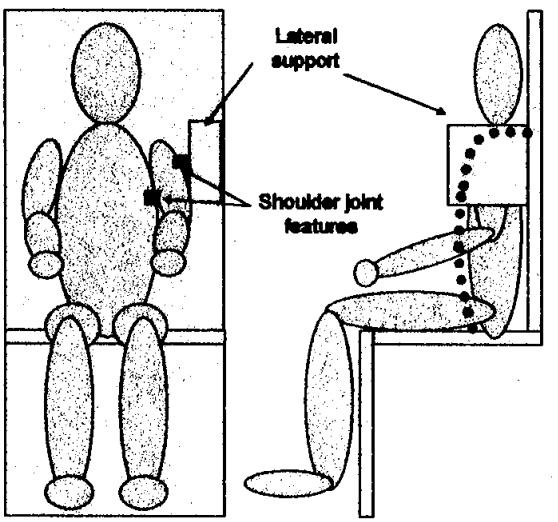

Figure 9: Potential Point Load Locations for Lateral Accelerations

- Physical fit within desired seated area: The shoulder design must not appreciably increase the bi-deltoid breadth, forearm to forearm breadth, or acromial seated height of the occupant's normal minimally clothed seated posture. Bulky features that increase these dimensions not only create potential point load hazards, but may inhibit mobility when combined with occupant protection bolsters, and prevent physical fit within the desired seated area. Figure 10 describes the three critical fit dimensions: bi-deltoid breadth, forearm to forearm breadth, and acromial seated height (measured from the seat pan to the top of the acromion process).

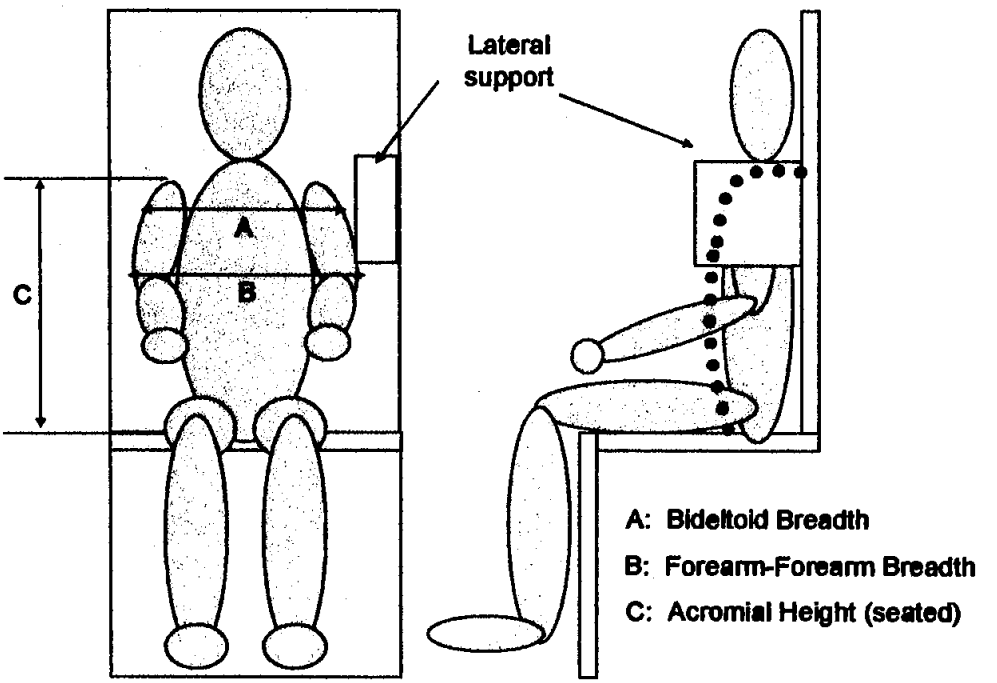

Figure 10: Critical Seated Dimensions

Seat Interface Assumptions:

1. The seat restraint shall be assumed to be a standard SFI 16.1 certified 5 point harness. Harnesses straps should be assumed to be a minimum of 2" and a maximum of 3" wide.
2. The seat shall be assumed to be simple in nature as depicted in Figure 6 with a planar seat back oriented at 90 degrees to the seat pan. The seat shall also contain lateral supports which fully support the occupant laterally in the bi-deltoid region.
3. The seatback should be assumed to be made of rigid, nonflexible material, without recesses or contours to allow for specific shoulder mobility features. Minimal comfort padding (less than 0.5 inches) may be assumed.

Shoulder Performance Goals:

1. While pressurized to 4.3 psid the soft shoulder design should demonstrate a range of motion that is greater than the Apollo A7LB suit when pressurized to 3.7 psid (See Table 2).
2. The soft shoulder concept should achieve a maximum discomfort rating of 1 and Borg RPE rating of 8 from 2 subjects after worn for 30 minutes of mobility testing in an unpressurized state.

3. The soft shoulder concept should achieve a maximum discomfort rating of 2 and Borg RPE rating of 10 from 2 subjects after worn for 30 minutes of mobility testing in a pressurized state.
4. The soft shoulder concept should be evaluated for crew injury concerns associated with the suit/seat interface as it would react during acceleration in all six axes.

Note: Although listed as a goal, NASA is very concerned that the soft shoulder concept takes into account the items of concern listed in the Suit/Seat Interface definition. The intent of this goal is that conscientious thought be given to these items although the contractor will not be asked to verify them in a test environment.

Shoulder Performance Requirements:

1. The soft shoulder concept shall be designed for nominal operation at 4.3 psid
2. The soft shoulder concept shall be designed with a load limit equivalent to the plug load plus a man load of 163 lbs. as described in the EMU Specification/Assembly Drawing (S/AD) for the Arm Assembly of the EMU.
3. All softgoods shall maintain a factor of safety of 2.0 against ultimate strength over the design limit load.
4. While pressurized to 4.3 psid the soft-shoulder shall demonstrate at least the range of motion of the D-Suit when pressurized to 4.3 psid (See Table 2).
5. The soft shoulder concept shall achieve a maximum discomfort rating of 2 and Borg RPE rating of 10 from 2 subjects after worn for 30 minutes of mobility testing in an unpressurized state.
6. The soft shoulder concept shall achieve a maximum discomfort rating of 3 and Borg RPE rating of 13 from 2 subjects after worn for 30 minutes of mobility testing in a pressurized state.
7. In an unpressurized state, the soft shoulder concept shall satisfy maximum seated dimensions per Figure 10 for a 99th percentile male. The maximum suited dimensions shall be:
   Bi-deltoid breadth – 23.7 in
   Forearm-forearm breadth – 27.0 in
   Acromial seated height – 27.1 in
8. After being seated (see Assumptions) in a recumbent (-z facing) position for 4 hours, the soft shoulder concept shall achieve a maximum discomfort rating of 3.
9. After being seated in a +z facing position for 15 minutes, the soft shoulder concept shall achieve a maximum discomfort rating of 4.

Note: The subject will be hanging face down by the seat harness, the intent being to simulate a 1g, –x acceleration as show in Figure 9.

Technical Document Library:

The contractor shall have access to the following documents:

1. CSD-A-017 Apollo Space Suit Assembly Design and Performance Specification
2. JSC 39522, Advanced Space Suit Isolated Joint Mobility Test
3. NASA/TM-2003-212058, EMU Shoulder Injury Tiger Team Report
4. EMU S/AD, Arm Assembly, Remote Powered Heated Glove (RPHG)
5. Grumman LSP-340-6, Space Suit Assembly Performance and Interface Specification

TO BE REMOVED FROM DO & INCLUDED IN RFQ LETTER:

UNIQUE CHARACTERISTICS: N/A

Deliverables/Products:

Product	Description	Qty	Due	Class
Hardware				
Shoulder Concept 1	Complete assembly with all necessary test-rig interface hardware and any specialized molds/jigs/equipment developed for the fabrication of the concept	1	15 weeks after ATP	CIII (prototype)
Shoulder Concept 2	Complete assembly with all necessary test-rig interface hardware and any specialized molds/jigs/equipment developed for the fabrication of the concept	1	15 weeks after ATP	CIII (prototype)
Shoulder Concept 3	Complete assembly with all necessary test-rig interface hardware and any specialized molds/jigs/equipment developed for the fabrication of the concept	1	15 weeks after ATP	CIII (prototype)
Test	n/a			
Software	n/a			
Other Products				
Soft Shoulder Concept Test Plan		1 hardcopy and 1 CD	7 weeks after ATP	
Final Soft Shoulder Design Report	A report detailing the results of all trade studies, concepts investigated, down selection rationale, and selected concept. Test data and results shall be included.	2 Hardcopies and 1 CD/DVD	Base contract final briefing	

SCHEDULE

Start Date: August 1, 2008 **Finish Date:** November 28, 2008

ITERIM MILESTONES	DUE DATES – Weeks After ATP
Kick-off Meeting	1
Midterm Presentation to NASA	5
Final Formal Presentation to NASA	15
Deliver Final Report	16

Government Estimate Located in RFQ File in Microsoft Excel File On CRAVE Web Site
The file is titled: Soft Shoulder DO Estimate.xls

Total Government Estimate for this DO: $190,250
Option 1: $ N/A (See Attachment 1)
Option 2: $ N/A (See Attachment 2)

TOTAL COST ESTIMATE FOR THIS DO: $190,250

FEE: $ (If Applicable)

OPTION 1: $ N/A (See Attachment 1)

OPTION 2: $ N/A (See Attachment 2)

TO BE REMOVED FROM DO & INCLUDED IN RFQ LETTER:

Proposal Evaluation Criteria:

1. Proposed Technical Concept, including design, understanding, development/ hardware production capability and schedules;

2. Cost/Price: Except when it is determined not to be in the Government's best interests, the Government will evaluate price of proposals, by adding the total price, including options. Evaluation of options will not obligate the Government to exercise the options;

3. Proposed Achievement of Small Business Goals;

4. Past Performance; and

5. Other: _____

DATA REQUIREMENTS

All DRs contained in the contract are applicable and required unless marked N/A below.

NOTES: 1. GREY SCALED ROWS NEED NO ADDITIONAL/REQUIRED FILL-INS.
2. ON ALL OTHER ROWS, IF NECESSARY, FILL IN ADDITIONAL RQMTS/DELIVERIES IN LAST COLUMN.

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
1	Written Approval	FlightGFE Configuration Management Plan	With Proposal	Once	Attachment J-8	
2	Mandatory Submittal	Regular Status Report/ Summary Review	Thirty (30) days following contract start	Monthly	Y	
3	Written Approval	Project Technical Requirements Specification	Per DO schedule		N	
4	Mandatory Submittal	GFE Systems Requirements Data Package	Specified in DO		N	
5	Written Approval	Flight GFE Projects Requirements & Verification Document	Specified in DO		N	
6	Mandatory Submittal	Preliminary Design Review Data Package	Specified in DO		N	
7	Written Approval	Flight GFE Workmanship Specifications List	Specified in DO		N	
8	Written Approval	Project Schedule	At kick-off meeting and every 30 days thereafter	Monthly	Y	MS Project Format
9	Written Approval	Flight GFE Interface Control Document	Specified in DO		N	
10	Written Approval	GFE End Item Specification	Specified in DO		N	
11	Mandatory Submittal	Flight GFE Failure Analysis Report	As agreed by TMR in DO		N	
12	Written Approval	Flight GFE Verification and Validation Plan	As Specified in EA-023		N	
13	Written Approval	GFE Software Requirements Specification	Specified in DO		N	
14	Written Approval	GFE Software Development Plan	Specified in DO		N	
15	Written Approval	GFE Software Design Document	Specified in DO		N	

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
16	Written Approval	Engineering Drawings	At PDR, as specified in DO		N	
17	Written Approval	EEE Parts Lists and Analysis Report	Specified in DO		N	
18	Mandatory Submittal	Critical Design Review Data Package	Specified in DO		N	
19	Mandatory Submittal	Engineering Drawing Change Proposal	As needed		N	
20	Written Approval	GFE Qualification Test Procedure	Specified in DO		N	
21	Written Approval	Flight Product User's Guide	Specified in DO		N	
22	Mandatory Submittal	Software Code	Specified in DO		N	
23	Written Approval	Information Technology (IT) Security Program Plan and Reports	(30) days after DO award, and as specified in JPG 2810.1	JPG 2810.1	**Attachment J-4 Due 30 days after DO award**	
24	Written Approval	Certification Plan	Specified in DO		N	
25	Mandatory Submittal	Certification Report	Specified in DO		N	
26	Mandatory Submittal	Engineering Analysis	Specified in DO		N	
27	Mandatory Submittal	Acceptance Data Package	Specified in DO		N	
28	Mandatory Submittal	Export Control Audit Results	After award of 1st DO, yearly on Sept. 30 thereafter	Yearly	Y	
29	Written Approval	Quality Plan	With Proposal	Once with Revisions	**Attachment J-11**	
30	Written Approval	Patent Rights-Retention	As Required	As Required	**Y (If Applic'ble)**	

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
31	Written Approval	Shuttle/Station Payload Safety Data Package	Specified in DO		N	
32	Mandatory Submittal	Limited Life Systems List	Specified in DO		N	
33	Written Approval	Space Station GFE Failure Modes and Effects Analysis and Critical Items List	As Early in process as possible.		N	
34	Written Approval	Space Shuttle GFE Safety and Analysis Report &Hazard Report	Specified in DO		N	
35	Written Approval	Software Quality Assurance Plan Report	90 Days Prior to Software Development		N	
36	Written Approval	ISS Hazard Report	Specified in DO		N	
37	Upon Request	Reliability and Maintainability Plan	With Proposal	One Time	Attachment J-9	
38	Written Approval	Government Certification Approval Request (GCAR)	Specified in DO		N	
39	Written Approval	Risk Assessment Executive Summary Report (RAESR)	Specified in DO		N	
40	Written Approval	Problem Reporting and Corrective Action (PRACA)	2 business days of problem isolation but no later than 10 days after detection		N	
41	Upon Request	Nonconformance Record	Specified in DO		N	
42	Mandatory Submittal	Government Industry Data Exchange Program and NASA Advisory Problem Data	Reported one time when discrepancy occurs		N	
43	Written Approval	Electrical, Electronic, and Electromechnical (EEE) Parts Control Plan	Specified in DO		N	
44	Mandatory Submittal	Certification Data Package	Specified in DO		N	
45	Written Approval	Certification and Acceptance Requirements Document	At CDR		N	
46	Upon Request	Wage/Salary and Fringe Benefit Data	Thirty (30) days after issuance of each DO		N	
47	Written Approval	GFE Acceptance Test Procedure	Specified in DO		N	
48	Mandatory Submittal	Flight GFE Verification & Validation Report	Specified in DO		N	

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
49	Mandatory Submittal	Space Shuttle GFE Failure Modes and Effects Analysis (FMEA) and Critical Items List	Specified in DO		N	
50		Reserved	—	—	—	—
51	Mandatory Submittal	NASA Contractor Financial Management Reporting	After Issuance of 1st DO	Monthly	Y	
52	Written Approval	Government Property Management Plan	With Proposal	Once with Revisions	Attachment J-7	
53	Mandatory Submittal	System Safety Plan	With Proposal	One Time	Attachment J-10	
54	Written Approval	R-Quality Plan Template	With Proposal/ Revisions as Required	Only applicable to B-CRAVE contracts in accordance with the SOW and the DRD	Y	

Type 1 = Written Approval Type 2 = Mandatory Submittal Type 3 = Submittal Upon Request

GOVERNMENT FURNISHED PROPERTY

The CRAVE contracts do not anticipate the Government providing any property or test facilities unless requested by the contractor in their response to a request for bid.

In some rare cases (such as sustaining engineering task) it is know ahead of time that government property will be provided to the contractor. In those cases the following list filled out to allow the proper control of government property:

A. List of Property the Contractor Shall Replace with modified or upgraded versions:

Item	Quantity	Acquisition Cost	Use of Property Location	Date to be Furnished to the Contractor

[Insert a description of the item(s), quantity, acquisition cost, and date the property will be furnished to the Contractor] - List of Property will be added as requirements are further identified and the determination to provide property is determined to be in the best interest of the Government.

B. List of Property the Contractor will return in the same configuration:

Item	Quantity	Acquisition Cost	Use of Property Location	Date to be Furnished to the Contractor

[Insert a description of the item(s), quantity, acquisition cost, and date the property will be furnished to the Contractor] - List of Property will be added as requirements are further identified and the determination to provide property is determined to be in the best interest of the Government.

GOVERNMENT FURNISHED PROPERTY
(Continued)

C. List of Property the Contractor Shall Replace if Damaged or lost during the course of the effort:

Item	Quantity	Acquisition Cost	Use of Property Location	Date to be Furnished to the Contractor

[Insert a description of the item(s), quantity, acquisition cost, and date the property will be furnished to the Contractor] - List of Property will be added as requirements are further identified and the determination to provide property is determined to be in the best interest of the Government.

B. List of Property the Government Will Replace if Damaged or lost during the course of the effort:

Item	Quantity	Acquisition Cost	Use of Property Location	Date to be Furnished to the Contractor

[Insert a description of the item(s), quantity, acquisition cost, and date the property will be furnished to the Contractor] - List of Property will be added as requirements are further identified and the determination to provide property is determined to be in the best interest of the Government.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LYNDON B. JOHNSON SPACE CENTER
HOUSTON, TX 77058

COST REIMBURSABLE INDEFINITE-DELIVERY
INDEFINITE-QUANTITY (IDIQ) TASK ORDER
TEXAS ENGINEERING EXPERIMENT STATION (TEES)
NNJ05HB41B

Task Order Number	*Amendment Number*	*Purchase Request Number*
37	2	Funded at Contract Level
SOW WBS	*Fiscal Year*	*Technical Monitor/Division/Extension*
	FY09	COTR: EC/Ralph Marak, 39144 / EC5/Luis Trevino

Task Order Title

Portable Life Support System (PLSS) Water Pump Development for Exploration Technology

Description/Purpose

Revision 2 to DO 37 is issued to increase the delivery order value by b4 . This increase to the delivery order encompasses the over-run stated by the contractor letter dated May 12, 2009.

