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Ball Aerospace Systems Group

# Zero-Gravity Quantity Gaging System

## Final Report

**18 December 1989**

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# Section 1
# EXECUTIVE SUMMARY

The Zero-Gravity Quantity Gaging System program is a technology development effort funded by NASA-LeRC and contracted by NASA-JSC to develop and evaluate zero-gravity quantity gaging system concepts suitable for application to large, on-orbit cryogenic oxygen and hydrogen tankage. The contract effective date was May 28, 1985. During performance of the program, 18 potential quantity gaging approaches were investigated for their merit and suitability for gaging two-phase cryogenic oxygen and hydrogen in zero-gravity conditions. These approaches were subjected to a comprehensive trade study and selection process, which found that the RF modal quantity gaging approach was the most suitable for both liquid oxygen and liquid hydrogen applications. This selection was made with NASA-JSC concurrence. The final selection was made from the approaches shown in Table 1-1.

Table 1-1
TWO-PHASE CRYOGENIC OXYGEN AND HYDROGEN QUANTITY GAGING CONCEPTS SURVIVING PRELIMINARY CONCEPT SCREENING

OXYGEN SYSTEMS

INDIVIDUAL CONCEPTS:

1. Capacitance Matrix
2. RF Mode Analysis
3. Resonant Infrasonic Gaging (RIGS)
4. PVT Gaging

INTEGRATED CONCEPTS:

1. Capacitance - RIGS
2. Capacitance - PVT Gaging
3. Microwave - PVT Gaging

HYDROGEN SYSTEMS

INDIVIDUAL CONCEPTS:

1. Capacitance Matrix
2. RF Mode Analysis
3. Gamma Radiation Attenuation

INTEGRATED CONCEPTS:

1. RF Mode Analyis - Gamma Radiation Attenuation

Following selection, the RF modal approach was subjected to an extensive and rigorous feasibility test program which included testing with $LN_2$, $LO_2$ and $LH_2$, as well as paraffin simulations of zero-gravity fluid orientations. The feasibility test data were used to develop the computer algorithm required to apply the gaging approach. These algorithms were verified using a protocol of referee test cases. Results of these efforts demonstrated the suitability of the RF modal quantity gaging approach.

A preliminary quantity gaging system design based on the RF modal approach was undertaken and carried to a 53 percent completion level. This provided partitioned schematics, preliminary parts lists, supplier lists, packaging concepts, and a completed antenna development.

Finally, in anticipation of future efforts to complete the design and fabrication of an RF modal gaging system and its subsequent ground and KC-135 testing, an Interface Control Document (ICD) was prepared and provided to NASA-JSC for review and input. The report herein is the final report for these activities and for the Quantity Gaging Program.

The Zero-Gravity Quantity Gaging Program has accomplished the following:

- Selected the RF modal quantity gaging approach as the most suitable for large low- or zero-gravity propellant tankage for two-phase cryogenic oxygen and hydrogen.
- Challenged the selected gaging approach feasibility extensively with cryogenic fluids and paraffin simulations of zero-gravity fluid/vapor interface configurations to demonstrate the viability of the approach.
- Developed and demonstrated the computational algorithms required to implement the selected gaging approach.
- Demonstrated that the approach can be accurately scaled and modeled, which permits testing and verification of potential applications using laboratory models and test equipment.

The operating principle of the RF modal quantity gaging approach is based on the following key ideas:

- The introduction of oscillating electromagnetic energy into a closed metallic cavity (a propellant tank) will form repeatable standing wave patterns at certain frequencies known as resonant modes.

- Frequencies of the resonant modes depend on:

| Physical Attributes of Cavity Boundaries | Electric Attributes of Dielectric in Cavity |
|---|---|
| • Size | • Conductivity |
| • Geometry | • Permeability |
| | • Dielectric Constant |

- The dielectric medium in the cavity must obey the Clausius-Mossotti equation relating density and dielectric constant, and should have a low loss tangent.

- The three ideas above provide the basis for determining the density of the dielectric medium in the cavity. Because the cavity volume is known, dielectric medium mass, or quantity, follows directly as the product of density and volume.

For the simplified case in which the cavity contents are uniformly disbursed throughout the cavity volume, the above ideas are complete and sufficient. When the cavity contents are not uniformly distributed in the cavity volume, the gaging approach becomes more complex because the cavity resonant mode frequencies become dependent on the location of the cavity contents. This occurs because the electromagnetic standing waves in the cavity do not sample its contents uniformly. This contents location problem is resolved by using the relationships between the modal responses. Results of program investigations have shown that using the relationship among the lowest three transverse magnetic (TM) modes is sufficient to resolve cavity contents density regardless of its distribution. A mass computational algorithm and a supporting algorithm which selects the three lowest TM mode responses from a significant population of responses have been developed to accomplish this task. Experimental work using laboratory equipment to implement the RF modal gaging approach and the algorithms has demonstrated full-scale average accuracies of ±1.51 percent with a standard deviation of 1 percent.

The demonstrated accuracies with cryogens and paraffin simulations of zero-gravity fluid/vapor interface configurations, and the advantages listed below, present a strong argument for the applicability of the approach to gaging large, on-orbit cryogenic propellant tanks:

- Low-weight system, and weight does not significantly vary with tank size
- Minimal intrusion into tank
- Small impact on pressure vessel (PV) structure and multilayer insulation (MLI) of cryogenic tanks
- No moving parts
- No special materials, components, or processes required
- Electronics located remotely from tank
- Operating power is low and power input to fluid is negligible
- Concept is particularly applicable to propulsion cryogens
- Not sensitive to thermodynamic properties of gageable fluids
- Not affected by species of pressurant gas

The strong potential of the approach indicates that it should be pursued further to assure its availability for application in time to support NASA's stated on-orbit propellant storage needs.

# Section 2
# RESULTS

Significant results obtained during the performance of the Zero-Gravity Quantity Gaging Program are presented in the following sections. The presentations are organized according to the program task relationships shown in the statement of work. In many instances, data given in this section are the summary of much larger data sets previously published in engineering reports documenting task activities.

## 2.1 ANALYSIS AND TRADE STUDIES

Data generated during the development of NASA-approved candidate quantity gaging concepts and selection criteria, and the results of the subsequent trade studies, are given in this section. Conclusions based on these results are provided in Section 3 of this report.

### 2.1.1 Candidate Concept Development

A literature search and review activity resulted in a primary citation base of 28 sources, which in turn lead to a secondary base of 122 sources to construct the beginning list of potential candidate concepts. A listing of these sources may be found in this report beginning at page 20 in Appendix B. The beginning list of potential candidate concepts was evaluated and reduced using the preliminary concept screening scheme shown in **Table 2-1**. The beginning candidate concepts for both oxygen and hydrogen systems are shown in **Tables 2-2** and **2-3** along with their scoring and disposition results from preliminary screening.

In addition to the single concepts obtained from the preliminary screening, integrated concepts formed by utilizing more than one gaging approach simultaneously were investigated with the results shown in **Table 2-4**. This, in turn, led to the final sets of candidate concepts which would be examined in the trade studies. **Tables 2-5** and **2-6** list the concept finalists for oxygen and hydrogen systems, respectively.

**Table 2-1**

**ZERO-GRAVITY QUANTITY GAGING SYSTEM**

**PRELIMINARY CONCEPT SCREENING**

1. Does the concept require the use of a trace gas?

| Response | Score |
|---|---|
| Yes | (Remove concept from any further consideration.) |
| No | (Retain concept for further screening.) |

2. What is the concept accuracy (percent of full scale) in a near zero-gravity environment?

| Response | Static Accuracy Score | Dynamic Accuracy Score |
|---|---|---|
| 1% or better | 70 | 30 |
| 1% to 5%* | 20 | 20 |
| 5% | (remove concept) | (remove concept) |

*See extended accuracy band explanation.

3. Is the concept accuracy independent of tank orientation?

| Response | Score |
|---|---|
| Independent | 100 |
| Nearly independent | 50 |
| Significantly dependent | (remove concept) |

4. Is the concept accuracy independent of the distribution of any gas/liquid interfaces?

| Response | Score |
|---|---|
| Independent | 100 |
| Nearly independent | 50 |
| Significantly dependent | (remove concept) |

Table 2-1

ZERO-GRAVITY QUANTITY GAGING SYSTEM

PRELIMINARY CONCEPT SCREENING (Continued)

5. Is the concept accuracy sensitive to tank size?

| Response | Score |
|---|---|
| Not sensitive | 70 |
| Moderately sensitive | 35 |
| Significantly sensitive | (remove concept) |

6. Is the concept accuracy sensitive to tank external shape?

| Response | Score |
|---|---|
| Not sensitive | 70 |
| Moderately sensitive | 35 |
| Significantly sensitive | (remove concept) |

7. Is the concept accuracy sensitive to fluid mass?

| Response | Score |
|---|---|
| Not sensitive | 70 |
| Moderately sensitive | 35 |
| Significantly sensitive | (remove concept) |

8. Is the concept accuracy sensitive to internal tank geometry?

| Response | Score |
|---|---|
| Not sensitive | 70 |
| Moderately sensitive | 35 |
| Significantly sensitive | (remove concept) |

**Table 2-1**

**ZERO-GRAVITY QUANTITY GAGING SYSTEM**

**PRELIMINARY CONCEPT SCREENING (Concluded)**

9. What is the maturity of the concept?

| Response | Score |
|---|---|
| Has been demonstrated in space flight | 100 |
| Has been demonstrated in conventional flight | 80 |
| Has been demonstrated in ground applications | 60 |
| Has been demonstrated conceptually (Note 1) | 40 |
| Has not been demonstrated | (remove concept) |

Note 1: If concept has scored at least 450 in screening questions 2 through 8, it should be retained in a list of concepts showing promise for future concept development. However, it should be removed from further consideration in this concept screening.

Note 2: In the case of integrated concepts, the score shall be the arithmetic average of the constituent concepts.

## Table 2-2

## OXYGEN SYSTEMS

| CONCEPT | SCREENING PARAMETERS | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | ST 2a | Dy 2B | 3 | 4 | 5 | 6 | 7 | 8 | 9 | TOTAL SCORE | COMMENTS |
| Capacitance | No | 20 | -- | 100 | 100 | 35 | 70 | 70 | 35 | 100 | 530 | |
| Capacitance flowmeter | No | -- | -- | | | | | | | | | Flowmeter 3-15% accuracy |
| Microwave | No | 70 | -- | 100 | 100 | 35 | 35 | 70 | 35 | 60 | 505 | |
| RF mode analysis | No | 70 | -- | 100 | 100 | 70 | 70 | 70 | 35 | 60 | 575 | |
| Beta radiation attenuation | No | 70 | -- | 100 | 100 | -- | 70 | 35 | 35 | 60 | | Eliminated |
| Gamma radiation attenuation | No | 20 | -- | 100 | 100 | -- | 70 | -- | 35 | 80* | | Eliminated radiation hazard<br>Dynamic accuracy: 5-10%<br>Quality 0.15% |
| Buoyancy | No | 70 | -- | | | | | | | | | Calibration reference |
| Ultrasonic temp and density | No | -- | -- | 50 | -- | 35 | 70 | 35 | 35 | -- | | Eliminated |
| Ultrasonic mass flowmeter | No | 70 | 20 | | | | | | | | | Flowmeter |
| Ultrasonic probe | No | -- | -- | 50 | -- | 35 | 35 | 70 | 35 | 60 | | Eliminated |
| RIGS | No | 70 | -- | 100 | 100 | 70 | 70 | 70 | 35 | 40 | 555 | |
| Vibrating cylinder | No | -- | 70 | | | | | | | | | Flowmeter |
| Vibrating reed | No | -- | -- | | | | | | | | | Flowmeter |
| Coriolis | No | -- | 70 | | | | | | | | | Flowmeter |
| PVT gaging | No | 70 | -- | 100 | 100 | 35 | 70 | 35 | 70 | 60 | 540 | ±2% empty, ±1% full<br>Ref vol 1% tank volume |
| Trace injection: | | | | | | | | | | | | |
| Radioactive gas | Yes | | | | | | | | | | | Eliminated |
| Infrared | Yes | | | | | | | | | | | Eliminated |
| Helium 3 | Yes | | | | | | | | | | | Eliminated |

* Quality meter flown 1966 SIVB

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# Table 2-3

## HYDROGEN SYSTEMS

| CONCEPT | SCREENING PARAMETERS 1 | ST 2a | Dy 2B | 3 | 4 | 5 | 6 | 7 | 8 | 9 | TOTAL SCORE | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capacitance | No | 20 | -- | 100 | 100 | 35 | 70 | 70 | 35 | 100 | 530 | |
| Capacitance flowmeter | No | -- | -- | | | | | | | | | Flowmeter 3-15% accuracy |
| Microwave | No | 70 | -- | 100 | 100 | 35 | 35 | 70 | 35 | 60 | 505 | |
| RF mode analysis | No | 70 | -- | 100 | 100 | 70 | 70 | 70 | 35 | 60 | 575 | |
| Beta radiation attenuation | No | 70 | -- | 100 | 100 | -- | 70 | 35 | 35 | 60 | | Eliminated |
| Gamma radiation attenuation | No | 20 | -- | 100 | 100 | 35 | 70 | 70 | 35 | 80* | 510 | Radiation hazard<br>Dynamic accuracy: 5-10%<br>Quality 0.15% |
| Buoyancy | No | 70 | -- | | | | | | | | | Calibration reference |
| Ultrasonic temp and density | No | -- | -- | 50 | -- | 35 | 70 | 35 | 35 | -- | | Eliminated |
| Ultrasonic mass flowmeter | No | -- | 20 | | | | | | | | | Flowmeter |
| Ultrasonic probe | No | -- | -- | 50 | -- | 35 | 35 | 70 | 35 | 60 | | Eliminated |
| RIGS | No | -- | -- | 100 | 100 | 70 | 70 | 70 | 35 | 40 | | Eliminated |
| Vibrating cylinder | No | -- | 70 | | | | | | | | | Flowmeter |
| Vibrating reed | No | -- | -- | | | | | | | | | Flowmeter |
| Coriolis | No | -- | 70 | | | | | | | | | Flowmeter |
| PVT gaging | No | -- | -- | 100 | 100 | 35 | 70 | 35 | 70 | 60 | | ±2% empty, ±1% full<br>Ref vol 1% tank volume |
| Trace injection: | | | | | | | | | | | | |
| Radioactive gas | Yes | | | | | | | | | | | Eliminated |
| Infrared | Yes | | | | | | | | | | | Eliminated |
| Helium 3 | Yes | | | | | | | | | | | Eliminated |

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* Quality meter flown 1966 SIVB



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**Table 2-4**

**INTEGRATED CONCEPTS COMPATIBILITY MATRICES**

| | CAPACITANCE | MICROWAVE | RF MODE ANALYSIS | RIGS |
|---|---|---|---|---|
| MICROWAVE | NC | | | |
| RF MODE ANALYSIS | NC | NC | | |
| RIGS | CPA | CNA | NC | |
| PVT GAGING | CPA | CPA | NC | NC |

**Integrated oxygen gaging concepts**

| | CAPACITANCE | MICROWAVE | RF MODE ANALYSIS |
|---|---|---|---|
| MICROWAVE | NC | | |
| RF MODE ANALYSIS | NC | NC | |
| GAMMA RADIATION | NC | CNA | CPA* |

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**Integrated hydrogen gaging concepts**

KEY: NC = Not compatible; signal interference or one interferes with the other physically

CNA = Compatible operation but no improved attributes

CPA = Compatible operation and positive reinforcing attributes

*Possibility of gamma radiation ionization which would interface with RF fields

## 2.1.2 Selection Criteria Development

A specific method for conducting the trade study evaluations of the most promising candidate concepts was developed in complete detail under NASA review and approval. The resulting method is documented as DD17392A "Zero-Gravity Quantity Gaging System Selection Criteria" and is included in this report beginning at page 34 of Appendix B. This criteria provided the hierarchy of major and detail selection attributes and their weights shown in Table 2-7.

**Table 2-5**

**POPULATION SET FOR OXYGEN SYSTEMS**

SINGLE CONCEPTS

1. Capacitance Matrix
2. RF Mode Analysis
3. Resonant Infrasonic Gaging (RIGS)
4. PVT Gaging

INTEGRATED CONCEPTS

1. Capacitance - RIGS
2. Capacitance - PVT Gaging
3. Microwave - PVT Gaging

**Table 2-6**

**POPULATION SET FOR HYDROGEN SYSTEMS**

SINGLE CONCEPTS

1. Capacitance Matrix
2. RF Mode Analysis
3. Gamma Radiation Attenuation

INTEGRATED CONCEPTS

1. RF Mode Analysis - Gamma Radiation Attenuation

NOTE: The order of candidates in these tables is not indicative of any preference.

**Table 2-7**

**HIERARCHY OF SELECTION ATTRIBUTES AND WEIGHTS**

| ATTRIBUTES | DETAIL ATTRIBUTE RELATIVE WEIGHT | MAJOR ATTRIBUTE RELATIVE WEIGHT |
|---|---|---|
| 1. Accuracy | | 0.35 |
| a) Basic accuracy | 0.273 | |
| b) Sensitivity to tank size, shape, internal geometry, and fluid mass | 0.182 | |
| c) Range | 0.136 | |
| d) Ease of calibration | 0.182 | |
| e) Maintenance of calibration | 0.227 | |
| 2. Design features | | 0.20 |
| a) System weight | 0.187 | |
| b) System electrical power requirements | 0.250 | |
| c) Energy input to fluid | 0.250 | |
| d) Number and complexity of fluid containment penetrations | 0.313 | |
| 3. Design quality | | 0.25 |
| a) Reliability | 0.222 | |
| b) Repairability | 0.186 | |
| c) Maintainability | 0.111 | |
| d) Safety | 0.296 | |
| e) Compatibility | 0.185 | |
| 4. Design state of the art | | 0.10 |
| a) Materials | 0.213 | |
| b) Construction | 0.204 | |
| c) Circuitry | 0.280 | |
| d) Performance | 0.101 | |
| e) Potential for improvement | 0.202 | |
| 5. Flight hardware development effort | | 0.10 |
| a) Development hardware estimate to complete (span time, manpower, and dollars, including risk) | 0.333 | |
| b) Prototype hardware estimate to complete (span time, manpower, and dollars, including risk) | 0.333 | |
| c) Flight hardware estimate to complete (span time, manpower, and dollars, including risk) | 0.334 | |

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### 2.1.3 Perform Trade Studies

The methods of the approved selection criteria were applied to the seven oxygen and four hydrogen concepts selected during the candidate development activities, with the results shown in the summary of major attribute scores presented in Table 2-8.

## 2.2 FEASIBILITY TESTING

This section provides data generated as a result of performing a series of proof-of-concept feasibility tests using specially designed test tanks to challenge the selected RF modal concept. These tests were in support of Task 1 and were known as Feasibility Testing Supporting Trades. These challenges were made using cryogenic liquid nitrogen, oxygen, and hydrogen in a test tank of differing internal configurations and capable of rotation about one axis to obtain differing liquid/vapor interfaces. In addition, the RF modal concept was further challenged with more realistic zero-gravity fluid/vapor interface configurations simulated with paraffin in a reduced scale bench-top test tank.

Data is also presented in this section for a series of feasibility tests used to support Design Task 4 by verifying an appropriate antenna development and providing further data for development of a mass computational algorithm.

### 2.2.1 Feasibility Testing Supporting Trades

Data presented in this section is the essence of over 3,900 modal plots. The original raw data has been compressed by eliminating all but the best four working modes and only includes data from three of the nine tank rotation angles, since the responses at the other angles were simple variants of these three angles. Only cryogenic test data is included in this section.

Organization of the data is as follows:

- Tank "Q" Data, Bare Tank (Figure 2-1)
- $LN_2$ Baseline, Bare Tank (Table 2-9)

# Table 2-8

## SUMMARY OF MAJOR ATTRIBUTE SCORES

| GAGING SYSTEMS | ACCURACY SCORE (a) | WEIGHT (a) x 0.35 = 1 | DESIGN FEATURES SCORE (b) | WEIGHT (b) x 0.20 = 2 | DESIGN QUALITY SCORE (c) | WEIGHT (c) x 0.25 = 3 | STATE-OF-ART SCORE (d) | WEIGHT (d) x 0.10 = 4 | FLIGHT HARDWARE EFFORT SCORE (e) | WEIGHT (e) x 0.10 = 5 | OVERALL SCORE 1 + 2 + 3 + 4 + 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **OXYGEN SYSTEMS** | | | | | | | | | | | |
| Cap Matrix | 85.311 | 29.86 | 26.705 | 5.34 | 75.536 | 18.88 | 58.479 | 5.85 | 91.207 | 9.12 | 69.05 |
| RF Mode Analysis | 95.207 | 33.32 | 88.694 | 17.74 | 80.349 | 20.09 | 60.590 | 6.06 | 96.642 | 9.66 | 86.87 |
| RIGS | 62.541 | 21.89 | 44.287 | 8.86 | 42.723 | 9.54 | 37.768 | 3.78 | 47.551 | 4.76 | 47.83 |
| PVT | 71.674 | 25.09 | 29.413 | 5.58 | 56.972 | 11.39 | 37.768 | 3.78 | 61.787 | 6.18 | 52.32 |
| Cap/ RIGS | 59.318 | 20.76 | 11.210 | 2.24 | 27.010 | 5.40 | 24.371 | 2.44 | 24.719 | 2.47 | 33.31 |
| Cap/ PVT | 61.915 | 21.67 | 9.594 | 1.92 | 32.414 | 8.10 | 24.371 | 2.44 | 32.082 | 3.21 | 37.34 |
| Micro/ PVT | 54.009 | 18.90 | 14.008 | 2.80 | 21.919 | 4.38 | 22.207 | 2.22 | 25.517 | 2.55 | 30.85 |
| **HYDROGEN SYSTEMS** | | | | | | | | | | | |
| Cap Matrix | 85.311 | 29.86 | 26.599 | 5.32 | 77.497 | 19.37 | 58.479 | 5.85 | 91.207 | 9.12 | 69.52 |
| RF Mode Analysis | 95.207 | 33.32 | 63.771 | 12.75 | 80.960 | 20.24 | 60.590 | 6.06 | 96.642 | 9.66 | 82.03 |
| Gamma Rad | 72.578 | 25.40 | 39.109 | 7.82 | 45.686 | 11.42 | 29.850 | 2.99 | 54.493 | 5.45 | 53.08 |
| RF/ Gamma | 66.910 | 23.42 | 9.909 | 1.98 | 28.788 | 7.20 | 21.986 | 2.20 | 28.609 | 2.86 | 37.66 |

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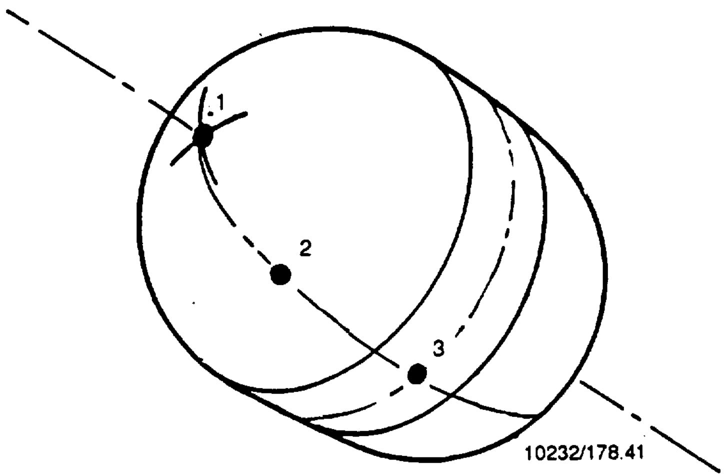
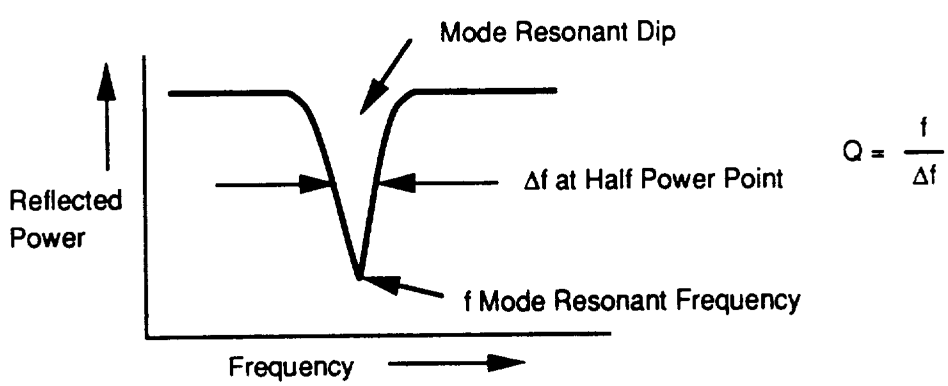



Antenna Positions




| WARM TANK DATA | | |
|---|---|---|
| F MHz | ΔF MHz | Q |
| 257.557 | 0.033 | 7,804 |
| 362.263 | 0.043 | 8,425 |
| 462.877 | 0.043 | 10,764 |

| COLD TANK DATA | | |
|---|---|---|
| F MHz | ΔF MHz | Q |
| 257.900 | 0.028 | 9,211 |
| 362.587 | 0.033 | 10,987 |
| 463.267 | 0.043 | 10,773 |

10232/178.15

**Figure 2-1.-Bare tank "Q" test results.**

- $LO_2$ Baseline, Bare Tank (Table 2-10)
- $LH_2$ Baseline, Bare Tank (Table 2-11)
- $LN_2$ Phase 1 Configuration (Table 2-12)
- $LN_2$ Phase 2 Configuration (Table 2-13)

References to Bare Tank, Phases 1 and Phase 2, are descriptions of the internal configuration of the test tank. Bare means that there are no internal components in the tank, a baseline condition while Phases 1 and 2 refer to the configurations shown in **Figure 2-2**.

Tank "Q" Test Results. The data was obtained with a dry room temperature nitrogen pad in the tank for the warm tank condition, and the cold tank data was obtained with the cold vapor over a 40-lb liquid fill in the tank. The Tank Cavity Q was determined from data read from modal plots as illustrated in **Figure 2-1**.

### 2.2.2 Feasibility Testing Supporting Design

Data presented in this section represents the results of feasibility test activities designed to obtain application-specific experimental information to support antenna design and mass computational algorithm development. A special test fixture, shown in **Figure 2-3**, was used in antenna mechanical design tests, and the Phase 2 configuration of the test tank was used with liquid nitrogen to obtain electrical antenna design data as well as additional modal response data to support development of the mass computational algorithm.

Antenna Mechanical Tests. Three antenna heads were subjected to cold shocks from ambient to liquid hydrogen temperature, which took approximately three minutes to stabilize. During the cold shock and for fifteen minutes following stabilization at liquid hydrogen temperature, the antenna head/tank port assembly was maintained at a constant 80 psi helium pressure across the seals. At the end of this period the helium pressure differential was reduced to 40 psi, and both the bagged seal flange and electrical feedthrough were leak checked with the test assembly still at liquid hydrogen temperature. Leak testing was performed using a helium mass spectrometer set and

## Table 2-9

## $LN_2$ BASELINE TEST RESULTS

### MODE TABLE

Fluid: Nitrogen

Tank Angle: 0

| MODE | TANK FILL LEVEL | | | | |
|---|---|---|---|---|---|
| | Wt = 861.8 | Wt = 694.4 | Wt = 468.5 | Wt = 220.0 | Wt = 4.0 |
| | FULL | 3/4 FULL | 1/2 FULL | 1/4 FULL | EMPTY |
| 1 | 216.305 | 219.603 | 230.631 | 249.547 | 257.515 |
| 2 | 216.653 | 219.927 | 230.943 | 249.877 | 257.875 |
| 3 | 233.945 | 240.129 | 250.869 | 265.962 | 277.267 |
| 4 | 366.220 | 373.179 | 390.741 | 420.059 | 435.865 |

Fluid: Nitrogen

Tank Angle: 45

| MODE | TANK FILL LEVEL | | | | |
|---|---|---|---|---|---|
| | Wt = 861.8 | Wt = 694.4 | Wt = 468.5 | Wt = 220.0 | Wt = 4.0 |
| | FULL | 3/4 FULL | 1/2 FULL | 1/4 FULL | EMPTY |
| 1 | 216.692 | 220.305 | 231.255 | 247.861 | 257.539 |
| 2 | 216.892 | 221.800 | 232.505 | 249.268 | 257.905 |
| 3 | 233.567 | 238.971 | 249.960 | 266.520 | 277.285 |
| 4 | 366.188 | 371.490 | 388.968 | 417.211 | 435.900 |

Fluid: Nitrogen

Tank Angle: 90

| MODE | TANK FILL LEVEL | | | | |
|---|---|---|---|---|---|
| | Wt = 861.8 | Wt = 694.4 | Wt = 468.5 | Wt = 220.0 | Wt = 4.0 |
| | FULL | 3/4 FULL | 1/2 FULL | 1/4 FULL | EMPTY |
| 1 | 216.781 | 220.545 | 231.460 | 246.673 | 257.551 |
| 2 | 217.841 | 224.480 | 234.405 | 249.077 | 257.951 |
| 3 | 233.033 | 236.877 | 248.570 | 267.960 | 277.287 |
| 4 | 366.107 | 370.241 | 388.429 | 411.500 | 435.901 |

10232/178.16

# Table 2-10
## $LO_2$ BASELINE TEST RESULTS

### MODE TABLE

Fluid: Oxygen — Tank Angle: 0

| MODE | TANK FILL LEVEL Wt = 1168.0 FULL | Wt = 960.0 3/4 FULL | Wt = 637.0 1/2 FULL | Wt = 310.0 1/4 FULL | Wt = 4.0 EMPTY |
|---|---|---|---|---|---|
| 1 | 212.489 | 216.117 | 228.717 | 248.461 | 257.917 |
| 2 | 230.543 | 236.487 | 248.619 | 264.427 | 277.295 |
| 3 | 305.300 | 315.459 | 328.070 | 341.749 | 362.695 |
| 4 | 303.557 | 312.213 | 329.685 | 361.747 | 374.611 |

Fluid: Oxygen — Tank Angle: 45

| MODE | TANK FILL LEVEL Wt = 1168.0 FULL | Wt = 960.0 3/4 FULL | Wt = 637.0 1/2 FULL | Wt = 310.0 1/4 FULL | Wt = 4.0 EMPTY |
|---|---|---|---|---|---|
| 1 | 212.573 | 216.573 | 228.987 | 247.753 | 257.923 |
| 2 | 229.709 | 235.239 | 247.629 | 264.853 | 277.300 |
| 3 | 302.185 | 313.710 | 328.143 | 344.107 | 362.700 |
| 4 | 300.805 | 308.091 | 325.192 | 358.597 | 374.617 |

Fluid: Oxygen — Tank Angle: 90

| MODE | TANK FILL LEVEL Wt = 1168.0 FULL | Wt = 960.0 3/4 FULL | Wt = 637.0 1/2 FULL | Wt = 310.0 1/4 FULL | Wt = 4.0 EMPTY |
|---|---|---|---|---|---|
| 1 | 212.705 | 216.825 | 229.221 | 247.579 | 257.929 |
| 2 | 228.593 | 232.851 | 246.159 | 266.353 | 277.303 |
| 3 | 300.875 | 312.663 | 329.235 | 349.615 | 362.695 |
| 4 | 299.651 | 304.703 | 321.273 | 351.710 | 374.617 |

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## Table 2-11
## $LH_2$ BASELINE TEST RESULTS

### MODE TABLE

Fluid: Hydrogen

Tank Angle: 0

| MODE | TANK FILL LEVEL | | | | |
|---|---|---|---|---|---|
| | Wt = 75.7 | Wt = 53.7 | Wt = 33.4 | Wt = 13.0 | Wt = 1.9 |
| | FULL | 3/4 FULL | 1/2 FULL | 1/4 FULL | EMPTY |
| 1 | 233.751 | 239.027 | 248.347 | 256.227 | 257.725 |
| 2 | 234.153 | 239.363 | 248.695 | 256.563 | 258.090 |
| 3 | 251.870 | 259.345 | 266.715 | 274.137 | 277.514 |
| 4 | 329.901 | 341.429 | 348.079 | 356.049 | 362.900 |

Fluid: Hydrogen

Tank Angle: 45

| MODE | TANK FILL LEVEL | | | | |
|---|---|---|---|---|---|
| | Wt = 75.7 | Wt = 53.7 | Wt = 33.4 | Wt = 13.0 | Wt = 1.9 |
| | FULL | 3/4 FULL | 1/2 FULL | 1/4 FULL | EMPTY |
| 1 | 233.991 | 239.677 | 247.993 | 255.381 | 257.785 |
| 2 | 234.213 | 240.277 | 248.449 | 256.449 | 258.121 |
| 3 | 251.913 | 258.815 | 266.765 | 274.721 | 277.532 |
| 4 | 329.450 | 340.670 | 347.839 | 357.055 | 362.971 |

Fluid: Hydrogen

Tank Angle: 90

| MODE | TANK FILL LEVEL | | | | |
|---|---|---|---|---|---|
| | Wt = 75.7 | Wt = 53.7 | Wt = 33.4 | Wt = 13.0 | Wt = 1.9 |
| | FULL | 3/4 FULL | 1/2 FULL | 1/4 FULL | EMPTY |
| 1 | 234.310 | 239.890 | 247.807 | 254.301 | 257.803 |
| 2 | 234.510 | 241.673 | 248.473 | 256.367 | 258.145 |
| 3 | 251.905 | 257.762 | 267.153 | 275.735 | 277.539 |
| 4 | 329.787 | 337.241 | 348.961 | 359.391 | 363.001 |

10232/178.18

**Table 2-12**

**$LN_2$ PHASE 1 CONFIGURATION**

**MODE TABLE**

Fluid: Nitrogen Phase I

Tank Angle: 0

| MODE | TANK FILL LEVEL | | | | |
|---|---|---|---|---|---|
| | Wt = 861.7 | Wt = 686.6 | Wt = 447.0 | Wt = 215.4 | Wt = 4.0 |
| | FULL | 3/4 FULL | 1/2 FULL | 1/4 FULL | EMPTY |
| 1 | 217.895 | 221.631 | 232.300 [3] | 251.910 [3] | 259.460 |
| 2 | 218.275 | 221.661 [1] | 232.773 [2] | 252.910 | 259.910 |
| 3 | 313.110 | 319.088 | 335.725 | 365.133 | 376.003 |
| 4 | 366.891 | 373.651 | 392.275 | 414.691 | 436.909 |

[1] Obtained from 180 deg
[2] Obtained from 180 deg
[3] Estimated

Fluid: Nitrogen Phase I

Tank Angle: 45

| MODE | TANK FILL LEVEL | | | | |
|---|---|---|---|---|---|
| | Wt = 861.7 | Wt = 686.6 | Wt = 447.0 | Wt = 215.4 | Wt = 4.0 |
| | FULL | 3/4 FULL | 1/2 FULL | 1/4 FULL | EMPTY |
| 1 | 218.007 | 221.377 [4] | 232.925 [4] | 250.267 [4] | 259.379 |
| 2 | 218.307 | 222.580 [4] | 234.362 | 252.146 | 259.879 |
| 3 | 313.077 | 318.961 | 335.670 | 364.545 | 376.000 |
| 4 | 367.047 | 372.937 [4] | 391.125 [3] | 420.261 | 436.897 |

[4] From 225 deg

Fluid: Nitrogen Phase I

Tank Angle: 90

| MODE | TANK FILL LEVEL | | | | |
|---|---|---|---|---|---|
| | Wt = 861.7 | Wt = 686.6 | Wt = 447.0 | Wt = 215.4 | Wt = 4.0 |
| | FULL | 3/4 FULL | 1/2 FULL | 1/4 FULL | EMPTY |
| 1 | 218.215 | 221.920 | 233.807 [5] | 248.700 [5] | 259.465 |
| 2 | 218.813 [5] | 225.955 [5] | 234.119 | 251.205 | 259.915 |
| 3 | 312.783 | 318.121 | 335.400 [3] | 361.332 | 375.985 |
| 4 | 367.215 | 371.017 [5] | 389.873 | 421.000 [3] | 436.883 |

[5] From 270 deg

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**Table 2-13**

**$LN_2$ PHASE 2 CONFIGURATION**

**MODE TABLE**

Fluid: Nitrogen Phase 2 — Tank Angle: 0

| MODE | TANK FILL LEVEL Wt = 822.5 FULL | Wt = 673.1 3/4 FULL | Wt = 440.5 1/2 FULL | Wt = 213.5 1/4 FULL | Wt = 4.0 EMPTY |
|---|---|---|---|---|---|
| 1 | 312.580 | 315.555 | 329.705 | 351.795 | 369.415 |
| 2 | 326.325 | 329.935 | 346.005 | 376.435 | 387.875 |
| 3 | 375.285[1] | 378.570 | 405.000[2] | 428.065[1] | 445.525 |
| 4 | 402.480 | 413.575 | 429.000[2] | 447.755 | 477.115 |

[1] Obtained from 180 deg
[2] Estimated

Fluid: Nitrogen Phase 2 — Tank Angle: 45

| MODE | TANK FILL LEVEL Wt = 822.5 FULL | Wt = 673.1 3/4 FULL | Wt = 440.5 1/2 FULL | Wt = 213.5 1/4 FULL | Wt = 4.0 EMPTY |
|---|---|---|---|---|---|
| 1 | 311.590 | 317.245[3] | 327.625 | 355.550[2] | 369.365 |
| 2 | 327.265 | 334.775 | 351.265 | 374.915[3] | 387.865 |
| 3 | 375.570 | 384.300[3] | 406.365 | 426.165 | 445.525 |
| 4 | 404.115 | 417.305 | 426.875 | 448.000[2] | 477.120 |

[3] From 225 deg

Fluid: Nitrogen Phase 2 — Tank Angle: 90

| MODE | TANK FILL LEVEL Wt = 822.5 FULL | Wt = 673.1 3/4 FULL | Wt = 440.5 1/2 FULL | Wt = 213.5 1/4 FULL | Wt = 4.0 EMPTY |
|---|---|---|---|---|---|
| 1 | 310.470 | 314.435 | 328.850 | 357.180[4] | 369.425 |
| 2 | 327.685 | 338.735 | 356.155 | 374.500[2] | 387.915 |
| 3 | 375.380[4] | 378.765[4] | 405.100[2] | 422.695[4] | 445.540 |
| 4 | 402.615 | 414.500 | 429.200[2] | 449.155 | 477.135 |

[4] From 270 deg

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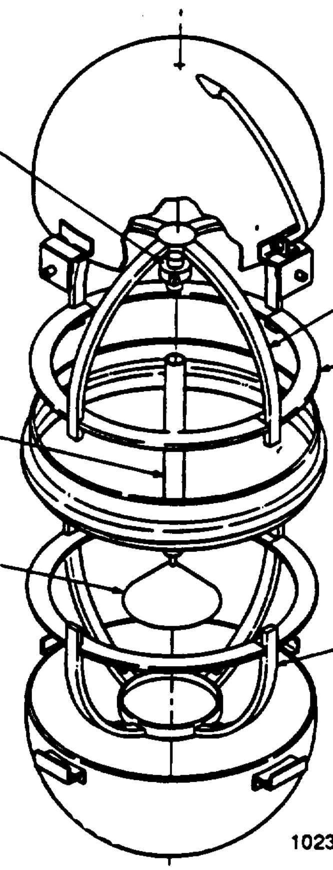


**Figure 2-2.-Tank internal componentry.**

verified to a sensitivity of 1 x $10^{-9}$ SCC He/sec. The bagged leak test was conducted for 15 minutes to integrate any small leakages. The seal paths were less than one inch in length so that leak path length was not an issue.