Recapitulation of the DO Value:

Summary	Current Value	This Action Revision 2	Total
Cost	b4	b4	b4
Fee			
TOTAL	$ 189,588.84	$ 19,374.00	$ 208,962.84

THE CONTRACTOR IS NOT AUTHORIZED TO EXCEED THE TASK ORDER VALUE SPECIFIED HEREIN. THIS IS A COST PLUS FIXED FEE TASK ORDER.

NASA Approval

Contracting Officer	*Signature*	*Date*
Ronald Johnson	Ronald Johnson	8/13/09

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, TX 77058

ORDER FOR SUPPLIES OR SERVICES

1. Order No.
NNJ05HB41B, DO37R1

2. Date of Order
See Block 10 Below

NOTE: MARK ALL PACKAGES AND PAPERS WITH ORDER NO.

Certified for National Defense under DPAS (15 CFR 700) DO-C9

3. Issuing Office:
NASA Johnson Space Center, 2101 Nasa Parkway
Houston, TX 77058-3696
Org./Buyer: BH2/Mary Thomas

Tel No.: 281-483-8828 Fax: 281-483-2138
E-mail: mary.f.thomas@nasa.gov

4. Ship To:
Transportation Officer, Building 421
NASA Johnson Space Center
Houston, TX 77058-3696
Mark For: **Accountable Property**

Order No.: NNJ05HB41B, DO37R1

5. Contractor:
Texas Engineering Experiment Station (TEES)
Attn: Wendy Gruninger
1470 William D. Fitch Parkway
College Station, TX 77845-4645

Phone: 979-862-1696 x Fax: 979-862-1698

TIN: 74-1974733 CAGE CODE: 0EBC6

6. Deliver On or Before: 05/22/08 - 03/24/09

F.O.B. Point: DESTINATION

Discount Terms: Net 30 Days.

7. BILLING ADDRESS:
NASA Johnson Space Center
Attn: LF231/Accounts Payable Group
Houston, TX 77058-3696
Order No.: NNJ05HB41B, D037R1

8. Type of Order:

☐ PURCHASE: Please furnish the following in accordance with the conditions specified on this order.
Reference:_____

☐ DELIVERY: Except for the Terms and Conditions of Purchase Order listed on the following page, this delivery order is subject to instructions contained on this form and is issued subject to the terms and conditions of contract number: _____

9. Written acceptance of this order by contractor [☐] is, [☒] is not required. Sign below if required and return to contracting officer.

Name: _____ (Person authorized to sign)

Signature: _____ Date: _____

10. Name: Ronald Johnson

Signature: Ronald Johnson Date: 9/5/08
CONTRACTING OFFICER

11. Schedule

ITEM NO.	DESCRIPTION	QUANTITY ORDEREO	UNIT	UNIT PRICE	AMOUNT	QUANTITY ACCEPTED
1	PORTABLE LIFE SUPPORT SYSTEM (PLSS) WATER PUMP DEVELOPMENT FOR EXPLORATION TECHNOLOGY PERIOD OF PERFORMANCE: 05/22/08 - 03/24/09 Revision 1 to DO 37 is issued to increase the DO value by b4 for the completion and assemble of the Custom Unit Pump and extend the completion date to 3/24/09. b4	b4			b4	

12. For JSC Internal Use Only:
Requisition No.: N/A ☐ COMP. ☐ PART. PPC: _____
Rissue To: EC/Ralph Marak For: EC5/Luis Trevino

13. Total
$ 189,588.84 NTE

14. Quantities in "Quantity Accepted" Column Have Been
☐ INSPECTED ☐ ACCEPTED ☐ RECEIVED
TO CONFORM TO THE CONTRACT.
ACCEPTANCE WILL BE AT JSC UNLESS OTHERWISE NOTED.

BY: _____
Authorized U.S. Government Representative

_____
Date

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, TX 77058

ORDER FOR SUPPLIES OR SERVICES

1. Order No.
NNJ05HB41B, CRAVE DO37

2. Date of Order
See Block 10 Below

NOTE: MARK ALL PACKAGES AND PAPERS WITH ORDER NO.

Certified for National Defense under DPAS (15 CFR 700) DO-C9

3. Issuing Office:
NASA Johnson Space Center, 2101 Nasa Parkway
Houston, TX 77058-3696
Org./Buyer: BH2/Mary Thomas

Tel No.: 281-483-8828 Fax: 281-483-2138
E-mail: mary.f.thomas@nasa.gov

4. Ship To:
Transportation Officer, Building 421
NASA Johnson Space Center
Houston, TX 77058-3696
Mark For: **Accountable Property**

Order No.: NNJ05HB41B, CRAVE DO37

5. Contractor:
Texas Engineering Experiment Station (TEES)
Attn: Wendy Gruninger
1470 William D. Fitch Parkway
College Station, TX 77845-4645

Phone: 979-862-1696 x Fax: 979-862-1698

TIN: 74-1974733 CAGE CODE: 0EBC6

6. Deliver On or Before: 05/22/08 - 10/10/08

F.O.B. Point: DESTINATION

Discount Terms: Net 30 Days.

7. BILLING ADDRESS:
NASA Johnson Space Center
Attn: LF231/Accounts Payable Group
Houston, TX 77058-3696
Order No.: NNJ05HB41B, CRAVE D037

8. Type of Order:

☐ PURCHASE: Please furnish the following in accordance with the conditions specified on this order. Reference:_____

☐ DELIVERY: Except for the Terms and Conditions of Purchase Order listed on the following page, this delivery order is subject to instructions contained on this form and is issued subject to the terms and conditions of contract number: _____

9. Written acceptance of this order by contractor [☐] is, [☒] is not required. Sign below if required and return to contracting officer.

Name: _____ (Person authorized to sign)

Signature: _____ Date: _____

10. Name: Ronald Johnson

Signature: Ronald Johnson Date: 5/22/08
CONTRACTING OFFICER

11. Schedule

ITEM NO.	DESCRIPTION	QUANTITY ORDERED	UNIT	UNIT PRICE	AMOUNT	QUANTITY ACCEPTED
1	PORTABLE LIFE SUPPORT SYSTEM (PLSS) WATER PUMP DEVELOPMENT FOR EXPLORATION TECHNOLOGY PERIOD OF PERFORMANCE: 05/22/08 - 10/10/08 The contractor shall perform and deliver to all requirements for the design and fabrication of a development PLSS water pump to be designated as the Custom Unit Pump (See attached SOW). There are no options in the delivery order. b4	b4			b4	

12. For JSC Internal Use Only:
Requisition No.: N/A ☐ COMP. ☐ PART. PPC: _____
Rissue To: EC/Joe Gensler, x30025 For: EC5/Luis Trevino

13. Total
$ 149,588.84 NTE

14. Quantities in "Quantity Accepted" Column Have Been
☐ INSPECTED ☐ ACCEPTED ☐ RECEIVED
TO CONFORM TO THE CONTRACT.
ACCEPTANCE WILL BE AT JSC UNLESS OTHERWISE NOTED.

BY:

Authorized U.S. Government Representative Date

CREW, ROBOTICS AND VEHICLE EQUIPMENT (CRAVE) CONTRACT
DELIVERY ORDER #: CRAVE-EC5-037

PROPOSAL INSTRUCTIONS: _X_ DRAFT – COMMENTS DUE BY: March 10, 2008
__ FINAL – PROPOSAL DUE BY: April 21, 2008

DO TITLE: PLSS Water Pump Development for Exploration Technology

DO Type: _X_ CPFF ___ FFP

DO Contact Information in Addition to the CRAVE Contract Specialist or CO:

TMR: Joe Gensler Phone: (281) 483-0025

DO Manager: Luis Trevino Phone: (281) 483-9141

DO Mgr. Alternate: Heather Paul Phone: (281) 483-3678

Concurrences:

Luis Trevino DO Manager	Raul Blanco DO Mgr. Management	Joe Gensler COTR
Kimberly Baird Division TMR	N/A S & MA	Ron Johnson Contracting Officer

Task Contains Flight Hardware, Flight Software or GSE? ___ Yes _X_ No

Program Supported: __Shuttle __ISS _X_EVA _X_Advanced __Cx

WBS: X 1.0 EVA __ 2.0 FCE __ 3.0 EVR __ ECLSS __ 5.0 ATCS __ 6.0 CHeCS

For purposes of complying with FAR 52.232-22, Limitation of Funds, the total amount allotted by the Government to contract is specified in clause B.6, Contract Funding. The funding listed in B.6 is the amount allotted for all Delivery Orders on the contract combined.

All terms and conditions of the contract apply to this Delivery Order. In the event of a conflict between the contract and this Delivery Order, the contract shall prevail.

WBS reporting shall be done in accordance with applicable WBS reporting categories, as shown above and in the contract within Section C, Table 1.

PLSS Water Pump Development for Exploration Technology

Background / Problem Description:

The current EMU PLSS water pump is a centrifugal multi-vane-type that operates at high revolutions per minute (rpm) (~ 20,200 rpm). This centrifugal pump is sensitive to gas bubbles and can require priming before EVA, resulting in additional EVA preparation time. The current EMU PLSS uses a special pressurizing system that maintains the water loop at 15 pounds per square inch (psi). A dedicated 15 psi oxygen regulator provides backpressure to the Shuttle PLSS feedwater bladder tanks in order to minimize outgassing and bubble formation during EVA operations. The Shuttle PLSS also uses a gas trap and a centrifugal water separator to remove gas from the water loop. Additionally, the Shuttle EMU pump has experienced cavitation issues and has shown susceptibility to water impurities on at least one occasion causing vane growth.

For future missions such as those required of the Constellation Space Suit Element (CSSE), the space suit will employ new technologies to ensure a safe, supportable, sustainable, and extensible suit system that allows for useful work to be performed by the crew during launch, landing, in-space, and on the lunar and Martian surfaces. The suit system protects the crew from nominal and off nominal environments associated with Constellation Program (CxP) mission phases. In order to meet the identified requirements for protecting crew during EVA, the PLSS water loop will use potable water from the vehicle or habitat that has been nominally delivered at 8 psi.

The CSSE PLSS schematic is shown in *Figure 1: CSSE PLSS Schematic.*

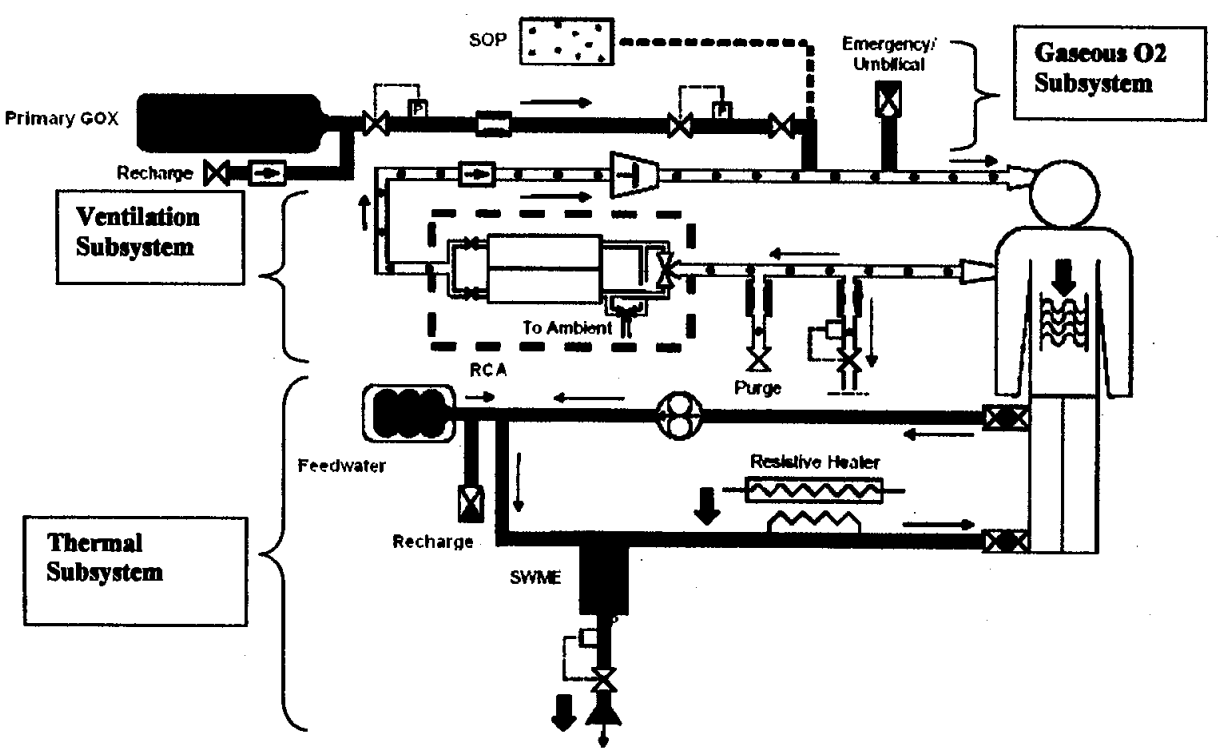

Figure 0-1: Simplified Baseline CSSE PLSS Schematic

(Modified from Bailey 2007)

This schematic contains simplifications from the Shuttle EMU schematic. As part of the preliminary CSSE PLSS layout, the feedwater bladder tanks will be housed within the pressurized suit volume and will be operated at suit pressure (nominally 4.3 psi) during EVA operations. When the water loop drops from 8 psi in the airlock or habitat down to 4.3 psi during EVA operations, some dissolved gas will come out of solution and produce bubbles within the water loop. Positive displacement (PD) pump technology has been chosen by the CSSE PLSS development team in order to tolerate bubbles expected within the CSSE PLSS design.

Purpose of Current Effort:
NASA is seeking technology development for the EVA portable life support system (PLSS) water pump to be used for lunar EVA's that will provide reliable operation for up to 100 EVA's in succession.

For this contract, the contractor will design, build, and demonstrate successful operation of a development PLSS water pump, and deliver the pump to NASA. After delivery, a follow-on effort separate from this contract will be to test the pump at JSC for useful life, water contamination sensitivity, and overall performance as described in JSC-65685, Development Requirements for Waterpump in EVA Technology System (WETS). The contractor shall use the requirements in JSC-65685 as a basis for the pump design and shall work with the NASA project within the limits described below to implement an optimal prototype design for the current PLSS schematic. The pump design shall also take advantage of other long life, low power, low sensitivity-to-water contaminant pumps used in the aerospace and other industries.

The contractors should be cognizant that the technologies and designs developed during this activity should be measured against the NASA TRL standard definitions.

Task Description: The tasks required for this effort are: Design and fabrication of a development PLSS water pump, to be designated as the Custom Unit Pump, or CUP, and successful demonstration of the CUP. Detailed requirements for these tasks are in the following sections.

Requirements

Overall performance requirements for the CUP development are derived from JSC-65685, Development Requirements for Waterpump in EVA Technology System (WETS), provided as a reference in the technical library, but are modified for this current effort for purposes of development testing. The functional requirements for WETS are to provide water flow for thermal regulation to suited EVA crewmember's Liquid Cooling Garment (LCG) and to spacesuit components during EVA in vacuum (micro-g), lunar, and Mars environments for up to 8 hours continuously, and during EVA preparation in airlocks or support vehicles for an additional 2 hours continuously. All of the detailed requirements are derived from the functional

requirements. For development design purposes, focus shall be on the lunar design with protection for key design features for the Mars capability.

Surface Temperatures for the Custom Unit Pump (CUP):

35 F to 100 F (1.7degC to 38 degC)

Water Flowrate and Pressure Rise through CUP:

82 kg/hr (180lbm/hr) minimum at 69 kPad (10 psid)

91 kg/hr (200lbm/hr) minimum at 35 kPad (5 psid)—DESIGN POINT

CUP Inlet Water Pressures:

23 - 69 kPag [3.3 - 10 psig] in Vacuum EVA environment.

Pressure units are absolute units at vacuum, and are referenced to ambient pressure in airlock and ground ops.

CUP Useful Life:

2000 hrs minimum (twice EVA life)

CUP Water Quality:

The water pump and PLSS shall accept potable water from Vehicle Interface Element, with and without silver biocide, as specified in the Potable Water Table (TBD-CSSE-136). (see Reference 2, CXP70024, for guidelines).

CUP External Operating Environment:

The CUP and its support equipment shall be designed for ambient test operation, with recommended changes included to allow for a vacuum compatability design.

CUP Standby and StartUp Capability:

After power is turned off to the CUP, the CUP shall be capable of startup at any time when the initial water inlet is between 35 F to 100 F (1.7degC to 38 degC.)

CUP Motor Type: Permanent magnet type

CUP Overall Power Consumption: 15 Watts +/10% maximum overall at 5 psid

CUP Supply Voltage: 28 VDC nominal

CUP Speed Control: Incorporate speed control to regulate water flowrate at each specified pressure rise to any level between 20% and 120% of the specified minimum water flowrates.

Goals

Goals are design needs that shall be addressed for this test unit , but are not required to be implemented exactly as specified, although some attempts to meet the goals stated are to be made for the test unit.

CUP Servicing and Maintenance Goal:

As a minimum, replacement of the water pump within the PLSS shall be carried out at the lunar lander, the lunar habitat, and in zero-g and micro-g while in the lunar transport vehicle.

CUP Packaging Geometry and Volume Goal:

Maximum CUP Volume Goal:	0.00025 cu m (15 cu in)
Packaging Geometry Goal:	2.25" x 2.75" x 2.25"

CUP External Operating Environments Goals:

Deep Space Vacuum , ($<10^{-4}$ torr pressure)

Mars, 6 to 10 torr (CO_2) pressure

Design Considerations

The following are design needs that are to be considered but not necessarily incorporated into the CUP test unit design.

- Replacement shall be considered on-orbit during lunar transit.
- The CUP must pass thru a minimal amount of gas bubbles from the liquid cooling water without significant performance degradation.
- Water contamination issues are to be addressed.
- Different packaging schemes are to be evaluated to minimize packaging volume of the CUP.
- Different materials are to be traded for the structure of the CUP to minimize mass while meeting structural requirements.

Demonstration/ Verification of CUP at Contractor

All the specifications shown in the requirements section of this DO are to be demonstrated by functional operation of the CUP at the contractor facility, with the exception of the CUP useful life. CUP useful life is to be demonstrated by analysis and/or similitary with pumps in similar applications. After delivery, a NASA follow-on effort separate from this contract will be to test the pump at JSC for useful life, water contamination sensitivity, and overall performance.

Design and Analyses Task

The contractor shall review/study, but not be limited to, the data provided to become familiar with and knowledgeable of the current Shuttle EMU pump design and with advanced EVA technology pump requirements. Then, using this data, the contractor conduct design analyses and develop a concept for the custom unit pump (CUP) which meets all requirements and attempts to meet all goals as stated above. If the goals cannot be achieved, the contractor shall provide information demonstrating the effort to meet the goals and rationale for why it was not possible. The design and analyses study shall include but not be limited to the items listed below. The rationale behind the results for each item listed shall be described in detail in the final report.

1. Candidate pump types considered, to include past applications and demonstrated service life where available.
2. Pump body materials available and material selected for the CUP application.
3. Motor types available and motor selected for the CUP application.
4. Ancillary equipment available and equipment selected for the CUP application (switches, controls, etc.)
5. Design impacts of various pump types in cold environments and hot environments.
6. Feasibility of incorporating test ports and sensors in the CUP design.
7. Sensitivity of various pumps and of CUP design to impact loads.
8. Candidate pump(s) and type selected for the CUP application.

Technical Document Library

The contractor shall have access to the following documents via the online technical library:

1. Constellation Space Suit Element Portable Life Support Subsystem Pump Technology Survey, J.T. Pinckey, ESCG, EM-CX-Suit-07-006, Dec 21, 2007.
2. Constellation Program Human-Systems Requirements, CxP 70024, Rev A, Section 3.2.2-Potable Water, Sept 26, 2007.
3. EMU/International Space Station (ISS) Coolant Failure Loop Failure and Recovery, J. Lewis et al, ICES Paper 2006-01-2240, SAE, July 2006.
4. One EVA EMU Requirements Evolution, Rev B, SEMU-66-017B, Contract NNJ04HA01C, Hamilton-Sundstrand, Sept 30, 2005.
5. Development Requirements for Waterpump in EVA Technology System (WETS), JSC-65685, CTSD-ADV-657, Nov 2007.

Progress Reports

The contractor will be required to provide NASA twice monthly status briefs (topics and scope to be provided by NASA POC) detailing the current status of their work, what has been accomplished, what work is planned for the next two weeks, what issues/problems/risks (if any) have arisen, and their plan to mitigate any issues/problems/risks. These status reports may be submitted via email. Additionally, the contractor will participate in bi-weekly telecons to address problems as they arise.

Conduct Mid-Term Presentation and Design Review

The contractor is to present their intermediate findings to NASA at a mid-term presentation and design review. The presentation will detail results from the design studies and analyses conducted to date, provide insight toward the selected design concept being developed, provide manufacturing status and delivery schedule for the custom pump unit (CUP), and provide a test requirements verification plan.

Generate Final Report

The contractor is to generate and publish a Custom Unit Pump Concept and Design Report, which includes the results of the design and market studies conducted by the contractor, the CUP design drawings they have developed, a test requirements verification plan with test results, and all conclusions.

Conduct Final Report Presentation

The contractor is to present their final report to NASA detailing the results of the design and market studies and analyses conducted by the Contractor, the CUP design concept they have developed, their test requirements plan and results, and all conclusions.

Deliverables/Products:

Product	Description	Qty	Due	Class
Hardware	Custom Unit Pump and all accessory items including motor, mounting hardware and controls to be delivered to NASA.	1 ea.	Contract completion	
	N/A			
Verification Data Package	The Verification Data Package shall consist of the following: 1) Component List 2) Verification Compliance Table (details how the design meets each requirement) 3) Verification Test Plan 4) Verification Test Data Sheets (i.e. the results of the verification testing) 5) Limited Life List 6) Shipping Document (DD250) 7) All associated construction, assembly, and testing documentation 8) Any special instructions for storage, handling, and maintenance 9) MSDS Sheets	3 EA paper and CD (PDF and Word format)		
	N/A			
Software	N/A			
	N/A			
Other Products				
Custom Pump Unit Concept and Design Report	A well documented report detailing the design study and/or analyses conducted, the CUP design concepts the contractor has developed, a test requirements verification plan and verification results, and all conclusions.	3 EA paper and CD (PDF and Word format)	Contract Completion	N/A

Materials Usage List	A materials list which details all the materials the contractor incorporated in the design and in the fabrication of the CUPS. This list should also provide the status of each material in the Marshall Space Flight Center MAPTIS database. If the material(s) is not listed in MAPTIS, the contractor shall provide a preliminary plan for having the material processed and documented per the Materials Analysis Tracking and Control (MATCO) system.	3 EA paper and CD (PDF and Word format)	Contract Completion	N/A
Operating Manual for CUP Test Unit	An operating manual for the CUP test unit delivered to NASA, to include motor as well as pump operating specifications.		Contract Completion	
Drawings	All assembly and major part drawings used in the fabrication of the CUP hardware.	3 EA	Contract Completion	

SCHEDULE

Start Date: May 5, 2008 **Finish Date:** September 22, 2008

ITERIM MILESTONES	DUE DATES (Weeks After ATP)
Kick-off Meeting	1
Review/Study of Custom Unit Pump Design and Requirements	2
Midterm Presentation to NASA	10
Final Formal Presentation to NASA	18
Hardware Delivery	18
Generate/Publish Final Report	20

Milestones, along with subjective measurements, are to be used for measuring performance. For schedule detail see Microsoft Project file located on the CRAVE web site for this DO listed under the Government Cost Estimate below.

Total Government Estimate for this DO: $150,000

TOTAL COST ESTIMATE FOR THIS DO: $

FEE: $ (If Applicable)

TO BE REMOVED FROM DO & INCLUDED IN RFQ LETTER:

Proposal Evaluation Criteria:

1. Proposed Technical Concept, including design, understanding, development/ hardware production capability and schedules;

2. Cost/Price: Except when it is determined not to be in the Government's best interests, the Government will evaluate price of proposals, by adding the total price, including options. Evaluation of options will not obligate the Government to exercise the options;

3. Proposed Achievement of Small Business Goals;

4. Past Performance; and

5. Other: _____

DATA REQUIREMENTS

All DRs contained in the contract are applicable and required unless marked N/A below.

NOTES: 1. GREY SCALED ROWS NEED NO ADDITIONAL/REQUIRED FILL-INS.
2. ON ALL OTHER ROWS, IF NECESSARY, FILL IN ADDITIONAL RQMTS/DELIVERIES IN LAST COLUMN.

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
1	Written Approval	FlightGFE Configuration Management Plan	With Proposal	Once	N	
2	Mandatory Submittal	Regular Status Report/ Summary Review	Thirty (30) days following contract start	Bi-Monthly	Y	Progress reports required twice monthly
3	Written Approval	Project Technical Requirements Specification	Per DO schedule	Once with Revisions	N	
4	Mandatory Submittal	GFE Systems Requirements Data Package	Specified in DO	Once with Revisions	N	
5	Written Approval	Flight GFE Projects Requirements & Verification Document	Specified in DO	Once with Revisions	N	
6	Mandatory Submittal	Preliminary Design Review Data Package	Specified in DO	Once with Revisions	N	
7	Written Approval	Flight GFE Workmanship Specifications List	Specified in DO	Once with Revisions	N	
8	Written Approval	Project Schedule	PDR or 10% effort complete Milestone	Once w/Revisions (due w/DO proposal, updates & details provided as DO progresses)	Y	MS Project Format
9	Written Approval	Flight GFE Interface Control Document	Specified in DO	Once with Revisions	N	
10	Written Approval	GFE End Item Specification	Specified in DO	Once with Revisions	N	
11	Mandatory Submittal	Flight GFE Failure Analysis Report	As agreed by TMR in DO	As Required	N	
12	Written Approval	Flight GFE Verification and Validation Plan	As Specified in EA-023	Once with Revisions	N	
13	Written Approval	GFE Software Requirements Specification	Specified in DO	Once with Revisions	N	
14	Written Approval	GFE Software Development Plan	Specified in DO	Once with Revisions	N	
15	Written Approval	GFE Software Design Document	Specified in DO	As Required	N	

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
16	Written Approval	Engineering Drawings	With final report	Once with Revisions	Y	
17	Written Approval	EEE Parts Lists and Analysis Report		As Required	N	
18	Mandatory Submittal	Critical Design Review Data Package		Once with Revisions	N	
19	Mandatory Submittal	Engineering Drawing Change Proposal		As Required	N	
20	Written Approval	GFE Qualification Test Procedure		Once with Revisions	N	
21	Written Approval	Flight Product User's Guide		Once with Revisions	N	
22	Mandatory Submittal	Software Code		As Required	N	
23	Written Approval	Information Technology (IT) Security Program Plan and Reports	(30) days after DO award, and as specified in JPG 2810.1	JPG 2810.1	N	
24	Written Approval	Certification Plan		Once with Revisions	N	
25	Mandatory Submittal	Certification Report		Once with Revisions	N	
26	Mandatory Submittal	Engineering Analysis		As Required	N	
27	Mandatory Submittal	Acceptance Data Package		One Time	N	
28	Mandatory Submittal	Export Control Audit Results	After award of 1st DO, yearly on Sept. 30 thereafter	Yearly	N	
29	Written Approval	Quality Plan	With Proposal	Once with Revisions	**Attachment J-11**	
30	Written Approval	Patent Rights-Retention	As Required	As Required	**Y (If Applic'ble)**	

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
31	Written Approval	Shuttle/Station Payload Safety Data Package		As Required	N	
32	Mandatory Submittal	Limited Life Systems List		As Required	Y	
33	Written Approval	Space Station GFE Failure Modes and Effects Analysis and Critical Items List		As Required	N	
34	Written Approval	Space Shuttle GFE Safety and Analysis Report &Hazard Report		As Required	N	
35	Written Approval	Software Quality Assurance Plan Report	90 Days Prior to Software Development	Once with Revisions	N	
36	Written Approval	ISS Hazard Report		As Required	N	
37	Upon Request	Reliability and Maintainability Plan	With Proposal	One Time	Attachment J-9	
38	Written Approval	Government Certification Approval Request (GCAR)		As Required	N	
39	Written Approval	Risk Assessment Executive Summary Report (RAESR)		As Required	N	
40	Written Approval	Problem Reporting and Corrective Action (PRACA)		As Required	N	
41	Upon Request	Nonconformance Record		As Required	N	
42	Mandatory Submittal	Government Industry Data Exchange Program and NASA Advisory Problem Data		Once with Revisions	N	
43	Written Approval	Electrical, Electronic, and Electromechnical (EEE) Parts Control Plan		Once with Revisions	N	
44	Mandatory Submittal	Certification Data Package		Once with Revisions	N	
45	Written Approval	Certification and Acceptance Requirements Document		Once with Revisions	N	
46	Upon Request	Wage/Salary and Fringe Benefit Data	Thirty (30) days after issuance of each DO	Once	N	
47	Written Approval	GFE Acceptance Test Procedure		One Time	N	
48	Mandatory Submittal	Flight GFE Verification & Validation Report		Once with Revisions	N	
49	Mandatory Submittal	Space Shuttle GFE Failure Modes and Effects Analysis (FMEA) and Critical Items List		As Required	N	
50		Reserved	—	—	—	—

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
51	Mandatory Submittal	NASA Contractor Financial Management Reporting	After Issuance of 1st DO	Monthly	Y	
52	Written Approval	Government Property Management Plan	With Proposal	Once with Revisions	Attachment J-7	
53	Mandatory Submittal	System Safety Plan	With Proposal	One Time	Attachment J-10	
54	Written Approval	R-Quality Plan Template	With Proposal/ Revisions as Required	Only applicable to B-CRAVE contracts in accordance with the SOW and the DRD	Y	

Type 1 = Written Approval Type 2 = Mandatory Submittal Type 3 = Submittal Upon Request

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, TX 77058

ORDER FOR SUPPLIES OR SERVICES

1. Order No.
DO-CRAVE-EC-006

2. Date of Order
SEE BLOCK 10

NOTE: MARK ALL PACKAGES AND PAPERS WITH ORDER NO.

Certified for National Defense under DPAS (15 CFR 700) DO-C9

3. Issuing Office:
NASA Johnson Space Center, 2101 Nasa Parkway
Houston, TX 77058-3696
Org./Buyer: BH2/Mike Ballard

Tel No.: 281-244-5350 Fax: ____
E-mail: michael.d.ballard@nasa.gov

4. Ship To:
Transportation Officer, Building 421
NASA Johnson Space Center
Houston, TX 77058-3696
Mark For: **Accountable Property**

Order No.: DO-CRAVE-EC-006

5. Contractor:
Texas Engineering Research Services
200 Greens Prairie Road, Rm 122
College Station, TX 77845-9493

Phone: 979-862-1696 x Fax: 979-862-1698

TIN: 74-1974733 CAGE CODE: 0EBC6

6. Deliver On or Before: SEE BLOCK 11

F.O.B. Point: ____

Discount Terms: Net 30 Days.

7. BILLING ADDRESS:
NASA Johnson Space Center
Attn: LF231/Accounts Payable Group
Houston, TX 77058-3696
Order No.: DO-CRAVE-EC-006

8. Type of Order:

☐ PURCHASE: Please furnish the following in accordance with the conditions specified on this order.
Reference:____

☒ DELIVERY: Except for the Terms and Conditions of Purchase Order listed on the following page, this delivery order is subject to instructions contained on this form and is issued subject to the terms and conditions of contract number: NNJ05HB B

9. Written acceptance of this order by contractor [☒] is, [☐] is not required. Sign below if required and return to contracting officer.

Name: Russell Brewer (Person authorized to sign)

Signature: ____ Date: 9/7/05

10. Name: N. L. Dawn Alexander

Signature: Dawn Alexander Date: 9/7/05
CONTRACTING OFFICER

11. Schedule

ITEM NO.	DESCRIPTION	QUANTITY ORDERED	UNIT	UNIT PRICE	AMOUNT	QUANTITY ACCEPTED
1	The Contractor shall perform and deliver to all requirements for: DO-CRAVE-EC-006: "Suit Architecture" The Period of Performance for this DO is: 09/01/2005 - 11/08/2005 (excluding any options)	b4	b4	b4	b4	

12. For JSC Internal Use Only:
Requisition No.: ____
Rissue To: ____
☐ COMP. ☐ PART. PPC: ____

13. Total
$ 234,229.52

14. Quantities in "Quantity Accepted" Column Have Been
☐ INSPECTED ☐ ACCEPTED ☐ RECEIVED
TO CONFORM TO THE CONTRACT.
ACCEPTANCE WILL BE AT JSC UNLESS OTHERWISE NOTED.

BY: ____
Authorized U.S. Government Representative ____ Date

JSC Form 1429 (Rev November 10, 2004) (MS Word August 1995)

CREW, ROBOTS AND VEHICLE EQUIPMENT (CRAVE) CONTRACT
DELIVERY ORDER #: CRAVE-EC-006

DO TITLE: Vision for Space Exploration Suit Architecture Study

DO Type: X CPFF ___ FFP

DO Contact Information in Addition to the CRAVE Contract Specialist or CO:

TMR: Robert Trevino **Phone: (281) 483-2597**

DO Manager: Joe Kosmo / EC 5 **Phone: (281) 483-9235**

DO Mgr. Alternate: Gretchen Thomas / EC 5 **Phone: (281) 483-7664**

Concurrences:

Original Signed	**Original Signed**	**Original Signed**
Joe Kosmo	**Craig Dinsmore**	**Joe Gensler**
DO Manager	**DO Mgr. Management**	**COTR**
Original Signed	**Original Signed**	_____
Robert Trevino	**Steve Miller**	**Name**
Division TMR	**S & MA**	

Task Contains Flight Hardware, Flight Software or GSE? ___ Yes _X_ No

Program Supported: __Shuttle __ISS __EVA _X_ Advanced EVA

WBS: _X_ 1.0 EVA __ 2.0 FCE __ 3.0 EVR __ ECLSS __ 5.0 ATCS __ 6.0 CHeCS

*For purposes of complying with FAR 52.232-22, Limitation of Funds, the total amount allotted by the Government to contract is specified in clause B.6, Contract Funding. The funding listed in B.6 is the amount allotted for **all** Delivery Orders on the contract combined.*

All terms and conditions of the contract apply to this Delivery Order. In the event of a conflict between the contract and this Delivery Order, the contract shall prevail.

WBS reporting shall be done in accordance with applicable WBS reporting categories, as shown above and in the contract within Section C, Table 1.