All three antenna head assemblies went through the test sequence without any evidence of structural deformation or leakage.

Antenna Electrical Performance. The objectives of these tests were to determine the most useful antenna element design and its best orientation in the available antenna positions 2 and 3. Another objective was to verify that the antenna head design had a low standing wave ratio (VSWR) and insertion loss, and that it remained stable relative to these parameters with temperature.

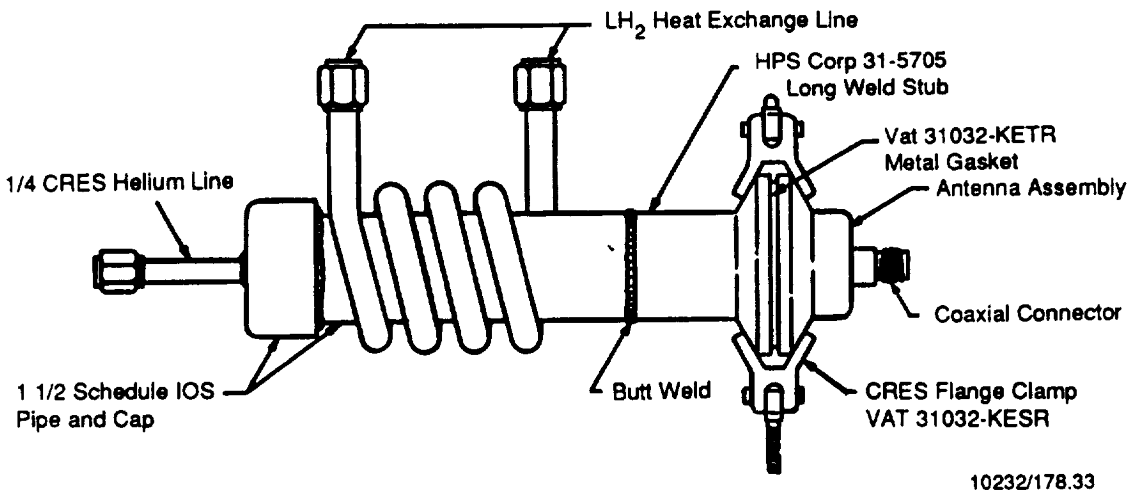


**Figure 2-3.-Antenna test fixture.**

The first objective was realized by screening a variety of loop and stub antenna element configurations and orientations in the test tank at room temperature. The tank was in the Phase 2 configuration and contained ambient air during these screening trials.

The screening test found that the two most useful antenna element designs were an 8.5-inch stub and a 4.5-inch loop at 45°CW to the antenna mounting meridian. Both antennas provided improved response amplitude and were able to pick up modes that had dropped out in the trades testing.

Each of these designs was then checked at discrete fill levels and tank angles using liquid nitrogen. The results indicated that the improved performance noted at room temperature in an empty tank did not hold up when the tank was filled with liquid nitrogen to nearly any level. The effect was not due to temperature because empty tank response was not significantly different with the tank at room temperature or liquid nitrogen temperature.

Further investigation of this phenomenon suggested that the mode patterns were changing sufficiently with fluid level to shift the most desirable antenna position from the room temperature placements established in the screening tests. Two approaches were tried to counter this. First, the antenna at position 3 was changed to a four-rod conical of about 26 degrees with 8.5-inch elements. This broadened the frequency response and increased the spatial extent of this antenna. The antenna at position 2 was changed to a curved stub of about 5.5 inches in length. The tube curvature was a circular segment with about a 7.5-inch radius, with the plane of curvature in the antenna meridian mounting plane. This permitted this antenna to couple more reliably with the changing E field patterns. These changes improved the antenna responses but are not considered an exhaustive treatment, nor are the resulting improvements considered the best that could be obtained.

The voltage standing wave ratio and insertion loss were evaluated approximately by terminating the antenna head element connection point with a 50-ohm termination and noting the reflected power. It was also noted that room temperature and cold antenna response measurements were not significantly different in amplitude. These results indicated that the VSWR and insertion loss parameters of the antenna head design were stable and acceptable.

<u>Modal Response Characteristics Test</u>. Mode behavior was observed at fill levels and tank angular attitudes other than the discrete points used in the trades tests. This was accomplished by modifying the experiment to allow continuous video recording of the spectrum analyzer screen while the tank fill level and attitude were changed. The screen was also set up to display fill fluid weight, tank attitude, and antenna position, as well as the normal modal response information. The data obtained was to be used to complete development of a mass computational algorithm.

The initial video recordings revealed that the erratic modal behavior of the Phase 2 configuration tank was even more complex than had been expected. This led to a series of investigative experiments to understand the reasons for the modal behavior and test methods for circumventing it. This proved to be successful enough to permit video recordings to be repeated for a truncated set of modal response characteristics tests.

Mass Computational Algorithm Data. Testing indicated that two modal segments would be required to uniquely determine tank loaded mass. These were identified as the "low" and "high" frequency segments. Summaries of the data defining these segments are given in Tables 2-14 and 2-15.

Mass Computational Computer Simulation Results. The algorithm development test data was used to construct a mass computation algorithm which would provide loaded mass in a Phase 2 configuration test tank loaded with liquid nitrogen at any tank attitude using only a coordinated low and high segment modal frequency. This algorithm was incorporated into a computer program and tested using 96 coordinated modal pairs. The results are given in Table 2-16.

### 2.2.3 Bench-Top Testing

A test tank one-half the scale of the cryogenic test tank used for feasibility testing was used for these bench-top tests. This tank incorporated eight antenna positions as shown in Figure 2-4. A series of modal scans of this tank were made from each antenna position for five basic mass fill conditions of empty, 1/4 full, 1/2 full, 3/4 full, and full. The configuration of the fill media, which was paraffin, could be either settled or wet wall, where settled represented a configuration which would be obtained by simply filling the tank in an upright attitude. Wet wall signifies that the paraffin is a uniformly thick paraffin layer on the inside surface of the tank. In addition, the wet wall configurations could also incorporate additional mass in the form of one or two quasispherical globules, which could be positioned in the top, bottom, or middle of the wet wall cavity. Finally, five random orientations of a fixed group of wet wall segments and two different sized globules were tested as a referee data set. Plots of the resulting test data are shown in Figures 2-5, 2-6 and 2-7 for the three lowest TM modal frequencies. The test data was then used to develop a mass computational algorithm capable of incorporation into an instrument-level microprocessor. Results of the algorithm performance are shown in Tables 2-17 and 2-18.

## Table 2-14
## "LOW" FREQUENCY SEGMENT
## (124 TO 154 MHz, EQUITORIAL ANTENNA)

| TANK ANGLE (degrees) | Δf FROM AVERAGE (MHz) LN$_2$ FLUID WIEGHT (lb) | | | | |
|---|---|---|---|---|---|
| | 0 | 192.7 | 401.2 | 693.3 | 829.9 |
| 0 | +0.045 | -1.438 | -0.624 | +0.420 | -0.302 |
| 15 | -0.065 | -1.301 | -0.404 | +0.447 | -0.220 |
| 30 | -0.010 | -0.971 | -0.404 | +0.200 | -0.302 |
| 45 | -0.065 | -0.257 | -0.322 | -0.020 | -0.550 |
| 60 | -0.093 | +1.336 | -0.074 | -0.130 | -0.083 |
| 75 | -0.038 | +2.738 | +0.585 | -0.349 | -0.083 |
| 90 | -0.038 | +3.040 | +0.695 | -0.514 | -0.083 |
| 105 | -0.038 | +2.875 | +1.024 | -0.377 | -0.083 |
| 120 | -0.038 | +1.913 | -0.212 | -0.130 | -0.055 |
| 135 | +0.154 | -1.988 | -0.789 | +0.008 | +0.165 |
| 150 | -0.010 | -2.070 | +0.008 | +0.063 | +0.329 |
| 165 | +0.099 | -2.070 | -0.129 | -0.157 | +0.412 |
| 180 | +0.099 | -2.455 | -0.129 | -0.130 | +0.522 |
| 225 | | -0.422 | +0.145 | +0.255 | +0.220 |
| 270 | | +2.435 | +0.832 | -0.185 | +0.055 |
| 315 | | -0.257 | +0.008 | +0.090 | +0.055 |
| Average MHz | 150.439 | 145.246 | 137.536 | 128.278 | 126.775 |

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Table 2-15

"HIGH" FREQUENCY SEGMENT

(210 TO 260 MHz, 45-DEG LATITUDE ANTENNA)

| TANK ANGLE (degrees) | Δf FROM AVERAGE (MHz) | | | | |
|---|---|---|---|---|---|
| | LN $_2$ FLUID WIEGHT (lb) | | | | |
| | 7.3 | 198.8 | 413.6 | 616.9 | 830.7 |
| 0 | -0.017 | +1.194 | +0.556 | -0.289 | -0.094 |
| 15 | +0.028 | +1.240 | +0.464 | +0.078 | -0.094 |
| 30 | -0.109 | +0.148 | +0.464 | -0.105 | -0.094 |
| 45 | -0.017 | +0.782 | +0.142 | +0.720 | -0.003 |
| 60 | +0.028 | +0.369 | +0.235 | +0.353 | +0.089 |
| 75 | +0.028 | +0.094 | +0.143 | +0.261 | -0.003 |
| 90 | -0.017 | -0.089 | +0.143 | +0.261 | +0.272 |
| 105 | +0.028 | -1.097 | -0.040 | -0.197 | +0.272 |
| 120 | +0.028 | -1.097 | -0.040 | -0.197 | +0.272 |
| 135 | +0.028 | -1.372 | -0.544 | -0.793 | +0.043 |
| 150 | -0.017 | -0.043 | -0.957 | -0.518 | -0.003 |
| 165 | -0.109 | +0.278 | -0.223 | +0.032 | -0.186 |
| 180 | +0.120 | +0.278 | -0.132 | -0.014 | -0.095 |
| 225 | | -0.593 | -0.819 | +1.086 | -0.094 |
| 270 | | -1.051 | +0.143 | -0.426 | +0.089 |
| 315 | | -0.731 | +0.281 | +0.032 | -0.003 |
| Average MHz | 258.574 | 253.696 | 239.348 | 227.406 | 219.054 |

10232/178.029

# Table 2-16

## COMPUTER SIMULATION RESULTS

| LOW MODE (MHz) | HIGH MODE (MHz) | TRUE WEIGHT (lb) | PERCENT FULL-SCALE ERROR | LOW MODE (MHz) | HIGH MODE (MHz) | TRUE WEIGHT (lb) | PERCENT FULL-SCALE ERROR |
|---|---|---|---|---|---|---|---|
| 149.9 | 258.4 | 0 | +0.004 | 137.2 | 239.7 | 407 | +0.000 |
| 150.3 | 258.4 | 0 | +0.004 | 137.5 | 240.9 | 407 | -0.004 |
| 150.4 | 258.4 | 0 | +0.004 | 138.1 | 239.4 | 407 | +0.001 |
| 150.6 | 258.4 | 0 | +0.004 | 137.3 | 239.8 | 407 | -0.000 |
| 150.5 | 258.5 | 0 | +0.003 | 135.4 | 236.5 | 463 | +0.300 |
| 150.3 | 258.4 | 0 | +0.004 | 135.9 | 236.2 | 463 | +0.100 |
| 150.4 | 258.4 | 0 | +0.004 | 135.0 | 236.8 | 463 | +0.200 |
| 150.6 | 258.4 | 0 | +0.004 | 133.4 | 233.2 | 519 | +0.001 |
| 148.1 | 257.5 | 52 | -1.100 | 133.3 | 233.5 | 519 | +0.001 |
| 148.8 | 257.0 | 52 | -0.200 | 133.5 | 233.3 | 519 | -0.002 |
| 149.7 | 256.9 | 52 | +1.200 | 132.8 | 232.4 | 519 | -0.000 |
| 146.7 | 256.6 | 104 | -0.002 | 133.3 | 233.0 | 519 | -0.006 |
| 147.5 | 256.4 | 104 | -0.001 | 133.7 | 233.1 | 519 | -0.002 |
| 149.2 | 255.9 | 104 | +0.006 | 133.7 | 232.9 | 519 | +0.003 |
| 146.7 | 255.2 | 104 | -0.003 | 133.6 | 233.1 | 519 | -0.002 |
| 146.4 | 256.2 | 104 | -0.005 | 131.8 | 229.3 | 575 | -1.100 |
| 147.4 | 255.7 | 104 | -0.002 | 131.2 | 230.0 | 575 | -0.900 |
| 148.9 | 255.4 | 104 | -0.003 | 131.7 | 229.9 | 575 | -0.200 |
| 147.6 | 255.6 | 104 | +0.003 | 130.8 | 227.4 | 608 | +0.002 |
| 145.1 | 255.7 | 156 | -2.000 | 130.4 | 228.4 | 608 | -0.001 |
| 145.9 | 254.3 | 156 | +2.400 | 129.9 | 228.0 | 608 | +0.002 |
| 148.1 | 253.9 | 156 | +2.500 | 129.9 | 227.2 | 608 | -0.002 |
| 143.8 | 255.0 | 197 | +0.003 | 130.3 | 227.7 | 608 | +0.002 |
| 144.9 | 254.6 | 197 | -0.001 | 130.7 | 227.0 | 608 | -0.006 |
| 148.1 | 253.7 | 197 | +0.003 | 130.2 | 227.8 | 608 | -0.002 |
| 143.2 | 252.4 | 197 | +0.004 | 130.5 | 228.0 | 608 | +0.002 |
| 142.7 | 254.1 | 197 | +0.001 | 129.6 | 225.7 | 667 | +0.900 |
| 144.8 | 253.2 | 197 | +0.001 | 129.7 | 224.8 | 667 | +2.500 |
| 147.6 | 252.7 | 197 | +0.006 | 129.0 | 225.7 | 667 | +1.700 |
| 144.9 | 253.1 | 197 | +0.002 | 128.6 | 223.0 | 726 | +0.004 |
| 145.1 | 249.2 | 244 | +1.400 | 128.2 | 223.5 | 726 | -0.001 |
| 141.2 | 250.2 | 244 | +2.500 | 128.2 | 223.4 | 726 | +0.004 |
| 142.8 | 249.8 | 244 | +2.100 | 128.2 | 223.0 | 726 | +0.004 |
| 140.0 | 247.1 | 311 | +0.004 | 128.7 | 223.1 | 726 | -0.002 |
| 140.6 | 246.6 | 311 | -0.001 | 128.9 | 223.0 | 726 | +0.004 |
| 142.6 | 246.2 | 311 | -0.000 | 128.5 | 223.2 | 726 | +0.005 |
| 139.6 | 245.1 | 311 | +0.001 | 128.6 | 223.3 | 726 | -0.001 |
| 139.7 | 246.3 | 311 | -0.000 | 127.7 | 221.0 | 785 | -1.600 |
| 140.9 | 246.5 | 311 | -0.001 | 127.8 | 220.6 | 785 | -0.100 |
| 142.5 | 245.5 | 311 | +0.001 | 127.3 | 221.2 | 785 | -2.300 |
| 140.8 | 245.9 | 311 | +0.000 | 126.5 | 219.0 | 830 | +0.002 |
| 139.9 | 242.1 | 368 | -0.200 | 126.3 | 219.1 | 830 | -0.004 |
| 138.0 | 243.1 | 368 | -0.200 | 126.7 | 219.4 | 830 | +0.002 |
| 138.8 | 243.1 | 368 | +0.700 | 126.7 | 219.1 | 830 | -0.004 |
| 136.7 | 240.4 | 407 | -0.002 | 127.3 | 219.0 | 830 | +0.002 |
| 137.0 | 239.9 | 407 | -0.002 | 127.0 | 219.0 | 830 | +0.002 |
| 138.0 | 239.8 | 407 | -0.001 | 126.9 | 219.2 | 830 | +0.002 |
| 136.5 | 239.0 | 407 | +0.003 | 126.9 | 219.1 | 830 | -0.004 |

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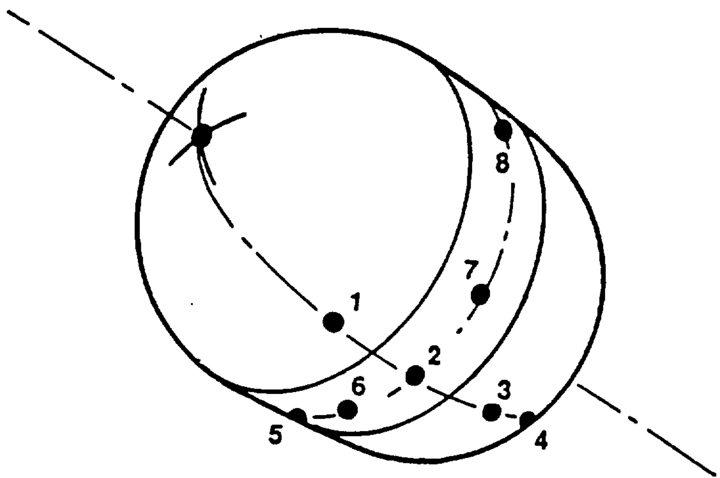



Figure 2-4.-Antenna positions.

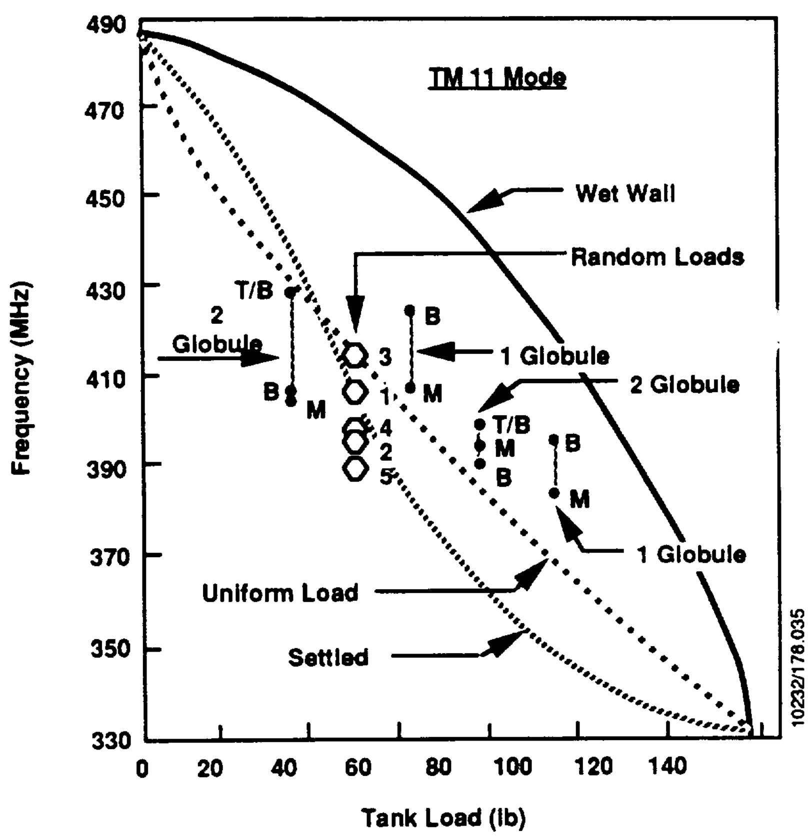



Figure 2-5.-TM11 test results.

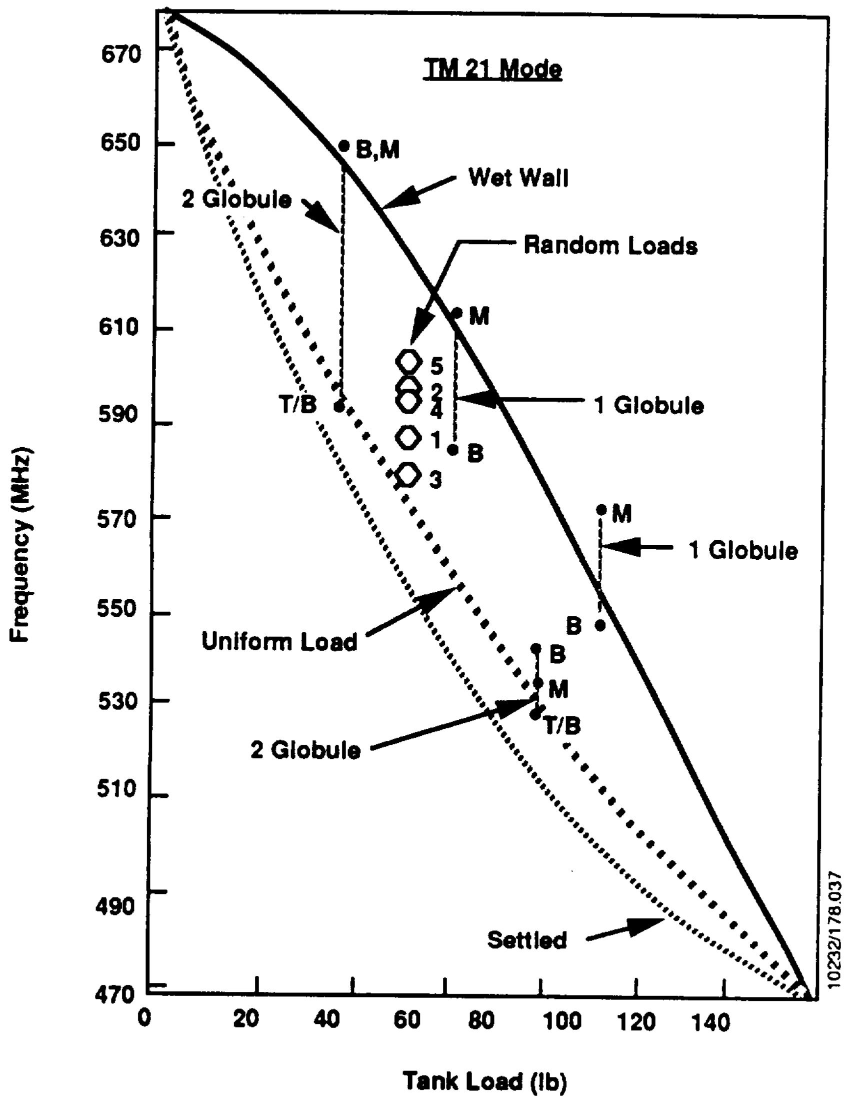



Figure 2-6.-TM21 test results.

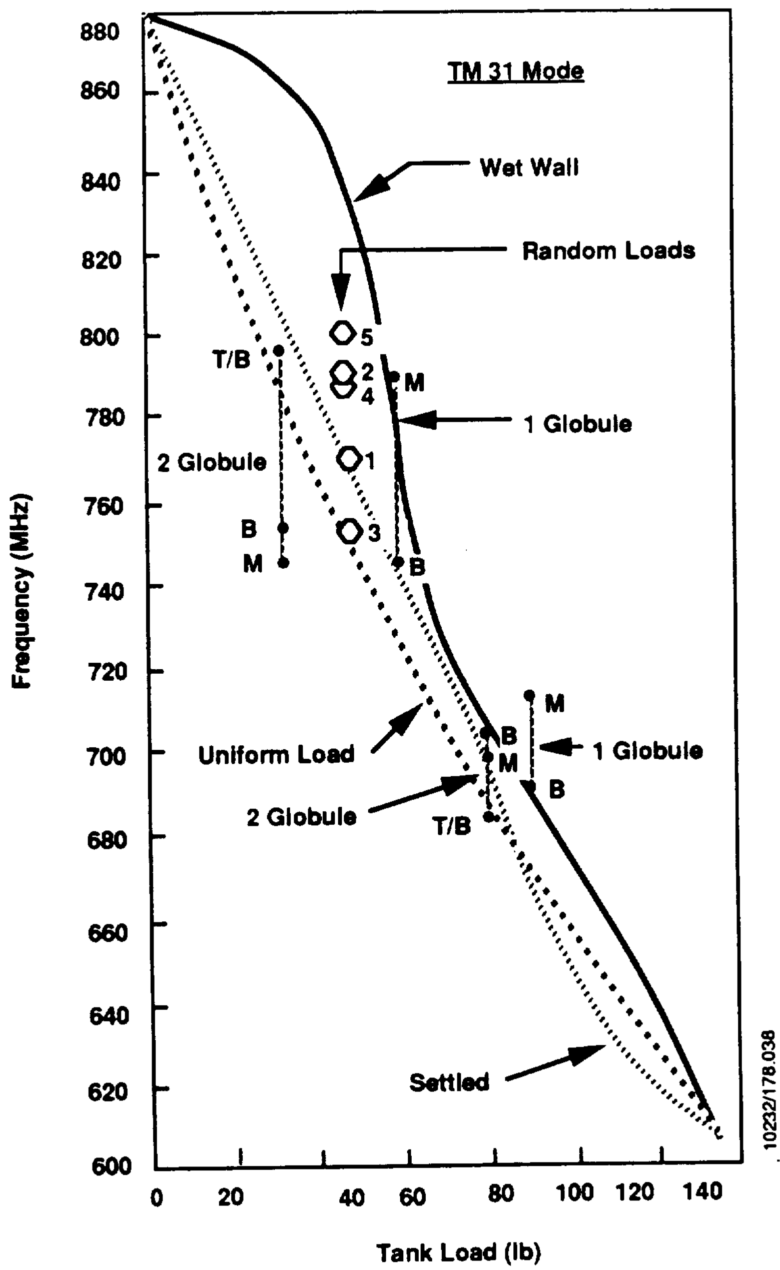



Figure 2-7.-TM31 test results.

Results of comparing tank dielectric media mass as computed using the algorithm with the known media mass load were as given in **Table 2-17**. Note that random configuration load data were not used in the development of the algorithm. Testing of the algorithm with the five random load cases gave the results shown in **Table 2-18**.

## 2.3 INTERFACE REQUIREMENTS

All data developed during performance of the Task 3 effort is documented in the Preliminary Interface Requirements Specification, BS18029, which is included in this report as Appendix E.

## 2.4 GAGING SYSTEM DESIGN

Development signal conditioner and antenna system design data for hardware are included in this report in Appendix F.

Results of the development of a mode tracking and identification algorithm using the bench-top test data base and its incorporation into a demonstration computer program for RF modal quantity gaging are provided below.

Raw data for the 38 bench-top test configurations was screened and the data for bench-top tests 2 and 32 was eliminated. Test 2 used a spray bar and test 32 had identically the same data as test 31 (mirror image tests). All 36 remaining bench-top test configurations were reduced to single-frequency listings by averaging across all eight antenna positions as shown in Figure 2-8. The data sets were identified by the data item numbers shown in the cross-reference listing of **Figure 2-9**.

Methods for selecting the required three lowest TM modal responses were investigated. Selection of the lowest TM modal response (TM011) was easy; it would be the lowest response and it would probably be twined with a second response less than 1 MHz away. These twin responses could be simply averaged to obtain a working value for TM011. The second (TM021) and third (TM031) responses were considerably more difficult to determine. The technique developed to accomplish this involved using the value determined for TM011 to

### Table 2-17
### ACCURACY RESULTS FOR ALGORITHM DEVELOPMENT CASES

| ACCURACY RANGE (% OF FS) | ALGORITHM DEVELOPMENT CASES | |
|---|---|---|
| *0.0 to 0.5 | 25 | Average accuracy 0.278 percent |
| *0.5 to 1.0 | 4 | Standard deviation 0.617 percent |
| *1.0 to 1.5 | 1 | |
| *1.5 to 2.0 | 1 | |
| *2.0 to 2.5 | 0 | |
| *2.5 to 3.0 | 1 | |

### Table 2-18
### ACCURACY RESULTS FOR RANDOM TEST CASES

| ACCURACY RANGE (% OF FS) | RANDOM TEST CASES CASES | |
|---|---|---|
| *0.0 to 0.5 | 1 | Average accuracy 0.900 percent |
| *0.5 to 1.0 | 2 | |
| *1.0 to 1.5 | 1 | |
| *1.5 to 2.0 | 1 | |
| *2.0 to 2.5 | 0 | |
| *2.5 to 3.0 | 0 | |

ITEM: 20

| ANTENNA POSITION | | | | | | | | AVERAGE RESPONSE FREQUENCY (MHz) |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | |
| 414.90 | 414.90 | | 414.58 | 414.79 | 414.79 | 414.79 | 414.37 | 414.72 |
| 419.41 | 419.20 | 419.41 | 419.52 | 419.41 | 419.20 | 419.33 | 419.52 | 419.38 |
| | 422.67 | 422.56 | 422.35 | | 422.56 | 422.46 | | 422.52 |
| | 572.50 | 572.71 | 572.71 | 572.50 | 572.50 | 572.50 | 572.40 | 572.55 |
| | 582.79 | | 582.79 | | | 582.69 | 582.69 | 582.74 |
| 587.62 | 587.94 | 587.52 | 587.10 | 587.94 | 587.94 | 587.94 | | 587.71 |
| 652.72 | 652.72 | 652.72 | 652.72 | 651.99 | 651.65 | 651.67 | 652.20 | 652.30 |
| 661.65 | 660.60 | 661.65 | 662.07 | 661.54 | 661.65 | 661.65 | 660.81 | 661.45 |
| | | | 667.50 | | | | 667.29 | 667.40 |
| | 677.61 | | | 677.50 | | 677.29 | | 677.47 |
| 697.24 | 697.14 | 697.03 | 696.82 | 697.14 | 697.03 | 696.93 | | 697.05 |

10232/178.009

Figure 2-8.-Frequency averaging example.

| DATA ITEM NO. | MASS (lb) | BENCH TEST NO. | DATA ITEM NO. | MASS (lb) | BENCH TEST NO. | DATA ITEM NO. | MASS (lb) | BENCH TEST NO. |
|---|---|---|---|---|---|---|---|---|
| 1 | 138.25 | 22 | 13 | 54.80 | 18 | 26 | 21.86 | 13 |
| 2 | 105.05 | 33 | 14 | 43.87 | 17 | 27 | 10.86 | 6 |
| 3 | 103.65 | 21 | 15 | 42.00 | 23 | 28 | 10.86 | 7 |
| 4 | 91.60 | 30 | 16 | 36.50 | 3 | 29 | 10.86 | 8 |
| 5 | 91.60 | 31 | 17 | 36.50 | 4 | 30 | 10.86 | 9 |
| | 91.60 | 32 | 18 | 36.50 | 5 | 31 | 0.00 | 1 |
| 6 | 78.50 | 24 | 19 | 36.05 | 19 | | 0.00 | 2 |
| 7 | 78.50 | 25 | 20 | 32.93 | 14 | R1 | 49.33 | RAN1 |
| 8 | 78.50 | 26 | 21 | 32.93 | 15 | R2 | 49.33 | RAN2 |
| 9 | 73.35 | 29 | 22 | 32.93 | 16 | R3 | 49.33 | RAN3 |
| 10 | 67.55 | 20 | 23 | 21.86 | 10 | R4 | 49.33 | RAN4 |
| 11 | 60.25 | 27 | 24 | 21.86 | 11 | R5 | 49.33 | RAN5 |
| 12 | 60.25 | 28 | 25 | 21.86 | 12 | | | |

10232/178.008

Figure 2-9.-Data item identification and cross reference.

calculate a scan range for the TM021 and TM031 frequencies and also resolve any overlap situations. The form of the scan range relation is shown in **Figure 2-10**. The reduced lists of possible frequencies, which are obtained from using the scan range, are further compressed using cluster compressions of 5 MHz in the TM021 range and 11 MHz in the TM031 range. An example of TM031 cluster compression is shown in **Figure 2-11**.

Final reduction of the compressed TM021 and TM031 frequency lists to a single working frequency is accomplished by taking the arithmetic average of any remaining frequencies from the lowest through no more than three succeeding values. These techniques provide a single working frequency value for each of the three lowest TM modes from the usually large beginning list of modal responses. The effects of this approach on a mode tracking and identification algorithm are shown in **Figure 2-12**.

Integration of the mode tracking and identification algorithm with the mass computational algorithm was straightforward. The equivalent response frequencies for the three lowest TM modes, as determined using the mode tracking and identification algorithm, were simply substituted for the exact modal frequencies that had been used to develop the mass computational algorithm.

This, of course, required some adjustment to the existing mass computational algorithm in the areas of uncorrected mass calculation and the correction correlation coefficient development. The need for these adjustments led to the discovery that the uncorrected mass calculation could best be done using a three-frequency least squares curve fit of the three lowest TM mode equivalent response frequencies. The curve fit equation was second order and was derived using only the 31 algorithm development test cases. This curve fit relation was capable of determining the tank-loaded fluid mass with an average error of ±6.7 percent of full load without any correction term.

It was also discovered that using the least squares curve fit mass and the equivalent uniform load mass average in a relation of the form shown below gave a much improved correction correlation coefficient:

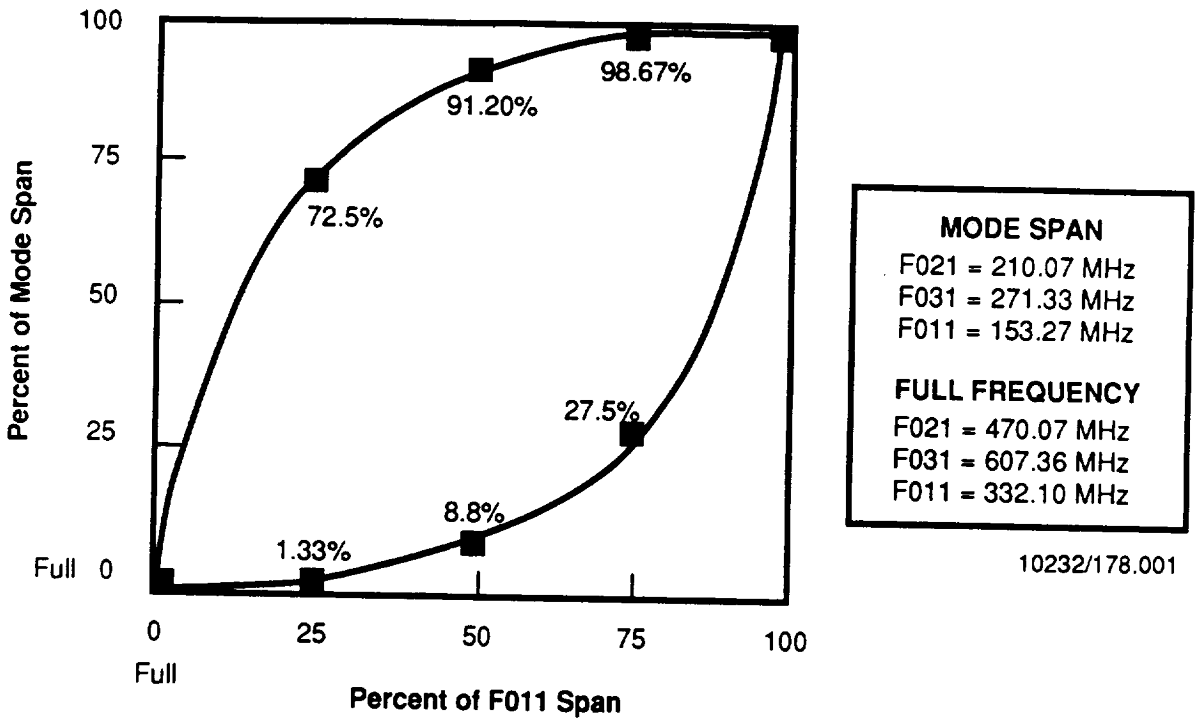



Figure 2-10.-The scan range relation.

| ORIGINAL F031 ARRAY | COMPRESS | COMPRESSED F031 ARRAY |
|---|---|---|
| 663.88 | Add 11.00 | |
| 664.48 | | 664.18 |
| 710.20 | Add 11.00 | |
| 711.13 | | |
| 715.58 | | 712.30 |
| 725.24 | Add 11.00 | |
| 729.19 | | |
| 730.55 | | 728.33 |
| 825.62 | Add 11.00 | |
| 825.85 | | 825.74 |

10232/178.007

Figure 2-11.-Example of cluster compression.

| REDUCTION TECHNIQUE | RESULTS (36 CASE AVERAGE) | |
|---|---|---|
| | F021 | F031 |
| (All data in range) | (20.5) | |
| After scan range | 4.5 | 10.1 |
| After compression | 2.7 | 4.7 |
| After final average | 1.0 | 1.0 |

10232/178.006

**Figure 2-12.-Frequency list reduction results.**

K = M - Z where: K = correction coefficient
M = least squares curve fit mass
Z = average uniform load mass

A plot of mass correction required vs. the correction correlation coefficient K is shown in **Figure 2-13**.

In **Figure 2-13** all 36 test cases are plotted. The four straight lines labeled Zone 1 through Zone 4 are each associated with a group of test cases within the dashed line boundaries on either side of the zone line. Membership of a test case in one of these groups is determined by its measurement class, and the value and sign of K. Measurement class is determined in the same manner as developed for the mass computational algorithm.

The correction equation then becomes a first order relation of the form:

C = -0.4066 * K + A where: C = the correction in lb
K = (M - Z) correction coefficient
A = ¯14.66 for Zone 1
-3.77 for Zone 2
+9.45 for Zone 3
+21.20 for Zone 4

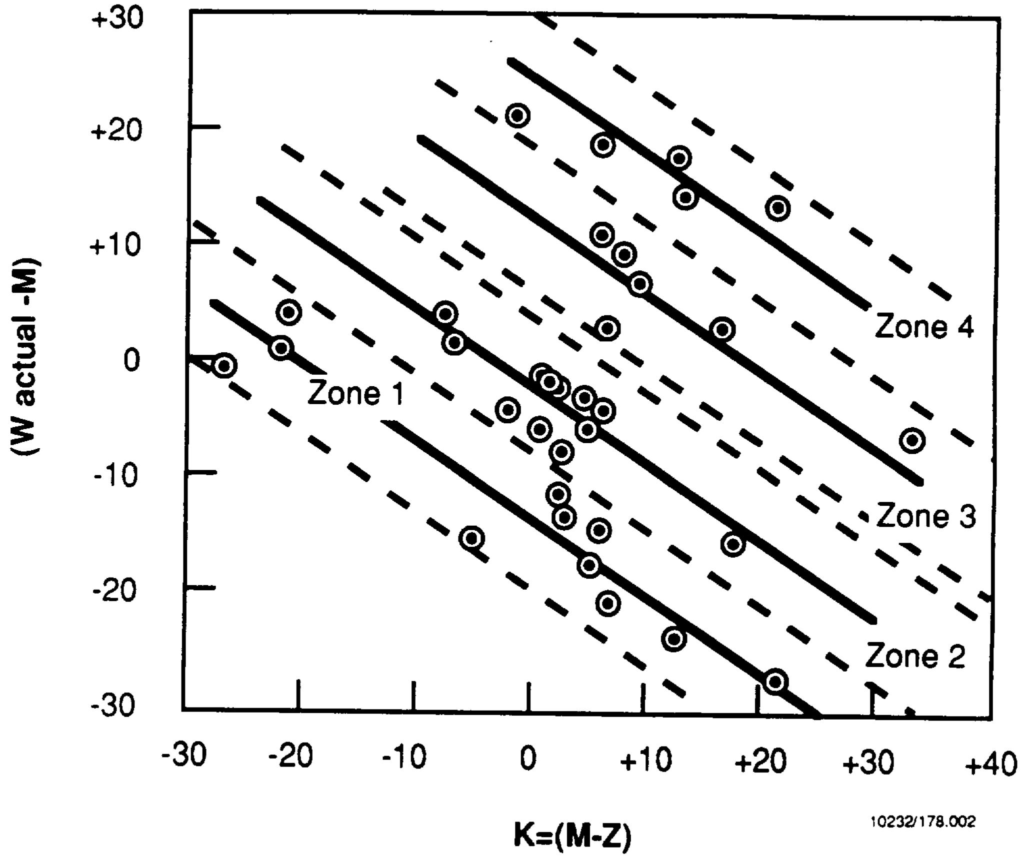


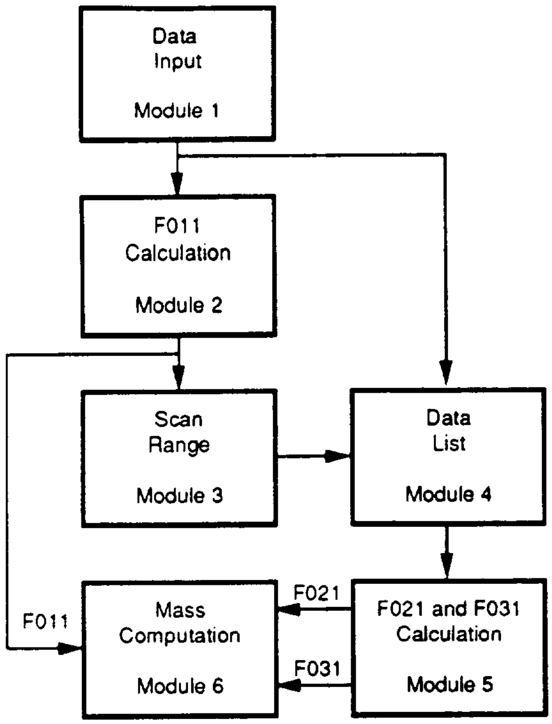

Figure 2-13.-Correction correlation coefficient.

The measured tank mass is computed by adding the correction value to the curve fit mass:

$$P = M + C \text{ lb}$$

A math model of the integrated algorithm was organized based on six computational modules. These are shown in Figure 2-14. Implementation of the math model and its application to all 36 test cases gave the accuracy performance histogram shown in Figure 2-15. The results showed that the integrated algorithm met the ±5 percent of full-scale criteria for gaging approach feasibility.

A computer program was written based on the six modules of the math model. This program was configured to provide a fully integrated demonstration of the RF modal quantity gaging approach. It took the full spectrum of modal




| MODULE | FUNCTION |
|---|---|
| 1 | List all modal frequencies in 330 to 879 MHz range |
| 2 | Use first 3 modal frequencies to calculate F011 |
| 3 | Use F011 to determine frequency range for F021 and F031 arrays |
| 4 | Sort list all modal frequencies into F021 and F031 arrays |
| 5 | Use array compression and final averaging rules to determine F021 and F031 |
| 6 | Compute mass using F011, F021, and F031 in least squares curve fit equation and adding a correction |

10232/178.005

**Figure 2-14.-Integrated algorithm math model.**

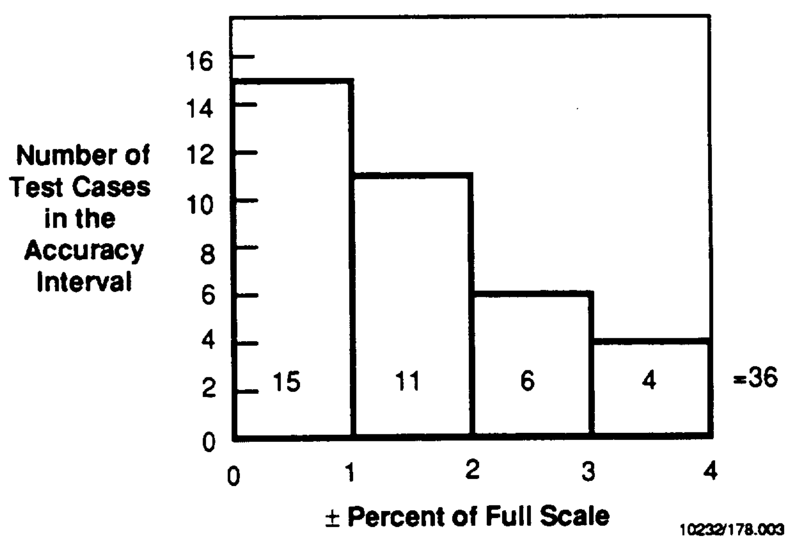



**Figure 2-15.-Math model accuracy.**

responses that would be encountered in actually sweeping the tank probing frequency over the algorithm specified ranges, and then used the responses to determine loaded tank mass to within ±3.5 percent of full load. The resulting demonstration program was written for use on IBM PCs or compatible clones. Disks containing the program and data files for all 36 test cases were provided to NASA-JSC along with a user's manual. A program flow chart is given in **Figure 2-16**.

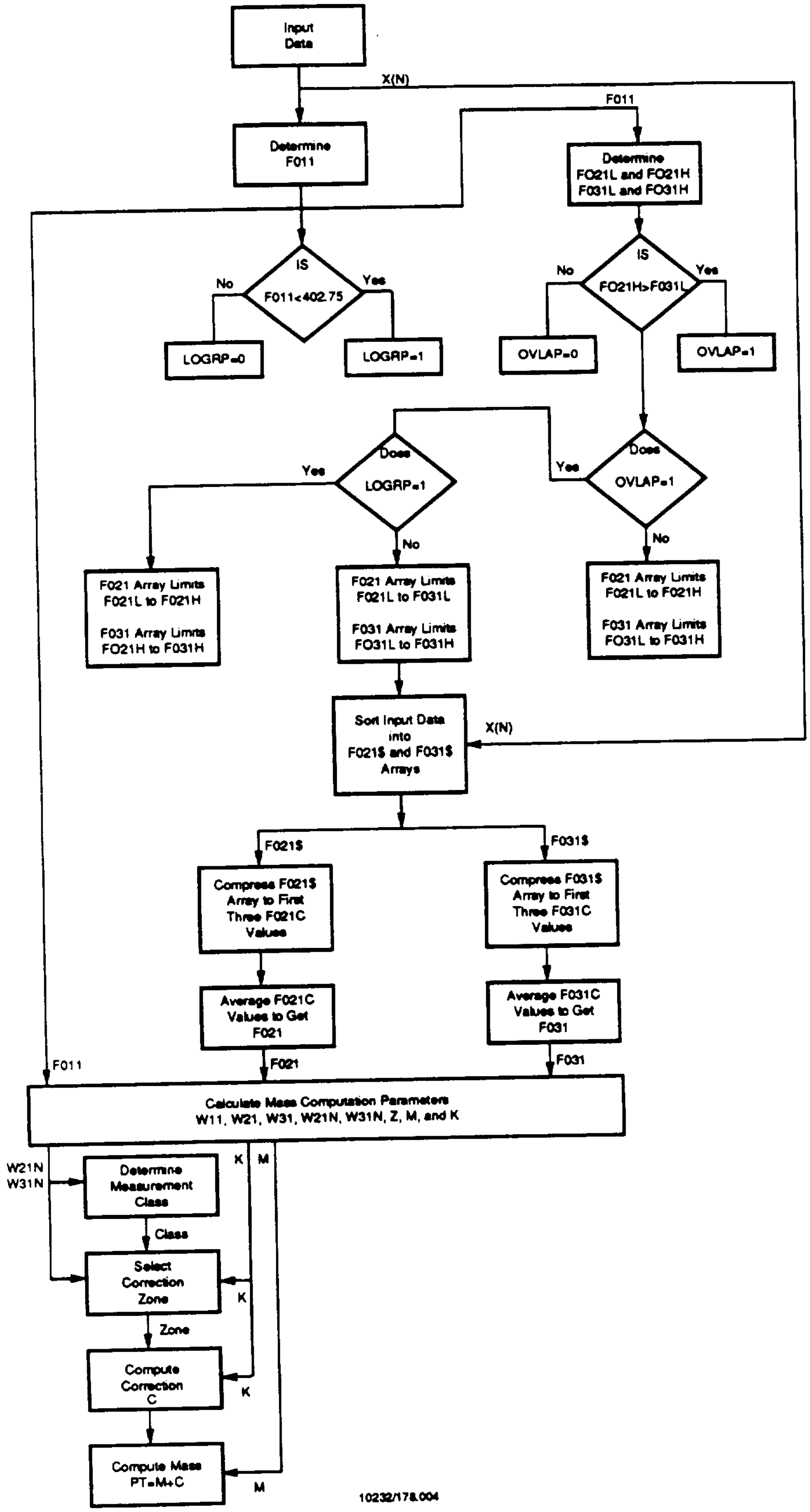



**Figure 2-16.-Demonstration program flow charts.**

# Section 3
# CONCLUSIONS

Evaluations of the results obtained during the performance of the Zero-Gravity Quantity Gaging Program are presented in the following sections. The presentations are organized according to the program task relationships shown in the statement of work.

## 3.1 ANALYSIS AND TRADE STUDIES

The final scoring results of the trade study effort clearly selected the RF modal gaging concept as the most promising for further development as the Zero-Gravity Quantity Gaging approach for both oxygen and hydrogen. In addition, because the RF modal gaging concept scored best in all of the major attribute categories, it would have been selected regardless of the major attribute weighing factors.

Comparisons of trade study scoring results for large storage size, OTV, and small size tanks (see tankage descriptions in Appendix B, page B-80) led to the conclusion that tank size was a minimal accuracy sensitivity issue. Tank size issues were primarily evident in the design features attribute.

## 3.2 FEASIBILITY TESTING

Conclusions reached on the basis of analyzing the feasibility test data are developed in the following sections.

### 3.2.1 Feasibility Testing Supporting Trades

Conclusions reached following examination and analysis of data obtained in the following test sequences are provided below:

- $LN_2$ "Q" Data, Bare Tank
- $LN_2$ Baseline, Bare Tank
- $LO_2$ Baseline, Bare Tank
- $LH_2$ Baseline, Bare Tank

- $LN_2$ Phase 1, Configuration
- $LN_2$ Phase 2, Configuration

Conclusions Regarding Tank "Q". In the RF modal quantity gaging approach, the "Q" (sharpness of the modal responses) is of concern because it directly affects the measurement system's ability to consistently resolve the modal resonance frequency with precision. Since the modal frequency is directly related to the mass quantity of fluid in the tank, any lack of precision in determining the modal resonance frequency causes an equal ambiguity in determining the mass quantity.

The criteria which was adopted to evaluate the suitability of mode response "Q"s was that one-half of the half-power response bandwidth should not exceed one-tenth of a percent of mode frequency change from full to empty tank conditions. In equation form:

$$\Delta f/2 \leq 0.001\ fe(1-(1-1/\epsilon^{1/2}) \quad (1)$$

Where: $\Delta f$ = Half power response bandwidth
fe = Empty tank modal frequency
$\epsilon$ = Dielectric constant of media that will fill tank

Since: $$Q = f/\Delta f \quad (2)$$

Substitution of (2) into (1) gives the "Q" criteria as:

$$Q \geq f/(0.002\ fe(1-1/\epsilon^{1/2}) \quad (3)$$

Empty tank measurements make f = fe and (3) becomes:

$$Q \geq /(0.002(1-1/\epsilon^{1/2}) \quad (4)$$

Let: $k = (1-(1/\epsilon^{1/2})$ Which gives $k = 0.1599$ for $LN_2$
$k = 0.1732$ for $LO_2$
$k = 0.0923$ for $LH_2$

And empty tank Q's of

$$Q \geq 1/(0.002 \times 0.1599) = 3{,}127 \text{ for } LN_2$$
$$Q \geq 1/(0.002 \times 0.1732) = 2{,}887 \text{ for } LO_2$$
$$Q \geq 1/(0.002 \times 0.0923) = 5{,}417 \text{ for } LH_2$$

Actual measurements of the test tank empty "Q", both warm and cold, over the frequency range of 257 to 463 MHz, provided a lowest measured "Q" of 7,804. This met the most severe criteria with sufficient margin to indicate that the combined tank/fluid "Q" would provide ample mode resolution to minimize "Q" effects on the gaging system accuracy.

Conclusions Regarding Liquid/Vapor Interface Location Sensitivity. Algorithms were developed to correct for liquid/vapor interface sensitivity. The sensitivity to liquid/vapor interface location was found to peak at 90 degrees and was symmetrical about the 90-degree axis. It was also found that the sensitivity was symmetrical about the 270-degree axis and the pattern repeated every 180 degrees. This allowed the sensitivity correction algorithms to be developed using the first three tank positions of 0, 45 and 90 degrees. Application of the correction algorithm results in a pseudo-frequency which should not vary appreciably for any given tank mass as the tank attitude is changed. How well this correction scheme worked when applied to the baseline and Phase 1 and 2 configuration data presented in Section 2 is shown in Tables 3-1 through 3-5.

Conclusions Regarding Sensitivity to Internal Components. Two configurations of internal components were investigated during the trades feasibility tests. The first configuration was identified as Phase 1 and consisted of screen acquisition channels, a start basket, and a thermodynamic vent. These internal components were metallic, nonfunctioning, scaled representations of operational hardware. The second configuration was identified as Phase 2 and consisted of all of the components of the Phase 1 configuration plus two ring slosh baffles and a longitudinal center tube.

**Table 3-1**

**$LN_2$ BASELINE BARE TANK**

**PSEUDO FREQUENCY TABLE**

Fluid: Nitrogen

| | TANK FILL LEVEL | | | | |
|---|---|---|---|---|---|
| TANK ANGLE | Wt = 861.8 FULL | Wt = 694.4 3/4 FULL | Wt = 468.5 1/2 FULL | Wt = 220.0 1/4 FULL | Wt = 4.0 EMPTY |
| 0 | 450.424 | 459.894 | 481.656 | 515.674 | 534.962 |
| 45 | 450.359 | 460.024 | 481.840 | 515.085 | 535.007 |
| 90 | 450.344 | 459.390 | 481.503 | 515.835 | 535.038 |

10232/178.31

**Table 3-2**

**$LO_2$ BASELINE BARE TANK**

**PSEUDO FREQUENCY TABLE**

Fluid: Oxygen

| | TANK FILL LEVEL | | | | |
|---|---|---|---|---|---|
| TANK ANGLE | Wt = 1168.0 FULL | Wt = 960.0 3/4 FULL | Wt = 637.0 1/2 FULL | Wt = 310.0 1/4 FULL | Wt = 4.0 EMPTY |
| 0 | 443.861 | 452.851 | 478.193 | 513.567 | 536.126 |
| 45 | 443.960 | 453.654 | 478.686 | 512.179 | 536.138 |
| 90 | 444.133 | 453.950 | 479.031 | 511.925 | 536.151 |

10232/178.21

**Table 3-3**

**$LH_2$ BASELINE BARE TANK**

**PSEUDO FREQUENCY TABLE**

Fluid: Hydrogen

| | TANK FILL LEVEL | | | | |
|---|---|---|---|---|---|
| TANK ANGLE | Wt = 75.7 FULL | Wt = 53.7 3/4 FULL | Wt = 33.4 1/2 FULL | Wt = 13.0 1/4 FULL | Wt = 1.9 EMPTY |
| 0 | 485.822 | 498.540 | 515.236 | 530.532 | 535.422 |
| 45 | 486.015 | 498.792 | 514.986 | 530.636 | 535.485 |
| 90 | 486.311 | 498.544 | 515.293 | 531.069 | 535.513 |

10232/178.22

Table 3-4

$LN_2$ PHASE 1 CONFIGURATION

PSEUDO FREQUENCY TABLE

Fluid: Nitrogen Phase I

| TANK ANGLE | TANK FILL LEVEL | | | | |
|---|---|---|---|---|---|
| | Wt = 861.7 | Wt = 686.6 | Wt = 447.0 | Wt = 215.4 | Wt = 4.0 |
| | FULL | 3/4 FULL | 1/2 FULL | 1/4 FULL | EMPTY |
| 0 | 584.976 | 595.297 | 624.812 | 667.101 | 696.594 |
| 45 | 585.204 | 594.916 | 624.769 | 671.468 | 696.526 |
| 90 | 585.729 | 594.955 | 623.836 | 670.953 | 696.573 |

10232/178.23

Table 3-5

$LN_2$ PHASE 2 CONFIGURATION

PSEUDO FREQUENCY TABLE

Fluid: Nitrogen Phase 2

| TANK ANGLE | TANK FILL LEVEL | | | | |
|---|---|---|---|---|---|
| | Wt = 822.5 | Wt = 673.1 | Wt = 440.5 | Wt = 213.5 | Wt = 4.0 |
| | FULL | 3/4 FULL | 1/2 FULL | 1/4 FULL | EMPTY |
| 0 | 746.413 | 760.638 | 796.353 | 837.685 | 884.585 |
| 45 | 474.695 | 768.078 | 793.870 | 838.858 | 884.565 |
| 90 | 745.540 | 761.100 | 796.175 | 839.093 | 884.618 |

10232/178.24

During the test sequences for Phases 1 and 2, changes were noted in the tank modal responses which were ascribed to the internal components. Specifically, Phase 1 tests results showed that:

1. The antenna 1 (polar) position became ineffective. This was traced to the very close proximity of the thermodynamic vent and the fluid acquisition channel support ring which encircled this antenna position.

2. The "Q" of the modal responses obtained at antenna positions 2 and 3 was somewhat lower than that of the corresponding bare tank responses, but was completely adequate.

In general, the Phase 1 internal component effects were benign except for blocking the antenna 1 position. Since the polar antenna position is eliminated in the Phase 2 configuration, this situation was not considered particularly serious.

Phase 2 test results indicated much more severe effects from the addition of slosh baffles and the longitudinal center tube. The center tube addition changed the fundamental modal character of the tank cavity from plain to coaxial. This change effectively reduced the population of lower frequency modes which were picked up at antenna positions 2 and 3. In addition, the "Q" of most of the modes which were picked up was significantly lower than that of typical bare tank responses, and the modal responses were of lower amplitude and much more complex. These results suggested that the added components were being coupled to the tank cavity in a lossy manner and that the degeneracy of the cavity had been significantly increased. It it anticipated that improvements in the antennas will be able to overcome most of these effects.

Conclusions Regarding Accuracy, Repeatability, and Hysteresis. The probable accuracy of the laboratory implementation of the RF modal quantity gaging system for $LO_2$ and $LH_2$ was assessed as follows:

1. The primary system errors are related as shown in the expression:
   total error = weighing system error + curve fit error + attitude error

2. The bare tank uncorrected total error for $LO_2$ and $LH_2$ can be converted to an estimated Phase 2 configuration tank value by using the ratio between the uncorrected Phase 2 full scale error and the bare tank $LN_2$ uncorrected error values from **Table 3-6**.

$$\text{The ratio:} \quad \frac{\text{Phase 2 uncorrected error}}{LN_2 \text{ uncorrected error}} = \frac{11.34\%}{7.83\%} = 1.448$$

$LO_2$ conversion: $LO_2$ uncorrected error x ratio = 9.93% x 1.448 = ±14.379%

$LH_2$ conversion: $LH_2$ uncorrected error x ratio = 11.23% x 1.448 = ±16.261%

3. The degree of correction for the liquid/vapor interface location can be estimated by noting the ratio between Phase 2 uncorrected and Phase 2 third order corrected error values from **Table 3-6**.

The ratio: $\dfrac{\text{Phase 2 uncorrected error}}{\text{Phase 2 third order corrected}} = \dfrac{11.34\%}{3.65\%} = 3.110$

$LO_2$ estimated corrected value: 14.379%/3.110 = ±4.623%

$LH_2$ estimated corrected value: 16.261%/3.110 = ±5.229%

4. The additional correction that could be obtained by correcting the curve fit by use of eighth order fittings can be estimated by noting the ratio between $LN_2$ third order and eighth order correction values from **Table 3-6**.

The ratio: $\dfrac{LN_2 \text{ third order}}{LN_2 \text{ eighth order}} = \dfrac{1.05\%}{0.68\%} = 1.544$

$LO_2$ estimate: 4.623%/1.544 = ±2.994%

$LH_2$ estimate: 5.229%/1.544 = ±3.387%

5. The weighing system accuracy effects can be removed to obtain the worst peak error values for the propellants by using the expression from 1, and noting that the weighing system errors have been estimated to be ±0.5 percent for $LO_2$ and ±1.75 percent for $LH_2$ worst case.

$LO_2$: 2.994 - 0.5 = ±2.49%

$LH_2$: 3.387 - 1.75 = ±1.64%

These are the probable worst-case peak full-scale error values for $LO_2$ and $LH_2$. Anticipated improvements to Phase 2 correction performance will directly influence these values.

Repeatability of the system was very good and was sensitive enough to detect tank dimensional changes due to temperature or pressure excursions, and the small vapor density changes traceable to pressurant gas throttling to maintain constant tank pressure.

No hysteresis effects were noted during the trades feasiblity testing.

**Table 3-6**
**UNCORRECTED AND CORRECTED FULL-SCALE ERROR**

| CONFIGURATION | APPARENT FULL-SCALE ERROR (%) | 3RD ORDER FULL-SCALE ERROR (%) | 8TH ORDER FULL-SCALE ERROR (%) |
|---|---|---|---|
| $LN_2$ (bare tank) | 7.83 | 1.05 | 0.68 |
| $LO_2$ | 9.93 | 1.61 | |
| $LH_2$ | 11.23 | 0.92 | |
| Phase 1 | 8.82 | 2.61 | |
| Phase 2 | 11.34 | 3.65 | |

### 3.2.2 Feasibility Testing Supporting Design

The primary objective of the design feasibility tests was to obtain experimental data to develop and verify design approaches to flange-mounted antenna and fluid mass computational algorithms. Conclusions reached following examination and analysis of the test data are provided below.

Conclusions Regarding Flange-Mounted Antenna. Mechanical and electrical performance testing of the ISO-KF flanged antenna design approach indicated that it was easily capable of meeting all design objectives. As a bonus, the more extensive than planned antenna element changes during the mode response investigative experiments provided proof that the design's indium flange seal was very tolerant to reuse.

Conclusions Regarding Mass Computational Algorithms. Analysis of the video recordings of the spectrum analyzer display during the further modal response testing undertaken in this test sequence led to three conclusions:

1. Modal responses from both antenna positions would be required to provide at least two coordinated modal frequencies at any tank fill level/attitude combination.

2. The best "low" frequency modal segment range would be 124 to 155 MHz.

3. The best "high" frequency modal segment range range would be 210 to 260 MHz.

The mass computational algorithm was developed based on a correction correlation matrix which used the measured high mode frequency to determine the matrix row, and the difference between fluid mass computed for high mode and low mode frequencies to determine the matrix column. The identified row and column provided a correction to be added to the fluid mass computed using the high mode frequency. The accuracy obtained using this algorithm is illustrated below.

| PERCENTAGE OF READINGS | ACCURACY |
|---|---|
| 75 | 1% or better |
| 21 | 1% to 2% |
| 4 | 2% to 2.5% |

Obviously, expanding the correlation matrix to 17x16 or incorporating interpolation schemes to accomplish an equivalent increase in resolution would result in achieving the target 1 percent accuracy.

The algorithm is straightforward and can be easily implemented in a microprocessor-based signal conditioner. In addition, the approach can be readily adapted to differing tank configurations by simply changing the contents of a data ROM. The approach will require a degree of experimental calibration of the tank, but the data required is basic, requires little manipulation, and is defined by the approach. It is expected that the approach can be scaled between cryogenic nitrogen, oxygen, and hydrogen by analysis once experimentally calibrated in any one of the fluids. The computer simulation of the algorithm agreed with the expected results in all particulars. These results also indicated that the approach would have no problem with converting any two of the measured coordinated modal response frequencies to a computed fluid weight in the tank with a full-scale accuracy of one percent, and that the required correction matrix would not have to be any larger than 17x16.

In obtaining the modal data for the algorithm development, the following design-specific conclusions were also developed:

1. Internal secondary volumes with conducting walls and any openings to the main tank volume should be avoided. If they cannot be avoided, all openings to the main tank volume should be closed or, as a minimum, covered with conducting mesh or screen.

2. Casual electrical contact between metallic constructs inside a tank should be avoided. The connections should be prevented or well made, but not allowed to be intermittent.

3. Optimum location and active element configuration of the tank antenna were not conclusively resolved in the testing accomplished to date. In addition, use of the universal test tank for further work in this area would be difficult and expensive. It is felt that some form of bench-top tank/antenna model testing would be more appropriate.

4. The fluid interface configurations obtainable by rotating a tank partially filled with liquid in a one-gravity environment does not expose a potential gaging system to most of the more provocative interface configurations which might be encountered in a near-zero or zero-gravity situation. Again, a bench-top test of not-too-small scale, using paraffin to model more realistic fluid interface configurations, could be used to investigate this issue more thoroughly.

### 3.2.3 Bench-Top Testing

The purpose of the bench-top tests was to obtain modal response data for liquid/vapor interface configurations more nearly representative of zero-gravity conditions; use the data to develop a more simplified mass computation algorithm; and then challenge the algorithm with a random orientation set of data. Feasibility of the RF modal approach would be judged on its ability to demonstrate at least ±5 percent accuracy under these conditions. The flow diagram for the algorithm which was developed is shown in Figure 3-1.

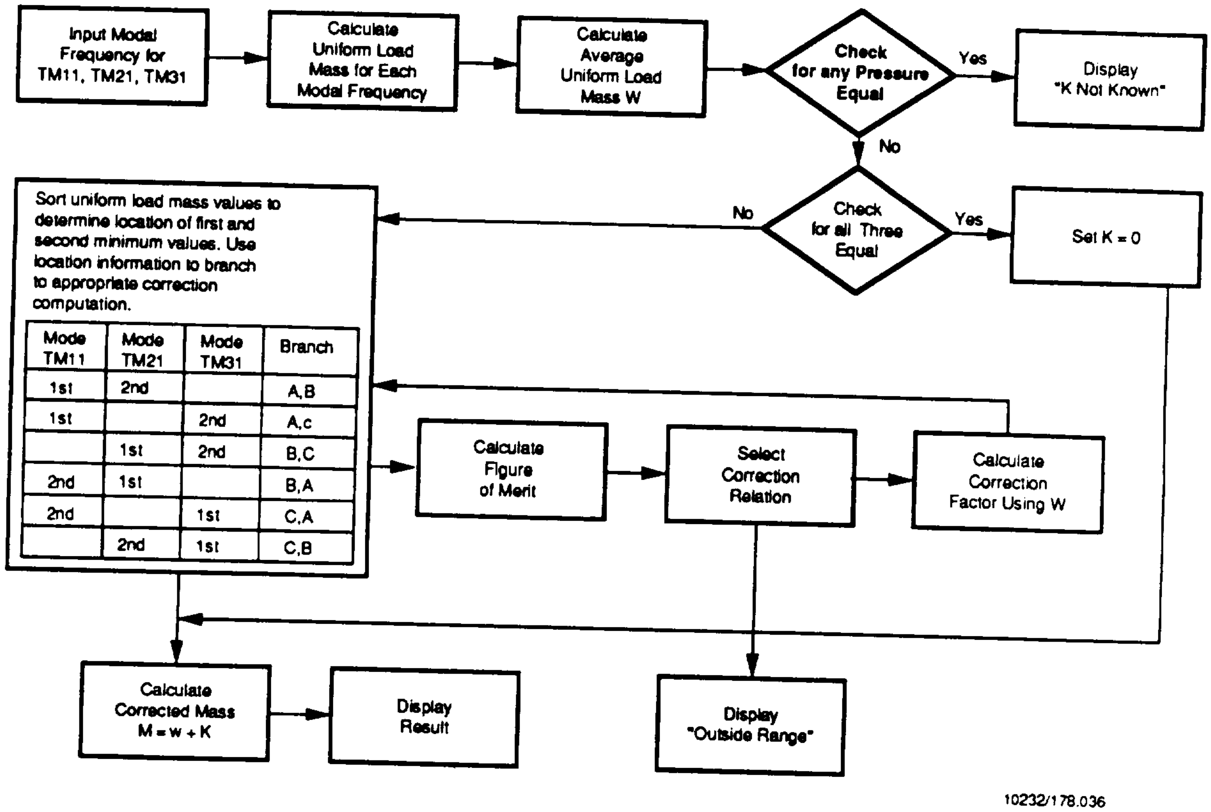



Figure 3-1.-Mass computation algorithm flow diagram.

Conclusion Regarding Bench-Top Tests. Performance of the RF modal quantity gaging approach met the objectives of the bench-top tests and demonstrated the ability to determine all test quantity values within ±3.0 percent. All random configuration values were determined to within ±2.0 percent. The gaging approach feasibility was verified.

## 3.3 INTERFACE REQUIREMENTS CONCLUSIONS

The objective of providing a documented set of gaging system interface requirements was completely met to the extent that specific NASA-JSC test hardware designs were available.

## 3.4 GAGING SYSTEM DESIGN CONCLUSIONS

The design of an RF modal quantity gaging system is completely within the capabilities of current electronic design techniques. The design does not require any unique or special materials or processes. The only interface with cryogenic fluids occurs at the system antennas, and the design developed has been demonstrated to be fluid compatible, leaktight, minimally invasive, and have very little impact on cryogenic performance of the gaged tankage.

Development of the integrated RF modal gaging algorithm was completed with the design of a method for identifying the three appropriate lowest TM modes from the full scan of modal responses. The resulting integrated algorithm was demonstrated to have an accuracy well within the ±5 percent feasibility limit.

## 3.5 OVERALL PROGRAM CONCLUSIONS

Program test results have shown that the RF modal quantity gaging approach has successfully survived the challenges to its feasibility. Reduction of the gaging approach to specific hardware should pose no significant problems to currently available technology. Overall, the program has accomplished the following:

- Selected the RF modal quantity gaging approach as the most suitable for large low- or zero-gravity propellant tankage for two-phase cryogenic oxygen and hydrogen.
- Challenged the selected gaging approach feasibility extensively with cryogenic fluid and paraffin simulations of zero-gravity fluid/vapor interface configurations to demonstrate the viability of the approach.
- Developed and demonstrated the computational algorithms required to implement the selected gaging approach.
- Demonstrated that the approach can be accurately scaled and modeled, which permits testing and verification of potential applications using laboratory models and test equipment.

# Section 4
# RECOMMENDATIONS

The need for developed quantity gaging systems appropriate for use on large, on-orbit, two-phase cryogenic propellant tanks is now more imperative than ever. Promising approaches in this area are rare, and approaches with demonstrated cryogenic performance are even rarer. The RF modal quantity gaging technology development has survived rigorous challenges to its feasibility and is at the point where actual low-gravity testing in KC-135 would be a logical next step.

We therefore recommend that the RF modal gaging approach be subjected to KC-135 low-gravity tests. We believe that a laboratory equipment implementation of the gaging electronics, operating under computer control and augmented with simple antenna switching capability, would be sufficient to gage the contents of a foam-insulated $LN_2$ dewar aboard the NASA-JSC KC-135 aircraft.

Also, the potential for using artificial neural network technology as a more accurate and much faster method for algorithm development should be further investigated.

## Section 5
## PROGRAM EXPOSITION

The Zero-Gravity Quantity Gaging System program was a technology development effort funded by NASA-LeRC and contracted by NASA-JSC to develop and evaluate zero-gravity quantity gaging system concepts suitable for application to large, on-orbit cryogenic oxygen and hydrogen tankage. The contract effective date was May 28, 1985.

Program efforts were to investigate, study, and select the best qualified gaging concept or group of concepts suitable for application to large, on-orbit cryogenic oxygen and hydrogen tankage, as well as the CFMF liquid hydrogen receiver tank. The selected concept(s) was to be subjected to rigorous feasibility testing followed by design of the development gaging system(s).

In addition, the contractor was to prepare and maintain a formal interface control document to regulate the development gaging system/test facility interfaces.

Potential quantity gaging approaches were investigated and subjected to a comprehensive trade study and selection process, which found that the RF modal quantity gaging approach was the most suitable for both liquid oxygen and liquid hydrogen applications. These findings were made with NASA-JSC concurrence.