SEP 0 8 2005

Narrative Task Description

Background / Problem Description:

1.0 Objective

In light of the planned milestone schedule goals for the Vision For Space Exploration (VSE) and the subsequent Constellation Program established by NASA to accomplish these goals, the purpose of this effort is to conduct an accelerated two month feasibility study of suit system architecture concepts. The length and depth of this study could be extended if the official Constellation mission milestones, soon to be released by NASA Headquarters, allow. If that schedule change occurs, a revision to the delivery order is anticipated.

2.0 *Task Description:* Scope and Guidelines

The objective of this study is to identify and define the appropriate suit system (pressure garment and life support system with attendant vehicle interfaces), architecture concepts and options for the corresponding class of Constellation Program vehicle systems and VSE mission architectural elements. **For the purposes of this study, the term "suit system" is defined as the pressure garment, the life support system and its attendant vehicle interfaces.**

For the purpose of the study the following Exploration mission milestones are assumed:

- Crew Exploration Vehicle (CEV) - to - ISS Missions:
  2012 CEV human flight to ISS
- Lunar Sortie Missions
  2017 goal of CEV/ Lunar Surface Access Module (LSAM) Low Earth Orbit (LEO) Integrated test (human mission)
  2018 goal of human mission to the Moon including landing, but no later than 2020
- Lunar Outpost Missions
  2022 goal for permanent/sustained human presence on the Moon
- Mars Missions
  2032 goal of first humans on Mars

The intent of the proposed accelerated two month feasibility study is for the contractor to conduct a comprehensive study to identify, investigate, evaluate and assess from a **technical, schedule** and projected **overall cost** base, what specific suit architecture option or combination of options would best meet the above Exploration Systems Architecture Study (ESAS) mission architectures. The contractor shall be responsible for conducting the necessary study investigations to identify the specific suit system related requirements that may be similar or unique between the identified ESAS mission architectures.

Although the in-depth technical requirements for the various ESAS mission architectures have not yet been finalized, the following technical considerations and guidelines are offered as a general starting point in order to determine specific suit system architectural features and factors

for the feasibility study. The contractor should consider these as only general guidelines and assumptions.

The following representative requirements for suit system capabilities are assumed for these expected Constellation mission phases: CEV to ISS, Lunar Sortie Missions, Lunar Outpost Missions, and Mars Missions

- Crew protection and survivability during launch, entry and abort scenarios
- No crew bailout capability needed (crew will stay in capsule until landing)
- Land return will be normal sequence
- Water survival (emergency/contingency landing)
- Cabin depressurization protection (96-hour duration)
- Zero-gravity EVA capability for contingency EVA for CEV missions.
- Zero-gravity EVA capability for activities such as:
    - Assembly/construction in support of CEV Lunar/Mars missions
    - Maintenance/repair in support of CEV Lunar/Mars missions
- Surface EVA capability for Lunar and Mars planetary exploration
    - Dust control and abatement methods are significant design factors

Because of the broad range of operational environments and mission objectives that a new suit system will be required to support, a single suit system option might be considered improbable. However, the potential programmatic benefits of developing, operating and sustaining a single suit system architecture warrant a more thorough examination. There are technical challenges associated with various aspects of a single-suit system option (e.g. combining launch, entry and EVA capabilities into one suit) versus a multi-suit option architecture (e.g. separate suit configurations to support different mission phases). Because of these challenges, it will be necessary to examine these options more closely to determine whether a single suit system approach or multiple suit system approach (or some other option variations) would better meet the needs of the VSE.

3.0 Detailed Task Description

The contractors' comprehensive feasibility study shall apply the engineering "lessons learned" and other experiences gained from the many years of space suit system technology developments and flight operations (ranging from Gemini, Apollo, Skylab, to the current Shuttle EMU & ACES systems) to the emerging Constellation requirements and operational scenarios in order to assess the suit system architecture options. As a minimum, the following four preliminary defined suit system architecture options are to be evaluated and assessed:

- Option 1 – Two Suits :
    - Combined Launch, Entry, Abort and 0-Gravity EVA (O-G EVA) contingency Suit
    - Planetary Surface Suit
- Option 2 – Two Suits :
    - Launch, Entry, Abort (LEA) only Suit
    - Combined O-G and Planetary Surface Suit

- Option 3 – One Suit :
  - Re-configurable between LEA, O-G and Planetary Surface Suit
- Option 4 – Three Suits :
  - LEA Suit
  - O-G Suit
  - Planetary Surface Suit

Other options, as identified by the contractor, may be added to the study and are considered within the scope of the effort.

All suit system architecture options within the study are to be evaluated in terms of the following criteria:

a.) **Technical feasibility to support mission objectives**
b.) **Ability to provide extensibility to other mission phases**
c.) **Logistics support, maintainability and commonality**
d.) **Operational performance and work efficiency index (operational overhead)**
e.) **Supportability of critical program schedule and milestone goals**
f.) **Life-cycle cost as estimated within the study**

The following outline describes the activities to be conducted by the contractor under this SOW effort. The contractor shall:

- Define any additional suit system architecture options or recommendations to meet VSE requirements. (It is expected additional suit system architecture options will be identified and included in the cost of the study during the proposal process. This task is to define them to the government and agree on a definition for the study)

- Evaluate each of the suit system architecture options in terms of the criteria listed above.

- Identify and summarize the advantages/disadvantages and potential technical short comings of each of the above mentioned suit system architecture options to meet VSE requirements.

- Provide a comprehensive interim review (If program milestones hold, this review will be very important in terms of the EVA program's ability to make inputs to the vehicle programs. So, the study should be structured to make as much progress as possible in the first 30 days)

- Provide details of study results in a comprehensive final report.

- Because the VSE, Constellation and CEV architectures and requirements are expected to be constantly evolving during the time frame of this study an on-going parallel task to the above DO tasks will be to evaluate available information and conduct the appropriate investigations to identify the suit system high-level requirements necessary to support the indicated VSE mission architecture phases of operation and to draw that information into the study as it becomes available.

Deliverables/Products:

Product	Description	Qty	Due	Class
Hardware				
Mock Up				
Prototype				
Certification				
Flight				
Training				
Other				
Test				
Software				
Other Products				
Study Bi Weekly Information Telecon	Bi Weekly telecom where critical information developed by the study is given to NASA via Webex presentations and telecom meeting		Bi Weekly	
Interim Review	Comprehensive Status Report of Study at midway point		**5 Oct 2005**	
Final Report	Comprehensive Final Report of Study at Completion		**1 Nov 2005**	

SCHEDULE

Start Date: 1 Sep, 2005 **Finish Date: 8 Nov. 2005**

ITERIM MILESTONES	DUE DATES
Interim Review	5 Oct 2005
Final Report	1 Nov 2005

Milestones, along with subjective measurements, are to be used for measuring performance. For schedule detail see Microsoft Project file located on the CRAVE web site for this DO listed under the Government Cost Estimate below.

Government Estimate Located in RFQ File in Microsoft Project File On CRAVE Web Site
The file is titled: CRAVE suit architecture.mpp

Total Government Estimate for this DO: $ 230 K
Option 1: $ N/A (See Attachment 1)
Option 2: $ N/A (See Attachment 2)

TOTAL COST ESTIMATE FOR THIS DO: $234,229.52

FEE: $ (If Applicable)

OPTION 1: $ N/A (See Attachment 1)

OPTION 2: $ N/A (See Attachment 2)

DATA REQUIREMENTS

All DRs contained in the contract are applicable and required unless marked N/A below.

NOTES: 1. GREY SCALED ROWS NEED NO ADDITIONAL/REQUIRED FILL-INS.
2. ON ALL OTHER ROWS, IF NECESSARY, FILL IN ADDITIONAL RQMTS/DELIVERIES IN LAST COLUMN.

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
1	Written Approval	FlightGFE Configuration Management Plan	With Proposal	Once	**Attachment J-8**	
2	Mandatory Submittal	Regular Status Report/ Summary Review	Thirty (30) days following contract start	Monthly	**Y**	
3	Written Approval	Project Technical Requirements Specification	Per DO schedule	Once with Revisions	**NA**	
4	Mandatory Submittal	GFE Systems Requirements Data Package	Specified in DO	Once with Revisions	**NA**	
5	Written Approval	Flight GFE Projects Requirements & Verification Document	Specified in DO	Once with Revisions	**NA**	
6	Mandatory Submittal	Preliminary Design Review Data Package	Specified in DO	Once with Revisions	**NA**	
7	Written Approval	Flight GFE Workmanship Specifications List	Specified in DO	Once with Revisions	**NA**	
8	Written Approval	Project Schedule	PDR or 10% effort complete Milestone	Once w/Revisions (due w/DO proposal, updates & details provided as DO progresses)	**In Proposal Only**	
9	Written Approval	Flight GFE Interface Control Document	Specified in DO	Once with Revisions	**NA**	
10	Written Approval	GFE End Item Specification	Specified in DO	Once with Revisions	**NA**	
11	Mandatory Submittal	Flight GFE Failure Analysis Report	As agreed by TMR in DO	As Required	**NA**	
12	Written Approval	Flight GFE Verification and Validation Plan	As Specified in EA-023	Once with Revisions	**NA**	
13	Written Approval	GFE Software Requirements Specification	Specified in DO	Once with Revisions	**NA**	
14	Written Approval	GFE Software Development Plan	Specified in DO	Once with Revisions	**NA**	
15	Written Approval	GFE Software Design Document	Specified in DO	As Required	**NA**	

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
16	Written Approval	Engineering Drawings	At PDR, as specified in DO	Once with Revisions	NA	
17	Written Approval	EEE Parts Lists and Analysis Report	Specified in DO	As Required	NA	
18	Mandatory Submittal	Critical Design Review Data Package	Specified in DO	Once with Revisions	NA	
19	Mandatory Submittal	Engineering Drawing Change Proposal	As needed	As Required	NA	
20	Written Approval	GFE Qualification Test Procedure	Specified in DO	Once with Revisions	NA	
21	Written Approval	Flight Product User's Guide	Specified in DO	Once with Revisions	NA	
22	Mandatory Submittal	Software Code	Specified in DO	As Required	NA	
23	Written Approval	Information Technology (IT) Security Program Plan and Reports	(30) days after DO award, and as specified in JPG 2810.1	JPG 2810.1	**Attachment J-4 Due 30 days after DO award**	
24	Written Approval	Certification Plan	Specified in DO	Once with Revisions	NA	
25	Mandatory Submittal	Certification Report	Specified in DO	Once with Revisions	NA	
26	Mandatory Submittal	Engineering Analysis	Specified in DO	As Required	**As Required**	
27	Mandatory Submittal	Acceptance Data Package	Specified in DO	One Time	NA	
28	Mandatory Submittal	Export Control Audit Results	After award of 1st DO, yearly on Sept. 30 thereafter	Yearly	Y	
29	Written Approval	Quality Plan	With Proposal	Once with Revisions	**Attachment J-11**	
30	Written Approval	Patent Rights-Retention	As Required	As Required	**Y (If Applic'ble)**	

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
31	Written Approval	Shuttle/Station Payload Safety Data Package	Specified in DO	As Required	NA	
32	Mandatory Submittal	Limited Life Systems List	Specified in DO	As Required	NA	
33	Written Approval	Space Station GFE Failure Modes and Effects Analysis and Critical Items List	As Early in process as possible.	As Required	NA	
34	Written Approval	Space Shuttle GFE Safety and Analysis Report &Hazard Report	Specified in DO	As Required	NA	
35	Written Approval	Software Quality Assurance Plan Report	90 Days Prior to Software Development	Once with Revisions	Y (If Applic'ble)	
36	Written Approval	ISS Hazard Report	Specified in DO	As Required	NA	
37	Upon Request	Reliability and Maintainability Plan	With Proposal	One Time	Attachment J-9	
38	Written Approval	Government Certification Approval Request (GCAR)	Specified in DO	As Required	NA	
39	Written Approval	Risk Assessment Executive Summary Report (RAESR)	Specified in DO	As Required	NA	
40	Written Approval	Problem Reporting and Corrective Action (PRACA)	2 business days of problem isolation but no later than 10 days after detection	As Required	NA	
41	Upon Request	Nonconformance Record	Specified in DO	As Required	NA	
42	Mandatory Submittal	Government Industry Data Exchange Program and NASA Advisory Problem Data	Reported one time when discrepancy occurs	Once with Revisions	NA	
43	Written Approval	Electrical, Electronic, and Electromechnical (EEE) Parts Control Plan	Specified in DO	Once with Revisions	NA	
44	Mandatory Submittal	Certification Data Package	Specified in DO	Once with Revisions	NA	
45	Written Approval	Certification and Acceptance Requirements Document	At CDR	Once with Revisions	NA	
46	Upon Request	Wage/Salary and Fringe Benefit Data	Thirty (30) days after issuance of each DO	Once		
47	Written Approval	GFE Acceptance Test Procedure	Specified in DO	One Time	NA	
48	Mandatory Submittal	Flight GFE Verification & Validation Report	Specified in DO	Once with Revisions	NA	

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
49	Mandatory Submittal	Space Shuttle GFE Failure Modes and Effects Analysis (FMEA) and Critical Items List	Specified in DO	As Required		
50		**Reserved**	---	---	---	---
51	Mandatory Submittal	NASA Contractor Financial Management Reporting	After Issuance of 1st DO	Monthly	**Y**	
52	Written Approval	Government Property Management Plan	With Proposal	Once with Revisions	**Attachment J-7**	
53	Mandatory Submittal	System Safety Plan	With Proposal	One Time	**Attachment J-10**	
54	Written Approval	R-Quality Plan Template	With Proposal/ Revisions as Required	Only applicable to B-CRAVE contracts in accordance with the SOW and the DRD	**Y**	

Type 1 = Written Approval Type 2 = Mandatory Submittal Type 3 = Submittal Upon Request

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, TX 77058

ORDER FOR SUPPLIES OR SERVICES

(SOW ATTACHED)

1. Order No.
DO-CRAVE-EC5-001 Rev. 2

2. Date of Order
See Block 10

NOTE: MARK ALL PACKAGES AND PAPERS WITH ORDER NO.

Certified for National Defense under DPAS (15 CFR 700) DO-C9

3. Issuing Office:
NASA Johnson Space Center, 2101 Nasa Parkway
Houston, TX 77058-3696
Org./Buyer: BH4/Michael Ballard

Tel No.: 281-244-5350 Fax: ____
E-mail: michael.d.ballard@nasa.gov

4. Ship To:
Transportation Officer, Building 421
NASA Johnson Space Center
Houston, TX 77058-3696
Mark For: **Accountable Property**

Order No.: DO-CRAVE-EC5-001 Rev. 2

5. Contractor:
Texas Engineering Experiment Station
3126 TAMU
College Station, TX 78743-3126

Phone: 979-862-1696 x Fax: 979-862-1698

TIN: 74-1974733 CAGE CODE: 0EBC6

6. Deliver On or Before: See Block 11

F.O.B. Point: Destination

Discount Terms: Net 30 Days.

7. BILLING ADDRESS:
NASA Johnson Space Center
Attn: LF231/Accounts Payable Group
Houston, TX 77058-3696
Order No.: DO-CRAVE-EC5-001 Rev. 2

8. Type of Order:

☐ PURCHASE: Please furnish the following in accordance with the conditions specified on this order.
Reference:____

☒ DELIVERY: Except for the Terms and Conditions of Purchase Order listed on the following page, this delivery order is subject to instructions contained on this form and is issued subject to the terms and conditions of contract number: NNJ05HB41B

9. Written acceptance of this order by contractor [☒] is, [☐] is not required. Sign below if required and return to contracting officer.

Name: Russell Brewer (Person authorized to sign)

Signature: _____ Date: 4/11/06

10. Name: J.R. Carpentier

Signature: _____ Date: 3-16-06
CONTRACTING OFFICER

11. Schedule

ITEM NO.	DESCRIPTION	QUANTITY ORDERED	UNIT	UNIT PRICE	AMOUNT	QUANTITY ACCEPTED
1	The contractor shall perform and deliver all requirements for: DO-CRAVE-EC5-001: Portable Life Support Subsystem Schematic (PLSS). This is revision 2 to this delivery order. This revision replaces the previous Delivery Order. The purpose of this revision is to: 1. Extend the period of performance for this DO through 3/22/06. 2. Increase the Delivery Order value. bH All other terms and conditions remain unchanged.					

12. For JSC Internal Use Only:
Requisition No.: N/A ☐ COMP. ☐ PART. PPC: ____
Rissue To: Gretchen Thomas/EC

13. Total
$ 567,239.11

14. Quantities in "Quantity Accepted" Column Have Been
☐ INSPECTED ☐ ACCEPTED ☐ RECEIVED
TO CONFORM TO THE CONTRACT. ACCEPTANCE WILL BE AT JSC UNLESS OTHERWISE NOTED.

BY: _____
Authorized U.S. Government Representative

_____
Date

JSC Form 1429 (Rev November 10, 2004) (MS Word August 1995)

ORDER FOR SUPPLIES OR SERVICES

1. Order No.
DO-CRAVE-EC5-001 Rev. 1

2. Date of Order
See Block 10

NOTE: MARK ALL PACKAGES AND PAPERS WITH ORDER NO.