The selected RF modal approach was subjected to an extensive and rigorous feasibility test program including testing with $LN_2$, $LO_2$, and $LH_2$, as well as paraffin simulation of zero-gravity fluid orientations. Algorithms required to apply the gaging approach were developed and tested, including referee test cases. The feasibility tests demonstrated the acceptability of the approach.

Design of a development RF modal gaging system was begun and was 53 percent complete when program funding constraints placed further work on hold.

An interface control document was prepared and submitted to NASA-JSC for their review and their inclusion of specific design data for the NASA-JSC ground and KC-135 test tankage. Because they have not yet designed this tankage, the review cycle has not been completed.

This report is the final report for these activities and the Quantity Gaging program.

## 5.1 OVERVIEW

This overview is provided to specifically address problems or program changes that caused significant changes from the original program definitions contained in Figures 5-1 and 5-2.

Program Task 1 was accomplished exactly as shown in the logic diagram of Figure 5-2. No program difficulties or changes were encountered. The completion of Task 1 activities overlapped the beginning of Tasks 2, 3, and 4 efforts.

Program Task 2, Feasibility Testing in Support of Trades and Design, encountered the following problems. Difficulties in the area of test hardware design included: (1) resolving the need for a take-apart pressure vessel by developing a reweldable equatorial flange, (2) modifying the wiring and insulation system design of the tank rotation motor to eliminate vacuum-induced arcing, and (3) converting the seals for the test antenna from CONX glands to hermetic seals to achieve acceptable leakage rates. Also, difficulties in finding a room temperature test fluid were encountered when the test fluid of record, benzine, was determined to be unacceptable for use in KC-135 flights. Subsequent testing of what appeared to be the most promising and acceptable substitute, Shell DIALA-AX oil, found that its loss tangent was too high to provide acceptable system operation. Program time constraints made it necessary to perform the room temperature simulant portion of the feasibility testing with liquid nitrogen instead. The bench-top test series was added to Task 2 as major subtask 2.3, with detail elements identical to those under

**Zero-Gravity Quantity Gaging System for Cryogenic Fluids**

- **Task 1 Analysis and Trade Studies**
  - 1.1 Candidate concept development
    - 1.1.1 Re-evaluate past concepts
      - 1.1.1.1 Research
      - 1.1.1.2 Identify concepts
      - 1.1.1.3 Define operating principles
      - 1.1.1.4 Characterize
      - 1.1.1.5 Assess state-of-art
    - 1.1.2 Integrated approaches
      - 1.1.2.1 Research
      - 1.1.2.2 Identify concepts
      - 1.1.2.3 Define operating principles
      - 1.1.2.4 Characterize
      - 1.1.2.5 Assess state-of-art
    - 1.1.3 Screen for most promising approaches
    - 1.1.4 Provide data to trade studies
  - 1.2 Selection criteria development
    - 1.2.1 Develop criteria definitions
      - 1.2.1.1 Design requirements
      - 1.2.1.2 State-of-art
      - 1.2.1.3 Development risk
      - 1.2.1.4 Producibility
      - 1.2.1.5 Development effort
    - 1.2.2 Develop evaluation methods
    - 1.2.3 JSC review selection criteria
      - 1.2.3.1 Modify with JSC comments
  - 1.3 Perform trade studies
    - 1.3.1 Initiate trade studies
      - 1.3.1.1 Evaluate trade results
      - 1.3.1.2 Identify option $H_2/O_2$ approaches
      - 1.3.1.3 Document selection
      - 1.3.1.4 Develop detailed definition
      - 1.3.1.5 Prepare selection presentation
      - 1.3.1.6 Modify based on JSC
    - 1.3.2 Define feasibility test requirements
      - 1.3.2.1 Write test requests (ETR)
- **Task 2 Feasibility Testing**
  - 2.1 Feasibility testing support trades
    - 2.1.1 Produce test plan
    - 2.1.2 Define test items
    - 2.1.3 Design test items
    - 2.1.4 Produce test item BOM
    - 2.1.5 Fabricate test items
    - 2.1.6 Design test fixtures
    - 2.1.7 Produce fixture BOM
    - 2.1.8 Fabricate test fixtures
    - 2.1.9 Write test procedure
    - 2.1.10 Set up test/ calibrate
    - 2.1.11 Conduct tests
    - 2.1.12 Reduce test data
    - 2.1.13 Document test report
  - 2.2 Feasibility testing support design
    - 2.2.1 Produce test plan
    - 2.2.2 Define test items
    - 2.2.3 Design test items
    - 2.2.4 Produce test item BOM
    - 2.2.5 Fabricate test items
    - 2.2.6 Write test procedure
    - 2.2.7 Set up test/ calibrate
    - 2.2.8 Conduct tests
    - 2.2.9 Reduce test data
    - 2.2.10 Document test report
  - 2.3 Bench-top testing
    - 2.3.1 Produce test plan
    - 2.3.2 Define test items
    - 2.3.3 Design test items
    - 2.3.4 Produce test item BOM
    - 2.3.5 Fabricate test items
    - 2.3.6 Conduct tests
    - 2.3.7 Reduce test data
    - 2.3.8 Document test report
- **Task 3 Interface Requirements**
  - 3.1 Establish interface requirements
    - 3.1.1 Identify requirements
    - 3.1.2 Coordinate with TTA
    - 3.1.3 Incorporate JSC comments
  - 3.2 Document interface requirements
    - 3.2.1 Prepare document
    - 3.2.2 Submit JSC review
  - 3.3 Maintain interface requirements
    - 3.3.1 Update document with JSC approval
- **Task 4 Gaging System Design**
  - 4.1 Prepare design specification
  - 4.2 Design development gaging system
    - 4.2.1 Trade-off details
    - 4.2.2 Complete preliminary design
    - 4.2.3 In-house review
    - 4.2.4 Incorporate review results
    - 4.2.5 Complete development design
    - 4.2.6 Assess design
    - 4.2.7 Document design assessment
    - 4.2.8 Submit design for JSC approval
    - 4.2.9 Incorporate JSC comments
    - 4.2.10 Identify changes to interface document
  - 4.3 Mode tracking and identification algorithm development
    - 4.3.1 Use bench-top test data
    - 4.3.2 Develop track and ID algorithm
    - 4.3.3 Integrate with mass computation
    - 4.3.4 RF modal demonstration program preparation
- **Task 5 Program Management**
  - 7.1 Conference/meetings
    - 7.1.1 JSC formal program reviews (7)
      - 7.1.1.1 Prepare viewgraphs
      - 7.1.1.2 Present review at JSC
    - 7.1.2 JSC informal meetings (1)
  - 7.2 Reporting
    - 7.2.1 Program plan
    - 7.2.2 Monthly (17)
      - 7.2.2.1 Financial
      - 7.2.2.2 Technical
    - 7.2.3 Data dump report
    - 7.2.4 Experimental test plan
    - 7.2.5 Final report

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Figure 5-1.-Program task breakdown structure.

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2.2 in the WBS shown in Figure 5-1. The data base obtained during the bench-top tests was also used to develop the mode tracking and identification algorithm described in Section 5.5.3 of this report.

Program Task 3, Interface Requirements, resulted in the preparation of a comprehensive Interface Control Document based on the requirements that were articulated by NASA-JSC Thermochemical Test Area (TTA) personnel. The document was submitted for NASA review.

Program Task 4, Gaging System Design efforts, did result in complete partitioned design schematics, parts requirements, packaging design, mass computation software, and full antenna design development.

For Program Task 7, Program Management, full effort has been provided to the level required by program activity. All required document submittals have been made.

## 5.2 TASK 1 - ANALYSIS AND TRADE STUDIES

Activities undertaken in this task were the parallel development of JSC-approved candidate concepts and selection criteria which were used in the subsequent trade studies. The trade study effort included the assessment of four single and three integrated concepts for oxygen systems, and three single and one integrated concept for hydrogen systems. Results of the trade study effort, along with conclusions and recommendations for the mass quantity gaging concept to be carried into development, were formally presented at the second Program Review on January 30, 1986.

Task 1 activities initiated the program effort following the contract kickoff meeting on June 17, 1985 and were the only activities, except for supporting program management tasks, until the beginning of the trade study effort which began in September 1985. During the trade study, analyses supporting feasibility testing activities were begun which continued through April 1986. The results of the trade study were documented in a summary descriptive data report issued February 4, 1986.

### 5.2.1 Subtask 1.1 - Candidate Concept Development

A data base of candidate quantity gaging concepts was developed with emphasis on concepts successfully used in the past and on possible advantageous combinations of proven concepts. Candidates from this data base were subjected to a preliminary screening to select the most promising for further evaluation in the trade study efforts. Results of this activity were documented in "Literature Search and Preliminary Review of Potential Concepts." A copy of this document is included in Appendix B of this report.

### 5.2.2 Subtask 1.2 - Section Criteria Development

The specific method for conducting the trade study evaluation of the most promising candidate concepts was developed in complete detail and presented to NASA-JSC for review. The results of this review were incorporated into the method, and it was released with NASA approval as DD 17392A "Zero-Gravity Quantity Gaging System Selection Criteria." A copy of this document is included in Appendix B of this report.

### 5.2.3 Subtask 1.3 - Perform Trade Studies

The methods of the approved selection criteria were applied to the seven oxygen and four hydrogen concepts selected during the candidate concept development activities. The results of this trade study activity resulted in selection of the RF modal quantity gaging concept to be carried forward into development for both oxygen and hydrogen systems. The detail results of the trade analyses, the conclusions, and the recommendations were documented in DD18024 "Summary Document Zero-Gravity Quantity Gaging Systems Trade Study." A copy of this document is included in Appendix B of this report.

## 5.3 TASK 2 - FEASIBILITY TESTING

Activities making up this task included feasibility testing in support of the trade study efforts of Task 1 and feasibility testing in support of the design efforts of Tasks 3 and 4. A series of bench-top tests were added to this task to further validate the results of the trade study effort of Task 1. All feasibility testing efforts included test plans, test item design and fabrication, test procedures, data reduction analysis, and a test report.

Task 2 activities were initiated in early September 1985 and continued through September 30, 1986, when testing was terminated on the design feasibility test series prior to completion of the planned activities. The added bench-top test activities were initiated March 10, 1987 and the test report was released in May 1988.

### 5.3.1 Subtask 2.1 - Feasibility Testing in Support of Trades

Test plans, procedures, equipment, and facilities were prepared to gain experimental assessment of the probable accuracy, repeatability, and hysteresis of the RF modal gaging approach, as well as its sensitivity to variations in fluid location and tankage internal components. Three cryogenic fluids ($LN_2$, $LO_2$, and $LH_2$) and one room temperature fluid (DIALA-AX oil) were evaluated in these tests. There were three configurations of the test tank: (1) empty, (2) with dummy start basket, fluid acquisition channels, and thermodynamic vent, and (3) all the components of (2) plus two slosh baffles and a longitudinal center tube.

Test results showed that the RF modal approach was feasible, that it worked well with the cryogenic fluids, that DIALA-AX was not usable as a room temperature test fluid, and that the gaging approach was sensitive to fluid location and tank internal components but that this could be overcome. A copy of the Trades Feasibility Test Plan and Procedure are included in Appendix C of this report. A full report of the "Feasibility Testing in Support of Trades" is contained in the Beech Aircraft Corporation Engineering Test Report ER18036, issued April 30, 1986.

### 5.3.2 Subtask 2.2 - Feasibility Testing in Support of Design

Test plans and procedures were prepared which made use of the equipment and facilities from the trades feasibility test program to further develop and verify antenna mechanical design and placement and orientation issues, and to investigate modal response behavior for fill levels and tank attitudes not evaluated in the trades testing.

Test results showed that an antenna design suitable for use with the development RF modal gaging system had been successfully developed. Also, the additional modal response testing was used to develop a NASA-requested computer simulation of a mass computational algorithm which was capable of ±1 percent of full-scale accuracy. The Design Feasibility Test Plan and Procedure are included in Appendix D of this report. A full report of the feasibility testing in support of design, including the mass computational algorithm and computer simulation program, is contained in the Beech Aircraft Corporation Interim Engineering Test Report ER18050, issued September 30, 1986.

### 5.3.3 Subtask 2.3 - Bench-top Testing

This task was added to the original feasibility testing efforts to provide a more realistic verification of the RF modal gaging approach, to accurately deal with zero-gravity fluid/vapor interface configurations such as single-bubble wet wall and multiple globules. The feasibility cut-off limit on gaging accuracy under these conditions was set by NASA at ±5 percent of full scale. The accuracy assessment included five reference test cases which were not used in the development of the mass computational algorithm. Thirty-six different test configurations were tested using paraffin to simulate zero-gravity fluid configurations. Ambient air simulated the fluid vapor. Thirty-one test configurations were used to develop the gaging mass computational algorithm, which was reduced to a small BASIC computer program using only the three lowest TM modal response frequencies as input. The feasibility of the approach was tested by assessing the accuracy of the computerized algorithm to calculate the mass of each of the 36 test configurations. The results indicated an average accuracy of better than ±0.9 percent, with only one case in the ±2.5 percent to ±3.0 percent range. A presentation of the bench-top testing activities was made to NASA-JSC on March 23, 1988. A copy of the bench-top tests statement of work (SOW) is included in Appendix G of this report. A full report of the bench-top testing activity is contained in Ball Aerospace Systems Group (BASG) Engineering Report #ZG-011, issued in May 1988.

## 5.4 TASK 3 - INTERFACE REQUIREMENTS

The primary objective of this task was to establish and formally document the interface requirements between the development gaging system being designed and built by the contractor and the test tankage and test facilities being provided by the NASA-JSC TTA. The interface requirements document was to provide key inputs to the development gaging system design specification of Task 4.

### 5.4.1 Subtask 3.1 - Establish Interface Requirements

As a result of three coordination meetings with TTA personnel (the major one occurring January 31, 1986) at NASA-JSC, it was decided that the contractor prepare an Interface Requirements Document with suggested approaches to the ground and KC-135 test tankage for NASA-JSC review. Areas in the document requiring specific NASA input were to be specifically identified as NASA-TBD.

### 5.4.2 Subtask 3.2 - Document Interface Requirements

An Interface Requirements Document was prepared following the suggested approach of paragraph 5.4.1 above, and was issued March 7, 1986 for NASA review and comments. A copy of the submitted document is included as Appendix E of this report.

### 5.4.3 Subtask 3.3 - Maintain Interface Requirements

Because a NASA-approved Interface Requirements Document was never released, no document existed to maintain.

## 5.5 TASK 4 - GAGING SYSTEM DESIGN

Activities undertaken in this task included completion of a working draft of the development gaging system design specification, which was used to prepare the Interface Requirements Document of Task 3. Also, a significant amount of work on preparing a structured development gaging system design was completed. In September 1988, an effort to develop a mode tracking and identification algorithm using the bench-top testing data base was added to the Task 4 work breakdown.

### 5.5.1 Subtask 4.1 - Design Specification Preparation

A working draft of the development gaging system design specification was prepared and used to support the Interface Requirements Document provided to NASA in March 1986.

### 5.5.2 Subtask 4.2 - Development Gaging System Design

Efforts in this area followed the activity plans shown in Figures 5-3, 5-4, and 5-5. Summaries of the actual work accomplished in each of these planned design areas are as follows.

Using the interface requirements and the results of the trades and design feasibility testing allowed completion of a conceptual RF modal gaging system schematic. This allowed creation of a major components bill of materials (BOM) and subsequent component specifications, and generation of a selected suppliers list with cost and lead time information. The preliminary circuit was partitioned for compatibility with the selected packaging concept and printed circuit board considerations. Detail circuit design work and preliminary packaging work was getting underway when the design effort was placed on hold. A matrix of potential microprocessor development approaches had been prepared, but selection had not been accomplished. Appendix F of this report provides partitioned schematics, a major item BOM with suppliers costs and lead time information, signal conditioner case vendor data, and microprocessor development systems approach options data.

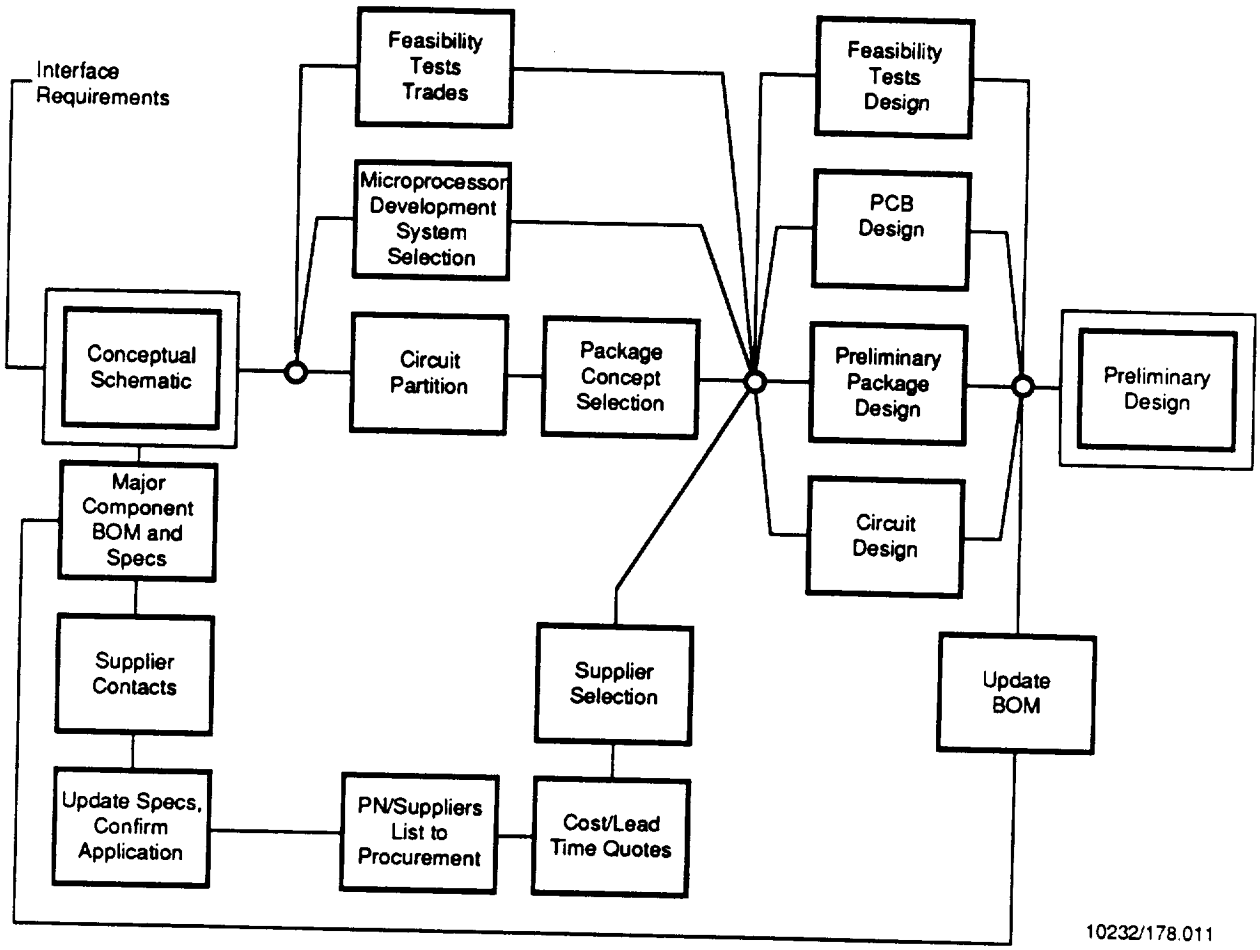


**Figure 5-3.-Signal conditioner design plan.**

Using the interface requirements and the trades and design feasibility testing results allowed completion of the development gaging system antennas design. The design was completed, antennas were fabricated, and their mechanical and electrical performance was verified by cryogenic testing with $LH_2$. Appendix F of this report provides copies of TCOs and drawings used to build the tested antennas. The test results are included in the Beech Aircraft Corporation Interim Engineering Test Report ER18050, issued September 30, 1986.

At the time that the work on the design tasks had been placed on hold, the final selection of the microprocessor development system had not been made. Because this selection significantly impacted the definition of software requirements, the only work that had been completed on software development

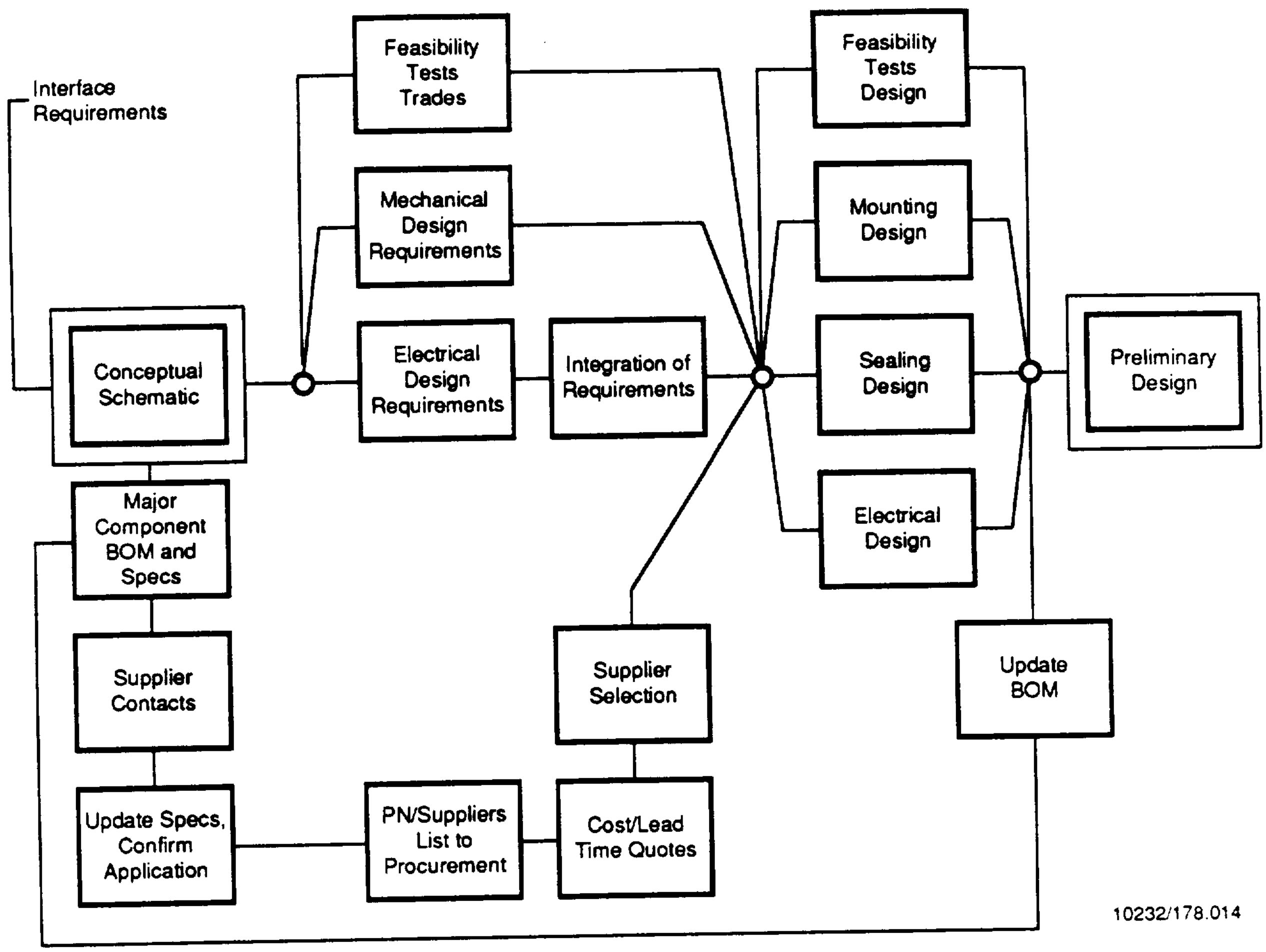


Figure 5-4.-Antenna design plan.

was the actual mass computational algorithm which resulted from the trades and design feasibility testing. In addition, some of the precursor signal conditioner control routines had been developed as a result of using computer-controlled testing during the feasibility tests. A significant hole in the software design at this point was the lack of a developed mode identification and tracking algorithm.

### 5.5.3 Subtask 4.3 - Mode Tracking and Identification Algorithm Development

Because of the obvious need for a mode tracking and identification algorithm to allow full definition of a workable RF modal gaging system, tasking was

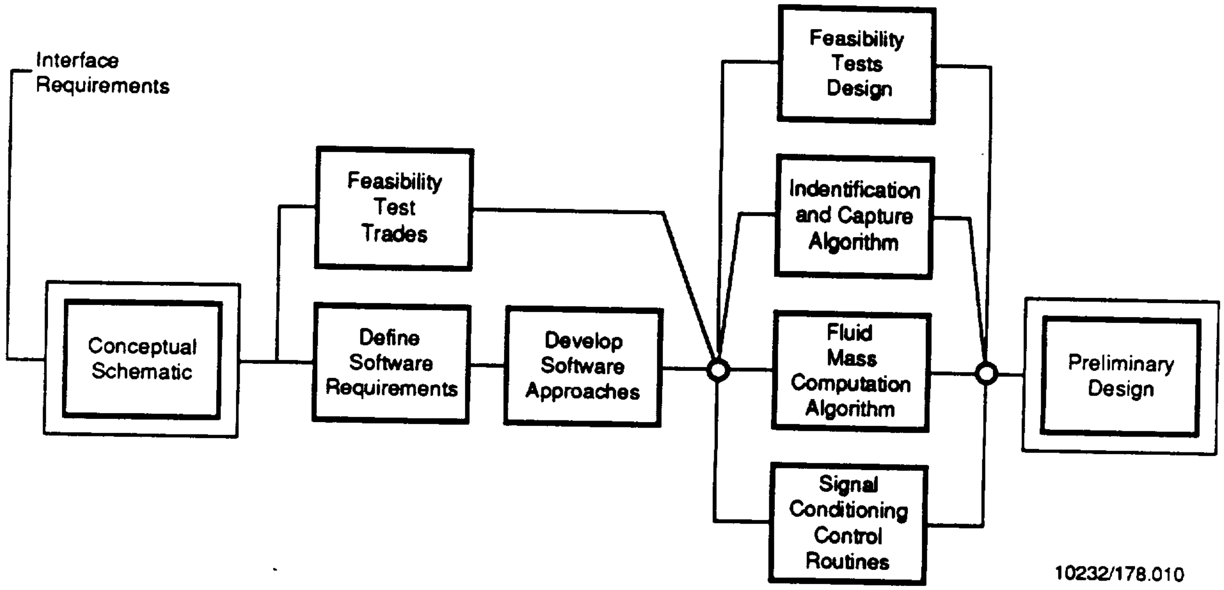


**Figure 5-5.-Software design plan.**

authorized in September 1988 to begin work on this last algorithm. The requirements for this effort were to:

- Use the bench-top test data base for algorithm development.
- Develop the algorithm using the same 31 test configurations used to develop the bench-top mass computational algorithm.
- Integrate the mass computational and mode tracking and identification algorithms and test using all 36 test configurations. Combined performance was to provide *5 percent of full-scale accuracy to be considered a viable approach.
- The integrated algorithm was to be programmed in BASIC as a Demonstration Program and supplied to NASA-JSC.

All of the mode tracking and identification algorithm development tasks were completed as planned. The development results were presented to NASA-JSC on April 19, 1989. Appendix H of this report contains the material used for this presentation and a copy of the demonstration program user's manual. The development algorithm was capable of determining loaded tank mass to within *3.5 percent of full load.

## 5.6 TASK 7 - PROGRAM MANAGEMENT

Activities undertaken in this task included the management of all program activities undertaken by Beech Aircraft Corporation and following, Ball Aerospace Systems Group, to fulfill the contractual requirements of NAS9-17378. In addition to management activities, this task also included formal program review presentations to NASA-JSC, support to informal meetings and visits, and formal reporting requirements. This report fulfills the last data requirements list item prior to close out of the contracted effort. All other authorized contractual requirements have been completed. Appendix I of this report includes a copy of the JANNAF 1989 meeting paper and supporting presentation viewgraphs. Preparation and presentation of this material was requested by NASA-JSC.

# Appendix A

Beechcraft
Boulder Division

# Beech Aircraft Corporation

Boulder, Colorado

**Code Ident. No. 07399**

BEECH AIRCRAFT CORPORATION

PROGRAM PLAN

ZERO GRAVITY QUANTITY GAGING SYSTEM

CONTRACT NUMBER NAS9-17378

Engineering Report
ER 17386

Issue Date: June 14, 1985
Revision A issued September 10, 1985

Approved By:

V. E. Isakson
Program Manager

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# 1.0 INTRODUCTION

1.1 Description of Program. The primary objective of this effort is to develop and evaluate zero-gravity quantity gaging system concepts, having one percent or better accuracy for application to large, on-orbit cryogenic oxygen and hydrogen tankage. The most immediate application of efforts under this contract will be the acceleration of technology suitable for providing zero-gravity quantity gaging for the CFMF experiment. As a results, this contracted effort addresses the development phase of a three-phase program which will provide a flight qualified zero-gravity gaging system for the CFMF when required.

The scope of effort covered by this contract includes contractor supplied analyses, trade studies, evaluation/selection and feasibility testing, leading to the design, fabrication, acceptance testing of development hardware, and support to NASA-JSC during ground and KC-135 zero-gravity aircraft testing of a development zero-gravity quantity gaging system.

This work is being conducted under contract NAS9-17378 of the Johnson Space Center under the guidance of Ronald Kahl, Technical Monitor.

1.2 Program Plan. The Program Plan as presented in this document consists of seven major tasks as shown in the Work Breakdown Structure (Figure 1). Each task is described and the input/output data expected is delineated for each of the tasks through the second level of the WBS. The interrelations of each of the major tasks is depicted in the Program Logic Diagram shown in Figure 2. The Program Milestone Schedule is presented in Figure 3 through the second level of the WBS. Schedule comments are contained in each of the task and subtask descriptions.

Paragraph 8.0 outlines our anticipated manhour expenditures for each of the first level WBS tasks throughout the program.

Updates to the schedule status and actual manhour utilization will be made in the Monthly Progress Reports for the duration of the program.

# ZERO-GRAVITY QUANTITY GAGING SYSTEM FOR CRYOGENIC FLUIDS

- **TASK 1 — ANALYSIS AND TRADE STUDIES**
  - 1.1 CANDIDATE CONCEPT DEVELOPMENT
    - 1.1.1 RE-EVALUATE PAST CONCEPTS
      - 1.1.1.1 RESEARCH
      - 1.1.1.2 IDENTIFY CONCEPTS
      - 1.1.1.3 DEF OPERATING PRINCIPLES
      - 1.1.1.4 CHARACTERIZE
      - 1.1.1.5 ASSESS STATE-OF-ART
    - 1.1.2 INTEGRATED APPROACHES
      - 1.1.2.1 RESEARCH
      - 1.1.2.2 IDENTIFY CONCEPTS
      - 1.1.2.3 DEF OPERATING PRINCIPLES
      - 1.1.2.4 CHARACTERIZE
      - 1.1.2.5 ASSESS STATE-OF-ART
    - 1.1.3 SCREEN FOR MOST PROMISING APPROACHES
    - 1.1.4 PROVIDE DATA TO TRADE STUDIES
  - 1.2 SELECTION CRITERIA DEVELOPMENT
    - 1.2.1 DEVELOP CRITERIA DEFINITIONS
      - 1.2.1.1 DESIGN REQUIREMENTS
      - 1.2.1.2 STATE-OF-ART
      - 1.2.1.3 DEVELOPMENT RISK
      - 1.2.1.4 PRODUCIBILITY
      - 1.2.1.5 DEVELOPMENT EFFORT
    - 1.2.2 DEV EVALUATION METHODS
    - 1.2.3 JSC REVIEW SELECTION CRITERIA
      - 1.2.3.1 MODIFY WITH JSC COMMENTS
  - 1.3 PERFORM TRADE STUDIES
    - 1.3.1 INITIATE TRADE STUDIES
      - 1.3.1.1 EVALUATE TRADE RESULTS
      - 1.3.1.2 IDENT OPT H2/O2 APPROACHES
      - 1.3.1.3 DOCUMENT SELECTION
      - 1.3.1.4 DEV DETAILED DEFINITION
      - 1.3.1.5 PREPARE SELECTION PRESENTATION
      - 1.3.1.6 MODIFY BASED ON JSC
    - 1.3.2 DEF FEASIBILITY TEST REQUIREMENTS
      - 1.3.2.1 WRITE TEST REQUESTS(ETR)
- **TASK 2 — FEASIBILITY TESTING**
  - 2.1 FEASIBILITY TESTING SUPPORT TRADES
    - 2.1.1 PRODUCE TEST PLAN
    - 2.1.2 DEFINE TEST ITEMS
    - 2.1.3 DESIGN TEST ITEMS
    - 2.1.4 PRODUCE TEST ITEM BOM
    - 2.1.5 FABRICATE TEST ITEMS
    - 2.1.6 DESIGN TEST FIXTURES
    - 2.1.7 PRODUCE FIXTURE BOM
    - 2.1.8 FABRICATE TEST FIXTURES
    - 2.1.9 WRITE TEST PROCEDURE
    - 2.1.10 SET-UP TEST/CALIBRATE
    - 2.1.11 CONDUCT TESTS
    - 2.1.12 REDUCE TEST DATA
    - 2.1.13 DOCUMENT TEST REPORT
  - 2.2 FEASIBILITY TESTING SUPPORT DESIGN
    - 2.2.1 PRODUCE TEST PLAN
    - 2.2.2 DEFINE TEST ITEMS
    - 2.2.3 DESIGN TEST ITEMS
    - 2.2.4 PRODUCE TEST ITEM BOM
    - 2.2.5 FABRICATE TEST ITEMS
    - 2.2.6 WRITE TEST PROCEDURE
    - 2.2.7 SET-UP TEST/CALIBRATE
    - 2.2.8 CONDUCT TESTS
    - 2.2.9 REDUCE TEST DATA
    - 2.2.10 DOCUMENT TEST REPORT
- **TASK 3 — INTERFACE REQUIREMENTS**
  - 3.1 ESTABLISH INTERFACE REQUIREMENTS
    - 3.1.1 IDENTIFY REQUIREMENTS
    - 3.1.2 COORDINATE WITH TTA
    - 3.1.3 INCORPORATE JSC COMMENTS
  - 3.2 DOCUMENT INTERFACE REQUIREMENTS
    - 3.2.1 PREPARE DOCUMENT
    - 3.2.2 SUBMIT JSC REVIEW
  - 3.3 MAINTAIN INTERFACE REQUIREMENTS
    - 3.3.1 UPDATE DOCUMENT WITH JSC APPROVAL
- **TASK 4 — GAGING SYSTEM DESIGN**
  - 4.1 PREPARE DESIGN SPECIFICATION
  - 4.2 DESIGN DEV GAGING SYS
    - 4.2.1 TRADE-OFF DETAILS
    - 4.2.2 COMPLETE PREL DES
    - 4.2.3 IN-HOUSE REVIEW
    - 4.2.4 INCORPORATE REVIEW RESULTS
    - 4.2.5 COMPLETE DEV DESIGN
    - 4.2.6 ASSESS DESIGN
    - 4.2.7 DOCUMENT DESIGN ASSESSMENT
    - 4.2.8 SUBMIT DESIGN FOR JSC APPROVAL
    - 4.2.9 INCORPORATE JSC COMMENTS
    - 4.2.10 IDENTIFY CHANGES TO INTERFACE DOC
- **TASK 5 — HARDWARE FAB & ACCEPTANCE**
  - 5.1 FAB DEV GAGING SYS
    - 5.1.1 RELEASE DRAWINGS
    - 5.1.2 RELEASE BOM
    - 5.1.3 PROCURE/RECEIVE COMPONENTS
    - 5.1.4 RELEASE SHOP PLANNING
    - 5.1.5 RELEASE TOOL PLANNING
    - 5.1.6 FAB/PROVE TOOLING
    - 5.1.7 FAB DEV GAGING SYS
    - 5.1.8 INSPECT DEV GAGING SYSTEM
    - 5.1.9 ENGINEERING LIAISON
    - 5.1.10 DELIVERY TO TEST DEPARTMENT
  - 5.2 ACCEPTANCE TEST
    - 5.2.1 PREPARE TEST REQUEST
    - 5.2.2 PREPARE PROCEDURE
    - 5.2.3 REVIEW PROCEDURE
    - 5.2.4 DESIGN TEST SET-UP
    - 5.2.5 BUILD TEST SET-UP
    - 5.2.6 CALIBRATE SET-UP
    - 5.2.7 CONDUCT TEST
    - 5.2.8 ENGINEERING LIAISON
- **TASK 6 — DEVELOPMENT TESTING**
  - 6.1 DESIGN GROUND DEV TEST PROGRAM
    - 6.1.1 PREPARE TEST PLAN
    - 6.1.2 COORDINATE WITH JSC
    - 6.1.3 DEV TEST SCHEDULE
    - 6.1.4 DEV TEST PROCEDURES
    - 6.1.5 COORDINATE TEST PROCEDURES
    - 6.1.6 EST DATA REDUCTION PROGRAMS
    - 6.1.7 PROVIDE JSC TEST SUPPORT
    - 6.1.8 RESOLVE ANOMALIES
    - 6.1.9 ANAL/REPORT RESULTS
  - 6.2 DESIGN KC-135 DEV TEST PROGRAM
    - 6.2.1 PREPARE TEST PLAN
    - 6.2.2 COORDINATE WITH JSC
    - 6.2.3 DEV TEST SCHEDULE
    - 6.2.4 DEV TEST PROCEDURES
    - 6.2.5 COORDINATE TEST PROCEDURES
    - 6.2.6 EST DATA REDUCTION PROGRAMS
    - 6.2.7 PROVIDE JSC TEST SUPPORT
    - 6.2.8 RESOLVE ANOMALIES
    - 6.2.9 ANAL/REPORT RESULTS
- **TASK 7 — PROGRAM MANAGEMENT**
  - 7.1 CONFERENCE/MEETINGS
    - 7.1.1 JSC FORMAL PROGRAM REVIEWS (7)
      - 7.1.1.1 PREPARE VIEWGRAPHS
      - 7.1.1.2 PRESENT REVIEW AT JSC
    - 7.1.2 JSC INFORMAL MEETINGS (1)
  - 7.2 REPORTING
    - 7.2.1 PROGRAM PLAN
    - 7.2.2 MONTHLY (17)
      - 7.2.2.1 FINANCIAL
      - 7.2.2.2 TECHNICAL
    - 7.2.3 DATA DUMP REPORT
    - 7.2.4 EXPERIMENTAL TEST PLAN
    - 7.2.5 FINAL REPORT

Figure 1. WORK BREAKDOWN STRUCTURE.

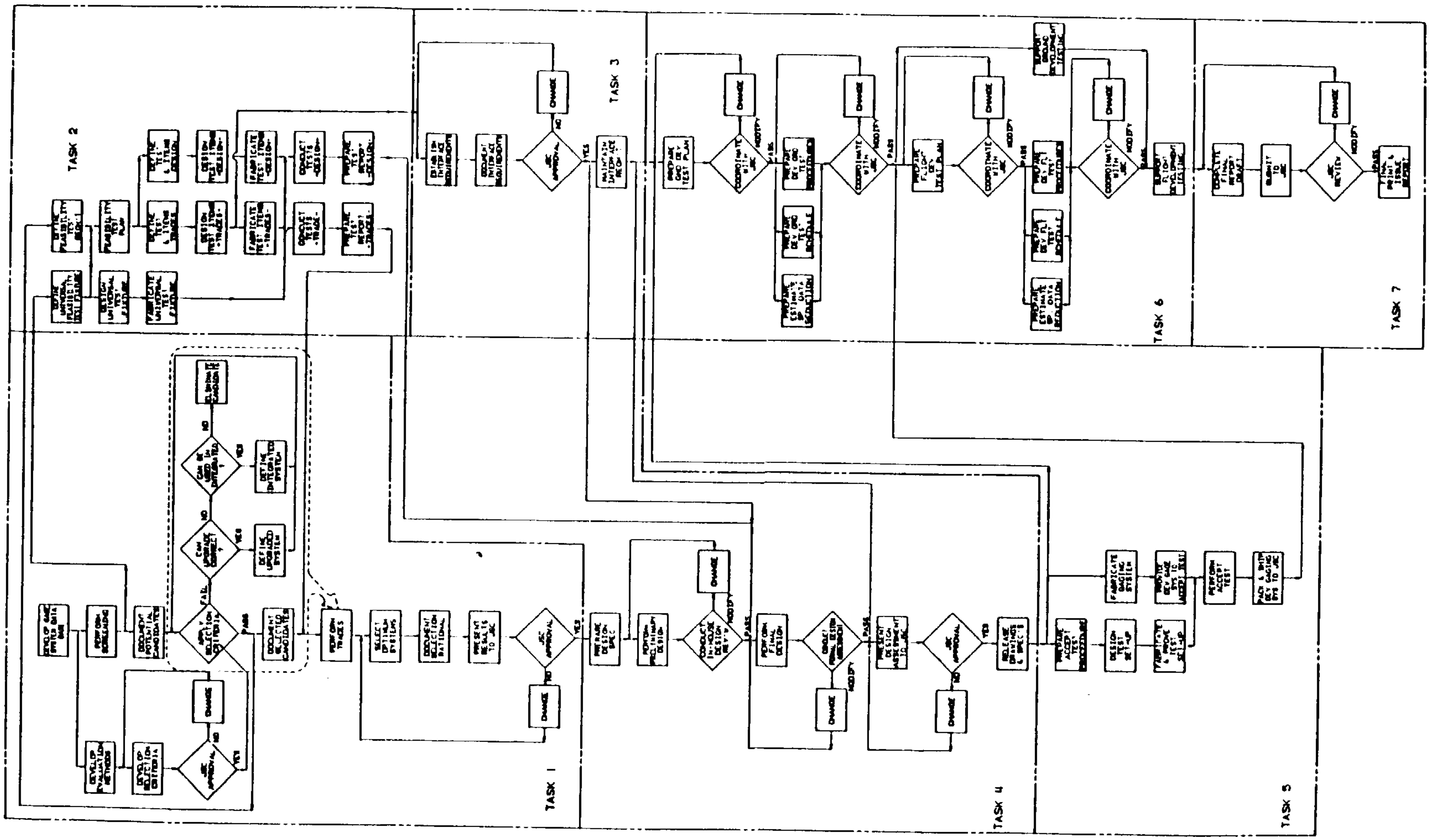



Figure 2. PROGRAM LOGIC DIAGRAM.

## 2.0 TASK 1.0 - ANALYSIS AND TRADE STUDIES

Activities of this task include the parallel development of candidate concepts and selection criteria, to be approved by the JSC Technical Manager, for use in the trade studies. Following this, the trade studies will be conducted, and will focus on a minimum, of two technology options. The trade studies will result in selection of optimum zero-gravity mass quantity gaging system(s) for cryogenic, two-phase liquid oxygen and liquid hydrogen, as well as the optimum system for gaging both fluids. Task activities conclude with a program presentation and request for approval of the recommended mass quantity gaging system(s) to be carried into development. The recommendations will be supported by documented rational.

| INPUTS | OUTPUTS |
| --- | --- |
| o Research material | o Screened & documented candidate concepts |
| o System application inputs | o JSC approved selection criteria |
| o Screening criteria inputs | o Documented trade study results |
| o System design requirements | o Selected optimum concept(s) with supporting rational |
| | o Presentation of results & recommendations |

Schedule Comment. The Task I Analysis and Trade Study activities initiate the zero-gravity quantity gaging system program and are the only activity except for the supporting program management efforts of Task 7 until the beginning of the trade study effort. During the trade studies, there are supporting feasibility testing activities from Task 2 and, at the conclusion of the trade studies, the design effort of Task 4 is initiated.

2.1 Subtask 1.1 - Candidate Concept Development. Activities of this supporting effort to Task I include the development of a data base of quantity gaging concepts with emphasis on concepts successfully used in the past and on possible advantageous combinations of proven concepts. Concepts from this data base will be screened for the most promising candidates for further evaluation. These chosen candidates will be documented and provided to the trade study effort.

| INPUTS | OUTPUTS |
| --- | --- |
| o Research material | o Screened & documented candidate concepts |
| o System application inputs | |
| o Screening criteria | |

Schedule Comment. The candidate concept development effort is an initiating activity that is undertaken in parallel with the selection criteria development effort, and makes use of a screening criteria obtained from that effort. This activity concludes with supplying screened and documented candidate concepts to the trade study effort.

2.2 Subtask 1.2 - Selection Criteria Development. Activities of this supporting effort to Task 1 include the development of the criteria attributes as well as the methods to be used to evaluate candidate rankings relative to these attributes. The resulting selection criteria melding the results of both of these activities will be submitted to the NASA-JSC Technical Manager for approval prior to use in the trade study effort.

| INPUTS | OUTPUTS |
|---|---|
| o System design requirements<br>o Information limits of concept data base | o Screening criteria<br>o NASA-JSC approved selection criteria |

Schedule Comment. The selection criteria development effort is an initiating activity that is undertaken in parallel with the Candidate Concept Development effort, and supplies a screening criteria to that effort. This activity concludes with supplying a NASA-JSC approved selection criteria to the trade study effort.

2.3 Subtask 1.3 - Perform Trade Studies. Activities of this supporting effort to Task 1 include the application of the NASA approved selection criteria to the most promising candidate quantity gaging concepts. In addition, feasibility testing required to support the trade studies will be identified and requested from the test activity. These efforts will result in the identification of the optimum zero-gravity mass quantity gaging system(s) for cryogenic, two-phase liquid oxygen and liquid hydrogen as well as the optimum system for gaging both fluids. These selected optimum systems will be defined and documented with supporting rational for presentation to NASA-JSC. The presentation will also include Beech recommendations and a request for NASA approval of the zero-gravity mass quantity gaging system(s) to be carried into development.

| INPUTS | OUTPUTS |
|---|---|
| o Screened & documented candidate concepts<br>o NASA-JSC approved selection criteria<br>o Feasibility testing results | o Feasibility test requests to support trades<br>o Selected optimum gaging system(s)<br>o Documentation supporting selection(s)<br>o Request to proceed with the recommended development system(s) design |

Schedule Comment. The trade study effort uses the results of the candidate concept development and selection criteria development efforts to begin the evaluation and selection activity which results in identifying the optimum system(s) and recommending a system(s) for initiating the design activity of Task 4.

## 3.0 TASK 2 - FEASIBILITY TESTING

Activities of this task include the selection of tests to be performed in the Beech cryogenic test facilities to support the candidate concept screening and trade study activities. Following selection the tests, test items, and a universal test fixture for their implementation will be designed. The test fixture and test items will be fabricated, proven and calibrated, and then used to conduct the tests. Test data will be reduced, analyzed and documented in a test report. Feasibility testing will also be conducted in support of the development system design. This testing will make maximum use of the universal test fixture and will be used to establish the working relationships between simulated and actual fluids.

| INPUTS | OUTPUTS |
|---|---|
| o Engineering test requests for trade and design support testing<br>o Engineering, Test & Tooling coordination of universal test fixture design requirements | o Universal test fixture<br>o Test items<br>o Test reports |

Schedule Comment. The feasibility testing in support of the trade study efforts of Task 1 will occur in parallel with that task. Test requests and the universal test fixture design/fabrication efforts will occur early in the activity, and then the test item designs, fabrications and installations will be completed. Testing in support of the trade study will then be completed late in the trade study period. Formal reporting of results will occur following the trade study period. Definitions of testing and test items required to support the design activity of Task 4 will parallel the trade study testing and the design activity. Design testing and reporting will be completed at the end of Task 4.

3.1 Subtask 2.1 - Feasibility Testing Supporting Trades. Activities of this supporting effort to Task 2 include the preparation of a test plan. The definition design, fabrication and installation in/on the universal test fixture of test items supporting the trade study effort. The preparation of test procedures, test setups and calibrations in support of testing of the test items. As tests are completed, the data is reduced and supplied directly to the Task 1 trades. At the conclusion of testing, a test report is prepared.

| INPUTS | OUTPUTS |
| --- | --- |
| o Engineering test requests for trade support testing | o Test plan |
| o Engineering, Test & Tooling coordination of universal test fixture design requirements | o Universal test fixture |
| | o Test items |
| | o Test report |

Schedule Comment. Definition and design of the universal test fixture is the initiating activity of this effort. Following this, the test plan and the trade study test items are defined and fabricated for installation in the test fixture which is being completed. The trade study testing is conducted and the preliminary results are supplied directly to the trade study effort of Task 1. The final test report is completed after the completion of the trade study effort.

3.2 Subtask 2.2 - Feasibility Testing Supporting Design. Activities of this supporting effort to Task 2 include the preparation of a test plan. The definition, design, fabrication and installation in/on the universal test fixture of test items supporting the design effort of Task 4. The preparation of test procedures, test setups and calibrations in support of testing of the test items. Following testing, the test data is reduced and a test report is prepared.

| INPUTS | OUTPUTS |
| --- | --- |
| o Engineering test requests for design support testing | o Test plan<br>o Test items<br>o Test report |

Schedule Comment. Planning and definition of design support test items parallels the testing portion of Subtask 2.1, as does the fabrication of the first test items. At the conclusion of the trades testing, the first test item for design support is installed in/on the universal test fixture. The subsequent testing and preparation of a test report parallels the design Task 4 and concludes just prior to the completion of Task 4.

## 4.0 TASK 3 - INTERFACE REQUIREMENTS

Activities of this task include preparation of a preliminary Draft Interface Requirements document. This draft document will be coordinated with the JSC TTA Project Engineer and the JSC Program Technical Manager. Results of this coordination will permit Beech preparation of a formal Interface Requirements Baseline document, which will be supplied to the JSC Technical Manager for interface definition and control. Beech will also maintain the Baseline document by incorporating all formally agreed to changes to the Baseline Interface Requirements.

| INPUTS | OUTPUTS |
| --- | --- |
| o Standard Interface Requirements document format<br>o Coordination meeting with JSC<br>o JSC review comments | o Draft of Interface Requirements Baseline document<br>o Final Baseline Interface Requirements document |

Schedule Comment. The establishment of the interface requirements portion of this task is completed at the start of preparing the Gaging System Design Specification, which initiates the design effort of Task 4. The subsequent preparation of the NASA-JSC approved Baseline Interface Requirements document is completed in the early stages of the preliminary design effort of Task 4. The Approved Baseline Requirements document is then maintained through the Task 4 design effort until the design is submitted for NASA approval.

4.1 Subtask 3.1 - Establish Interface Requirements. Activities of this supporting effort to Task 3 include the preparation of a draft Interface Requirements document which will be coordinated with the NASA-JSC TTA Project Engineer and the Program Technical Manager. The results of the coordination will be incorporated into the draft document to form the basis for the final Baseline Requirements document.

| INPUTS | OUTPUTS |
|---|---|
| o Standard Interface Requirement document format<br>o Coordination meeting with JSC | o Draft Interface Requirements document<br>o Revised Draft Interface Requirements document |

Schedule Comment. This activity is scheduled to be completed just after starting preparation of the gaging system design specification which initiates Task 4 design.

4.2 Subtask 3.2 - Document Interface Requirements. Activites of this supporting effort to Task 3 include the preparation of the final Baseline Interface Requirements document and coordinating its review and acceptance by NASA-JSC as the controlling Interface document.

| INPUTS | OUTPUTS |
|---|---|
| o Revised Draft Interface Requirements document<br>o NASA-JSC review comments to final Baseline document | o NASA-JSC approved Baseline Interface Requirements document |

Schedule Comment. This activity begins shortly following the start of preparation of the gaging system design specification portion of Task 4 and concludes early in the preliminary design effort of Design Task 4.

4.3 Subtask 3.3 - Maintain Interface Requirements. Activities of this supporting effort to Task 3 include maintenance of the Baseline Interface Requirements and the incorporation of all formally approved changes to the Baseline Requirements.

| INPUTS | OUTPUTS |
|---|---|
| o Authorized Baseline Requirements changes | o Changes incorporated into the Baseline Requirements document |

Schedule Comment. The Baseline Requirements document is maintained through the Task 4 design effort until the gaging system design is submitted for NASA approval.

## 5.0 TASK 4.0 - GAGING SYSTEM DESIGN

Activities of this task include the preparation of the development gaging system design specification. Followed by the design of the gaging system in a structured manner consisting of design trade offs, preliminary design, inhouse reviews, and final design phases. The completed design will be formally assessed. This assessment will include considering Reliability, Safety and Quality Assurance. The results of this assessment will be documented and submitted to JSC for approval along with identification of any required changes to the Interface Requirements Baseline document.

INPUTS

- o Baseline Interface Requirements document
- o NASA-JSC approved gaging system(s)
- o Design feasibility test results

OUTPUTS

- o Gaging system design specification
- o Drawings, specifications and analyses documenting the final design
- o Final Design Assessment document
- o Baseline Interface Requirements document changes

Schedule Comment. The Gaging System Design activities are initiated with the preparation of the design specification. This effort is started at the conclusion of coordinating the Baseline Interface Requirements with NASA-JSC. The gaging system design phases are supported by the parallel feasibility testing activities of Task 2 and the interface requirements maintenance activities of Task 3. The concluding portions of the design task are overlapped by tool planning, fabrication and proving activites of the Gaging System Fabrication, Task 5.

5.1 Subtask 4.1 - Prepare Design Specification. The only activity of this supporting effort to Task 4 is the preparation of a comprehensive design specification to guide and control the design of the development zero-gravity quantity gaging system.

INPUTS

- o Baseline Interface Requirements Document

OUTPUTS

- o Gaging System(s) Design Specification

Schedule Comment. The preparation of the development gaging system design specification is started as soon as the draft copy of the Interface Requirements document is available from Task 3, and a good idea of the direction the trade study effort is headed regarding the recommended gaging system concept. The preparation period is brief: only a little over two and a half weeks.

5.2 Subtask 4.2 - Design Development Gaging System. Activities of this supporting effort to Task 4 include a brief design trade off effort to focus the design approach, a preliminary design effort with in-house design reviews to resolve design problems and issues, and a final design phase which is concluded with a formal gaging system design assessment. Results of the design assessment will be documented and submitted to NASA-JSC along with the design documents and an identification of any required changes to the Baseline Interface Requirements document. This effort concludes with NASA-JSC approval of the design.

INPUTS

- o Gaging system design specifications

OUTPUTS

- o Drawings, specifications and analyses
- o Final Design Assessment document
- o Baseline Interface Requirements document

Schedule Comment. Initiation of the design begins following the availability of the design specification. There is a significant overlap between the preliminary design phase and the conclusion of the trade study effort of Task 1. The design feasibility testing effort parallels the design effort with test results becoming available late in the final design effort. The ordering of long lead time items, tool planning and tooling efforts associated with development gaging system fabrication effort of Task 5 begin before the final release of the design drawings.

## 6.0 TASK 5.0 - HARDWARE FABRICATION AND ACCEPTANCE TESTING

Activities of this task include the ordering and receiving of components and materials required for the fabrication of the development gaging system. The subsequent shop planning, tool fabrication and manufacture of the development gaging system including in-process testing. With fabrication completed, the development gaging system will be acceptance tested and subsequently packed and shipped to the Johnson Space Center.

INPUTS

- o Preliminary & then NASA-JSC approved design drawings & specifications
- o Bill of Materials
- o Acceptance test requirements

OUTPUTS

- o Acceptance test procedure
- o Acceptance test results
- o Development gaging system

Schedule Comment. Task 5 is initiated with the ordering of long lead time items (with NASA-JSC concurrance) prior to the final release of the design drawings. Tool planning and tool design efforts will also be initiated prior to final release of the design drawings to minimize any schedule impact from this activity. Fabrication and acceptance testing of the development quantity gaging unit takes place in the last half of Task 5 effort.

6.1 Subtask 5.1 - Fabricate Development Gaging System. Activities of this supporting effort to Task 5 include the ordering and receipt of components and materials required for the fabrication of the development gaging system. The provision of shop planning for the buildup of the development gaging system, the design and fabrication of any required tooling, the fabrication of the development gaging system including in-process testing, and finally the delivery of the completed development gaging system to the Test Department for acceptance testing.

INPUTS

- o Preliminary & then NASA-JSC approved design drawings & specifications
- o Bill of Materials

OUTPUTS

- o Development gaging system

Schedule Comment. The acquisition of materials and components along with the parallel efforts of planning and tool design/fabrication occupy the first half of the Task 5 activity period. The fabrication of the development gaging system takes place over most of the second half of Task 5.

6.2 Subtask 5.2 - Acceptance Test. Activities of this supporting effort to Task 5 include the preparation of an acceptance test procedure; the design and building of the acceptance test setup, the proving and calibration of the acceptance test setup, and finally the conduction of the acceptance test and documentation of the results.

| INPUTS | OUTPUTS |
| --- | --- |
| o Acceptance Test Requirements | o Acceptance test procedure<br>o Acceptance test results |

Schedule Comment. Preparation of the acceptance test procedure and the subsequent design, build and calibration of the test setup take place in parallel with the development gaging system pre-fabrication and fabrication phases. The acceptance test itself is only one week in duration and concludes the Task 5 activity with the shipment of the development quantity gaging system to NASA-JSC.

## 7.0 TASK 6.0 - DEVELOPMENT TESTING

Activities of this task include the overall development test planning coordination and scheduling for both ground testing in the JSC TTA facility and the KC-135 zero-gravity aircraft facility. Further, Beech has the specific additional responsibilities of providing the following:

(1) Formulation of detailed test plans and procedures to support the overall test plan.
(2) Establishment of any specialized data reduction programs, formats or requirements.
(3) On-site support as required.
(4) Resolution of all anomalies and/or failures of the development gaging system.
(5) Analysis and reporting of all development test results.

| INPUTS | OUTPUTS |
| --- | --- |
| o Baseline Interface Requirements document<br>o Coordinations with NASA-JSC | o Overall test plan with schedule<br>o Development test procedures<br>o Data reduction program rqm'ts<br>o Test reports |

Schedule Comment. Preliminary planning, procedure development, and documentation of any special data reduction requirements parallels nearly the entire development gaging system fabrication and acceptance test effort of Task 5. In addition, the preparation efforts for the KC-135 flight testing activity parallel the ground development testing activity.

7.1 Subtask 6.1 - Design Ground Development Test Program. Activities of this supporting effort to Task 6 include the preparation of an overall test plan; coordination of the plan with NASA-JSC, preparation of a test schedule, preparation of test procedures, coordination of the test procedures with the NASA-JSC TTA Project Engineer, the provision of estimates for any special data reduction programs required, and finally the provision of on-site support to NASA-JSC during performance of the ground development tests and the Beech documentation of the test results.

| INPUTS | OUTPUTS |
|---|---|
| o Baseline Interface Requirements document | o Overall ground test plan with schedule schedule |
| o Coordinations with NASA-JSC | o Ground development test procedures |
| | o Data reduction program requirements |
| | o Ground development testing report |

Schedule Comment. Initiation of this activity is coordinated with the formal release of NASA-JSC approved design drawings and specifications. The planning, procedure development and data reduction definition activities parallel the Task 5 fabrication of the develoment gaging system. Actual test activity starts shortly after receipt of the development gaging system by JSC, following acceptance testing at Beech. The activity concludes with Beech preparation of a test report.

7.2 Subtask 6.2 - Design KC-135 Development Test Program. Activities of this supporting effort to Task 6 include the preparation of an overall test plan; coordination of the plan with NASA-JSC, preparation of a test schedule, preparation of test procedures, coordination of the test procedures with the NASA-JSC KC-135 flight test office, the provision of estimates for any special data reduction programs required, and finally the provision of on-site support to NASA-JSC during performance of the KC-135 development tests and the Beech documentation of the test results.

| INPUTS | OUTPUTS |
|---|---|
| o Baseline Interface Requirements document | o Overall KC-135 test plan with schedule |
| o Coordinations with NASA-JSC | o Ground development test procedures |
| | o Data reduction program requirements |
| | o KC-135 development testing report |

Schedule Comment. Formal initiation of this activity coincides with the start of the ground development test program and parallels this activity. Actual test activity starts about three weeks following the completion of the ground development tests. The activity concludes with Beech preparation of a test report.

## 8.0 TASK 7.0 - PROGRAM MANAGEMENT

Activities of this task include the overall monitoring and control of the program to insure achievement of the program objectives on schedule and within budget. It additionally specifically includes the activities associated with the preparation for and support of the program's conferences and meetings, as well as the preparation and submittal of specific reports contracted by the program data requirements list.

| INPUTS | OUTPUTS |
| --- | --- |
| o Program data requirements | o Presentation of regularly schedule program reviews<br>o Submittal of DRL items |

Schedule Comment. The program management activity spans the duration of the program and concludes with NASA-JSC acceptance of the final report.

8.1 Subtask 7.1 - Conferences/Meetings. Activities of this supporting effort to Task 7 include the preparations for and presentation of program material at the kickoff meeting and the seven subsequent program reviews. All conferences and meetings are to take place at NASA-JSC.

| INPUTS | OUTPUTS |
| --- | --- |
| o Program material<br>o Program data requirements | o Presentations at the program kickoff meeting<br>o Presentations at seven program reviews |

Schedule Comment. The regularly scheduled meetings and conferences occur at roughly three month intervals over the duration of the program.

8.2 Subtask 7.2 - Reporting. Activities of this supporting effort to Task 7 include the preparation and submittal of the reports and other specifically required documents contracted for and identified in the program data requirements list.

Beechcraft
Boulder Division

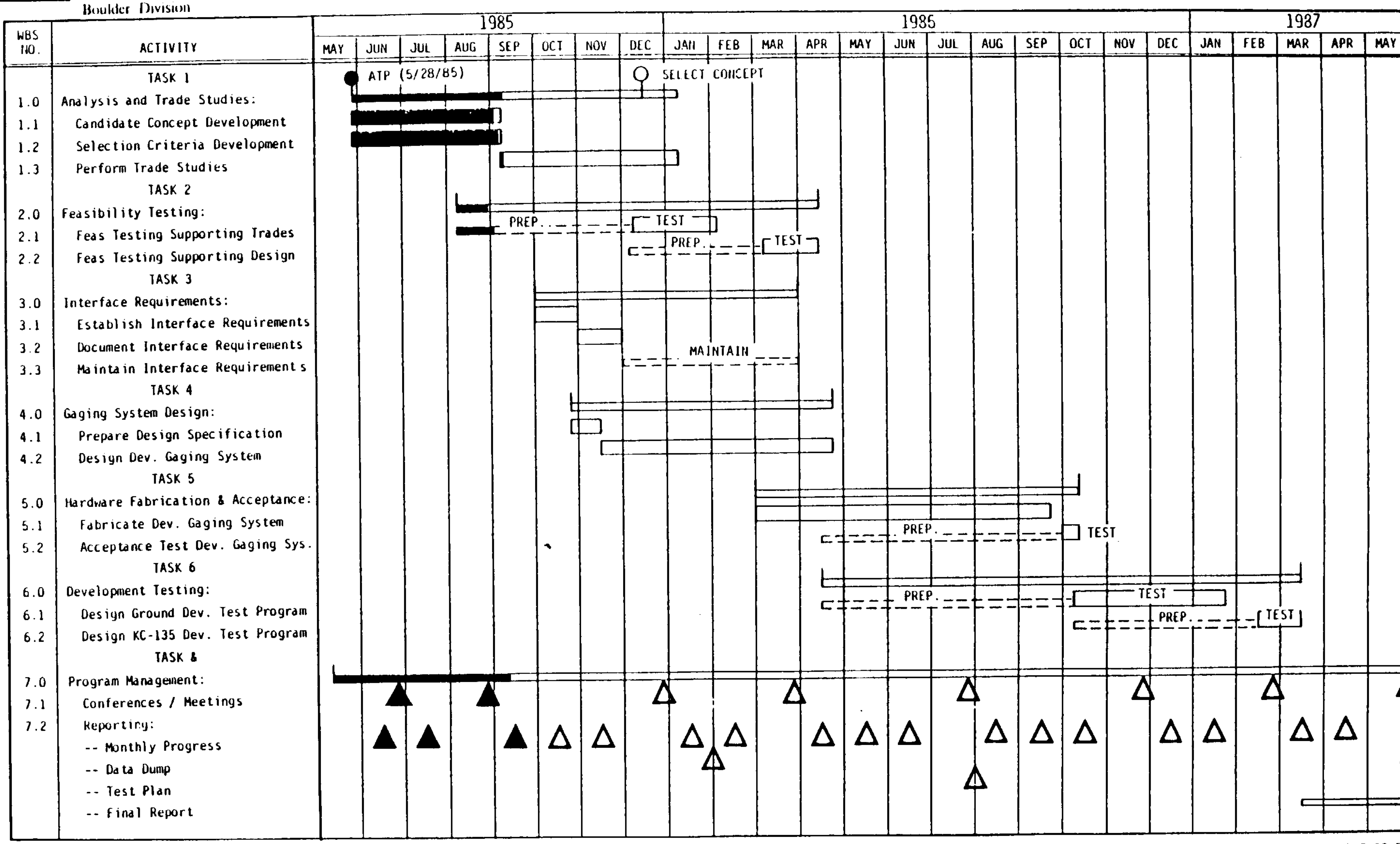



Figure 3. PROGRAM MILESTONE SCHEDULE.

INPUTS

- o Program material
- o Program data requirements

OUTPUTS

- o Program plan
- o Monthly progress reports
- o Data dump reports
- o Experimental test plan
- o Final report

Schedule Comment. Submittal of the reporting items is governed by the requirements set out in the program data requirements list.

## 9.0 PROJECTED MANPOWER

The projected manpower for each of the major WBS tasks is as follows:

### 9.1 Task I - Analysis and Trade Studies.

| ACCT PERIOD | EQUIV MEN (tenths) | INCR MANHRS | CUM MANHRS |
|---|---|---|---|
| JUN 85 | 1.6 | 227 | 227 |
| JUL 85 | 1.8 | 264 | 491 |
| AUG 85 | 2.3 | 363 | 854 |
| SEP 85 | 1.4 | 260 | 1,114 |
| OCT 85 | 1.2 | 199 | 1,313 |
| NOV 85 | 1.3 | 211 | 1,524 |
| DEC 85 | 1.9 | 268 | 1,792 |
| JAN 86 | 0.2 | 32 | 1,824 |
| TOTAL FOR TASK I | | | 1,824 |

## 9.2 Task 2 - Feasibility Testing.

| ACCT PERIOD | EQUIV MEN (tenths) | INCR MANHRS | CUM MANHRS |
|---|---|---|---|
| AUG 85 | 0.0 | 0 | 0 |
| SEP 85 | 1.2 | 236 | 236 |
| OCT 85 | 3.5 | 566 | 802 |
| NOV 85 | 3.8 | 612 | 1,414 |
| DEC 85 | 5.4 | 776 | 2,190 |
| JAN 86 | 10.6 | 1,444 | 3,634 |
| FEB 86 | 0.7 | 113 | 3,747 |
| MAR 86 | 0.3 | 52 | 3,799 |
| APR 86 | 0.3 | 43 | 3,842 |
| TOTAL FOR TASK 2 | | | 3,842 |

## 9.3 Task 3 - Interface Requirements

| ACCT PERIOD | EQUIV MEN (tenths) | INCR MANHRS | CUM MANHRS |
|---|---|---|---|
| OCT 85 | 0.3 | 53 | 53 |
| NOV 85 | 0.5 | 87 | 140 |
| DEC 85 | 0.5 | 10 | 150 |
| JAN 86 | 0.1 | 6 | 158 |
| FEB 86 | 0.0 | 4 | 162 |
| TOTAL FOR TASK 3 | | | 162 |

9.4 Task 4 - Gaging System Design

| ACCT PERIOD | EQUIV MEN (tenths) | INCR MANHRS | CUM MANHRS |
|---|---|---|---|
| DEC 85 | 1.4 | 197 | 197 |
| JAN 86 | 2.2 | 305 | 502 |
| FEB 86 | 6.8 | 1,095 | 1,597 |
| MAR 86 | 3.5 | 708 | 2,305 |
| APR 86 | 0.1 | 19 | 2,324 |
| TOTAL FOR TASK 4 | | | 2,324 |

9.5 Task 5 - Hardware Fabrication and Acceptance Testing

| ACCT PERIOD | EQUIV MEN (tenths) | INCR MANHRS | CUM MANHRS |
|---|---|---|---|
| MAR 86 | 0.2 | 38 | 38 |
| APR 86 | 0.3 | 48 | 86 |
| MAY 86 | 0.6 | 90 | 176 |
| JUN 86 | 0.4 | 60 | 236 |
| JUL 86 | 0.8 | 110 | 346 |
| AUG 86 | 2.5 | 394 | 740 |
| SEP 86 | 2.2 | 418 | 1,158 |
| OCT 86 | 0.0 | 2 | 1,160 |
| TOTAL FOR TASK 5 | | | 1,160 |

9.6 Task 6 - Development Testing

| ACCT PERIOD | EQUIV MEN (tenths) | INCR MANHRS | CUM MANHRS |
|---|---|---|---|
| APR 86 | 0.1 | 21 | 21 |
| MAY 86 | 1.6 | 259 | 280 |
| AUG 86 | 0.3 | 40 | 320 |
| OCT 86 | 0.6 | 96 | 416 |
| NOV 86 | 1.6 | 259 | 675 |
| DEC 86 | 0.6 | 98 | 773 |
| JAN 87 | 0.6 | 109 | 882 |
| FEB 87 | 0.8 | 132 | 1,014 |
| MAR 87 | 0.4 | 86 | 1,100 |
| TOTAL FOR TASK 6 | | | 1,100 |

9.7 Task 7 - Program Management

| ACCT PERIOD | EQUIV MEN (tenths) | INCR MANHRS | CUM MANHRS |
|---|---|---|---|
| MAY 85 | 0.0 | 0 | 0 |
| JUN 85 | 0.3 | 43 | 43 |
| JUL 85 | 0.2 | 35 | 78 |
| AUG 85 | 0.0 | 5 | 83 |
| SEP 85 | 0.0 | 9 | 92 |
| OCT 85 | 0.0 | 7 | 99 |
| NOV 85 | 0.2 | 32 | 131 |
| DEC 85 | 0.5 | 65 | 196 |
| JAN 86 | 0.0 | 2 | 198 |
| FEB 86 | 0.0 | 7 | 205 |
| MAR 86 | 0.5 | 80 | 285 |
| APR 86 | 0.2 | 19 | 304 |
| MAY 86 | 0.0 | 7 | 311 |
| JUN 86 | 0.0 | 7 | 318 |
| JUL 86 | 0.2 | 32 | 350 |
| AUG 86 | 0.0 | 7 | 357 |
| SEP 86 | 0.0 | 7 | 364 |
| OCT 86 | 0.0 | 7 | 371 |
| NOV 86 | 0.5 | 72 | 443 |
| DEC 86 | 0.0 | 7 | 450 |
| JAN 87 | 0.0 | 7 | 457 |
| FEB 87 | 0.2 | 32 | 489 |
| MAR 87 | 0.4 | 84 | 573 |
| APR 87 | 0.2 | 31 | 604 |
| MAY 87 | 0.3 | 46 | 650 |
| JUN 87 | 0.0 | 2 | 652 |
| TOTAL FOR TASK 7 | | | 652 |

# Appendix B

# ZERO-GRAVITY QUANTITY GAGING SYSTEM
# FOR
# CRYOGENIC FLUIDS

## LITERATURE SEARCH
## AND
## PRELIMINARY REVIEW
## OF
## POTENTIAL CONCEPTS

August 1985

This Literature Search and Preliminary Review was conducted as a part of Task I, Analysis and Trade Studies. The literature search was begun by researching key words through several data bases of unclassified reports from DOE, DOD and NASA. In addition, the data bases: STAR, AOSR, ASRCRYO, ASRFIRE, ASRMECH, COSMIC, CSTAR, IAA, OCSTARE, OSTARE, R&DCS, and RTOP were searched using the same key words.

Several documents were acquired as a result of the data base searches. These documents are listed in the bibliography. Two survey reports included in these documents provided extensive bibliographies which are included for reference purposes. The additional references were adequately abstracted in the survey reports and were not re-examined as part of this review.

The acquired reference material has been reviewed and categorized by type of concept. Table I lists several concept types and subcategories for which the literature search produced information of interest. It was found that several of these concepts applied to laboratory type devices. Although these concepts are not applicable to the requirement of the program study, they may be useful as references for calibration of other instrumentation systems. The summarization of the reviewed literature will be described by the various concept types.

References are cited as bibliography number followed by the page number in the reference ie: (7:22-24).

## CAPACITANCE.

Capacitance gaging senses changes in the dielectric properties of the fluid. The difference between liquid and vapor dielectric values would provide a signal that indicates the average density of fluids in contact with the sensing device. This concept has been demonstrated and used extensively for supercritical fluids. The sensing elements could be of several physical configurations. The most common has been concentric tubes with a relatively small space between the two elements. Also parallel plates or a three dimensional wire grid matrix could be assembled to sense the total volume of a vessel.

Table I. CONCEPTS EXAMINED FOR APPLICATION TO ZERO GRAVITY QUANTITY GAGING

| | |
|---|---|
| A. Capacitance | E. Acoustic |
| Fluid Denstiy Coaxial Capacitor | Ultrasonic Mass Flowmeter |
| Density Measurement Device | |
| Two-Phase Capacitance Meter | |
| Liquid Level and Mass Systems | F. Forced Harmonic Oscillation |
| | Densitometer |
| B. Microwave | Density & Specific Gravity Inst. |
| Open-Ended Microwave Cavity | Cryogenic Densitometer |
| Liquid Storage Measuring System | Supercritical Mass Sensor |
| Microwave Densitometers | |
| RF Mode Analysis | Z. Quantity Gaging, Zero "g" |
| | Trace Injection of Radioactive Gas |
| C. Radiation Attenuation | Trace Injection of Infrared |
| Local & Average Liquid Density | Sensitive Gas |
| Beta-Ray Densitometer | Ullage Pressure Gage |
| Nuclear Densitometer | Spherical Tank Gage |
| Gamma-Ray Densitometer | Tank Level in Space |
| | |
| D. Buoyancy | |
| Magnetic Densitometer | |

In the application of this concept for very large cryogenic tanks in zero-gravity conditions, the capacitance gaging would become very difficult to construct and install. The concentric tube arrangement would hold liquid between the plates due to fluid surface tension and give a 100% full indication continuously. The three dimensional grid matrix would be very complicated to install.