Certified for National Defense under DPAS (15 CFR 700) DO-C9

3. Issuing Office:
NASA Johnson Space Center, 2101 Nasa Parkway
Houston, TX 77058-3696
Org./Buyer: BH2/Michael Ballard

Tel No.: 281-244-5350 Fax: ____
E-mail: michael.d.ballard@nasa.gov

4. Ship To:
Transportation Officer, Building 421
NASA Johnson Space Center
Houston, TX 77058-3696
Mark For: **Accountable Property**

Order No.: DO-CRAVE-EC5-001 Rev. 1

5. Contractor:
Texas Engineering Experiment Station
3000 TAMU
College Station, TX 78743-3000

Phone: 979-862-1696 x Fax: 979-862-1698

TIN: 74-1974733 CAGE CODE: 0EBC6

6. Deliver On or Before: See Block 11

F.O.B. Point: Destination

Discount Terms: Net 30 Days.

7. BILLING ADDRESS:
NASA Johnson Space Center
Attn: LF231/Accounts Payable Group
Houston, TX 77058-3696
Order No.: DO-CRAVE-EC5-001 Rev. 1

8. Type of Order:

☐ PURCHASE: Please furnish the following in accordance with the conditions specified on this order.
Reference:____

☒ DELIVERY: Except for the Terms and Conditions of Purchase Order listed on the following page, this delivery order is subject to instructions contained on this form and is issued subject to the terms and conditions of contract number: NNJ05HB41B

9. Written acceptance of this order by contractor [☒] is, [☐] is not required. Sign below if required and return to contracting officer.

Name: Russell Brewer (Person authorized to sign)

Signature: _____ Date: 10/21/05

10. Name: N.L. Dawn ALexander

Signature: Dawn Alexander Date: 10/27/05
CONTRACTING OFFICER

11. Schedule

ITEM NO.	DESCRIPTION	QUANTITY ORDERED	UNIT	UNIT PRICE	AMOUNT	QUANTITY ACCEPTED
1	The contractor shall perform and deliver all requirements for: DO-CRAVE-EC5-001: Portable Life Support Subsystem Schematic (PLSS). This is revision 1 to this delivery order. The purpose of this revision is to: 1. Extend the period of performance for this DO through 2/15/2006 2. Modify the SOW. Changes are vertically bar-marked and a replacement page is attached. b4 All other terms and conditions remain unchanged.					

12. For JSC Internal Use Only:
Requisition No.: N/A ☐ COMP. ☐ PART. PPC: ____
Rissue To: Gretchen Thomas/EC

13. Total
$ 540,952.76

14. Quantities in "Quantity Accepted" Column Have Been
☐ INSPECTED ☐ ACCEPTED ☐ RECEIVED
TO CONFORM TO THE CONTRACT. ACCEPTANCE WILL BE AT JSC UNLESS OTHERWISE NOTED.

BY:

Authorized U.S. Government Representative Date

CREW, ROB[illegible]S AND VEHICLE EQUIPMENT (C[illegible]) CONTRACT
DELIVERY ORDER #: CRAVE-EC5-001

DO TITLE: PORTABLE LIFE SUPPORT SUBSYSTEM (PLSS) SCHEMATIC STUDY

DO Type: _X_ CPFF ___ FFP

DO Contact Information:

TMR:	B. Mike Lawson	Phone	39124
DO Manager:	Gretchen Thomas	Phone	37664
DO Mgr. Alternate:	Mike Rouen	Phone	39242

Concurrences:

S/ 2-15-05	S/ 2-15-05	S/ 2-15-05
Gretchen Thomas	Craig Dinsmore	Joe Gensler
DO Manager	DO Mgr. Management	COTR
S/ 2-15-05	S/ 2-15-05	
B. M. Lawson	Steve Miller	
Division TMR	S & MA	

Task Contains Flight Hardware, Flight Software or GSE? ___ Yes _X_ No

Program Supported: __Shuttle __ISS __EVA _X_ Advanced All Spirals

---

WBS: X 1.0 EVA __ 2.0 FCE __ 3.0 EVR __ ECLSS __5.0 ATCS __ 6.0 CHeCS

*For purposes of complying with FAR 52.232-22, Limitation of Funds, the total amount allotted by the Government to contract is specified in clause B.6, Contract Funding. The funding listed in B.6 is the amount allotted for **all** Delivery Orders on the contract combined.*

All terms and conditions of the contract apply to this Delivery Order. In the event of a conflict between the contract and this Delivery Order, the contract shall prevail.

WBS reporting shall be done in accordance with applicable WBS reporting categories, as shown above and in the contract within Section C, Table 1.

Narrative Task Description

Background / Problem Description:

Schematic Definition
For this study, a Portable Life Support Subsystem (PLSS) schematic is the single page diagram that describes the technologies selected to accomplish the life support functions and the fluid mechanical functional interconnections. A Portable Life Support Subsystem is here taken to mean a self contained life support subsystem along with the emergency life support system required to accomplish a fail safe design. This excludes such umbilical supplied life support subsystems such as the Skylab ALSA. It does not exclude such arrangements as having recharge capability carried on a rover or other methods used to off load crew person carried weight. For this study, the term "schematic" is limited to the fluid and mechanical functions and only the electrical functions necessary to maintain safety. This definition purposely excludes the information handling architecture of the EVA informatics related hardware which is another study itself.

Schematic History
An example of the schematic currently in use in the United States space program is shown in Figure 1. The only other US portable life support subsystem, the Apollo PLSS, used a similar schematic as does the current Russian space suit. All three share in common the following technologies: high pressure oxygen storage, sublimator for heat rejection, battery for power, lithium hydroxide for CO_2 control, and charcoal for trace contaminant control. Although they each have some different interconnections (for example the Shuttle is set up for zero g operation while the Apollo system was optimized for gravity field operation) the basic schematic is the same from the stand point of use of the technologies listed above. The only deviation from this list is the replacement of lithium hydroxide with an in orbit regenerable metal oxide for CO_2 control on the ISS which was driven by a storage volume and launch cost tradeoff.

Prior Studies
Prior studies of Portable Life Support Subsystem schematic arrangements have been accomplished. A particularly comprehensive study, the Advanced Extravehicular Protective Systems (AEPS) Study, was accomplished for the Ames Research Center (NAS 2-6021) by J. G. Sutton, P. H. Heimlich, and E. H. Tepper of the Hamilton Standard Division of United Technologies in 1972 (NASA CR114384). A broader study of the EVA system as a work system included portable life support considerations and was accomplished in 1980 but it was focused on zero g operations and so did not include lunar and mars related information. In anticipation of the space station and in preparation to direct the technology program leading up to selection of a schematic for space station use, NASA accomplished an in house study in the 1987 time frame. It was titled the Point Design Study and was only documented via presentation charts. But, again, this study was focused on Zero G operations only. During the First Lunar Outpost activity some schematic study was done focused on the lunar destination. This work identified radiators as a viable heat rejection mechanism. This work is documented in "First Lunar Outpost Extravehicular Life Support System Evaluation,"

Bruce C. Conger, Luis A. Trevino and B. Michael Lawson, ICES[1] paper number 932188. This study did not cover the breath of technologies of interest being mainly concerned with the thermal subsystem. Consequently, the best study to use as a base for the present effort is the 1972 AEPS study.

Prior studies of the EVA system needed to accomplish Lunar and Mars exploration were accomplished in 1988. These studies provide excellent context for how and where the PLSS will be used. The studies were performed under the generic title of "Extravehicular Activity Systems Requirements Definition Study" resulting in "Extravehicular Activity at a Lunar Base," September 1988 and "Extravehicular Activity in Mars Surface Exploration," May 1989 lead by the ESSEX Co. and performed under contract NAS 9-17779.

PLSS Interfaces:
The PLSS is strongly driven by vehicle life support and power systems for it is the vehicle systems that determine what resources are available for PLSS recharge. This interaction creates a strong tie of the PLSS technology selections to the vehicle technology selections requiring the EVA community to be ready to support vehicle trade studies with a complete picture of the impacts of various vehicle technology selections on the PLSS. Some vehicle technology selections close entire technology class path ways and others can force the PLSS into selections that tend to open loops the vehicle life support community has been striving hard to close. It is important that the PLSS community "do its homework" early so the vehicle trade studies can be properly supported.

New Technology
Certainly in the 32 years since the 1972 study there has been a significant amount of technology development accomplished both inside the aerospace industry (most often documented in the ICES conference) and outside that is applicable to the PLSS schematic. Besides the life support technology development directly, there has been significant work done on basic materials (CO_2 absorption chemistry, MEMS and nanotechnology) and fundamental process (Microchannel heat and mass transfer).

Three major areas of technology that are expected to have considerable impact on the PLSS schematic are: 1) the shrinking size of power supplies making it possible to go from battery supplied power to a fuel based power supply which can raise the power available from the current 100W range to the 1000W range, 2) the Microsystems elements that are becoming available for heat transfer and chemical processes and 3) the distributed sensing / processing technologies. The first makes it possible to consider high power thereby allowing the use of technologies that have been rejected in all previous studies because of the weight cost of the power supply required. The second aids this trend and makes all processes potentially smaller and lighter. The third has profound implications on the packaging (which accounts for half the system weight) of a PLSS but, more germane to this study, provides the opportunity to better monitor PLSS performance and thereby aid in accomplishing the needed increases in PLSS life time and reduction in testing to assure safety.

Outside of NASA, significant work has been done on portable life support for Earth based use by the military in response to chemical and biological warfare threats and there is current interest

[1] The ICES conference, cosponsored by multiple engineering societies and managed by the SAE, is one of the primary places the EVA community publishes.

concerning similar threats for first responders for homeland defense. Commercial applications for some subsystems of the portable life support subsystem (thermal control) have arisen for work in extreme environments and for mitigation of symptoms of some medical conditions such as MS. Even the fundamental engineering process of how to do selection trade off studies has undergone significant change as documented in books by authors such as Pugh[2] and Ullman[3].
All of these facts suggest it is time for a new comprehensive study that builds on but does not repeat prior work as we prepare to plan and implement the technology program focused on fulfillment of the Vision for Space Exploration. A study drawing on NASA and non NASA expertise is warranted and needed to lay out a development roadmap that directs budget planning for future exploration efforts. In addition, new analysis capabilities and design methodologies are available allowing a more comprehensive study than previous studies with the same resources.

PROCESS TO BE FOLLOWED:

Form Design Team(s)
An interdisciplinary design team that includes both NASA and the contractor personnel is to be formed for the generation and evaluation of schematic concepts. The contractor is to plan to accomplish the entire job without dependence on NASA effort. NASA effort will provide operational experience and additional depth of study but shall not be planned into the critical path to accomplish the study requirements. If it is deemed advisable, teams can be formed that focus on subsystems of the schematic and team selection, and may include or may not include NASA participants to supply the team with additional expertise. The availability of NASA expertise is described below in the Table 1 – Potentially Available NASA Expertise is planned to be provided as a "best efforts" arrangement.

Develop Tasks Assignment
Since the exact nature of the expertise to be provided by NASA is needed in order to do an in-depth plan, internal team planning will be accomplished as agreed to by NASA and the contractor for accomplishment of tasks. This planning shall not affect the scope of the contractor's work but can increase or decrease the scope of potentially available NASA participation.

Schedule Project
Since the exact schedule availability of the potentially available NASA expertise is subjective, internal team planning for adjustments to various task schedules will be accomplished as agreed to by NASA and the contractor. These schedule adjustments shall not affect the scope of the contractor's work.

Form Teams
Team composition shall be based not only on the technical expertise needed but with due considerations for the different roles[4] needed to form an effective design team. Design teams are to be limited to the number of people required to form an effective team. The teams shall solicit the input of those outside the team, as needed, to accomplish the design task at hand. The teams shall

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[2] Pugh, S.: *Total Design Integrated Methods for Successful Product Engineering*, Addison-Wesley, Wokingham, England, 1991
[3] Ullman, D. G.: *The Mechanical Design Process*, McGraw Hill, 1992
[4] For example see *3.5.2 Team Roles*, Page 55 of Ullman's Second Edition.

support the contract milestone reviews and respond to any Review Item Discrepancies (RIDs) generated during those reviews that affect the design team's efforts.

Define the Problem
Success of a design process depends heavily on good problem definition which is not a trivial exercise. As a minimum the following steps shall be accomplished to fully define the problem of PLSS schematic selection.

-- Review and Update Prior Work
The following studies shall be reviewed and updated as needed to take into account new knowledge of the technologies included in those studies since their completion. Where entirely new technology or techniques have come to fore, this study is expected to address those issues. Consequently, this update task is expected to be of limited scope.

1. "Advanced Extravehicular Protective Systems (AEPS) Study," 1972
2. "Extravehicular Activity at a Lunar Base," September 1988
3. "Extravehicular Activity in Mars Surface Exploration," May 1989

One area of concern where update of the Lunar Base study is known to be required is operation in the lunar pole area. The potential for extremely cold environments (order of 40°K) is a concern and a specific analysis of the impacts on the PLSS schematic and technology selection of this case is required.

-- Develop Vehicle Interfaces
The PLSS is strongly driven by the resources available from the vehicle on which it is based and used. The PLSS potentially receives resources from the vehicle life support, propulsion, and power systems. An effort shall be accomplished to scope the potentially available resources that are likely to be available for the Lunar and Mars missions. To accomplish this task the NASA will provide support to address the impacts of EVA system resource needs on other spacecraft systems.

-- Prepare the Functional Decomposition
A functional decomposition[5] shall be accomplished that is designed to drive out "what" is needed to accomplish the PLSS purpose. This decomposition is specifically done without regard to "how" the functions are to be accomplished. A functional decomposition shall be accomplished for the PLSS as a whole and for the major subsystems that the PLSS decomposition identifies. The purpose of the functional decomposition is to break the problem down in a way that generates the greatest understanding of the PLSS and forms a basis to allow the generation of creative solutions for the PLSS functions.

-- Develop Specifications
As a basis for the customer specification, the Advanced Technology Space Suit Design Requirements Document DRD, July 1999 shall be used. This specification shall be reviewed and those portions of it applicable to this effort updated as necessary by NASA with input from design

[5] Guidance on how to accomplish the kind of functional decomposition contemplated is contained in Ullman, 2nd Edition, Chapter 7.

team members. This customer specification includes those areas that must be controlled to accomplish the end use of the PLSS.

Engineering "Mini specifications" shall be prepared for each function that must be met to "tier down" the customer specification to the measurable, verifiable specifications needed for engineering design. These specifications shall capture the essence of the engineering requirements for any functional component or subsystem that satisfies the functional need. Except in rare cases, these specifications shall be contained on one page for each function.

-- Develop Evaluation Criteria
Evaluation criteria and their rankings shall be developed prior to the effort to generate concepts so that the figures of merit for concepts are well understood by those who generate the concepts and to avoid the pitfall of subliminally designing selection criteria that favor particular concepts. In terms of criteria ranking, safety (both Flight and Ground Operational), shall rank first.

1. The ability of the concept to be used in non-NASA applications shall be used as a criterion.
2. The degree a concept supports commonality shall be used as a criterion.

-- Develop Concepts
The basic premise is that to find a good idea of how to accomplish a function many ideas must be generated. So a divergent convergent path is planned.

-- Search for Function Satisfying Ideas
This activity is meant to be a primary place where creativity has a chance to happen at the function level. The idea is to generate as many concepts as possible for each of the lowest level functions identified in the functional decomposition. A concept is an idea that is sufficiently developed so that its behavior in the intended use can be evaluated.

-- Generate PLSS Concepts
This activity is meant to be the primary place where creativity has a chance to happen at the PLSS level. For this activity a PLSS concept is a combination of the concepts generated to satisfy each function which is capable of accomplishing the entire PLSS job. System level considerations shall be used to keep the number of concepts within bounds. For example, one function concept may generate an output (waste heat for example) that can be effectively used as an input for a function satisfying concept for a different function. In such a case the logical thing to do is use those different concepts together.

-- Document Concepts
Since there is expected to be a range of technological maturity in the concepts (i.e. the concepts currently in use in flight systems versus a wholly new concept that is the result of a creative search) it is important that all concepts be described and documented to a similar degree for comparison purposes.

At the functional concept level a Failure Modes and Effects Analysis (FMEA) will be generated for each viable concept. For the PLSS level, an FMEA will be generated using as a basis all of the functional concept level FMEAs and including system interactions so that the safety of each

schematic concept can be judged. As concepts are being generated, the FMEAs are expected to be a design tool; consequently, they must be generated as early in the process as possible.

-- Evaluate Concepts

Criteria are expected to lend themselves to two types of comparisons to requirements, absolute and relative. Where the criteria are to be evaluated in a relative manner, the Decision-matrix[6] method shall be used. Several rounds of evaluation are expected both at the lower function level and at the PLSS level. The absolute comparisons made by engineering analysis shall be used in the rankings done as part of the Decision-matrix method so that a complete picture of concept performance is formulated and used in the final selection ranking.

Where the criteria are to be evaluated in an absolute manner, the contractor shall use the government provided EVA System Sizing Analysis Tool (EVASSAT) to generate mass, power, volume, performance, and logistics data. For new schematic combinations where the data is not currently available in EVASSAT, the contractor shall provide technology information on generic input forms so that the new technology functions can be modeled to increase the EVASSAT capabilities. The contractor shall provide review and verification of the output results according to the data supplied to ensure validity of the model results prior to entering into the final evaluation stage of the effort.

[6] See Ullman, D. G.: *The Mechanical Design Process*, McGraw Hill, 1992, chapter 8.