This concept is not deemed feasible for consideration in this study (16:13-15).

Capacitance Flow Meter.

A further consideration of the three dimensional wire matrix concept was for the measurement of two-phase flow density in a propellant feed-line. Static assuracies were estimated to be ±3% in 100% liquid and 15% going from 100% gas to 100% liquid. The concept as applied created a flow blockage of 13% of the pipe area.

MICROWAVE.

The microwave sensing concept is basically a linear densitometer measurement. Two microwave horns are used with three possible electronic configurations for interpreting the signal. These are changes of wave attenuation, phase-shift or transmission time. Each of these measured effects is directly relatable to changes of the fluid density in the microwave propagation path. Due to the linear sampling of the fluid and the inability to use multiple sensors (excessive cross talk), this concept is not applicable to the current program. It may be a consideration for concepts in which fluid settling could be accomplished prior to taking measurements (7:250, 16:16).

Another microwave application uses the "open-ended cavity" concept for density determination. This concept requires both a smooth-walled and regular shaped vessel and fluid in the supercritical state. Therefore, it is not a candidate for the program (16:16-17).

RF MODE ANALYSIS.

The Radio Frequency (RF) Mode Analysis is similar to the microwave concept; however, the frequencies are slightly lower for RF than the microwave frequencies. The RF energy is introduced into the tank so as to illuminate the entire volume of the tank. There are two basic approaches to RF gaging: one uses very wide frequency sweeps (1-2 $GH_z$) of the tank antenna and totals all modes (resonances) detected over the sweep range. To achieve satisfactory resolution and accuracy, the detected resonances should number one to two thousand. The second approach uses a significantly narrower frequency sweep range, perhaps only the first five to seven modes, and makes use of the interelationships between model responses as well as the basic response frequencies to uniquely determine the overall dielectric constant of the tank contents. A significant amount of development has been performed under several contracts. The primary problems identified in past work include:

1. Mode degeneracy and noise; possible improvement include optimization of the scanning range, improved antenna design, and development of electronic mode counter schemes to distinguish noise and mode degeneracy.

2. Flight testing showed accuracies of 3.5 to 8.5 percent at tank levels of 0 to 80 percent full. The antenna design was the attributed problem. A change of antenna design to a ground plane monopole was proposed but no further work was performed.

A change from the "linear readout" to a quadratic interpolation was expected to improve results to better than one percent accuracy. (15:11-12, 16:18-19, 14:1-31).

This concept has significant potential for the zero-gravity gaging program.

RADIATION ATTENUATION.

Beta Radiation Attenuation: The primary application of the beta radiation instrumentation concept has been liquid/slush hydrogen density and a hydrogen quality measurement as a point sensor. Typical distances between the source and detector are about four centimeters. The radioactive sources have been Thalium-204 and Strontium-90, both being beta negative emission isotopes.

In the application of this concept as a densitometer, static accuracies of one percent are considered possible. The dynamic applications as a quality meter had a specified accuracy of plus or minus five percent. A significant portion of the error may be attributed to pressure sensing and determining the fluid saturated vapor density. Since this work was accomplished in the late 60's, significant improvements of electronic circuits may provide better system capability than was achieved on the original efforts (9:48-55, 2:232-237, 16:19).

The beta radiation attenuation will not be useful for the quantity measurement systems, however. The concept may be useful as flow density measurements and in integrated concepts with other measurements.

Gamma Radiation Attenuation: The penetrating power of the emitted gamma radiation is approximately 100 times that of beta rays. With this advantage, gamma ray attenuation concepts may be applied to larger volumes as an average density measurement between the source and detector. Many applications of this concept have developed for one-g situations to determine the bulk liquid (or slush hydrogen) density. For a large vessel in zero gravity, it has been proposed that multiple source and detector pairs will provide a quantity measurement system for large hydrogen tanks. However, for oxygen systems, considerably higher energy sources are required to penetrate the denser fluid. This could present a personnal hazard due to possible radiation exposure.

The accuracies of gamma attenuation detectors is quoted as one-half percent for density measurements in linear sensing arrangements. Volumetric systems would require multiple pairs to measure the whole tank fluid quantity.

Several discussions also mentioned the use of gamma radiation attenuation concepts for quality measurement in flowing systems in combination with velocity meters for mass measurement.

BOUYANCY.

A magnetic densitometer concept has been used extensively in laboratory applications for high accuracy measurements of fluid density. Obviously these are for one-gravity usage but do offer basic information for calibration techniques (25:1237-1250.

ACOUSTIC.

Ultrasonic Temperature and Density. This concept uses an ultrasonic device to produce sharp impulses to the tank wall and senses time of travel through the wall and through fluid in intimate contact with the wall. Based on the differences of speed of sound through different media and the attenuation factor, the fluid quantity may be ascertained. The concept is highly dependent on fluid orientation in the storage vessel, it must be in direct contact with the wall and not tend to "float" in several random masses.

It was considered to be an extensive development and testing effort to firmly establish this concept for actual application (1:3-16 to 3-21).

For the above reason and the fluid location requirement, the concept is not considered to be applicable for the current program.

Ultrasonic Mass Flowmeter. This is complete system concept using flow velocity, densitometer and time intervalometer to determine mass flow rate. The densitometer applies the acoustic reflection principle as a function of fluid density and capacitance. The application has not been explored for two-phase flow. Accuracy is estimated to be plus or minus one percent in flowing fluids and plus or minus two percent in a static density measurement. For density measurement, it would only apply as a point sensor (16:21). Not a likely candidate for zero-gravity gaging program. However, the flow meter concept may be useful in an integrated measurement concept.

Ultrasonic Probe. This is a linear type sensing device to determine temperature and fluid density. The transit time of pulse is a measure of the tube temperature, and the amplitude of the pulse is a measure of the density of the fluid in contact with the tube. Therefore, it depends on fluid orientation or requires settling of the fluid prior to taking a measurement. Also the described configuration, a tube surrounding the longitudinal bar, would tend to fill with liquid in the zero-gravity environment, giving a false indication (ie: 100% full for all conditions). Not a candidate for the zero-gravity gaging system (1·3-21 to 3-25).

## FORCED HARMONIC OSCILLATION.

Resonant Infrasonic Gaging System (RIGS). This concept applies the principle of resonant frequency of the ullage gas volume and the properties of gas compressibility and specific heat ratio. The prior work (NAS9-6750, September 1967) performed was to analyze, design and do breadboard testing. This work showed promise of an acceptable concept for zero-gravity quantity, especially for oxygen. Hydrogen fluid has a larger specific heat ratio variation with temperature changes and a higher compressibility which would tend to lead to a higher error bond than with oxygen.

The system actually uses the anti-resonant frequency response for determining ullage volume and, consequently, the fluid mass. The relationship of this anti-resonant frequency is:

$$f = \frac{1}{2\pi} \frac{A^2 \gamma P}{MV}$$

Where: A = Area of vibrating diaphram

M = Vibrating mass

V = Ullage volume

$\gamma$ = Specific heat ratio

P = Ullage pressure

The system is comprised of a constant amplitude/variable frequency driver, an isolated driver cavity, and a weighted flexible diaphragm. The weighted diaphragm is designed to resonate as a function of the ullage compressibility compared to the known drive compressibility. The resonate frequency is essentially a function of the ullage volume, pressure and specific heat ratio.

Three key problems have been identified to be solved prior to adapting this concept for the zero-gravity gaging program:

1) Compatibility and fatigue properties of the bellows at cryogenic temperatures.

2) Variation of ullage gas properties

3) Presence of baffles and/or surface tension screens in the tanks.

These concerns do not appear to be significantly difficult to prohibit the application of this concept (1:3-10 to 3-16, 15:14).

Vibrating Cylinder. These concepts use a forced harmonic oscillation, applied to a free cylinder (hoop mode vibration), or a vibrating section of the flow passage. The density of the flowing fluids may be determined from the acceleration reaction or the resonant frequency of the segment. Neither concept applies to large static masses.

The vibration line segment has an estimated accuracy of ±2%. The free cylinder has a very high accuracy of ±0.1% for liquids or gases. Two phase flow is not addressed.

These concepts may be applicable to integrated measurement concepts but are not applicable to quantity gaging.

Vibrating Reed. A sensing vane is positioned across a supporting cylinder. The vane is driven in simple harmonic motion, causing an acceleration in the surrounding fluid. This concept may be applied in conjunction with a volume flow measuring instrument to determine mass flow. No accuracy information is available.

## TRACE INJECTION.

Several types of mass determination are available. These include radioactive gas, infrared sensitive gas or helium 3. These concepts are not being considered due to the trace gas concept being eliminated in the basic requirements for the zero gravity quantity gaging program.

## CORIOLIS FLOW METER.

This concept is a mass flow meter in a single package. It does not require both density and volumetric measurements to compute mass flow. The concept consists of two parallel U-tubes which are excited (vibrated) at the natural frequency. The resulting lateral acceleration of the fluid passing through the U-bend produces a coriolis acceleration of the tube, causing the legs of the U to oscillate with the number of such oscillations being directly proportional to the mass flow. Counting these oscillations electromagnetically provides a signal indicating the mass flow.

Reported accuracy is 0.4% at full flow.

Potential difficulties of the unit are as follows:

1. High pressure drop through the device especially for low density fluids.
2. Vaporization of liquid due to pressure change and heat leak.
3. Two-phase flow that is not well mixed.
4. System weight.

Preliminary Screening

The preliminary screening of the concepts was performed following the literature review. The screening process was performed using the criteria and scoring as outlined in Table II. The application of the screening process was applied to all concepts twice, once for oxygen systems and again for hydrogen systems. Tables II and IV are the results of this process. Concepts with an overall score of at least 510 will be included in a population set for further evaluation in the trade study.

Population Sets

Single Concepts - The results of the preliminary screening have eliminated the less applicable concepts leaving the concepts listed as single concepts in Table V for oxygen systems and Table VI for hydrogen systems.

Integrated Concepts - Integrated concepts are formed by simultaneously utilizing more than one gaging approach in such a manner that the combined results of the approaches is capable of providing more accurate quantity information than either of the concepts individually. To achieve this benefit, the individual gaging approaches should have complimentary features so that shortcomings of one are countered by strong features of the other.

In reviewing the preliminary scoring of all the approaches for possible combinations for integrated concepts, a matrix of the gaging approaches was developed for both oxygen and hydrogen systems. Figures 1 and 2 show these matrices and the evaluation of possible pairs. Several pairs are shown to be incompatible (ie: microwave and RF mode analysis approaches would have a signal interference which would probably invalidate the resulting output of each gaging system). Other pairs may be compatible but the particular combination does not offer a significant improvement over either individual approaches. Finally, a few paired approaches that are compatible and do provide positive reinforced attributes to enhance the overall gaging concept.

Individual approaches which were eliminated due to serious shortcomings in the preliminary screening, were not considered since the system could not provide acceptable gaging signals.

Flow meters used in conjunction with any one of the singly acceptable gaging approaches could be useful in providing improved response times during fluid transfer operations. However, it would be necessary that the flow meter output be time-integrated as a totalizer and be resettable for each new transfer process.

These integrated concepts are also listed in Tables V and VI.

TABLE II

ZERO-GRAVITY QUANTITY GAGING SYSTEM

PRELIMINARY CONCEPT SCREENING

1. Does the concept require the use of a trace gas?

| Response | Score |
|---|---|
| Yes | (remove concept from any further consideration) |
| No | (retain concept for further screening) |

2. What is the concept accuracy (percent of full scale) in a near zero-gravity environment?

| | Static Accuracy | Dynamic Accuracy |
|---|---|---|
| Response | Score | Score |
| 1% or better | 70 | 30 |
| 1% to 5%* | 20 | 20 |
| 5% | (remove concept) | (remove concept) |

*See Extended Accuracy Band explanation.

3. Is the concept accuracy independent of tank orientation?

| Response | Score |
|---|---|
| Independent | 100 |
| Nearly Independent | 50 |
| Significantly Dependent | (remove concept) |

4. Is the concept accuracy independent of the distribution of any gas/liquid interfaces?

| Response | Score |
|---|---|
| Independent | 100 |
| Nearly Independent | 50 |
| Significantly Dependent | (remove concept) |

5. Is the concept accuracy sensitive to tank size?

| Response | Score |
|---|---|
| Not Sensitive | 70 |
| Moderately Sensitive | 35 |
| Significantly Sensitive | (remove concept) |

6. Is the concept accuracy sensitive to tank external shape?

| Response | Score |
| --- | --- |
| Not Sensitive | 70 |
| Moderately Sensitive | 35 |
| Significantly Sensitive (remove concept) | |

7. Is the concept accuracy sensitive to fluid mass?

| Response | Score |
| --- | --- |
| Not Sensitive | 70 |
| Moderately Sensitive | 35 |
| Significantly Sensitive (remove concept) | |

8. Is the concept accuracy sensitive to internal tank geometry?

| Response | Score |
| --- | --- |
| Not Sensitive | 70 |
| Moderately Sensitive | 35 |
| Significantly Sensitive (remove concept) | |

9. What is the maturity of the concept?

| Response | Score |
| --- | --- |
| Has been demonstrated in space flight | 100 |
| Has been demonstrated in conventional flight | 80 |
| Has been demonstrated in ground applications | 60 |
| Has been demonstrated conceptually (Note 1) | 40 |
| Has not been demonstrated | (remove concept) |

Note 1: If concept has scored at least 450 in screening questions 2 through 8, it should be retained in a list of concepts showing promise for future concept development. However, it should be removed from further consideration in this concept screening.

Note 2: In the case of integrated concepts, the score shall be the arithmetic average of the constituent concepts.

The individual concept and integrated concept screening scores will be summarized, and the candidates ranked with the highest scoring candidate at the top of the list. Only candidates with overall scores of 510 or greater will be included in the list. In the event that no candidates are found with scores of at least 510, the screening criteria will require re-evaluation.

Extended Accuracy Band Criteria

It was prepared to extend the limitation of two percent accuracy up to five percent to allow consideration of additional concepts in the trade studies.

A review of the accuracy criteria of all concepts did not reveal any additional systems for inclusion in the trade studies. Any systems that fall in the two to five percent limit were already eliminated for some other criteria shortcoming.

## TABLE III

## OXYGEN SYSTEMS

| CONCEPT | I | St 2a | Dy 2b | 3 | 4 | 5 | 6 | 7 | 8 | 9 | TOTAL SCORE | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | SCREENING PARAMETERS | | | | | | | | | | |
| Capacitance | No | 20 | — | 100 | 100 | 35 | 70 | 70 | 35 | 100 | 530 | |
| Capacitance Flow Meter | No | -- | -- | | | | | | | | | Flow meter 3-15% Accuracy |
| Microwave | No | 70 | — | 100 | 100 | 35 | 35 | 70 | 35 | 60 | 505 | |
| RF Mode Analysis | No | 70 | — | 100 | 100 | 70 | 70 | 70 | 35 | 60 | 575 | |
| Beta Radiation Attenuation | No | 70 | — | 100 | 100 | — | 70 | 35 | 35 | 60 | | Eliminated |
| Gamma Radiation Attenuation | No | 20 | — | 100 | 100 | — | 70 | — | 35 | 80* | | Eliminated Radiation Hazard; Dynamic Accy: 5-10%, Quality: .15% |
| Bouyancy | No | 70 | — | | | | | | | | | Calibration Reference |
| Ultrasonic Temp and Density | No | -- | -- | 50 | — | 35 | 70 | 35 | 35 | — | | Eliminated |
| Ultrasonic Mass Flow Meter | No | 70 | 20 | | | | | | | | | Flow Meter |
| Ultrasonic Probe | No | -- | -- | 50 | — | 35 | 35 | 70 | 35 | 60 | | Eliminated |
| RIGS | No | 70 | — | 100 | 100 | 70 | 70 | 70 | 35 | 40 | 555 | |
| Vibrating Cyl | No | -- | 70 | | | | | | | | | Flow Meter |
| Vibrating Reed | No | -- | — | | | | | | | | | Flow Meter |
| Coriolis | No | -- | 70 | | | | | | | | | Flow Meter |
| PVT Gaging | No | 70 | — | 100 | 100 | 35 | 70 | 35 | 70 | 60 | 540 | ±2% empty, ±1% full Ref Vol 1% tank volume |
| Trace Injection: | | | | | | | | | | | | |
| Radioactive Gas | Yes | | | | | | | | | | | Eliminated |
| Infrared | Yes | | | | | | | | | | | Eliminated |
| Helium 3 | Yes | | | | | | | | | | | Eliminated |

* QUALITY METER FLOWN 1966 SIVB

## TABLE IV
## HYDROGEN SYSTEMS

| CONCEPT | SCREENING PARAMETERS 1 | St 2a | Dy 2b | 3 | 4 | 5 | 6 | 7 | 8 | 9 | TOTAL SCORE | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Capacitance | No | 20 | — | 100 | 100 | 35 | 70 | 70 | 35 | 100 | 530 | |
| Capacitance Flow Meter | No | -- | -- | | | | | | | | | Flow meter 3-15% Accuracy |
| Microwave | No | 70 | — | 100 | 100 | 35 | 35 | 70 | 35 | 60 | 505 | |
| RF Mode Analysis | No | 70 | — | 100 | 100 | 70 | 70 | 70 | 35 | 60 | 575 | |
| Beta Radiation Attenuation | No | 70 | — | 100 | 100 | — | 70 | 35 | 35 | 60 | | Eliminated |
| Gamma Radiation Attenuation | No | 20 | — | 100 | 100 | 35 | 70 | 70 | 35 | 80* | 510 | Radiation Hazard; Dynamic Accy: 5-10% Quality: .15% |
| Bouyancy | No | 70 | — | | | | | | | | | Calibration Reference |
| Ultrasonic Temp and Density | No | -- | -- | 50 | — | 35 | 70 | 35 | 35 | — | | Eliminated |
| Ultrasonic Mass Flow Meter | No | — | 20 | | | | | | | | | Flow Meter |
| Ultrasonic Probe | No | -- | -- | 50 | — | 35 | 35 | 70 | 35 | 60 | | Eliminated |
| RIGS | No | — | — | 100 | 100 | 70 | 70 | 70 | 35 | 40 | | Eliminated |
| Vibrating Cyl | No | — | 70 | | | | | | | | | Flow Meter |
| Vibrating Reed | No | — | — | | | | | | | | | Flow Meter |
| Coriolis | No | — | 70 | | | | | | | | | Flow Meter |
| PVT Gaging | No | — | — | 100 | 100 | 35 | 70 | 35 | 70 | 60 | | Eliminated ±2% empty, ±1% full Ref Vol 1% tank volume |
| Trace Injection: | | | | | | | | | | | | |
| Radioactive Gas | Yes | | | | | | | | | | | Eliminated |
| Infrared | Yes | | | | | | | | | | | Eliminated |
| Helium 3 | Yes | | | | | | | | | | | Eliminated |

* QUALITY METER FLOWN 1966 SIVB

CAPACITANCE

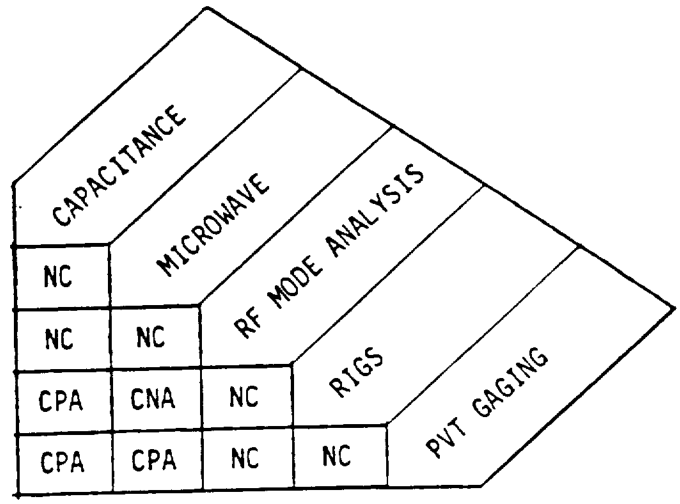
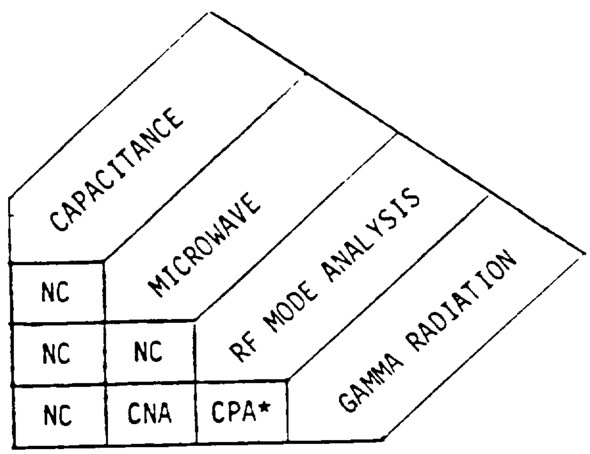



Figure 1. INTEGRATED OXYGEN GAGING CONCEPTS.




* Possibility of gamma radiation ionization which would interface with RF fields

Figure 2. INTEGRATED HYDROGEN GAGING CONCEPTS.

KEY:

NC = Not compatible, signal interference or physically one interferes with the other

CNA = Compatible operation but no improved attributes

CPA = Compatible operation and positive reinforcing attributes

TABLE V

POPULATION SET FOR OXYGEN SYSTEMS

SINGLE CONCEPTS

1. Capacitance Matrix
2. RF Mode Analysis
3. Resonant Infrasonic Gaging (RIGS)
4. PVT Gaging

INTEGRATED CONCEPTS

1. Capacitance - RIGS
2. Capacitance - PVT Gaging
3. Microwave - PVT Gaging

TABLE VI

POPULATION SET FOR HYDROGEN SYSTEMS

SINGLE CONCEPTS

1. Capacitance Matrix
2. RF Mode Analysis
3. Gamma Radiation Attenuation

INTEGRATED CONCEPTS

1. RF Mode Analysis - Gamma Radiation Attenuation

NOTE: THE ORDER OF CANDIDATES IN THESE TABLES IS NOT INDICATIVE OF ANY PREFERENCE.

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Beechcraft
Boulder Division

# Beech Aircraft Corporation

Boulder, Colorado

**Code Ident. No. 07399**

ZERO-GRAVITY

QUANTITY GAGING SYSTEM

SELECTION CRITERIA

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TABLE OF CONTENTS

## 1.0 INTRODUCTION

This descriptive data documents the Selection Criteria developed for use during trade studies to determine the zero-gravity quantity gaging system(s) that are optimum for cryogenic two phase oxygen, cryogenic two phase hydrogen, and both oxygen and hydrogen gaging. All effort expended in developing the Selection Criteria was associated with Work Breakdown Structure Task 1, subelement 1.2 "Selection Criteria Development".

Organization of the Selection Criteria presented in this descriptive data is as follows: First, a Preliminary Screening method is presented in Section 2.0 which will be used to find candidates of promise in the total candidate population. Then in Section 3.0, the Selection Criteria approach is presented. This is followed by detailed development of the selection model, methods, definitions and assigned weights in subparagraphs 3.1 through 3.3. Finally, the Criteria is completed by appendices detailing strawman tankage configurations and a presentation of the method of paired comparisons.

## 2.0 PRELIMINARY CONCEPT SCREENING

The following section details a preliminary screening method which will be applied twice to the candidate concepts: once when they are evaluated for gaging two-phase cryogenic oxygen, and again for two phase cryogenic hydrogen. Candidate concepts will be considered individually and in combinations that appear to be advantageous. The purpose of this preliminary concept screening is to improve the efficiency of the selection process by identifying the candidates of promise in the total candidate population quickly and without lengthy analyses.

1. Does the concept require the use of a trace gas?

| Response | Score |
|---|---|
| Yes | (remove concept from any further consideration) |
| No | (retain concept for further screening) |

2. What is the concept accuracy (percent of full scale) in a near zero-gravity environment?

| | Static Accuracy | Dynamic Accuracy |
|---|---|---|
| Response | Score | Score |
| 1% or better | 70 | 30 |
| 1% to 5% | 20 | 20 |
| >5% | (remove concept) | (remove concept) |

3. Is the concept accuracy independent of tank orientation?

| Response | Score |
|---|---|
| Independent | 100 |
| Nearly Independent | 50 |
| Significantly Dependent | (remove concept) |

4. Is the concept accuracy independent of the distribution of any gas/liquid interfaces?

| Response | Score |
|---|---|
| Independent | 100 |
| Nearly Independent | 50 |
| Significantly Dependent (remove concept) | |

5. Is the concept accuracy sensitive to tank size?

| Response | Score |
|---|---|
| Not Sensitive | 70 |
| Moderately Sensitive | 35 |
| Significantly Sensitive (remove concept) | |

6. Is the concept accuracy sensitive to tank external shape?

| Response | Score |
|---|---|
| Not Sensitive | 70 |
| Moderately Sensitive | 35 |
| Significantly Sensitive (remove concept) | |

7. Is the concept accuracy sensitive to fluid mass?

| Response | Score |
|---|---|
| Not Sensitive | 70 |
| Moderately Sensitive | 35 |
| Significantly Sensitive (remove concept) | |

8. Is the concept accuracy sensitive to internal tank geometry?

| Response | Score |
|---|---|
| Not Sensitive | 70 |
| Moderately Sensitive | 35 |
| Significantly Sensitive (remove concept) | |

9. What is the maturity of the concept?

| Response | Score |
|---|---|
| Has been demonstrated in space flight | 100 |
| Has been demonstrated in conventional flight | 80 |
| Has been demonstrated in ground applications | 60 |
| Has been demonstrated conceptually (see Note 1) | 40 |
| Has not been demonstrated (see Note 2) | (remove concept) |

NOTE 1: If concept has scored at least 450 in screening questions 2 through 8, it should be retained in a list of concepts showing promise for future concept development. However, it should be removed from further consideration in this concept screening.

NOTE 2: In the case of integrated concepts, the score shall be the arithmetic average of the constituent concepts.

The individual concept and integrated concept screening scores will be summarized, and the candidates ranked with the highest scoring candidate at the top of the list. Only candidates with overall scores of 510 or greater will be included in the list. In the event that no candidates are found with scores of at least 510, the screening criteria will require re-evaluation.

## 3.0 SELECTION CRITERIA APPROACH

The selection criteria for determining the optimum candidate concept(s) for zero-gravity quantity gaging of cryogenic two-phase hydrogen and oxygen will be developed using the techniques of multiattribute utility analysis. This approach will be used because it is particularly effective in situations where multiple factors are important, no alternative is clearly best on all factors, and some factors are difficult to quantify.

Implementation of multiattribute utility analysis requires the careful construction of the selection model or criteria in the following steps.

(1) Attribute Selection: The attributes selected should be comprehensive enough to account for most of what is important in evaluating the candidates. The selected attributes should highlight differences between candidates, reflect separate nonoverlapping values, and should be independent of each other.

(2) Organize Attributes: The selected attributes are arranged in a hierarchy showing the logical relationships between them. This will result in an outline of major attributes which are each supported by directly related detail attributes.

(3) Assess Detail Attribute Values: The performance of a candidate when evaluated for each detail attribute can be expressed by one of two types of measures: scales with natural standard units (e.g., dollars, pounds, hours, etc.) or relative scales such as excellent, good, average, etc. In either case, the value assigned to the detailed attribute is transformed from the original measure to a value on a 0 to 100 point scale. The candidate with the best performance is valued at 100, while the one with the worst is valued at 0.

(4) Assess Cross Attribute Trade-Off Weights: Weights are assessed to each detail attribute to represent the relative importance of improving performance from the worst to the best level for each attribute. This allows the assessment to be based on range of performance rather than purely abstract notions of importance. The weights assessed to all detail attributes associated with the same major attribute are normalized to sum to one.

(5) Assess Major Attribute Weights: The relative weights assessed to the major attributes are judgments made to realistically represent the priorities and preferences between items which most likely have different value systems. The relative weights of all major attributes sum to one.

Once the five modeling steps have been completed, calculation of overall ranking values for each candidate are easily obtained. The mechanics of these calculations are shown below. It should also be pointed out that this analysis technique preserves the identity of judgmental and factual assessments and is obviously suited to a variety of sensitivity analyses should further clarification be required.

Overall Ranking Value Calculations:

Notations

| | | |
|---|---|---|
| 1, 2, 3, | ..... | Represent Candidate Number |
| A, B, C, | ..... | Represent Major Attributes |
| wa, wb, wc, | ..... | Represent the Relative Weights of Attributes A, B, and C |
| A1, A2, A3, | ..... | Represent Detail Attributes associated with Major Attribute A |
| ka1, ka2, ka3, | ..... | Represent Detail Attribute trade-off weights |
| VA11, VA21, VA31, | ..... | Represent Detail Attribute values on a 0-to-100 point scale for candidate 1 |
| SA1, SA2, SA3, | ..... | Represent Major Attribute scores for candidates 1, 2 and 3 |
| R1, R2, R3, | ..... | Represent overall ranking scores for candidates 1, 2 and 3 |

## Hierarchy of Attributes and Their Weights

| A (wa) | B (wb) | C (wc) | D (wd) |
|---|---|---|---|
| A1 (ka1) | B1 (kb1) | C1 (kc1) | D1 (kd1) |
| A2 (ka2) | Bw (kb2) | C2 (kc2) | D2 (kd2) |
| A3 (ka3) | B3 (kb3) | C3 (kc3) | |
| A4 (ka4) | | C4 (kc4) | |

### Normalization of Weights:

$ka1 + ka2 + ka3 + ka4 = 1$
$kb1 + kb2 + kb3 = 1$
$kc1 + kc2 + kc3 + kc4 = 1$
$kd1 + kd2 = 1$
$wa + wb + wc + wd = 1$

### Detail Attribute Values for Four Candidate Cases:

| | | | |
|---|---|---|---|
| VA11 | VA12 | VA13 | VA14 |
| VA21 | VA22 | VA23 | VA24 |
| VA31 | VA32 | VA33 | VA34 |
| VA41 | VA42 | VA43 | VA44 |
| | | | |
| VB11 | VB12 | VB13 | VB14 |
| VB21 | VB22 | VB23 | VB24 |
| VB31 | VB32 | VB33 | VB34 |
| | | | |
| VC11 | VC12 | VC13 | VC14 |
| VC21 | VC22 | VC23 | VC24 |
| VC31 | VC32 | VC33 | VC34 |
| VC41 | VC42 | VC43 | VC44 |
| | | | |
| VD11 | VD12 | VD13 | VD14 |
| VD21 | VD22 | VD23 | VD24 |

### Calculation of Major Attribute Scores for Four Candidate Cases:

$VA11 \times ka1 + VA21 \times ka2 + VA31 \times ka3 + VA41 \times ka4 = SA1$
$VA12 \times ka1 + VA22 \times ka2 + VA32 \times ka3 + VA42 \times ka4 = SA2$
$VA13 \times ka1 + VA23 \times ka2 + VA33 \times ka3 + VA43 \times ka4 = SA3$
$VA14 \times ka1 + VA24 \times ka2 + VA34 \times ka3 + VA44 \times ka4 = SA4$
$VB11 \times kb1 + VB21 \times kb2 + VB31 \times kb3 = SB1$
$VB12 \times kb1 + VB22 \times kb2 + VB32 \times kb3 = SB2$
$VB13 \times kb1 + VB23 \times kb2 + VB33 \times kb3 = SB3$
$VB14 \times kb1 + VB24 \times kb2 + VB34 \times kb3 = SB4$
$VC11 \times kc1 + VC21 \times kc2 + VC31 \times kc3 + VC41 \times kc4 = SC1$
$VC12 \times kc1 + VC22 \times kc2 + VC32 \times kc3 + VC42 \times kc4 = SC2$
$VC13 \times kc1 + VC23 \times kc2 + VC33 \times kc3 + VC43 \times kc4 = SC3$
$VC14 \times kc1 + VC24 \times kc2 + VC34 \times kc3 + VC44 \times kc4 = SC4$
$VC11 \times kd1 + VD21 \times kd2 = SD1$
$VC12 \times kd1 + VD22 \times kd2 = SD2$
$VC13 \times kd1 + VD23 \times kd2 = SD3$
$VC14 \times kd1 + VD24 \times kd2 = SD4$

Calculation of Overall Candidate Scores for Four Candidate Cases

SA1 x wa + SB1 x wb + SC1 x wc + SD1 x wd = R1
SA2 x wa + SB2 x wb + SC2 x wc + SD2 x wd = R2
SA3 x wa + SB3 x wb + SC3 x wc + SD3 x wd = R3
SA4 x wa + SB4 x wb + SC4 x wc + SD4 x wd = R4

3.1 Initial Selection Model Construction. The guidelines given in selection model construction steps (1) Attribute Selection, (2) Organize Attributes and (5) Assess Major Attribute Weights, were employed to construct the following hierarchy of attributes.

Hierarchy of Major Attributes and Supporting Detail Attributes

| | Major Attribute Relative Weight |
|---|---|
| 1. Accuracy | 0.35 |
| (a) Basic accuracy | |
| (b) Sensitivity to tank size, shape, internal geometry, and fluid mass | |
| (c) Range | |
| (d) Ease of calibration | |
| (e) Maintenance of calibration | |
| 2. Design Features | 0.20 |
| (a) System weight | |
| (b) System electrical power requirements | |
| (c) Energy input to fluid | |
| (d) Number and complexity of fluid containment penetrations | |
| 3. Design Quality | 0.25 |
| (a) Reliability | |
| (b) Repairability | |
| (c) Maintainability | |
| (d) Safety | |
| (e) Compatibility | |
| 4. Design State of the Art | 0.10 |
| (a) Materials | |
| (b) Construction | |
| (c) Circuitry | |
| (d) Performance | |
| (e) Potential for improvement | |
| 5. Flight Hardware Development Effort | 0.10 |
| (a) Development hardware estimate to complete (span time, manpower and dollars, including risk) | |
| (b) Prototype hardware estimate to complete (span time, manpower and dollars, including risk) | |
| (c) Flight hardware estimate to complete (span time, manpower and dollars, including risk) | |
| | 1.00 |

3.2 Detail Attribute Value Assessment. The method for assessing a value to each of the detail attributes shown in the "Hierarchy of Major Attributes and Supporting Detail Attributes" is developed below. This material corresponds to selection model contruction step (3) Assess Detail Attribute Values.

3.2.1 Evaluation and Scoring Method for Major Attribute I "Accuracy".

Detail Attribute I-a "Basic Accuracy": This detail attribute is defined as the characteristic accuracy of the candidate gaging system concept when the issues of static and dynamic system accuracy are considered. The terms "dynamic" and "static" are related to the gross fluid motion state of fluid contained in the tank. The "static" state is considered to commence once gross fluid motions have died out. Scoring of candidate concepts is based on comparing their cited performance with the desired nominal system accuracy. This nominal system accuracy has been defined as a capability for determining the mass of fluid in a tank to within one percent of a full tank load. Concepts will be considered, however, with accuracies of only five percent of full tank load over ranges as narrow as full to half full. The specific scoring issues that must be addressed in determining the system characteristic accuracy are:

(1) Static system accuracy in a zero-gravity environment.
(2) Dynamic system accuracy in a zero-gravity environment.
(3) Degree to which distribution of the gas/liquid interface can affect accuracy.

It is anticipated that candidate concept evaluations will be based on two factual, natural scale parameters. They are the system static accuracy expressed as a percent and the system dynamic accuracy expressed as a percent. These data will be obtained from one of the following source classes

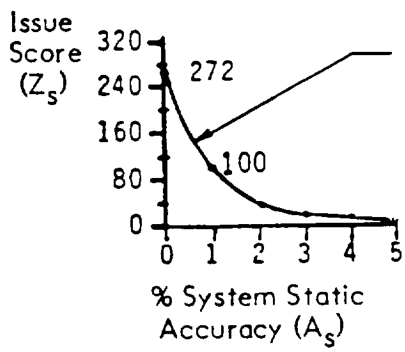
First Class: A concensus of creditable published research data representing current technology.

Second Class: A concensus of creditable published research data representing outdated technology.

Third Class: An estimate based on implied performance from the published literature.

The source class will be identified for all data used in scoring evaluations. Prior to scoring, all accuracy data will be adjusted, if required, to account for the probable improvement that application of current technology could provide. Detailed development of the scoring schemes and their rationals are addressed below.

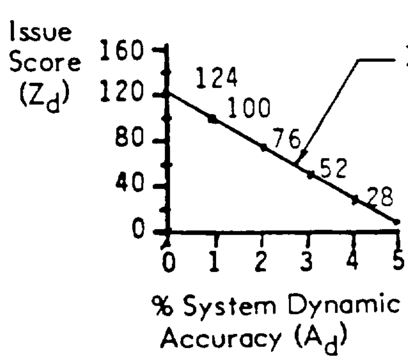
Scoring Scheme for Static Accuracy - The Rational: The system static accuracy is a very strong operations cost driver and has been scaled exponentially to score 100 at nominal one percent system accuracy and reward or penalize accuracies better or worse than nominal in an exponential manner.




$$Z_s = \frac{100e^{(2-As)}}{2.72} = 36.765\ e^{(2-As)}$$

Where: $Z_s$ = System Static Accuracy Issue Score
$A_s$ = Static Accuracy - %

Scoring Scheme for Dynamic Accuracy - The Rational: The system dynamic accuracy is a moderate level linear driver of operations cost. It has been scaled linearly with a slope of 24 score points per degree dynamic accuracy. A score of 100 occurs at the nominal one percent system accuracy and rewards or penalizes for accuracies better or worse than the nominal one percent.




$$Z_d = (5-A_d)(24)+4 = 4(31-6A_d)$$

Where: $Z_d$ = System Dynamic Accuracy Issue Score
$A_d$ = Dynamic Accuracy - %

Scoring Scheme for Accuracy Independent of the Distribution of Gas/Liquid Interfaces - The Rational:

(1) Since the candidate concepts have been screened to only include concepts perceived to be in the range of completely independent to nearly independent, a reasonable corresponding accuracy effect range would be a 0 to 1 percent effect.

(2) Distribution of liquid/gas interfaces into patterns other than the minimum energy wetted surfaces pattern would only result from local dynamic accelerations of sufficient magnitude to overcome the liquid surface tension forces. As a result, accuracy effects resulting from random gas/liquid interface distributions (ie: streamers, floating globules, etc.) would only be associated with dynamic effects, and would be included in the system dynamic accuracy scoring assessment.

Determination of Overall Detail Attribute "Basic Accuracy" Score: The relative additional emphasis on static accuracy as the more important parameter has already been accounted for by the use of the expotential scaling scheme. Also, the effects of non-minimum energy distributions of gas/liquid interface are included in the dynamic accuracy assessment. The overall detail attribute score is the arithmetic average of the static accuracy score and the dynamic accuracy score. Since the attribute issue scoring schemes included positive rewards for accuracies better than the target one percent, it is possible to obtain overall detail attribute scores exceeding one hundred.

$$V_{1-a} = \frac{Z_s + Z_d}{2}$$

Where: $V_{1-a}$ = Detail Attribute Score for 1-a (Basic Accuracy)

$Z_s$ = $36.765\ e^{(2-As)}$

$Z_d$ = $4\ (31\text{-}6A_d)$

$A_s$ = System Percent Static Accuracy

$A_d$ = System Percent Dynamic Accuracy

Detail Attribute 1-b "Sensitivity to Tank Size, External Shape, Fluid Mass and Internal Geometry": This detail attribute is defined as the susceptibility of a candidate gaging system concept to the scaling issues of volume and fluid bulk as well as the geometrical issues of external shape and internal secondary constructions.

For the purposes of this evaluation, the range of tank sizes, shapes, fluid capacities and internal constructs will be as defined by the attached Appendix A ("Zero-gravity Quantity Gaging System Strawman Tankage Descriptions"). Scoring issues that must be addressed in evaluating this attribute are:

(1) Tank Size
(2) Tank External Shape
(3) Fluid Mass
(4) Internal Geometry

Significant technical considerations associated with each scoring issue and the gaging system effects attributable to the technical considerations are summarized in Table 1-b-1.

Nine basic technical considerations are identified in the table, they are:

1. Surface Area
2. Propogation Path Length
3. Cavity Volume
4. Shadowing
5. Degeneracy
6. Propogation Attenuation
7. Force Required to Accelerate
8. Magnitude of Slosh Loads
9. Physical Obstructions

Each candidate gaging system will be evaluated using the nine basic technical considerations over the ranges indicated in the Appendix A Strawman Tankage Descriptions. The evaluation will consist of estimating the degree of sensitivity of a candidate gaging system to the effects traceable to the nine basic technical considerations. Each estimate will involve two parts. First the degree of sensitivity will be estimated, and then a judgement will be made as to whether the sensitivity could be completely, or for the most part compensated for, in a practical application of the gaging concept. Scoring of the estimates will be based on the scheme shown in Table 1-b-11.

Table 1-b-1
Technical Considerations - Matrix

| SCORING ISSUE | TECHNICAL CONSIDERATION | POTENTIAL GAGING SYSTEM EFFECTS |
|---|---|---|
| Tank Size | 1 Surface area<br>2 Propogation path length<br>3 Cavity volume | 1 Electrical resistance of surface Q of RF resonances<br>2 Attenuation over total path length<br>3a Resonant frequency<br>3b Extent and complexity of sensing system |
| Tank Shape | 1 Propogation path length<br>2 Shadowing<br>3 Degeneracy | 1 Attenuation over total path length<br>2 Obscuring illuminating radiation<br>3 Number and interval of cavity resonances |
| Fluid Mass | 1 Propogation attenuation<br>2 Force required to accelerate<br>3 Magnitude of slosh loads | 1 Attenuation per unit path length<br>2a Impulse response<br>3 Extent of slosh suppression required |
| Internal Geometry | 1 Shadowing<br>2 Degeneracy<br>3 Physical obstructions | 1 Obscuring illuminating radiation<br>2 Number and interval of cavity resonances<br>3a Local areas of high attenuation<br>3b Physical interference<br>3c Impact on number and complexity of sensors |

Scoring Scheme Rational: As can be seen from Table 1-b-1, the technical considerations associated with the sensitivity issues overlap and are, in some cases, interrelated. The basic technical considerations were isolated and a set selected to be as even-handed as possible for all potential candidates. This approach resolved the overlaps and interelations of the sensitivity issues. The scoring scales and method for determining the overall detail attribute score are linear and give equal weight to each of the nine basic technical considerations.

Table I-b-II
Scoring Table

| CANDIDATE CONCEPT DEGREE OF SENSITIVITY | SCORING SCALE CAN'T COMP* | SCORING SCALE CAN COMP | 1. SURFACE AREA | 2. PROPOGATION PATH LENGTH | 3. CAVITY VOLUME | 4. SHADOWING | 5. DEGENERACY | 6. PROPOGATION ATTENUATION | 7. FORCE REQ'D TO ACCELERATE | 8. MAGNITUDE OF SLOSH LOADS | 9. PHYSICAL OBSTRUCTIONS | ROW TOTALS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Not Sensitive | 100 | 100 | | | | | | | | | | |
| Minor Sensitivity | 75 | 85 | | | | | | | | | | |
| Moderate Sensitivity | 50 | 65 | | | | | | | | | | |
| Major Sensitivity | 25 | 35 | | | | | | | | | | |
| Will not Function | 0 | 0 | | | | | | | | | | |

(CONSIDERATION SCORES: columns 1–9)

÷ 9 =

* COMP = COMPENSATE

OVERALL DETAIL ATTRIBUTE "SENSITIVITY" SCORE

Detail Attribute I-c "Range": This detail attribute is defined as the characteristic range of measurement that can be achieved with the candidate gaging system concept operating within its rated basic accuracy. Scoring of candidate concepts is based on comparing their cited performance with the desired nominal system range. This nominal system range has been defined as any tank load from one hundred percent to two percent full. The only scoring issue is the candidate system's measurement range.

Scoring Scheme for "Range" - The Rational: This scoring issue is based on a ranking of the candidate system's measurement range with strong preference given to systems which have their best basic accuracies over the span from full to half full. This ranking and the corresponding numerical score are determined by locating a candidates position on a descriptor scale detailing appropriate measurement ranges. The scale can be interpolated and the score obtained is the detail attribute score.

| Measurement Range Descriptors | | Score Value |
|---|---|---|
| Full nominal range system | 100% to 2% full | 100 |
| 75 percential range system | 100% to 25% full | 81 |
| 50 percential range system | 100% to 50% full | 62 |
| Low 3/4 range system | 75% to 2% full | 43 |
| Mid half range system | 75% to 25% full | 24 |
| Low half range system | 50% to 2% full | 5 |

Detail Attribute 1-d "Ease of Calibration": This detail attribute is defined as a ranking of the relative level of effort required to perform an operational system calibration. It is assumed that normal good design practices have been employed to produce a system with all reasonable features condusive to conducting a calibration of a system of the concept type being evaluated. The attribute further assumes that all useful information obtainable from a more extensive "factory" calibration would be available.

Scoring issues that must be addressed in evaluating this detail attribute are:

(1) Calibration procedure difficulty
(2) Required skill level to perform calibration
(3) Equipment requirements to perform calibration

It is anticipated that candidate concept evaluations will be based on judgemental rankings in a "High-Mid-Low" context for each of the scoring issues.

Scoring Scheme for "Ease of Calibration" - The Rational: Each of the three scoring issues has been structured in a "High-Mid-Low" scale by means of appropriate queries. The scoring values assigned to each of the query break points are 100 for the highest, 60 for the midpoint and 20 for the lowest. The reason 20 was chosen as the lowest score was the belief that any reasonable range of calibration difficulties should not exceed a five to one ratio. The midpoint score of 60 is midway between 20 and 100. The specific queries and score assignments are shown below. Note that scores between the break points are possible if the judemental insight is sufficiently clear.

Calibration Procedure Difficulty

Execution of the candidate concept calibration procedure would require:

| Break Points | Score Value |
|---|---|
| Little Effort | 100 |
| Average Effort | 60 |
| Major Effort | 20 |

Required Skill Level to Perform Calibration

Conduct of the calibration would require personnel possessing:

| Break Points | Score Value |
|---|---|
| No Special Skills | 100 |
| Moderate Skills | 60 |
| High Level Skills | 20 |

Equipment Requirements to Perform Calibration

Equipment requirements to perform the calibration would be:

| Break Points | Score Value |
|---|---|
| Minimal | 100 |
| Moderate | 60 |
| Extensive | 20 |

Overall Detail Attribute Score: The three scoring issue scores are summed and divided by three to give each issue equal weight.

Detail Attribute 1-e "Maintenance of Calibration": This detail attribute is defined as a ranking of the relative abilities of candidate concepts to hold their calibration and to provide minimum interference with normal system operation when they are calibrated. It is assumed that normal good design practices have been employed to produce systems with reasonable levels of self check features to permit extended calibration intervals.

Scoring issues that are addressed in evaluating this detail attribute are:

(1) Ability of concept to hold calibration

(2) Extent to which calibration interferes with normal operation

(3) Implication of component replacement on recalibration

It is anticipated that candidate concept evaluations will be based on judgemental rankings in a "High-Mid-Low" context for each of the scoring issues.

Scoring Scheme for "Maintenance of Calibration" - The Rational: Each of the scoring issues has been structured in a "High-Mid-Low" scale by means of appropriate queries. The scoring values assigned to each of the query break points are 100 for the highest, 60 for the midpoint and 20 for the lowest. The specific queries and score assignments are shown below. Note that scores between the break points are possible if the judgemental insight is sufficiently clear.

Ability of Concept to Hold Calibration

The ability of the concept to hold calibration is:

| Break Points | Score Value |
|---|---|
| Good | 100 |
| Average | 60 |
| Poor | 20 |

Extent of Calibration Interference with Normal Operation

The extent to which in flight calibration would interfere with normal system operation would be:

| Break Points | Score Value |
|---|---|
| Minimal | 100 |
| Moderate | 60 |
| Extensive | 20 |

Implication of Component Replacement on Recalibration

The extent to which component replacement would impact the system calibration would be:

| Break Points | Score Value |
|---|---|
| Minimal | 100 |
| Moderate | 60 |
| Extensive | 20 |

Overall Detail Attribute Score: The scoring issue scores are summed and divided by three to give each issue equal weight.

### 3.2.2 Evaluation and Scoring Method for Major Attribute 2 "Design Features"

Detail Attribute 2-a "System Weight": This detail attribute is defined as a relative ranking of the estimated system weight of a fully functional candidate gaging system capable of sensing, conditioning, processing and display of a tank quantity reading from the OTV tank delineated in the Strawman Tankage Descriptions of Appendix A.

The only scoring issue is the relative system weight of each candidate concept. Evaluation can be based on factual natural scale parameters or be derived by a technique of paired comparisons (see Appendix B). In either case, a specific numerical ranking value will be determined for each concept evaluated.

Scoring Scheme for "System Weight" - The Rational: The rankings of the candidate concepts will be converted to a zero to one hundred point scale to obtain the overall detail attribute score for each candidate. This will be done by dividing each candidate system's weight value by the lowest system weight value, then the scoring will be inverted (the lowest weight system should score highest) by taking the reciprocal of the normalized ranking value, and finally the inverted-normalized ranking values are converted to a zero to one hundred scoring scale by multiplying by one hundred. These resulting overall detail attribute scores are linearly based on the actual weight rankings of the concepts evaluated.

Detail Attribute 2-b "System Electrical Power Requirement": This detail attribute is defined as a relative ranking of the estimated system electrical power requirement for a fully functional candidate gaging system capable of sensing, conditioning, processing and display of a tank quantity reading from a median sized tank.

The only scoring issue is the relative system power requirement of each candidate concept. Evaluation can be based on factual natural scale parameters or be derived by a technique of paired comparisons. In either case, a specific numerical ranking value will be determined for each concept evaluated.

Scoring Scheme for "System Electrical Power Requirement" - The Rational: The rankings of the candidate concepts will be converted to a zero to one hundred point scale to obtain the overall detail attribute score for each candidate. This will be done by normalizing, inverting and converting the ranking values as described above in the scoring scheme for system weight. Again, the resulting overall detail attribute scores are linearly based on the actual electrical power rankings of the concepts evaluated.

Detail Attribute 2-c "Energy Input to Fluid: This detail attribute is defined as a relative ranking of the estimated energy input to fluid, characteristic of a fully functional candidate gaging system, capable of sensing, conditioning, processing and display of a tank quantity reading from a median sized tank.

The only scoring issue is the relative fluid energy input of each candidate concept. Evaluation can be based on factual natural scale parameters or be derived by a technique of paired comparisons. In either case, a specific numerical ranking value will be determined for each concept evaluated.

Scoring Scheme for "Energy Input to Fluid" - The Rational: The rankings of the candidate concepts will be converted to a zero to one hundred point scale to obtain the overall detail attribute score for each candidate. This will be done by normalizing, inverting and converting the ranking values as described above in the scoring scheme for system weight. The resulting overall detail attribute scores are linearly based on the actual fluid energy input rankings of the concepts evaluated.

Detail Attribute 2-d "Complexity of Tank Sensor(s) and Their Installation": This detailed attribute is defined as a relative ranking of the perceived complexity of a candidate concept's gaging sensors and their installation in a median sized tank.

The only scoring issue is this relative complexity. Evaluation is based on evenly ranked descriptor scales of sensor and sensor installation complexity. Identification of a candidate concepts position on the descriptor scales provides a numerical ranking.

Scoring Scheme for "Complexity of Tank Sensors and Their Installation" - The Rationale: The scoring issue of sensor and sensor installation complexity has been structured into two ranking and scoring scales by means of a set complexity descriptors. These are shown below. Each candidate concept is evaluated by selecting the most appropriate descriptor or extrapolating between the two most appropriate descriptors. The scores from each of the descriptor scales are summed and divided by two to obtain the overall detail attribute score.

| Sensor Complexity Ranking Descriptors | Score Value |
|---|---|
| Low complexity - rugged construction | 100 |
| Low complexity - medial construction | 81 |
| Average complexity - rugged construction | 62 |
| Average complexity - medial construction | 43 |
| High complexity - rugged construction | 24 |
| High complexity - medial construction | 5 |

| Sensor Installation Complexity Ranking Descriptors | Score Value |
|---|---|
| Sensor installed on outside of tank, no PV penetrations | 100 |
| Sensor installed from outside of tank, moderate PV penetrations | 81 |
| Sensor installed from outside of tank, major PV penetrations | 62 |
| Sensor installed inside PV (prior to closure), moderate intrusion on inner volume | 43 |
| Sensor installed inside PV (prior to closure), major intrusion on inner volume | 24 |
| Sensor installed inside PV (prior to closure), extensive intrusion on inner volume | 5 |

### 3.2.3 Evaluation and Scoring Method for Major Attribute 3 "Design Quality.

Detail Attribute 3-a "Reliability": This detail attribute is defined as the probability that a candidate system will give satisfactory performance for a stated period of time under specified operating conditions. The specific scoring issues that will be addressed in evaluating the reliability of candidate systems are:

(1) The relative complexity of the system.

(2) The relative maturity of the system development.

(3) The relative tolerance of each system to the environments appropriate to its application.

The issue of operating time is normalized by assuming that all candidate systems have been designed to the same requirement. However, the confidence level of these assumed designs will be reflected in the relative rankings on issues 1 through 3 above.

Scoring Scheme for System Complexity - The Rational: This scoring issue is directly related to the probability of satisfactory system performance. The probability of success decreases as system complexity increases. A measure of system complexity is a direct function of the number of components in a system and the intricacy of their interconnection. An estimate of each system's complexity is made by estimating the expected number of components making up each system and the intricacy of their assembly. These estimates will provide a specific numerical ranking for each candidate, with the higher numerical values representing the more reliabile systems. The ranking will be normalized by dividing through by the lowest system ranking. Scaling to a zero to one hundred point scale is obtained by dividing one hundred by the highest normalized ranking value and multiplying the value obtained times each normalized ranking value to obtain the issue scores for each candidate.

Scoring Scheme for System Maturity - The Rational: This scoring issue is based on a ranking of the demonstrated design maturity of the candidate gaging systems being evaluated.

This evaluation is obtained from an evenly ranked descriptor scale detailing appropriate maturity levels. Identification of a candidate concepts position on the descriptor scale provides a numerical ranking.

The system maturity descriptor scale is shown below along with the corresponding scoring scale.

| Concept Maturity Descriptors | Score Value |
|---|---|
| System has been demontrated in space flight | 100 |
| System has been demonstrated in conventional flight | 70 |
| System has been demonstrated in ground applications | 40 |
| System has been demonstrated | 10 |

Scoring Scheme for Tolerance of System Environments - The Rational: This scoring issue is based on the premise that the gaging system which requires its system elements to be exposed to the most severe environmental stress will be the least reliable. Evaluation of the candidates will make use of the method of paired comparisons which will provide a numerical ranking of the relative environmental stress applied to each system. The system with the least stress will be given the highest (100 points) score.

Overall Detail Attribute "Reliability" Score: The three issue scores for each candidate will be summed and divided by three to obtain the overall detail attribute score. This gives each scoring issue equal weight.

Detail Attributes 3-b "Repairability": This detail attribute is defined as a relative ranking of the average time that would be required to detect and isolate a malfunction, effect repair and restore a system to a satisfactory level of performance. It is assumed that normal good design practice has been exercised in each candidate system to permit a reasonable level of repair to be effected. The specific scoring issues that will be addressed in evaluating the repairability of candidate gaging systems are:

(1) Fault Detection Time
(2) Fault Isolation Time
(3) Fault Correction Time
(4) Final Check Out Time

Scoring Scheme for Detail Attribute "Repairability" - The Rational: The scoring issue times are derived by application of the method of paired comparisons (see Appendix B). Since the shortest average time is the most repairable system, it will be necessary to perform a scale inversion. This will be done prior to summing and averaging the issue scores for each of the candidates. The complete scoring methodology then becomes:

(1) Detemine a numerical ranking of candidate times for each issue using the method of paired comparisons.
(2) Normalize the numerical rankings for each issue time, by dividing through by the value of the shortest time in each, issue ranking.

(3) Take the reciprocal of each normalized ranking value and multiply by one hundred.

(4) Sum the four issue scores obtained in Step three for each candidate and divide this sum by four. The resulting value is the overall detail attribute score for each candidate.

Detail Attribute 3-c "Maintainability": Maintainability, for this study, is the speed and economy with which a system can be kept in full performance capability. It is assumed that good maintainability design practices have been employed so that the best and most economical approach is somewhere between the extremes of high cost system reliability and an easily maintained failure prone system. This detail attribute is evaluated by scoring the following issues:

(1) Time required to perform preventive maintenance
(2) Difficulty of performing the preventive maintenance operation
(3) Skill level required to perform preventive maintenance

It is anticipated that candidate concept evaluation will be based on relative rankings in a high-mid-low context for each scoring issue.

Scoring Scheme for "Maintainability" - The Rational: Each of the three scoring issues has been structured in a "high-mid-low" scale by means of appropriate queries. The scoring values assigned to each of the query break points are 100 for the highest, 60 for the midpoint and 20 for the lowest. The reason 20 was chosen as the lowest score was the belief that any reasonable range of maintainability difficulties should not exceed a five to one ratio. The mid point score of 60 is midway between 20 and 100. The specific queries and score assignments are shown below. Note that scores between the break points are possible if the judgemental insight is sufficiently clear.

Preventive Maintenance Time. The "hands on" time to complete the maintenance operation is:

| Break Points | Score Value |
|---|---|
| Minimal | 100 |
| Moderate | 60 |
| Extensive | 20 |

Maintenance Performance. The effort required to assure that the maintenance actions can be accomplished is:

| Break Points | Score Value |
|---|---|
| Minimal | 100 |
| Average | 60 |
| Major | 20 |

Required Skill Level to Perform Maintenance Actions. Maintenance actions would require personnel possessing:

| Break Points | Score Value |
|---|---|
| No Special Skills | 100 |
| Moderate Skills | 60 |
| High Level Skills | 20 |

Overall detail attribute score - The three scoring issue scores are summed and divided by three to give each issue equal weight.

Detail Attribute 3-d "Safety": This detail attribute is defined as a relative ranking of candidate concepts regarding their inherent safety (instrinsic lack of threat or hazard to personnel) and their ability to resist hazardous situations caused by personnel error, environmental extremes or malfunctions. It is assumed that normal good design practices have been followed in the design of each candidate system and that each is as fail-safe as reasonable design considerations would provide. The specific scoring issues that will be addressed in evaluating the safety of candidate gaging systems are:

(1) The inherent safety of the system

(2) The ability to resist hazardous situations

Scoring Scheme for Inherent Safety - The Rational: This scoring issue is directly related to the basic safety characteristics of the candidate systems. The method of paired comparisons will be used to obtain both a relative and numerical ranking for each candidate. The numerical ranking will be normalized and converted to a value on a zero to one hundred point scale so that the inherently safest system will score one hundred.

Scoring Scheme for Ability to Resist Hazardous Situations - The Rational: This scoring issue is directly related to three primary sources of hazardous situations:

(1) Personnal errors

(2) Environmental extremes

(3) Malfunctions

The candidates will be evaluated by summing scores obtained for each of these considerations. Each of the three considerations has been structured in a "High-mid-low" scale by means of appropriate queries. The scores assigned to each of the query break points are 100 for the highest, 20 for the lowest and 60 for midpoint. The specific queries and score assignments are shown below.

Personnel errors - An error or sequence of errors during installation, operation, maintenance or repair. The candidate system's resistance to this hazardous situation is:

| Break Points | Score Value |
|---|---|
| Good | 100 |
| Average | 60 |
| Poor | 20 |

Environmental Extremes - The worst case environmental extremes. The candidate system's resistance to this hazardous situation is:

| Break Points | Score Value |
|---|---|
| Good | 100 |
| Average | 60 |
| Poor | 20 |

Malfunctions - The candidate system's resistance to this hazardous situation is:

| Break Points | Score Value |
|---|---|
| Good | 100 |
| Average | 60 |
| Poor | 20 |

The overall score for this issue is obtained by adding the three consideration scores together and dividing by three.

Overall Detail Attribute Score: The scoring issue scores are summed and divided by two to give each issue equal weight.

Detail Attribute 3-e "Compatibility": This detail attribute is defined as the relative degree to which special material compatibility issues may be encountered in satisfying the design requirement that all materials will be compatible with their intended function, environments and fluid exposures. The specific scoring issues that will be addressed in evaluating the relative degree of inherent compatibility of the candidate gaging systems are:

(1) The extent of compatibility issues associated with intended function.

(2) The extent of compatibility issues associated with environment.

(3) The extent of compatibility issues associated with fluid exposure.

Scoring Scheme for Above Issues 1, 2 and 3 - The Rational: All three of the scoring issues will be individually evaluated by means of estimated position on a "High-mid-low" scale. Position on the scale is established by means of appropriate queries. The scores assigned to the query break points are: 100 for the candidate with the highest degrees of inherent or natural compatibility (has the fewest compatibility issues of concern), 50 for the candidate with moderate or average levels of inherent compatibility, and 5 for candidates with extensive areas of compatibility concern. The low score value of five was chosen to permit a twenty to one ratio of inherent compatibility levels. The queries and scoring scales for the three issues are shown below.

Intended Function - The extent of material compatibility issues concerned with, intended function are believed to be:

| Break Points | Score Value |
|---|---|
| Minimal | 100 |
| Average | 50 |
| Extensive | 5 |

Environment - The extent of material compatibility issues concerned with, environment are believed to be:

| Break Points | Score Value |
|---|---|
| Minimal | 100 |
| Average | 50 |
| Extensive | 5 |

Fluid Exposure - The extent of material compatibility issues concerned with, fluid exposure are believed to be:

| Break Points | Score Value |
|---|---|
| Minimal | 100 |
| Average | 50 |
| Extensive | 5 |

Overall Detail Attribute Score: The overall score for this detail attribute is obtained by adding the three issue scores together for each candidate and dividing by three.

3.2.4 Evaluation and Scoring Method for Major Attribute 4 "Design State of Art.

Detail Attribute 4-a "Materials": This detail attribute is defined as a relative assessment of a candidate system's potential to use advanced or optimized materials. It is assumed that any candidate would meet basic material compatibility requirements but that some would be capable of making use of special materials to provide enhanced or superior performance or capabilities. The only scoring issue is the candidate system's potential to obtain any benefit from the use of special state of the art materials.

Scoring Scheme for Materials - The Rational: This scoring issue is based on a ranking of the perceived level of benefit a candidate gaging system would obtain by making use of special state of the art materials. This ranking is obtained from a descriptor scale detailing appropriate levels of benefit. A candidate's specific numerical ranking is dependent on its position on the descriptor scale. The descriptor and corresponding scoring scales are shown below. Interpoloation between descriptors is possible if finer graduations are needed. The structure of the scoring scale is based on the premise that: If a concept cannot receive any benefit from application of the most advanced available technology, it is either already completely current with the start of the art, or is not sensitive to current technological advances. In either case, it is as state of the art, as it is meaningful for it to be and will be scored as 100. The score obtained is the intermediate detail attribute score.

| Concept Maturity Descriptors | Score Value |
|---|---|
| System could obtain significant benefit | 55 |
| System could obtain moderate benefit | 70 |
| System could obtain minimal benefit | 85 |
| System could obtain no benefit | 100 |

Detail Attribute 4-b "Construction": This detail attribute is defined as a relative assessment of a candidate system's potential to make beneficial use of advanced or state of the art construction techniques or methods. The only scoring issue is the candidate system's potential to benefit from advanced construction methods.

Scoring Scheme for Construction - The Rational: This scoring issue is based on a ranking of the perceived level of benefit a candidate gaging system could obtain by making use of special state of the art construction methods. This ranking and a corresponding numerical score are determined by locating a candidate's position on a descriptor scale detailing appropriate levels of benefit. The scale can be interpolated and the score obtained is the intermediate detail attribute score. The scales are shown below. The scoring premise is the same as described under the "Materials" rational.

| Concept Maturity Descriptors | Score Value |
|---|---|
| System could obtain significant benefit | 55 |
| System could obtain moderate benefit | 70 |
| System could obtain minimal benefit | 85 |
| System could obtain no benefit | 100 |

Detail Attribute 4-c "Circuitry": This detail attribute is defined as a relative assessment of a candidate system's potential to be improved by application of state of the art circuit design techniques and componetry. The only scoring issue is the candidate system's potential to benefit from advanced circuit design and componentry.

Scoring Scheme for Circuity - The Rational: This scoring issue is based on an ranking of the perceived level of benefit a candidate gaging system could obtain by making use of state of the art circuit design techniques and componetry. This ranking and a corresponding numerical score are determined by locating a candidate's position on a descriptor scale, detailing appropriate levels of benefit. The scale can be interpolated and the score obtained is the intermediate detail attribute score. The scoring premise is the same as described under the "Materials" rational.

| Circuit Detail/Components Benefit Descriptors | Score Value |
|---|---|
| System could obtain significant benefit | 55 |
| System could obtain moderate benefit | 70 |
| System could obtain minimal benefit | 85 |
| System could obtain no benefit | 100 |

Detail Attribute 4-d "Performance": This detail attribute is defined as a relative assessment of a candidate system's potential for improvement in performance by application of any advanced technology or strategy of use not covered in the above scoring issues of material, construction or circuitry. The only scoring issue is the candidate system's potential for performance improvement by using other advanced technologies or use strategies.

Scoring Scheme for Performance - The Rational: This scoring issue is based on a ranking of the perceived level of performance benefit a candidate gaging system could obtain by making use of any other advanced technologies or use strategies. This ranking and a corresponding numerical score are determined by locating a candidate's position on a descriptor scale detailing appropriate levels of benefit. The scale can be interpolated, and the score obtained is the intermediate detail attribute score. The scoring premise is the same as desribed under the "Materials" rational.

| Performance Benefit Descriptors | Score Value |
|---|---|
| System could obtain significant benefit | 55 |
| System could obtain moderate benefit | 70 |
| System could obtain minimal benefit | 85 |
| System could obtain no benefit | 100 |

Detail Attribute 4-e "Potential for Improvement": This detail attribute is defined as a relative assessment of the overall difficulty of actually incorporating any of the potentially beneficial state of the art technology advances into a candidate system's design. The only evaluation issue is an assessment of the difficulty of actually incorporating the full measure of benefit into the design of any candidate capable of improvement by technological advances in the areas of materials, construction, circuitry or other performance enhancing technologies.

Scoring Scheme for Potential for Improvement - The Rational: This scoring issue is viewed as a normalizing adjustment to the candidate scores obtained in the other detail attributes: materials, construction, circuitry and performance. The purpose is to adjust these scores to account for the difficulty that would be encountered if the full measure of any available benefit were to be incorporated into the candidate system's design. The adjustment factors are obtained by locating a candidate's position on a descriptor scale detailing appropriate levels of difficulty. The scale can be interpoloated.

| Difficulty Descriptor Scale | Adjustment Factor |
|---|---|
| Great Difficulty | 0.10 |
| Moderate Difficulty | 0.40 |
| Minimal Difficulty | 0.70 |
| No Difficulty* | 1.00 |

* Candidates which can receive "no benefit" by application of any of the technology issues can obviously incorporate that level of benefit with "no difficulty".

Overall detail attribute scores are obtained for the issues of materials, construction, circuitry, and performance by multiplying each candidate's intermediate detail attribute score by the corresponding adjustment factor from the potential for Improvement Attribute. The overall potential for improvement detail attribute score for each candidate is the sum of the four adjustment factors obtained for the issues of materials, construction, circuitry and performance; divided by four and multiplied by 100.

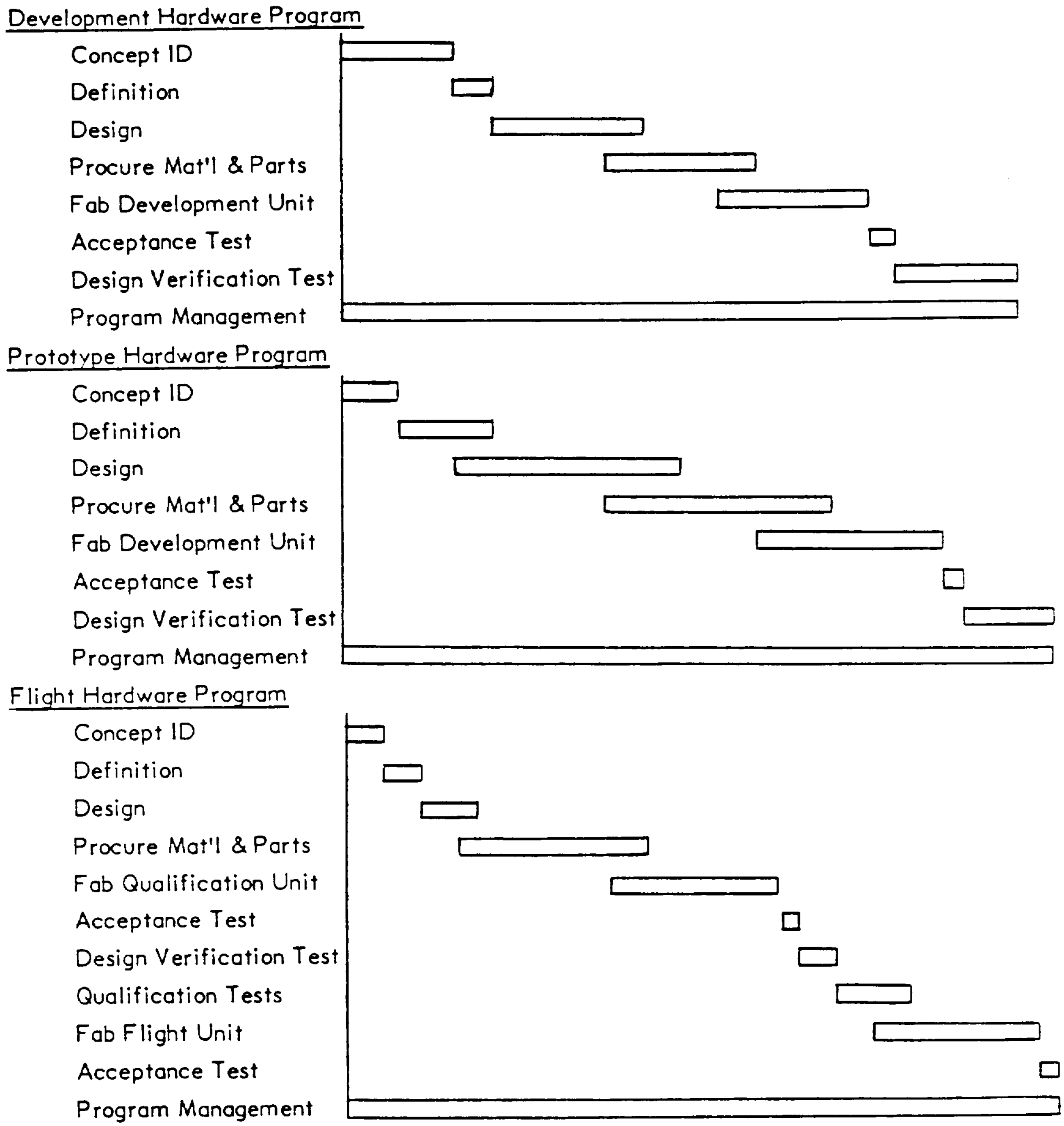
3.2.5 Evaluation and Scoring Method for Major Attribute 5 "Flight Hardware Development Effort.

Detail Attribute 5-a "Development Hardware Estimate to Complete": This detail attribute is defined as a relative ranking of the resources and time that would be required to complete a development hardware program for the candidate concepts. The specific scoring issues that will be addressed in evaluating the Development Hardware Estimate to Complete are:

(1) Total development hardware program span time
(2) Total estimated labor requirement
(3) Total estimated dollar requirement (other than labor costs)
(4) Risk factors affecting schedule and labor requirements

It is anticipated that the scoring issue input data will be natural scale parameters. It is also anticipated that, following adjustment of span time and labor requirements by the appropriate risk factors, the resulting dollar requirement will be further adjusted to include consideration of the time value of money. In this way, the candidate dollar requirements will be normalized for the span time issue and probable program risks. The resulting rankings of the candidates total dollar requirements are then comparable and may be used following normalization (dividing through by the lowest dollar ranking), inversion (taking the reciprocal of the normalized ranking) and scaling (multiplying by one hundred) as the overall detail attribute score. The details associated with evaluating the scoring issues are detailed below.

Scoring Scheme for "Span Time" - The Rational: Total program span times will be derived from estimates of program task span times and allowable overlaps. A standardized set of Gantt charts for Development, Prototype and Flight Hardware will be used to develop these estimates. The charts are shown below. A table indicating the activities associated with the Gantt chart elements for each type of hardware program is also shown below. All span time estimates will be in months.




NOTE THAT FLIGHT HARDWARE PROGRAM DESIGN TASK IS SIMPLY AN UPDATE OF THE PROTOTYPE PROGRAM DESIGN.