Table 1 - Potentially Available NASA Expertise

Background and Expertise
Experience with NASA Advanced PLSS Technology. Expertise in Systems Engineering & Integration, ventilation and thermal technology; 10+ years experience as NASA project manager for advanced and flight systems. Experience acting in the shaper role on design teams
Experience as lead for PLSS group for NASA during the development of the Shuttle EMU. 20 years PLSS Advanced Technology leadership experience. Pro-E modeler. Experience with significant study of design methods including techniques to foster creativity. Experience acting in the coordinator role on design teams.
Experience as a subsystem manager for Shuttle active thermal control freon loop (radiators, flash evaporator, ammonia boiler, etc.) and EMU thermal and systems analysis manager for NASA during early Shuttle missions. Experience in Shuttle EMU thermal certification, vent loop pressure drop analyses, smoke-in-cabin contingency analyses, suit purge analysis-testing-certification, and visor thermal certification. Experience in advanced spacesuit Lunar and Mars spacesuit insulation. Experience in working well in various team roles, including creativity and implementation.
Experience in designing various Payload and EVA tools and equipment, EVA systems engineering, integration of space suit with vehicle, EVA operations and training, human/robotics interaction, advanced EVA concepts and designs, use of advanced technologies in EVA systems, and with design team roles: Creator, Resource-investigator, and monitor-evaluator.
Advanced EVA experience, including insulation testing and research, airlock concept development, and PLSS packaging concepts and lead for the PLSS ventilation system. Experience in all design team roles, especially as a coordinator, shaper, and implementer.
Approximately 15 years of spacecraft thermal control and life support analysis, thermal control system development for Space Station and advanced development projects. Experience performing systems analysis for Advanced Life Support and coordination of many trade-off studies. Experience in the development of the "equivalent system mass (ESM)" analysis methodology.
Approximately 16 years of experience in development of analytical and computational tools for performance predictions and design optimization of thermal, mechanical and chemical systems relating to extravehicular activity (EVA) and pressure suits. Specific experience with thermal, chemical and mass transfer analysis, integration and modeling for Zero g, Lunar and Mars environments, including analysis of human thermal comfort and efficiency. Experience in design teams as a shaper, to find practical but creative ways of solving complex technical problems, including stripping needless conservatism from models.
Approximately 20 years of R&D battery experience. Lead experience for the design and implementation of EVA batteries including the new lithium-ion design for the PLSS. Experience playing, coordinator, creator, and implementer in the past design teams."
Approximately 20 years battery experience and experience managing the NASA ISS Battery Team. Experience leading contractor teams for design, deployment, storage, and operation of ISS batteries. Evaluation and recommendation expertise for Lithium-ion and Nickel-Hydrogen battery technology. Polymer Energy Rechargeable System program expertise. Experience as coordinator, monitor-evaluator, team worker, implementer, and completer-finisher on past teams.
Approximately 20 years experience in analysis of electrochemical energy storage systems for a range of applications including: earth-orbiting and planetary spacecraft; lunar and Mars outpost and rover vehicle power; and unmanned air vehicles.

Note: Please refer to specifics concerning Potentially Available NASA Expertise in the above "Processes to be Followed" section, within this DO.

Technical Library Contents –

Advanced Extravehicular Protective Systems (AEPS) Study, was accomplished for the Ames Research Center (NAS 2-6021) by J. G. Sutton, P. H. Heimlich, and E. H. Tepper of the Hamilton Standard Division of United Technologies in 1972 (NASA CR114384).

"Extravehicular Activity Systems Requirements Definition Study" resulting in "Extravehicular Activity at a Lunar Base," September 1988 and "Extravehicular Activity in Mars Surface Exploration," May 1989 lead by the ESSEX Co. and performed under contract NAS 9-17779.

Advanced Technology Space Suit Design Requirements Document DRD, July 1999

Government Project Plan and Cost estimate as documented in the Microsoft Project file titled: PLSS Schematic Study 12-01-04.mpp

RAESR_Template.doc

GFE EVA FEMA Guide.pdf

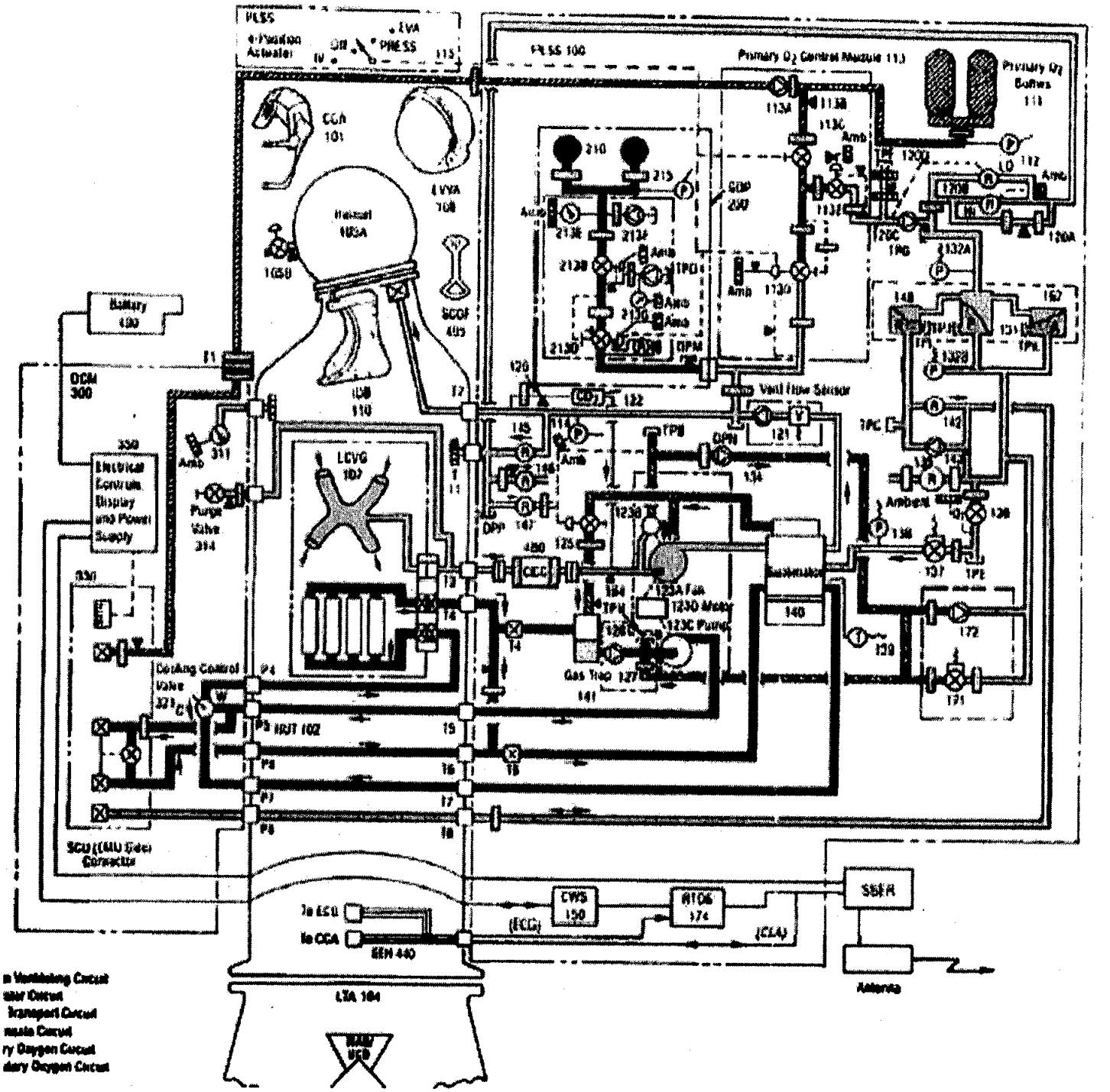

Figure 1 - Shuttle EMU Schematic

Deliverables/Products:

Product	Description	Qty	Due	Class
Hardware	**None Required**			
Mock Up				
Prototype				
Certification				
Flight				
Training				
Other				
Test	**None Required**			
Software	**None Required**			
Other Products				
Road Map	A well documented and justified, multi-concept development road map that is phased by mission and spiral. Several parallel paths may be included in the road map with one listed as the baseline along with statements of the evaluation criteria that are expected to cause a change to the baseline concept. The selected concepts must be part of a planned evolutionary path that steps in a logical way to provide a good solution for the upcoming missions and spirals. The road map should assume a PLSS packaging technology that allows reasonable cost technology evolution and upgrade as the programs progress to more challenging environments and operating conditions.	**1 Electronic Copy**	**Upon Completion (Drafts as Required to Support Scheduled Milestones)**	**N/A**

Product	Description	Qty	Due	Class
Documentation	The schematics will be documented with the following as a minimum. • Top level Failure Mode and Effect Analysis • Size variation with metabolic rate and EVA duration and the math models used in the sizing. • Vehicle interface requirements. Rational for selection of the technology and PLSS Schematic concept	**1 Electronic Copy**	**Upon Completion (Drafts as Required to Support Scheduled Milestones)**	**N/A**
Math Models	The information needed to upgrade the mission study support tool EVA System Sizing Analysis Tool (EVASSAT) that is used to support advanced mission and vehicle studies is also a required product.	**1 Electronic Copy**	**Upon Completion (Drafts as Required to Support Scheduled Milestones)**	**N/A**
Lunar Pole Operation Impact Report	Report on the impact of operation at the lunar poles.	**1 Electronic Copy**	**Upon Completion (Drafts as Required to Support Scheduled Milestones)**	**N/A**
Commonality Report	Report on commonality analysis accomplished.	**1 Electronic Copy**	**Upon Completion (Drafts as Required to Support Scheduled Milestones)**	**N/A**
Final Report	Final Report	**1 Electronic Copy**	**Upon Completion**	**N/A**

SCHEDULE

Start Date: 03/28/05 **Finish Date:** 02/20/05

ITERIM MILESTONES	DUE DATES
Kick-Off Meeting	2 weeks after DO Award
Problem Definition Review	6 weeks after DO Award
Concept Design Review	24 weeks after DO Award
Project Complete	02/20/05

For schedule detail see Microsoft Project file located on the CRAVE web site for this DO listed under the Government Cost Estimate below.

Government Estimate Located in RFQ File in Microsoft Project File On CRAVE Web Site
The file is titled: PLSS Schematic Study 12-01-04R3.mpp

Total Government Estimate for this DO: $ 400 K
Option 1: $ N/A (See Attachment 1)
Option 2: $ N/A (See Attachment 2)

TOTAL COST ESTIMATE FOR THIS DO: $540,952.76

FEE: $0 (If Applicable)

OPTION 1: $ N/A (See Attachment 1)

OPTION 2: $ N/A (See Attachment 2)

DATA REQUIREMENTS

All DRs contained in the contract are applicable and required unless marked N/A below.

Notes: 1. Grey Scaled Cells Need No Additional/Required Fill-ins.
2. On All Other Cells, If Necessary, Fill in Additional Rqmts/Deliveries in Last Column.

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
1	Written Approval	FlightGFE Configuration Management Plan	With Proposal	Once	**Attachment J-8**	
2	Mandatory Submittal	Regular Status Report/ Summary Review	Thirty (30) days following contract start	Monthly	**Y**	
3	Written Approval	Project Technical Requirements Specification	Per DO schedule	Once with Revisions	**Y**	Support Government modification of existing specification
4	Mandatory Submittal	GFE Systems Requirements Data Package	Specified in DO	Once with Revisions	**N**	
5	Written Approval	Flight GFE Projects Requirements & Verification Document	Specified in DO	Once with Revisions	**N**	
6	Mandatory Submittal	Preliminary Design Review Data Package	Specified in DO	Once with Revisions		
7	Written Approval	Flight GFE Workmanship Specifications List	Specified in DO	Once with Revisions	**N**	
8	Written Approval	Project Schedule	PDR or 10% effort complete Milestone	Once w/Revisions (due w/DO proposal, updates & details provided as DO progresses)	**Y**	First update that includes detail NASA participation 2 weeks after Kickoff meeting.
9	Written Approval	Flight GFE Interface Control Document	Specified in DO	Once with Revisions	**Y**	Informal ICDS only with team generating vehicle impacts as no vehicle engineering teams are in place at this time. Flight approval rigor is not required
10	Written Approval	GFE End Item Specification	Specified in DO	Once with Revisions	**N**	
11	Mandatory Submittal	Flight GFE Failure Analysis Report	As agreed by TMR in DO	As Required	**N**	

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
12	Written Approval	Flight GFE Verification and Validation Plan	As Specified in EA-023	Once with Revisions	Y	Only those unique to the schematic understudy and to a depth to assist evaluation and comparison of the schematics. Flight approval rigor is not required
13	Written Approval	GFE Software Requirements Specification	Specified in DO	Once with Revisions	Y	Only those unique to the schematic understudy and to a depth to assist evaluation and comparison of the schematics. Flight approval rigor is not required
14	Written Approval	GFE Software Development Plan	Specified in DO	Once with Revisions	N	
15	Written Approval	GFE Software Design Document	Specified in DO	As Required	N	
16	Written Approval	Engineering Drawings	At PDR, as specified in DO	Once with Revisions	N	
17	Written Approval	EEE Parts Lists and Analysis Report	Specified in DO	As Required	N	
18	Mandatory Submittal	Critical Design Review Data Package	Specified in DO	Once with Revisions	N	
19	Mandatory Submittal	Engineering Drawing Change Proposal	As needed	As Required	N	
20	Written Approval	GFE Qualification Test Procedure	Specified in DO	Once with Revisions	N	
21	Written Approval	Flight Product User's Guide	Specified in DO	Once with Revisions	N	
22	Mandatory Submittal	Software Code	Specified in DO	As Required	N	
23	Written Approval	Information Technology (IT) Security Program Plan and Reports	(30) days after DO award, and as specified in JPG 2810.1	JPG 2810.1	**Attachment J-4 Due 30 days after DO award**	
24	Written Approval	Certification Plan	Specified in DO	Once with Revisions	N	
25	Mandatory Submittal	Certification Report	Specified in DO	Once with Revisions	N	

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
26	Mandatory Submittal	Engineering Analysis	Specified in DO	As Required	Y	Analysis rigor sufficient for use in hardware certification are not required. Rigor needed is that to support understanding of and selection of schematics. Flight approval rigor is not required
27	Mandatory Submittal	Acceptance Data Package	Specified in DO	One Time	N	
28	Mandatory Submittal	Export Control Audit Results	After award of 1st DO, yearly on Sept. 30 thereafter	Yearly	Y	
29	Written Approval	Quality Plan	With Proposal	Once with Revisions	**Attachment J-11**	
30	Written Approval	Patent Rights-Retention	As Required	As Required	Y (If Applic'ble)	
31	Written Approval	Shuttle/Station Payload Safety Data Package	Specified in DO	As Required	N	
32	Mandatory Submittal	Limited Life Systems List	Specified in DO	As Required	Y	Only to rigor necessary to understand schematic logistics issues. Flight approval rigor is not required
33	Written Approval	Space Station GFE Failure Modes and Effects Analysis and Critical Items List	As Early in process as possible.	As Required	Y	Flight preparation and approval rigor is not required and detail appropriate for the schematic level of understanding, evaluation and selection.
34	Written Approval	Space Shuttle GFE Safety and Analysis Report &Hazard Report	Specified in DO	As Required	N	
35	Written Approval	Software Quality Assurance Plan Report	90 Days Prior to Software Development	Once with Revisions	Y (If Applic'ble)	
36	Written Approval	ISS Hazard Report	Specified in DO	As Required	N	
37	Upon Request	Reliability and Maintainability Plan	With Proposal	One Time	**Attachment J-9**	

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
38	Written Approval	Government Certification Approval Request (GCAR)	Specified in DO	As Required	N	
39	Written Approval	Risk Assessment Executive Summary Report (RAESR)	Specified in DO	As Required	Y	Use as an outline for the safety section of the schematic documentation. Flight preparation and approval rigor is not required Detail only as necessary to understand and select schematics.
40	Written Approval	Problem Reporting and Corrective Action (PRACA)	2 business days of problem isolation but no later than 10 days after detection	As Required	N	
41	Upon Request	Nonconformance Record	Specified in DO	As Required	N	
42	Mandatory Submittal	Government Industry Data Exchange Program and NASA Advisory Problem Data	Reported one time when discrepancy occurs	Once with Revisions	N	
43	Written Approval	Electrical, Electronic, and Electromechnical (EEE) Parts Control Plan	Specified in DO	Once with Revisions	N	
44	Mandatory Submittal	Certification Data Package	Specified in DO	Once with Revisions	N	
45	Written Approval	Certification and Acceptance Requirements Document	At CDR	Once with Revisions	N	
46	Upon Request	Wage/Salary and Fringe Benefit Data	thirty (30) days after issuance of each DO	Once	N	
47	Written Approval	GFE Acceptance Test Procedure	Specified in DO	One Time	N	
48	Mandatory Submittal	Flight GFE Verification & Validation Report	Specified in DO	Once with Revisions	N	
49	Mandatory Submittal	Space Shuttle GFE Failure Modes and Effects Analysis (FMEA) and Critical Items List	Specified in DO	As Required	N	
50		**Reserved**	---	---	---	---
51	Mandatory Submittal	NASA Contractor Financial Management Reporting	After Issuance of 1st DO	Monthly	Y	

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
52	Written Approval	Government Property Management Plan	With Proposal	Once with Revisions	**Attachment J-7**	
53	Mandatory Submittal	System Safety Plan	With Proposal	One Time	**Attachment J-10**	
54	Written Approval	R-Quality Plan Template	With Proposal/ Revisions as Required	Only applicable to B-CRAVE contracts in accordance with the SOW and the DRD	**Y**	

Type 1 = Written Approval Type 2 = Mandatory Submittal Type 3 = Submittal Upon Request

GOVERNMENT FURNISHED PROPERTY

None Required

DO TITLE: PORTABLE LIFE SUPPORT SUBSYSTEM (PLSS) SCHEMATIC STUDY

DO Type: X CPFF ___ FFP

DO Contact Information:

TMR:	B. Mike Lawson	**Phone**	39124
DO Manager:	Gretchen Thomas	**Phone**	37664
DO Mgr. Alternate:	Mike Rouen	**Phone**	39242

Concurrences:

S/ 2-15-05 Gretchen Thomas DO Manager	S/ 2-15-05 Craig Dinsmore DO Mgr. Management	S/ 2-15-05 Joe Gensler COTR
S/ 2-15-05 B. M. Lawson Division TMR	S/ 2-15-05 Steve Miller S & MA	

Task Contains Flight Hardware, Flight Software or GSE? ___ Yes X No

Program Supported: ___Shuttle ___ISS ___EVA X Advanced All Spirals

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WBS: X 1.0 EVA ___ 2.0 FCE ___ 3.0 EVR ___ ECLSS ___5.0 ATCS ___ 6.0 CHeCS

*For purposes of complying with FAR 52.232-22, Limitation of Funds, the total amount allotted by the Government to contract is specified in clause B.6, Contract Funding. The funding listed in B.6 is the amount allotted for **all** Delivery Orders on the contract combined.*

All terms and conditions of the contract apply to this Delivery Order. In the event of a conflict between the contract and this Delivery Order, the contract shall prevail.

WBS reporting shall be done in accordance with applicable WBS reporting categories, as shown above and in the contract within Section C, Table 1.

Narrative Task Description

Background / Problem Description:

Schematic Definition
For this study, a Portable Life Support Subsystem (PLSS) schematic is the single page diagram that describes the technologies selected to accomplish the life support functions and the fluid mechanical functional interconnections. A Portable Life Support Subsystem is here taken to mean a self contained life support subsystem along with the emergency life support system required to accomplish a fail safe design. This excludes such umbilical supplied life support subsystems such as the Skylab ALSA. It does not exclude such arrangements as having recharge capability carried on a rover or other methods used to off load crew person carried weight. For this study, the term "schematic" is limited to the fluid and mechanical functions and only the electrical functions necessary to maintain safety. This definition purposely excludes the information handling architecture of the EVA informatics related hardware which is another study itself.

Schematic History
An example of the schematic currently in use in the United States space program is shown in Figure 1. The only other US portable life support subsystem, the Apollo PLSS, used a similar schematic as does the current Russian space suit. All three share in common the following technologies: high pressure oxygen storage, sublimator for heat rejection, battery for power, lithium hydroxide for CO_2 control, and charcoal for trace contaminant control. Although they each have some different interconnections (for example the Shuttle is set up for zero g operation while the Apollo system was optimized for gravity field operation) the basic schematic is the same from the stand point of use of the technologies listed above. The only deviation from this list is the replacement of lithium hydroxide with an in orbit regenerable metal oxide for CO_2 control on the ISS which was driven by a storage volume and launch cost tradeoff.

Prior Studies
Prior studies of Portable Life Support Subsystem schematic arrangements have been accomplished. A particularly comprehensive study, the Advanced Extravehicular Protective Systems (AEPS) Study, was accomplished for the Ames Research Center (NAS 2-6021) by J. G. Sutton, P. H. Heimlich, and E. H. Tepper of the Hamilton Standard Division of United Technologies in 1972 (NASA CR114384). A broader study of the EVA system as a work system included portable life support considerations and was accomplished in 1980 but it was focused on zero g operations and so did not include lunar and mars related information. In anticipation of the space station and in preparation to direct the technology program leading up to selection of a schematic for space station use, NASA accomplished an in house study in the 1987 time frame. It was titled the Point Design Study and was only documented via presentation charts. But, again, this study was focused on Zero G operations only. During the First Lunar Outpost activity some schematic study was done focused on the lunar destination. This work identified radiators as a viable heat rejection mechanism. This work is documented in "First Lunar Outpost Extravehicular Life Support System Evaluation,"

Bruce C. Conger, Luis A. Trevino and B. Michael Lawson, ICES[1] paper number 932188. This study did not cover the breath of technologies of interest being mainly concerned with the thermal subsystem. Consequently, the best study to use as a base for the present effort is the 1972 AEPS study.

Prior studies of the EVA system needed to accomplish Lunar and Mars exploration were accomplished in 1988. These studies provide excellent context for how and where the PLSS will be used. The studies were performed under the generic title of "Extravehicular Activity Systems Requirements Definition Study" resulting in "Extravehicular Activity at a Lunar Base," September 1988 and "Extravehicular Activity in Mars Surface Exploration," May 1989 lead by the ESSEX Co. and performed under contract NAS 9-17779.

PLSS Interfaces:
The PLSS is strongly driven by vehicle life support and power systems for it is the vehicle systems that determine what resources are available for PLSS recharge. This interaction creates a strong tie of the PLSS technology selections to the vehicle technology selections requiring the EVA community to be ready to support vehicle trade studies with a complete picture of the impacts of various vehicle technology selections on the PLSS. Some vehicle technology selections close entire technology class path ways and others can force the PLSS into selections that tend to open loops the vehicle life support community has been striving hard to close. It is important that the PLSS community "do its homework" early so the vehicle trade studies can be properly supported.

New Technology
Certainly in the 32 years since the 1972 study there has been a significant amount of technology development accomplished both inside the aerospace industry (most often documented in the ICES conference) and outside that is applicable to the PLSS schematic. Besides the life support technology development directly, there has been significant work done on basic materials (CO_2 absorption chemistry, MEMS and nanotechnology) and fundamental process (Microchannel heat and mass transfer).

Three major areas of technology that are expected to have considerable impact on the PLSS schematic are: 1) the shrinking size of power supplies making it possible to go from battery supplied power to a fuel based power supply which can raise the power available from the current 100W range to the 1000W range, 2) the Microsystems elements that are becoming available for heat transfer and chemical processes and 3) the distributed sensing / processing technologies. The first makes it possible to consider high power thereby allowing the use of technologies that have been rejected in all previous studies because of the weight cost of the power supply required. The second aids this trend and makes all processes potentially smaller and lighter. The third has profound implications on the packaging (which accounts for half the system weight) of a PLSS but, more germane to this study, provides the opportunity to better monitor PLSS performance and thereby aid in accomplishing the needed increases in PLSS life time and reduction in testing to assure safety.

Outside of NASA, significant work has been done on portable life support for Earth based use by the military in response to chemical and biological warfare threats and there is current interest

[1] The ICES conference, cosponsored by multiple engineering societies and managed by the SAE, is one of the primary places the EVA community publishes.

concerning similar threats for first responders for homeland defense. Commercial applications for some subsystems of the portable life support subsystem (thermal control) have arisen for work in extreme environments and for mitigation of symptoms of some medical conditions such as MS. Even the fundamental engineering process of how to do selection trade off studies has undergone significant change as documented in books by authors such as Pugh[2] and Ullman[3].
All of these facts suggest it is time for a new comprehensive study that builds on but does not repeat prior work as we prepare to plan and implement the technology program focused on fulfillment of the Vision for Space Exploration. A study drawing on NASA and non NASA expertise is warranted and needed to lay out a development roadmap that directs budget planning for future exploration efforts. In addition, new analysis capabilities and design methodologies are available allowing a more comprehensive study than previous studies with the same resources.

PROCESS TO BE FOLLOWED:

Form Design Team(s)
An interdisciplinary design team that includes both NASA and the contractor personnel is to be formed for the generation and evaluation of schematic concepts. The contractor is to plan to accomplish the entire job without dependence on NASA effort. NASA effort will provide operational experience and additional depth of study but shall not be planned into the critical path to accomplish the study requirements. If it is deemed advisable, teams can be formed that focus on subsystems of the schematic and team selection, and may include or may not include NASA participants to supply the team with additional expertise. The availability of NASA expertise is described below in the Table 1 – Potentially Available NASA Expertise is planned to be provided as a "best efforts" arrangement.

Develop Tasks Assignment
Since the exact nature of the expertise to be provided by NASA is needed in order to do an in-depth plan, internal team planning will be accomplished as agreed to by NASA and the contractor for accomplishment of tasks. This planning shall not affect the scope of the contractor's work but can increase or decrease the scope of potentially available NASA participation.

Schedule Project
Since the exact schedule availability of the potentially available NASA expertise is subjective, internal team planning for adjustments to various task schedules will be accomplished as agreed to by NASA and the contractor. These schedule adjustments shall not affect the scope of the contractor's work.

Form Teams
Team composition shall be based not only on the technical expertise needed but with due considerations for the different roles[4] needed to form an effective design team. Design teams are to be limited to the number of people required to form an effective team. The teams shall solicit the input of those outside the team, as needed, to accomplish the design task at hand. The teams shall

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[2] Pugh, S.: *Total Design Integrated Methods for Successful Product Engineering*, Addison-Wesley, Wokingham, England, 1991
[3] Ullman, D. G.: *The Mechanical Design Process*, McGraw Hill, 1992
[4] For example see *3.5.2 Team Roles*, Page 55 of Ullman's Second Edition.

support the contract milestone reviews and respond to any Review Item Discrepancies (RIDs) generated during those reviews that affect the design team's efforts.

Define the Problem
Success of a design process depends heavily on good problem definition which is not a trivial exercise. As a minimum the following steps shall be accomplished to fully define the problem of PLSS schematic selection.

-- Review and Update Prior Work
The following studies shall be reviewed and updated as needed to take into account new knowledge of the technologies included in those studies since their completion. Where entirely new technology or techniques have come to fore, this study is expected to address those issues. Consequently, this update task is expected to be of limited scope.

1. "Advanced Extravehicular Protective Systems (AEPS) Study," 1972
2. "Extravehicular Activity at a Lunar Base," September 1988
3. "Extravehicular Activity in Mars Surface Exploration," May 1989

One area of concern where update of the Lunar Base study is known to be required is operation in the lunar pole area. The potential for extremely cold environments (order of 40°K) is a concern and a specific analysis of the impacts on the PLSS schematic and technology selection of this case is required.

-- Develop Vehicle Interfaces
The PLSS is strongly driven by the resources available from the vehicle on which it is based and used. The PLSS potentially receives resources from the vehicle life support, propulsion, and power systems. An effort shall be accomplished to scope the potentially available resources that are likely to be available for the Lunar and Mars missions. To accomplish this task the NASA will provide support to address the impacts of EVA system resource needs on other spacecraft systems.

-- Prepare the Functional Decomposition
A functional decomposition[5] shall be accomplished that is designed to drive out "what" is needed to accomplish the PLSS purpose. This decomposition is specifically done without regard to "how" the functions are to be accomplished. A functional decomposition shall be accomplished for the PLSS as a whole and for the major subsystems that the PLSS decomposition identifies. The purpose of the functional decomposition is to break the problem down in a way that generates the greatest understanding of the PLSS and forms a basis to allow the generation of creative solutions for the PLSS functions.

-- Develop Specifications
As a basis for the customer specification, the Advanced Technology Space Suit Design Requirements Document DRD, July 1999 shall be used. This specification shall be reviewed and those portions of it applicable to this effort updated as necessary by NASA with input from design

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[5] Guidance on how to accomplish the kind of functional decomposition contemplated is contained in Ullman, 2nd Edition, Chapter 7.

team members. This customer specification includes those areas that must be controlled to accomplish the end use of the PLSS.

Engineering "Mini specifications" shall be prepared for each function that must be met to "tier down" the customer specification to the measurable, verifiable specifications needed for engineering design. These specifications shall capture the essence of the engineering requirements for any functional component or subsystem that satisfies the functional need. Except in rare cases, these specifications shall be contained on one page for each function.

-- Develop Evaluation Criteria
Evaluation criteria and their rankings shall be developed prior to the effort to generate concepts so that the figures of merit for concepts are well understood by those who generate the concepts and to avoid the pitfall of subliminally designing selection criteria that favor particular concepts. In terms of criteria ranking, safety (both Flight and Ground Operational), shall rank first.

1. The ability of the concept to be used in non-NASA applications shall be used as a criterion.
2. The degree a concept supports commonality shall be used as a criterion.

-- Develop Concepts
The basic premise is that to find a good idea of how to accomplish a function many ideas must be generated. So a divergent convergent path is planned.

-- Search for Function Satisfying Ideas
This activity is meant to be a primary place where creativity has a chance to happen at the function level. The idea is to generate as many concepts as possible for each of the lowest level functions identified in the functional decomposition. A concept is an idea that is sufficiently developed so that its behavior in the intended use can be evaluated.

-- Generate PLSS Concepts
This activity is meant to be the primary place where creativity has a chance to happen at the PLSS level. For this activity a PLSS concept is a combination of the concepts generated to satisfy each function which is capable of accomplishing the entire PLSS job. System level considerations shall be used to keep the number of concepts within bounds. For example, one function concept may generate an output (waste heat for example) that can be effectively used as an input for a function satisfying concept for a different function. In such a case the logical thing to do is use those different concepts together.

-- Document Concepts
Since there is expected to be a range of technological maturity in the concepts (i.e. the concepts currently in use in flight systems versus a wholly new concept that is the result of a creative search) it is important that all concepts be described and documented to a similar degree for comparison purposes.

At the functional concept level a Failure Modes and Effects Analysis (FMEA) will be generated for each viable concept. For the PLSS level, an FMEA will be generated using as a basis all of the functional concept level FMEAs and including system interactions so that the safety of each

schematic concept can be judged. As concepts are being generated, the FMEAs are expected to be a design tool; consequently, they must be generated as early in the process as possible.

-- Evaluate Concepts

Criteria are expected to lend themselves to two types of comparisons to requirements, absolute and relative. Where the criteria are to be evaluated in a relative manner, the Decision-matrix[6] method shall be used. Several rounds of evaluation are expected both at the lower function level and at the PLSS level. The absolute comparisons made by engineering analysis shall be used in the rankings done as part of the Decision-matrix method so that a complete picture of concept performance is formulated and used in the final selection ranking.

Where the criteria are to be evaluated in an absolute manner, the contractor shall use the government provided EVA System Sizing Analysis Tool (EVASSAT) to generate mass, power, volume, performance, and logistics data. For new schematic combinations where the data is not currently available in EVASSAT, the contractor shall provide technology information on generic input forms so that the new technology functions can be modeled to increase the EVASSAT capabilities. The contractor shall provide review and verification of the output results according to the data supplied to ensure validity of the model results prior to entering into the final evaluation stage of the effort.

[6] See Ullman, D. G.: *The Mechanical Design Process*, McGraw Hill, 1992, chapter 8.

Table 1 - Potentially Available NASA Expertise

Background and Expertise
Experience with NASA Advanced PLSS Technology. Expertise in Systems Engineering & Integration, ventilation and thermal technology; 10+ years experience as NASA project manager for advanced and flight systems. Experience acting in the shaper role on design teams
Experience as lead for PLSS group for NASA during the development of the Shuttle EMU. 20 years PLSS Advanced Technology leadership experience. Pro-E modeler. Experience with significant study of design methods including techniques to foster creativity. Experience acting in the coordinator role on design teams.
Experience as a subsystem manager for Shuttle active thermal control freon loop (radiators, flash evaporator, ammonia boiler, etc.) and EMU thermal and systems analysis manager for NASA during early Shuttle missions. Experience in Shuttle EMU thermal certification, vent loop pressure drop analyses, smoke-in-cabin contingency analyses, suit purge analysis-testing-certification, and visor thermal certification. Experience in advanced spacesuit Lunar and Mars spacesuit insulation. Experience in working well in various team roles, including creativity and implementation.
Experience in designing various Payload and EVA tools and equipment, EVA systems engineering, integration of space suit with vehicle, EVA operations and training, human/robotics interaction, advanced EVA concepts and designs, use of advanced technologies in EVA systems, and with design team roles: Creator, Resource-investigator, and monitor-evaluator.
Advanced EVA experience, including insulation testing and research, airlock concept development, and PLSS packaging concepts and lead for the PLSS ventilation system. Experience in all design team roles, especially as a coordinator, shaper, and implementer.
Approximately 15 years of spacecraft thermal control and life support analysis, thermal control system development for Space Station and advanced development projects. Experience performing systems analysis for Advanced Life Support and coordination of many trade-off studies. Experience in the development of the "equivalent system mass (ESM)" analysis methodology.
Approximately 16 years of experience in development of analytical and computational tools for performance predictions and design optimization of thermal, mechanical and chemical systems relating to extravehicular activity (EVA) and pressure suits. Specific experience with thermal, chemical and mass transfer analysis, integration and modeling for Zero g, Lunar and Mars environments, including analysis of human thermal comfort and efficiency. Experience in design teams as a shaper, to find practical but creative ways of solving complex technical problems, including stripping needless conservatism from models.
Approximately 20 years of R&D battery experience. Lead experience for the design and implementation of EVA batteries including the new lithium-ion design for the PLSS. Experience playing, coordinator, creator, and implementer in the past design teams."
Approximately 20 years battery experience and experience managing the NASA ISS Battery Team. Experience leading contractor teams for design, deployment, storage, and operation of ISS batteries. Evaluation and recommendation expertise for Lithium-ion and Nickel-Hydrogen battery technology. Polymer Energy Rechargeable System program expertise. Experience as coordinator, monitor-evaluator, team worker, implementer, and completer-finisher on past teams.
Approximately 20 years experience in analysis of electrochemical energy storage systems for a range of applications including: earth-orbiting and planetary spacecraft; lunar and Mars outpost and rover vehicle power; and unmanned air vehicles.

Note: Please refer to specifics concerning Potentially Available NASA Expertise in the above "Processes to be Followed" section, within this DO.

Technical Library Contents –

Advanced Extravehicular Protective Systems (AEPS) Study, was accomplished for the Ames Research Center (NAS 2-6021) by J. G. Sutton, P. H. Heimlich, and E. H. Tepper of the Hamilton Standard Division of United Technologies in 1972 (NASA CR114384).

"Extravehicular Activity Systems Requirements Definition Study" resulting in "Extravehicular Activity at a Lunar Base," September 1988 and "Extravehicular Activity in Mars Surface Exploration," May 1989 lead by the ESSEX Co. and performed under contract NAS 9-17779.

Advanced Technology Space Suit Design Requirements Document DRD, July 1999

Government Project Plan and Cost estimate as documented in the Microsoft Project file titled: PLSS Schematic Study 12-01-04.mpp

RAESR_Template.doc

GFE EVA FEMA Guide.pdf

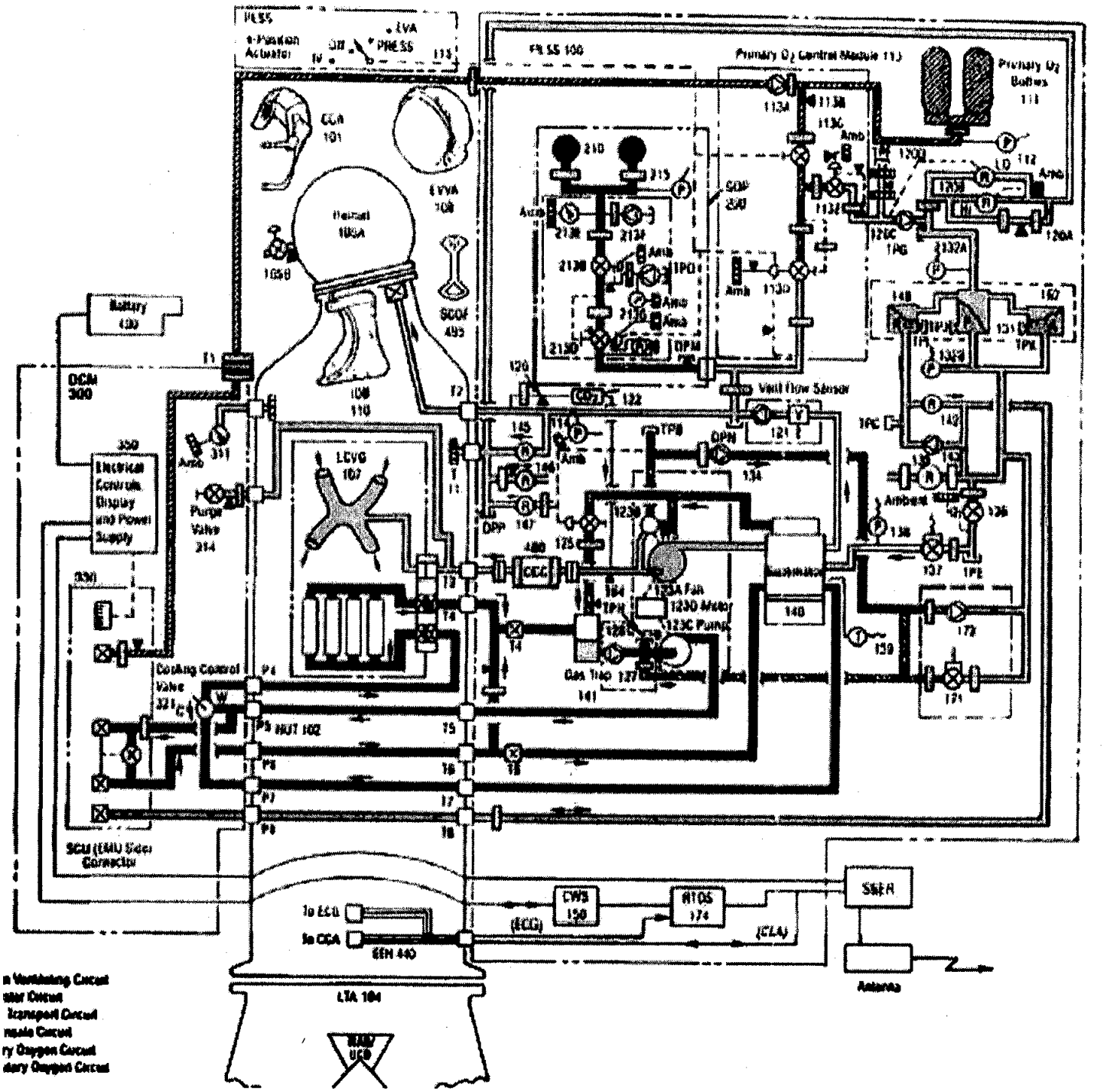

Figure 1 - Shuttle EMU Schematic

Deliverables/Products:

Product	Description	Qty	Due	Class
Hardware	**None Required**			
Mock Up				
Prototype				
Certification				
Flight				
Training				
Other				
Test	**None Required**			
Software	**None Required**			
Other Products				
Road Map	A well documented and justified, multi-concept development road map that is phased by mission and spiral. Several parallel paths may be included in the road map with one listed as the baseline along with statements of the evaluation criteria that are expected to cause a change to the baseline concept. The selected concepts must be part of a planned evolutionary path that steps in a logical way to provide a good solution for the upcoming missions and spirals. The road map should assume a PLSS packaging technology that allows reasonable cost technology evolution and upgrade as the programs progress to more challenging environments and operating conditions.	**1 Electronic Copy**	**Upon Completion (Drafts as Required to Support Scheduled Milestones)**	**N/A**

Product	Description	Qty	Due	Class
Documentation	The schematics will be documented with the following as a minimum. • Top level Failure Mode and Effect Analysis • Size variation with metabolic rate and EVA duration and the math models used in the sizing. • Vehicle interface requirements. Rational for selection of the technology and PLSS Schematic concept	**1 Electronic Copy**	**Upon Completion (Drafts as Required to Support Scheduled Milestones)**	**N/A**
Math Models	The information needed to upgrade the mission study support tool EVA System Sizing Analysis Tool (EVASSAT) that is used to support advanced mission and vehicle studies is also a required product.	**1 Electronic Copy**	**Upon Completion (Drafts as Required to Support Scheduled Milestones)**	**N/A**
Lunar Pole Operation Impact Report	Report on the impact of operation at the lunar poles.	**1 Electronic Copy**	**Upon Completion (Drafts as Required to Support Scheduled Milestones)**	**N/A**
Commonality Report	Report on commonality analysis accomplished.	**1 Electronic Copy**	**Upon Completion (Drafts as Required to Support Scheduled Milestones)**	**N/A**
Final Report	Final Report	**1 Electronic Copy**	**Upon Completion**	**N/A**

SCHEDULE

Start Date: 03/28/05 **Finish Date:** 03/22/06

ITERIM MILESTONES	DUE DATES
Kick-Off Meeting	2 weeks after DO Award
Problem Definition Review	6 weeks after DO Award
Concept Design Review	24 weeks after DO Award
Project Complete	03/22/06

For schedule detail see Microsoft Project file located on the CRAVE web site for this DO listed under the Government Cost Estimate below.

Government Estimate Located in RFQ File in Microsoft Project File On CRAVE Web Site
The file is titled: PLSS Schematic Study 12-01-04R3.mpp

Total Government Estimate for this DO: $ 400 K
Option 1: $ N/A (See Attachment 1)
Option 2: $ N/A (See Attachment 2)

TOTAL COST ESTIMATE FOR THIS DO: $567,239.11

FEE: $0 (If Applicable)

OPTION 1: $ N/A (See Attachment 1)

OPTION 2: $ N/A (See Attachment 2)

DATA REQUIREMENTS

All DRs contained in the contract are applicable and required unless marked N/A below.

Notes: 1. Grey Scaled Cells Need No Additional/Required Fill-ins.
2. On All Other Cells, If Necessary, Fill in Additional Rqmts/Deliveries in Last Column.

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
1	Written Approval	FlightGFE Configuration Management Plan	With Proposal	Once	**Attachment J-8**	
2	Mandatory Submittal	Regular Status Report/ Summary Review	Thirty (30) days following contract start	Monthly	**Y**	
3	Written Approval	Project Technical Requirements Specification	Per DO schedule	Once with Revisions	**Y**	Support Government modification of existing specification
4	Mandatory Submittal	GFE Systems Requirements Data Package	Specified in DO	Once with Revisions	**N**	
5	Written Approval	Flight GFE Projects Requirements & Verification Document	Specified in DO	Once with Revisions	**N**	
6	Mandatory Submittal	Preliminary Design Review Data Package	Specified in DO	Once with Revisions		
7	Written Approval	Flight GFE Workmanship Specifications List	Specified in DO	Once with Revisions	**N**	
8	Written Approval	Project Schedule	PDR or 10% effort complete Milestone	Once w/Revisions (due w/DO proposal, updates & details provided as DO progresses)	**Y**	First update that includes detail NASA participation 2 weeks after Kickoff meeting.
9	Written Approval	Flight GFE Interface Control Document	Specified in DO	Once with Revisions	**Y**	Informal ICDS only with team generating vehicle impacts as no vehicle engineering teams are in place at this time. Flight approval rigor is not required
10	Written Approval	GFE End Item Specification	Specified in DO	Once with Revisions	**N**	
11	Mandatory Submittal	Flight GFE Failure Analysis Report	As agreed by TMR in DO	As Required	**N**	

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
12	Written Approval	Flight GFE Verification and Validation Plan	As Specified in EA-023	Once with Revisions	Y	Only those unique to the schematic understudy and to a depth to assist evaluation and comparison of the schematics. Flight approval rigor is not required
13	Written Approval	GFE Software Requirements Specification	Specified in DO	Once with Revisions	Y	Only those unique to the schematic understudy and to a depth to assist evaluation and comparison of the schematics. Flight approval rigor is not required
14	Written Approval	GFE Software Development Plan	Specified in DO	Once with Revisions	N	
15	Written Approval	GFE Software Design Document	Specified in DO	As Required	N	
16	Written Approval	Engineering Drawings	At PDR, as specified in DO	Once with Revisions	N	
17	Written Approval	EEE Parts Lists and Analysis Report	Specified in DO	As Required	N	
18	Mandatory Submittal	Critical Design Review Data Package	Specified in DO	Once with Revisions	N	
19	Mandatory Submittal	Engineering Drawing Change Proposal	As needed	As Required	N	
20	Written Approval	GFE Qualification Test Procedure	Specified in DO	Once with Revisions	N	
21	Written Approval	Flight Product User's Guide	Specified in DO	Once with Revisions	N	
22	Mandatory Submittal	Software Code	Specified in DO	As Required	N	
23	Written Approval	Information Technology (IT) Security Program Plan and Reports	(30) days after DO award, and as specified in JPG 2810.1	JPG 2810.1	**Attachment J-4 Due 30 days after DO award**	
24	Written Approval	Certification Plan	Specified in DO	Once with Revisions	N	
25	Mandatory Submittal	Certification Report	Specified in DO	Once with Revisions	N	

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
26	Mandatory Submittal	Engineering Analysis	Specified in DO	As Required	Y	Analysis rigor sufficient for use in hardware certification are not required. Rigor needed is that to support understanding of and selection of schematics. Flight approval rigor is not required
27	Mandatory Submittal	Acceptance Data Package	Specified in DO	One Time	N	
28	Mandatory Submittal	Export Control Audit Results	After award of 1st DO, yearly on Sept. 30 thereafter	Yearly	Y	
29	Written Approval	Quality Plan	With Proposal	Once with Revisions	**Attachment J-11**	
30	Written Approval	Patent Rights-Retention	As Required	As Required	Y **(If Applic'ble)**	
31	Written Approval	Shuttle/Station Payload Safety Data Package	Specified in DO	As Required	N	
32	Mandatory Submittal	Limited Life Systems List	Specified in DO	As Required	Y	Only to rigor necessary to understand schematic logistics issues. Flight approval rigor is not required
33	Written Approval	Space Station GFE Failure Modes and Effects Analysis and Critical Items List	As Early in process as possible.	As Required	Y	Flight preparation and approval rigor is not required and detail appropriate for the schematic level of understanding, evaluation and selection.
34	Written Approval	Space Shuttle GFE Safety and Analysis Report &Hazard Report	Specified in DO	As Required	N	
35	Written Approval	Software Quality Assurance Plan Report	90 Days Prior to Software Development	Once with Revisions	Y **(If Applic'ble)**	
36	Written Approval	ISS Hazard Report	Specified in DO	As Required	N	
37	Upon Request	Reliability and Maintainability Plan	With Proposal	One Time	**Attachment J-9**	

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
38	Written Approval	Government Certification Approval Request (GCAR)	Specified in DO	As Required	N	
39	Written Approval	Risk Assessment Executive Summary Report (RAESR)	Specified in DO	As Required	Y	Use as an outline for the safety section of the schematic documentation. Flight preparation and approval rigor is not required Detail only as necessary to understand and select schematics.
40	Written Approval	Problem Reporting and Corrective Action (PRACA)	2 business days of problem isolation but no later than 10 days after detection	As Required	N	
41	Upon Request	Nonconformance Record	Specified in DO	As Required	N	
42	Mandatory Submittal	Government Industry Data Exchange Program and NASA Advisory Problem Data	Reported one time when discrepancy occurs	Once with Revisions	N	
43	Written Approval	Electrical, Electronic, and Electromechnical (EEE) Parts Control Plan	Specified in DO	Once with Revisions	N	
44	Mandatory Submittal	Certification Data Package	Specified in DO	Once with Revisions	N	
45	Written Approval	Certification and Acceptance Requirements Document	At CDR	Once with Revisions	N	
46	Upon Request	Wage/Salary and Fringe Benefit Data	thirty (30) days after issuance of each DO	Once	N	
47	Written Approval	GFE Acceptance Test Procedure	Specified in DO	One Time	N	
48	Mandatory Submittal	Flight GFE Verification & Validation Report	Specified in DO	Once with Revisions	N	
49	Mandatory Submittal	Space Shuttle GFE Failure Modes and Effects Analysis (FMEA) and Critical Items List	Specified in DO	As Required	N	
50		**Reserved**	---	---	---	---
51	Mandatory Submittal	NASA Contractor Financial Management Reporting	After Issuance of 1st DO	Monthly	Y	

DRD #	DATA TYPE	DRD TITLE	DUE	FREQUENCY	REQUIRED FOR DO? Y/N	ADDITIONAL REQUIREMENTS
52	Written Approval	Government Property Management Plan	With Proposal	Once with Revisions	**Attachment J-7**	
53	Mandatory Submittal	System Safety Plan	With Proposal	One Time	**Attachment J-10**	
54	Written Approval	R-Quality Plan Template	With Proposal/ Revisions as Required	Only applicable to B-CRAVE contracts in accordance with the SOW and the DRD	**Y**	

Type 1 = Written Approval Type 2 = Mandatory Submittal Type 3 = Submittal Upon Request

GOVERNMENT FURNISHED PROPERTY

None Required

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center
Houston, TX 77058

ORDER FOR SUPPLIES OR SERVICES

1. Order No.
DO-CRAVE-EC5-001

2. Date of Order
See Block 10

NOTE: MARK ALL PACKAGES AND PAPERS WITH ORDER NO.

Certified for National Defense under DPAS (15 CFR 700) DO-C9

3. Issuing Office:
NASA Johnson Space Center, 2101 Nasa Parkway
Houston, TX 77058-3696
Org./Buyer: BH2/Mike Ballard

Tel No.: 281-244-5350 Fax: ____
E-mail: michael.d.ballard@nasa.gov

4. Ship To:
Transportation Officer, Building 421
NASA Johnson Space Center
Houston, TX 77058-3696
Mark For: **Accountable Property**

Order No.: DO-CRAVE-EC5-001

5. Contractor:
Texas Engineering Experiment Station
3126 TAMU
College Station, TX 78743-3126

Phone: 979-862-1696 x Fax: 979-862-1698

TIN: 74-1974733 CAGE CODE: 0EBC6

6. Deliver On or Before: 10-17-05

F.O.B. Point: ____

Discount Terms: Net 30 Days.

7. BILLING ADDRESS:
NASA Johnson Space Center
Attn: LF231/Accounts Payable Group
Houston, TX 77058-3696
Order No.: DO-CRAVE

8. Type of Order:

☐ PURCHASE: Please furnish the following in accordance with the conditions specified on this order.
Reference:____

☒ DELIVERY: Except for the Terms and Conditions of Purchase Order listed on the following page, this delivery order is subject to instructions contained on this form and is issued subject to the terms and conditions of contract number: [redacted]. MB
NNJ05 H841B

9. Written acceptance of this order by contractor [☒] is, [☐] is not required. Sign below if required and return to contracting officer.

Name: ____ (Person authorized to sign)

Signature: [signature] Date: 03/30/05

10. Name: N. L. Dawn Alexander

Signature: Dawn Alexander Date: 3/30/05
CONTRACTING OFFICER

11. Schedule

ITEM NO.	DESCRIPTION	QUANTITY ORDERED	UNIT	UNIT PRICE	AMOUNT	QUANTITY ACCEPTED
1	The Contractor shall perform and deliver to all requirements for: DO-CRAVE-EC5-001: Portable Life Support Subsystem Schematic (PLSS) Study The Period of Performance for this DO is 3-30-05 thru 10-17-05	64		64	64	

12. For JSC Internal Use Only:
Requisition No.: ____ ☐ COMP. ☐ PART. PPC: ____
Rissue To: ____

13. Total
$ NTE: ____

14. Quantities in "Quantity Accepted" Column Have Been
☐ INSPECTED ☐ ACCEPTED ☐ RECEIVED
TO CONFORM TO THE CONTRACT.
ACCEPTANCE WILL BE AT JSC UNLESS OTHERWISE NOTED.

BY: ____
Authorized U.S. Government Representative ____ Date