TABLE OF TASK ACTIVITIES

| PGM ACTIVITY | TYPE OF PROGRAM HARDWARE | | |
|---|---|---|---|
| | DEVELOPMENT | PROTOTYPE | FLIGHT |
| 1. Concept Identification | Screen and Select Best Approach, Feasibility Test | Identify Application | Identify Application Updates |
| 2. Definition | Design Specification, Interface Control Doc. | Design Spec, ICD, Integration Plan | Update Design Spec, ICD & Integration Plan |
| 3. Design | Design Dev Hardware, BOM, Feasibility Testing | Prel Design - PDR, Dev Testing, Final Design - CDR, BOM Approval | Update Design, BOM, CDR Changes |
| 4. Fabricate First Unit | Fab Dev Unit - Acceptance Test | Fab Design Verification Unit - Acceptance Test | Fab Design Verification Unit - Acceptance Test |
| 5. Design Verification | Ground and KC135 Dev Testing, Test Report | Design Ver Testing Including Environ/ Structural, Test Report | Design Verification Test Portion of Formal Qualification |
| 6. Qualification | | | Formal Qualification Test and Qualification Test Report |
| 7. Fabricate Flight Hardware | | | Fabricate Flight Hardware, Acceptance Test |
| 8. Program Management | Program Reporting and Reviews<br>Technical Design Assessments<br>Plans<br>Final Report<br>Test Procedures<br>Engr'g Support<br>Development Testing<br>FMEA, Safety Reviews<br>Design Review<br>Process Approvals<br>Plans<br>Test Procedures<br>Final Report<br>Pgm Mgr & Project Eng | Program Reporting and Reviews<br>Technical Design Assessments<br>Data Management<br>Configuration Mgmt<br>Traceability<br>EEE Parts<br>Conferences<br>FMEA,Safety Updates<br>Design Review<br>Process Updates<br>Plans<br>Test Procedures<br>Final Report<br>Qual Test Report<br>Flight Readiness Review<br>Engr Support Integration<br>Program Manager & Project Engineer | Program Reporting & Reviews<br>Technical Assessment Update<br>Data Management<br>Configuration Mgmt<br>Traceability<br>EEE Parts<br>Conferences |

Scoring Scheme for "Labor Requirements" - The Rational: The total engineering manhours required for support of a candidate in each of the three hardware program types will be estimated based on the standardized program activities detailed in the span time scoring scheme. The labor requirements for other functional cost centers (eg: manufacturing, test, program management, etc.) will be factored from the engineering estimate using ratios based on past program experience. The factors will be applied using relations as as shown below to obtain labor requirements for the other functional cost centers. The ratios are assumed to be different for each of the hardware program types.

Development Hardware:

$$Hd_{mfg} = Hd_{eng}(hd_{mfg})$$
$$Hd_{test} = Hd_{eng}(hd_{test})$$
$$Hd_{pm} = Hd_{eng}(hd_{pm})$$

Prototype Hardware:

$$Hp_{mfg} = Hp_{eng}(hp_{mfg})$$
$$Hp_{test} = Hp_{eng}(hp_{test})$$
$$Hp_{pm} = Hp_{eng}(hp_{pm})$$

Flight Hardware:

$$Hf_{mfg} = Hf_{eng}(hf_{mfg})$$
$$Hf_{test} = Hf_{eng}(hf_{test})$$
$$Hf_{pm} = Hf_{eng}(hf_{pm})$$

Where:

Hdxxx = Total labor hrs for xxx
Hdeng = Total engr labor hr est
hdxxx = Experience ratio of xxx labor hrs to engr hrs

Scoring Scheme for "Dollar Requirements" - The Rational: Nonlabor dollar estimates for each candidate system in each of the three program types will be made in 1985 dollars. The estimates will be made in the following categories using the nomenclature shown in the following relation.

$$\$xd = \$xgsd \left(\frac{RT + 1}{2}\right) + \$xnpd + \$xtrd + \$xcad$$

Where:

$xd = Total program, nonlabor, dollar requirement adjusted for technical goal risk for hardware type x.

$xgsd = Hardware type x gaging system material dollars

$xnpd = Hardware type x nonproduction material and supplies dollars

$xtrd = Hardware type x travel expense dollars

$xcad = Hardware type x CADAM/computer expense dollars

RT = Technical goal risk factor (see writeup below)

Scoring Scheme for "Risk Factors" - The Rational: This scoring issue is viewed as a means of adjusting the candidate labor and span time requirements determined in those specific detail attribute evaluations so as to incorporate the effects of risk. The methods for deriving these two risk factors and their subsequent application are detailed below.

Technical Goal Risk Factor: This risk factor is calculated using estimates of the probability of meeting the following technical goals. The estimates are expressed as decimal fractions and are identified with the nomenclature shown.

$P_a$ = Probability of meeting range and accuracy goals
$P_s$ = Probability of meeting susceptibility avoidance goals
$P_q$ = Probability of meeting design quality goals

The technical Goal Risk factor ($R_T$) is computed as follows:

$$R_T = \frac{1}{P_a \cdot P_s \cdot P_q}$$

The technical Goal Risk factor is applied by multiplying it by one half of the total program labor requirement and adding the resulting product to the other half of the total labor requirement to obtain the adjusted labor requirement. The technical Goal Risk factor is also multiplied by one half of the total material costs determined in the dollar requirement issue and the resulting product added to the other half of the total material cost to obtain an adjusted dollar cost.

Projected Schedule Risk Factor: This risk factor is derived as follows: first, the probability of meeting the projected program schedule with a technical Risk Factor of one is estimated (call this probability $P_t$). Then, since the actual technical Goal Risk factor is probably greater than one, an increase in program span time due to an increase in gaging system design labor is calculated using the following relation.

$$Sd_{new} = R_T \, Sd_{orig}$$

Where: $Sd_{new}$ = The new gaging system design span time

$R_T$ = Technical Goal Risk Factor

$Sd_{orig}$ = The original gaging system design span time

The increase in design span time is obtained by subtracting the original span time from the new, which gives:

$$\Delta S_{design} = (R_T - 1) \, Sd_{orig}$$

The new total program span time is then obtained by summing the schedule probability and Technical Risk factor effects.

$$St_{new} = St_{orig}\left[\left(\frac{1}{P_t}\right) + \left(\frac{Sd_{orig}}{St_{orig}}\right)(R_T - 1)\right]$$

Where: $St_{orig}$ = The original total program span time

The projected schedule risk factor then becomes:

$$R_t = \frac{St_{new}}{St_{orig}} = \left[\left(\frac{1}{P_t}\right) + \left(\frac{Sd_{orig}}{St_{orig}}\right)(R_T - 1)\right]$$

The projected schedule Risk factor is applied by multiplying it by the total program span time of the candidate being evaluated. This adjustment results in the final scoring issue (span time) value.

Calculation of Detail Attribute Scoring: Two considerations remain to be incorporated into the candidate evaluation data generated thus far. They are: the normalization of the various candidate adjusted program span times and the conversion of the adjusted labor requirements to dollars. Once this has been accomplished, the labor requirement dollars are summed with other dollar requirements and adjusted by the normalized span time "time value of money factor" to obtain comparable rankings of the candidate systems total dollar costs. This ranking is also normalized by dividing through by the lowest candidate program cost. Since the candidate program with the lowest cost should be scored the highest, it will be necessary to invert this ranking by taking the reciprocal of each of the ranking values. The final step of scaling the ranking values to a zero to one hundred point scale is done by simply multiplying by one hundred. The resulting scores are the overall detail attribute scores of the candidates.

Specific details of incorporating the span time normalization and conversion of labor requirements to dollars are developed below.

Conversion of Adjusted Labor Requirements to Dollars: This conversion will make use of the total adjusted engineering labor hours resulting from the labor requirement issues' final value for each candidate. The labor hours for Manufacturing, Test and etc. were derived from the Engineering labor hours by factors based on experience in the labor requirement scoring issue. Representative Aerospace rate factors will be used to derive coefficients for a total labor cost conversion relation based on only the engineering labor hour's estimates and judgements as to the relative difficulty level of the manufacturing, test, etc., tasks. The relation will be of the following form:

$$\$_t = Lx_{eng}\,(k_0)\quad 1.00 + hx_{mfg}\,d_1k_1 + hx_{test}\,d_2k_2 + \dots + \$_{xd}$$

Where:

- $\$_{xd}$ = Total dollar requirement for hdw type x
- $\$_t$ = Total program cost (dollars)
- $Lx_{eng}$ = Total adjusted engineering labor hours = $Hx_{eng}\left(\frac{1+R_T}{2}\right)$
- $k_0$ = Coefficient to convert engineering labor to dollars
- $k_1$ = Coefficient to obtain manufacturing labor dollars as a ratio of engineering labor dollars
- $d_1$ = Manufacturing difficulty correction factor (normal difficulty equals one)
- $k_2$ = Coefficient to obtain test labor dollars as a ratio of engineering labor dollars
- $d_2$ = Test difficulty correction factor
- $hx_{mfg}$, $hx_{test}$ = Manufacturing and test labor ratios as a function of engineering labor (see labor requirement scoring issue)

Span Time Normalization: This is the final adjustment to the candidate program costs to account for: the time value of money. The calculation is simplified by assuming that the program expenditures are equal in every quarter (3 months) of the total program span time, and that a payment for these expenditures is received from the procuring agency each quarter. Under these conditions, the total program adjusted cost ($\$_{adj}$) is given by the relation:

$$\$_{adj} = \frac{3\$_t}{T_t}\left(\frac{(1 + i/4)^{T_t/3} - 1}{i/4}\right)$$

Where: $\$_t$ = Total program dollars
$T_t$ = Total program span time (months)
$i$ = Annual rate of interest

The adjusted dollar costs for all candidates are now comparable and ready for computation of the final detail attribute scores as explained above.

Detail Attribute 5-b "Prototype Hardware Estimate to Complete": This detail attribute is defined as a relative ranking of the resources and time that would be required to complete a prototype hardware program for the candidate concepts. The specific scoring issues that will be addressed in evaluating the prototype hardware estimate to complere are:

(1) Total prototype hardware program span time
(2) Total estimated labor requirement
(3) Total estimated dollar requirement (other than labor costs)
(4) Risk factors affecting schedule and labor requirements

It is anticipated that the scoring issue input data will be natural scale parameters. It is also anticipated that, following adjustment of span time and labor requirements by the appropriate risk factors, the resulting dollar requirement will be further adjusted to include consideration of the time value of money. In this way the candidate dollar requirements will be normalized for the span time issue and probable program risks. The resulting rankings of the candidates total dollar requirements are then comparable and may be used following normalization, inversion and scaling, as the overall detail attribute score. The details associated with evaluating the scoring issues are detailed below.

Scoring Scheme for "Span Time" - The Rational: (See writeup under detail attribute 5-a)

Scoring Scheme for "Labor Requirements" - The Rational: (See writeup under detail attribute 5-a.

Scoring Scheme for "Dollar Requirements" - The Rational: (See writeup under detail attribute 5-a)

Scoring Scheme for "Risk Factors" - The Rational: (See writeup under detail attribute 5-a)

Overall Detail Attribute Score: (See "Calculation of Detail Attribute Scoring" under detail attribute 5-a).

Detail Attribute 5-c "Flight Hardware Estimate to Complete": This detail attribute is defined as a relative ranking of the resources and time that would be required to complete a flight hardware program for the candidate concepts. The specific scoring issues that will be addressed in evaluating the Flight Hardware Estimate to complete are:

(1) Total flight hardware program span time
(2) Total estimated labor requirement
(3) Total estimated dollar requirement (other than labor costs)
(4) Risk factors affecting schedule and labor requirements

It is anticipated that the scoring issue input data will be natural scale parameters. It is also anticipated that, following adjustment of span time and labor requirements by appropriate risk factors, the resulting dollar requirement will be further adjusted to include consideration of the time value of money. In this way, the candidate dollar requirements will be normalized for the span time issue and probable program risks. The resulting rankings of the candidates total dollar requirements are then comparable and may be used following normalization, inversion and scaling, as the overall detail attribute score. The details associated with evaluating the scoring issues are detailed below.

Scoring Scheme for "Span Time" - The Rational: (See writeup under detail attribute 5-a).

Scoring Scheme for "Labor Requirements" - The Rational: (See writeup under detail attribute 5-a).

Scoring Scheme for "Dollar Requirements" - The Rational: (See writeup under detail attribute 5-a).

Scoring Scheme for "Risk Factors" - The Rational: (See writeup under detail attribute 5-a).

Overall Detail Attribute Score: (See "Calculation of Detail Attribute Scoring" under detail attribute 5-a).

3.3 Cross Attribute Trade-Off Weights: The method for assessing cross attribute trade-off weights to each detail attribute is developed below. This material corresponds to selection model construction step (4) Assess Cross Attribute Trade-Off Weights.

In order to properly account for the significance of the contribution of each detail attribute to the major attribute it supports, it is necessary to assign a weight to each detail attribute. This assessment of detail attribute weights is a difficult task and involves issues beyond purely abstract notions of importance to permit valid trade-offs between detail attributes supporting the same major attribute. The method that will be used to derive these weights deals with the trade-off function by specifically addressing the range of candidate scores for each detail attribute. Once the range of candidate scores from worst to best is established for each detail attribute, the method of paired comparisons (using the strong diagonal option) is used to establish the trade-off weights. This approach allows the weight assessment to be based on range of major attribute benefit available from improvement in the performance of each detail attribute. The details of the method are shown in the following example.

Assume major attribute "Maj" is supported by three detail attributes a, b and c. Further assume that the range of candidate scores from worst to best for each of these detail attributes is as shown below.

| Detail Attribute | Range of Score |
|---|---|
| a | 30 |
| b | 20 |
| c | 50 |

The first step is to construct a ballot to compare each functional pair of attributes (ie: ab, ac and bc). The ballot would have a form similar to the one shown below for pair ab.

Ballot

Which do you believe will provide the greatest benefit to Major Attribute "Maj":

(1) 30 Scale Units Improvement in Detail Attribute a, or ☐

(2) 20 Scale Units Improvement in Detail Attribute b? ☑

How much benefit?

About the same? ☐

Moderately more? ☑

Considerably more? ☐

SCORE [- 1]

The second step is to provide sets of the ballots to a group qualified to register their assessment of the issues involved. Their vote on each pair comparison is obtained and scored on the ballots. Ballots are scored as follows. If the box marked "moderately more" was checked, the ballot scored 1; "considerably more" was similarly scored 2; and "about the same" scored 0. If the "(1)" detail attribute was checked, the score was given a plus sign and if "(2)" was checked, a minus sign.

The third step is to construct a matrix showing the ballot results. This is shown below assuming four ballot sets were obtained.

By inspection of the matrix average column, the detailed attributes can be ranked in order of greatest benefit (ie: b, a, c).

| Attribute Pairs | Set 1 | Set 2 | Set 3 | Set 4 | Sum | Average |
|---|---|---|---|---|---|---|
| ab | -1 | 0 | -1 | -1 | -3 | -.75 |
| ac | 0 | +1 | 0 | 0 | +1 | +.25 |
| bc | +2 | +1 | +1 | +2 | +6 | +1.50 |

b greater than a +0.75
a greater than c +0.25
b greater than c +1.50

The fourth step is to construct a preferential matrix with the attributes ranked in greatest to least benefit order; then only the strong diagonal pair values are taken as shown below:

Is greater than

| | b | a | c |
|---|---|---|---|
| b | 0 | +.75 | |
| a | | 0 | +1.50 |
| c | | | 0 |

Strong Diagonal

| Strong Diagonal Pairs | Value |
|---|---|
| ba | +.75 |
| ac | +1.50 |
| c- | -- |

The fifth step is to obtain a relative ranking of the detail attributes with the least benefit attribute being assigned a value of 1.00. The technique is shown below:

| Strong Diagonal Pairs | Diagonal Pair Value | Detail Attributes Least to → Greatest c | a | b |
|---|---|---|---|---|
| ba | +0.75 | | | 0.75 |
| ac | +1.50 | | 1.50 | 1.50 |
| c- | +1.00* | 1.00 | 1.00 | 1.00 |
| | | 1.00 | 2.50 | 3.25 |

SUM

| Detail Attribute | Relative Attribute Ranking |
|---|---|
| b | 3.25 |
| → a | 2.5 |
| c | 1.00 |
| SUM | 6.75 |

* Arbitrarily assigned a value of 1.00

The sixth step is to convert the relative ranking to a decimal fraction such that all detail attributes sum to 1.00.

| Detail Attribute | Conversion | Decimal Fraction |
|---|---|---|
| b | 3.25/6.75 | 0.48 |
| a | 2.50/6.75 | 0.37 |
| c | 1.00/6.75 | 0.15 |
| | | 1.00 SUM |

These are the cross attribute trade-off weights

# APPENDIX A

## ZERO-GRAVITY QUANTITY GAGING SYSTEM

## STRAWMAN TANKAGE DESCRIPTIONS

## 1.0 INTRODUCTION

Evaluation of Zero Gravity Quantity Gaging concepts will require analysis methods for judging the candidates for sensitivity to:

(a) Total fluid mass
(b) Tank size
(c) Tank shape
(d) Tank orientation
(e) Tank internal geometry (e.g.: slosh baffles, screen acquisition systems, etc).

Since such analyses require fairly definitive descriptions of appropriate "strawman" tank configurations, we have used information from the following resources to generate the required descriptions.

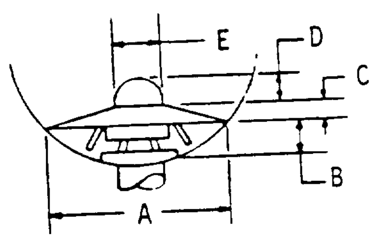
(a) Statement of Work for "Zero Gravity Quantity Gaging System for Cryogenic Fluids", page 7. Used for tankage size, fluid mass, shape and thermal protection scheme data.
(b) NASA CR-165150, GDC-ASP-80-013, "Conceptual Design of an Orbital Propellant Transfer Experiment, Volume II." Used for configuration and scaleable dimensions for start baskets, fluid acquisition devices, thermo vents, fill spray bars and bubbler rings.
(c) NASA CR-406 "Slosh Design Handbook I." Used for slosh baffle configurations and dimensional data.

The following illustrations and tabular data present our current view of the "strawman" tankage configurations which are suitable for use in Zero Gravity Quantity Gaging System evaluation analyses.

Tankage Size, Shape, Thermal Protection Scheme and Fluid Mass:

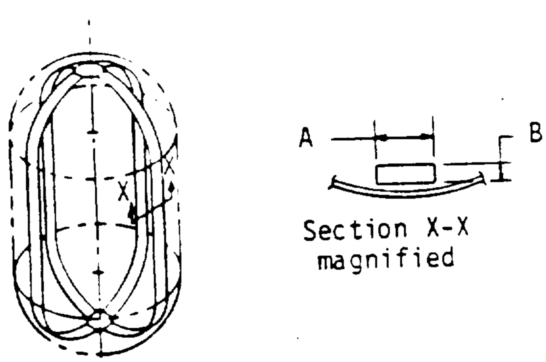
| TANK CONFIG | TANK SHAPE | DIAMETER (FT) | LENGTH (FT) | FLUID MASS (LBS) | THERMAL PROTECTION SCHEME | TANK MATERIAL |
|---|---|---|---|---|---|---|
| OTV $O_2$ | Spherical | 13 0 | — | 73 490 | Single Wall;MLI | Inconel/Cress |
| Storage $O_2$ | Cyl(W)HemiHeads | 14 0 | 22 0 | 166 379 | Single Wall;MLI | Inconel/Cress |
| OTV $H_2$ | Cyl(W)HemiHeads | 14 0 | 27 0 | 12 535 | Single Wall;MLI | Alum Alloy |
| Storage $H_2$ | Cyl(W)HemiHeads | 14 0 | 55 0 | 28 250 | Single Wall;MLI | Alum Alloy |

START BASKET/ACQUISITION MANIFOLD:




| TANK CONFIG | DIMENSIONAL VALUE (in) | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| OTV $O_2$ | 33.8 | 1.9 | 8.5 | 2 | 2 |
| Storage $O_2$ | 31.4 | 1.5 | 8.6 | 2 | 2 |
| OTV $H_2$ | 47 | 3.4 | 13.1 | 6 | 2 |
| Storage $H_2$ | 56 | 4.8 | 19.5 | 6 | 2 |

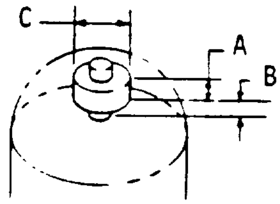
ACQUISITION CHANNELS:




Section X-X
magnified

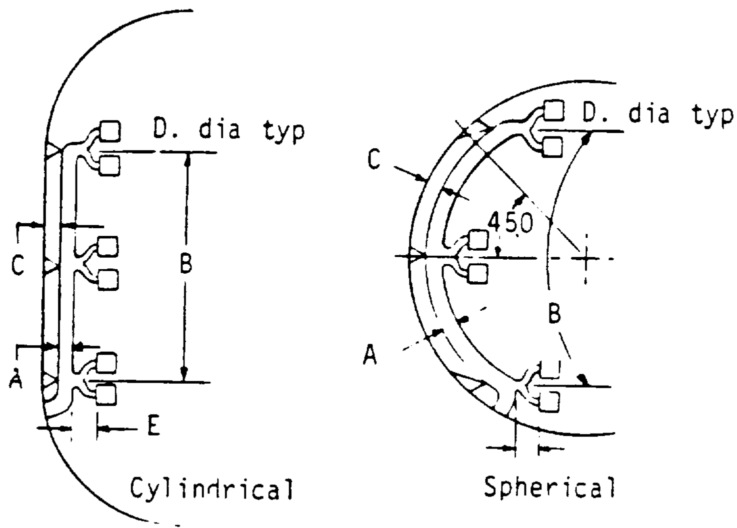
| TANK CONFIG | DIMENSIONAL VALUE (in) | |
|---|---|---|
| | A | B |
| OTV $O_2$ | — | — |
| Storage $O_2$ | 2.3 | .8 |
| OTV $H_2$ | — | — |
| Storage $H_2$ | 5 | 2 |

THERMAL VENT:



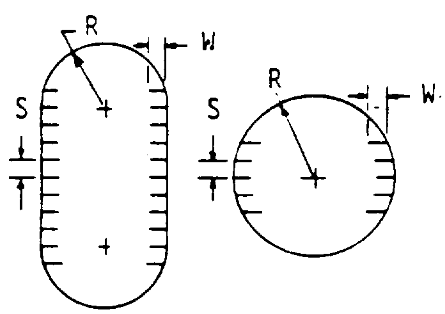

| TANK CONFIG | DIMENSIONAL VALUE (in) | | |
|---|---|---|---|
| | A | B | C |
| OTV $O_2$ | -- | -- | -- |
| Storage $O_2$ | 6 | 4 | 10 |
| OTV $H_2$ | -- | -- | -- |
| Storage $H_2$ | 8.5 | 5.5 | 14 |

FILL SPRAY BAR:




| TANK CONFIG | DIMENSIONAL VALUE (in) | | | | |
|---|---|---|---|---|---|
| | A | B | C | D | E |
| OTV $O_2$ | .75 | 118 | 1 | 1.5 | 2 |
| Storage $O_2$ | .75 | 82 | 1 | 1.5 | 2 |
| OTV $H_2$ | 1.5 | 156 | 1 | 3 | 4 |
| Storage $H_2$ | 1.5 | 492 | 1 | 3 | 4 |

RING BAFFLES:




Ring Baffles concentric with longitudinal axis.

| TANK CONFIG | DIM. (in) | | | No.* BAFFLES |
|---|---|---|---|---|
| | R | S | W | |
| OTV $O_2$ | 78 | 19.5 | 12 | 5 |
| Storage $O_2$ | 84 | 21 | 13 | 11 |
| OTV $H_2$ | 84 | 21 | 13 | 11 |
| Storage $H_2$ | 84 | 21 | 13 | 11 |

*Center ring on equator of spherical tanks or aligned with midpoint of longitudinal axis of cylindrical tanks.

# APPENDIX B

# METHOD
# OF
# PAIRED COMPARISONS

## 1.0 INTRODUCTION

Frequently, in the evaluation of complex questions, it is desirable to be able to set relative values on the alternatives. If the issues are too complex, this may not be possible or desirable to accomplish in an arbitrary manner. In these cases, however, it is usually possible to make judgements between any two alternatives. Using this premise, Thurstone and Masteller (1) devised a method of using such comparison pairs to evolve a relative ranking of the item of interest.

## 2.0 DESCRIPTION OF MODEL

The method is best illustrated by means of an example. Assume that six complex entities or issues are to be evaluated and given a relative ranking consistent with their significance to a common characteristic or item of interest. The following nomenclature is assigned to the six entities and the common item of interest.

| ENTITIES | ITEM OF INTEREST |
|---|---|
| a | "101" |
| b | |
| c | |
| d | |
| e | |
| f | |

Ballots are prepared for each of the basic pairs (inverts are omitted) so that the judgements of eight qualified assessors could be registered. the ballots contained a question framed as follows: "Of the two (entities) listed below, which do you believe will provide the greatest ("101")." The question was followed by the entity pair being evaluated with the entity first in alphabetical sequence being listed first. The basic pairs and a sample ballot for entity pair ab is shown below.

Eight sets of fifteen ballots were prepared, and a set was provided to each of the qualified assessors who registered their judgements by checking the ballot choices in the appropriate boxes.

Sample Ballot

Score [-1]

Of the two (entities) listed below, which do you believe will provide the greatest ("101"):

(1) Entity a, or ☐

(2) Entity b? ☑

How much ("101")?

About the same? ☐

Moderately more? ☑

Considerably more? ☐

Analyses of Results: The individual ballots were scored as follows: if the box marked "Moderately more" was checked, the card scored 1; "Considerably more" scored 2; and "About the same" scored 0. If the entity first in the alphabetical sequenced was checked, the card was scored +. Otherwise, -. The sample ballot was scored -1 and this was noted in the score box in the upper right hand corner. After all ballots have been scored, the results are entered in an average preference matrix, such as the one shown below.

| ENTITIES | a | b | c | d | e | f |
|---|---|---|---|---|---|---|
| a | | +1,0,+1,0<br>+2,+1,+1,0<br>Ave: .750 | -1,+1,+1,-1<br>+1,-1,0,-1<br>Ave: -.125 | +1,+2,+2,+2<br>+2,0,+2,+1<br>Ave: 1.50 | +1,+1,+2,+2<br>+2,0,+1,+1<br>Ave: 1.25 | +2,+1,+2,+1<br>+2,+2,+2,+2<br>Ave: 1.75 |
| b | | | -2,0,-1,-1<br>-1,-2,0,-2<br>Ave: -1.125 | +1,+2,+2,+2<br>0,-1,+2,+1<br>Ave: 1.125 | 0,+1,+1,0<br>+1,-1,0,0<br>Ave: .25 | +1,+1,-1,+1<br>+2,+1,+2,+2<br>Ave: 1.25 |
| c | | Strong Diagonal | | +2,+2,+2,+2<br>+1,+1,+2,+2<br>Ave: 1.75 | +2,+1,+1,+1<br>+1,+1,+2,+2<br>Ave: 1.375 | +2,0,+1,+2<br>+2,+2,+2,+2<br>Ave: 1.625 |
| d | | | | | -1,-1,-1,-2<br>0,0,-2,0<br>Ave: -.875 | 0,-2,-1,-1<br>+1,+2,-1,+1<br>Ave: -.125 |
| e | | | | | | +1,0,0,+1<br>+1,+2,+1,+1<br>Ave: .875 |
| f | | | | | | |

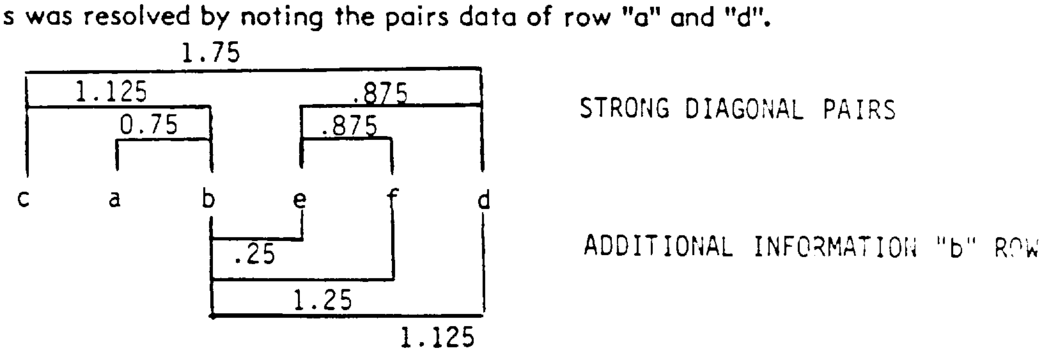
At this point, the entities can be arranged in order from greatest ("101") to least using the following technique. Arrange the strong diagonal paris (ie: ab, bc, cd, de, ef) in a column with the dominate member of a pair on the left and indicate their average score. A minus sign on the score indicates an inversion of the dominate member should be made.

| DOMINATE MEMBER OF PAIR | AVERAGE SCORE |
|---|---|
| ab | +0.750 |
| bc | -1.125 |
| cd | +1.750 |
| de | -0.875 |
| ef | +0.875 |

Correct for Inversions →

| DOMINATE MEMBER OF PAIR | AVERAGE SCORE |
|---|---|
| ab | +0.750 |
| cb | +1.125 |
| cd | +1.750 |
| ed | +0.875 |
| ef | +0.857 |

Reading the corrected table as "a" is greater than "b" by 0.75, "c" is greater than "b" by 1.125, etc., allows the construction of an ordering diagram where the greater entity is always to the left. The diagram is shown below. Notice that the strong diagonal data did not conclusively sort out the ordering through entities "b", "e" and "f", so additional pairs of data from the entity "b" row was used which located entity "e" but left "f" and "d" in question. This was resolved by noting the pairs data of row "a" and "d".




The result of this exercise is the following ordering of the entities with the greatest at the top of the list and the least at the bottom.

<u>Entitity</u>

c
a
b
e
f
d

Again, a matrix is constructed with the entity order developed above used in the row and column headings. Since only the strong diagonal pairs are of interest, only these values are filled in.

| Entity | c | a | b | e | f | d |
|---|---|---|---|---|---|---|
| c | | 0.125 | | | | |
| a | | | 0.750 | | | |
| b | | | | 0.250 | | |
| e | | | | | 0.875 | |
| f | | | | | | 0.125 |
| d | | | | | | |

Normalized relative ranking values are developed for the entities using the above strong diagonal matrix information and by setting the least entity equal to a value of 1.000.

| STRONG DIAGONAL PAIRS | DIAGONAL PAIR VALUE | ENTITY<br>Least to → Greatest<br>d | f | e | b | a | c |
|---|---|---|---|---|---|---|---|
| ca | 0.125 | | | | | | 0.125 |
| ab | 0.750 | | | | | 0.750 | 0.750 |
| be | 0.250 | | | | 0.250 | 0.250 | 0.250 |
| ef | 0.875 | | | 0.875 | 0.875 | 0.875 | 0.875 |
| fd | 0.125 | | 0.125 | 0.125 | 0.125 | 0.125 | 0.125 |
| d- | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| | | 1.000 | 1.125 | 2.000 | 2.250 | 3.000 | 3.125 |

| ENTITY | NORMALIZED RELATIVE RANKING |
|---|---|
| c | 3.125 |
| a | 3.000 |
| b | 2.250 |
| e | 2.000 |
| f | 1.125 |
| d | 1.000 |

The above method is known as the strong diagonal option. It is possible to make use of all of the information in the matrix data to obtain more refined results, but it will be at the expense of considerably more analysis and computational effort. The basis for this total matrix approach is described in reference (2).

Again the method is best illustrated by an example. We will use the same data as that used in the strong diagonal method so as to obtain a comparison of the methods.

We will start with the ordered matrix from the strong diagonal method but with all the data filled in.

| Entity | c | a | b | e | f | d |
|---|---|---|---|---|---|---|
| c | 0 | 0.125 | 1.125 | 1.375 | 1.625 | 1.750 |
| a | | 0 | 0.750 | 1.250 | 1.750 | 1.500 |
| b | | | 0 | 0.250 | 1.250 | 1.125 |
| e | | | | 0 | 0.875 | 0.875 |
| f | | | | | 0 | 0.125 |
| d | | | | | | 0 |

This matrix will be normalized using the following relation:

$$X_{norm} = \frac{X_{matrix} + 2}{4}$$

ie: cc $X_{matrix} = 0$ $\quad X_{norm} = \frac{0 + 2}{4} = 0.500$

ca $X_{matrix} = 0.125$ $\quad X_{norm} = \frac{0.125+2}{4} = 0.531$

The normalized matrix then becomes:

| Entity | c | a | b | e | f | d |
|---|---|---|---|---|---|---|
| c | 0.500 | 0.531 | 0.781 | 0.845 | 0.905 | 0.938 |
| a | 0.469 | 0.500 | 0.686 | 0.812 | 0.938 | 0.875 |
| b | 0.219 | 0.314 | 0.500 | 0.562 | 0.813 | 0.781 |
| e | 0.155 | 0.188 | 0.438 | 0.500 | 0.718 | 0.718 |
| f | 0.095 | 0.062 | 0.188 | 0.282 | 0.500 | 0.531 |
| d | 0.062 | 0.125 | 0.129 | 0.282 | 0.469 | 0.500 |

NOTE: Entity pairs such as ac use the inverse value of ca which is -0.125 so $X_{norm} = \frac{-0.125+2}{4} = 0.469$

The deviates for the normalized matrix values are computed using the relation:

$$(X_{norm})_{is} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{r_{is}} e^{-x^2/2} \, dx$$

A matrix of deviate values is shown below. The values can be obtained from Tables 1 and 2. The deviates contained in the matrix elements correspond to areas under the normal curve. The average of each matrix row deviates is computed and shown in column $r_i$ of the matrix. The difference in the values of $r_i$ between rows are used in the following relation to obtain values of T. These values of T are assumed to be proportional to the level of ("101") associated with each entity, and are included in the matrix column T.

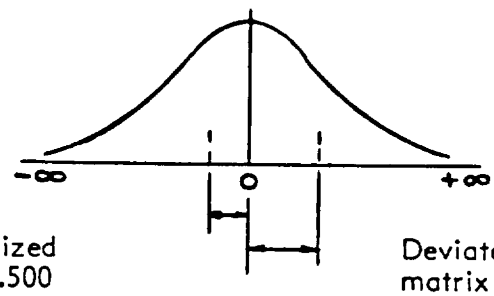
$$r_i = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{T} e^{-x^2/2} \, dx$$

| Entity | c | a | b | e | f | d | $r_i$ | T |
|---|---|---|---|---|---|---|---|---|
| c | 0 | .08 | .78 | 1.15 | 1.31 | 1.54 | .810 | .791 |
| a | -.08 | 0 | .48 | .89 | 1.54 | 1.15 | .663 | .746 |
| b | -.78 | -.48 | 0 | .16 | .89 | .78 | .095 | .538 |
| e | -1.15 | -.89 | -.16 | 0 | .58 | .58 | -.163 | .434 |
| f | -1.31 | -1.54 | -.89 | -.58 | 0 | .08 | -.706 | .240 |
| d | -1.54 | -1.15 | -.78 | -.58 | -.08 | 0 | -.690 | .245 |

Computational Notes:

The Normal Curve

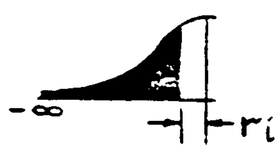
1. Obtaining deviate values:

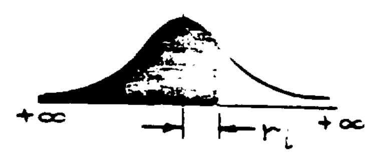



Total area under the curve equals 1.000

Deviate value for normalized matrix values less than 0.500 corresponds to area under normal curve from - to the deviate value.

Deviate value for normalized matrix values greater than 0.500. Corresponds to area under normal curve from - to the deviate value.




Use Table 1: look up normal matrix value in body of table (ie: area under curve), find x value that corresponds, give it a minus sign: this is deviate value.

Use Table 2: look up normal matrix value in body of table (ie: area under curve), find x value that corresponds: this is deviate value.

2. Obtaining $r_i$: Sum row deviates and divide by number of entities. For example:

$$\text{Row c} \quad \frac{0.00 + 0.08 + 0.78 + 1.15 + 1.31 + 1.54}{6} = 0.81 = \text{row c } r_i$$

3. Obtaining T: If the "$r_i$" value is negative, enter table 1 with the $r_i$ as x (ignore sign) and find corresponding "T" in body of table. If the "$r_i$" value is positve, enter table 2 with $r_i$ as x and find corresponding "T" in body of table.

Comparison of strong diagonal and total matrix options to the method of paired comparisons.

First the total matrix "T" values are normalized by dividing through by the least ("101") value for entity d (ie: 0.245) so they can be compared to the strong diagonal values. When this is done, the following direct comparison can be made.

| ENTITY | STRONG DIAGONAL | TOTAL MATRIX | DIFFERENCE WITH STRONG DIAGONAL |
|---|---|---|---|
| c | 3.125 | 3.229 | +0.104 |
| a | 3.000 | 3.045 | +0.045 |
| b | 2.250 | 2.160 | -0.090 |
| e | 2.000 | 1.771 | -0.229 |
| f | 1.125 | 0.980* | -0.145 |
| d | 1.000 | 1.000 | 0.000 |

* The use of the total matrix data indicates that perhaps entity "f" should be the least ("101") entity though there is little difference between "f" and "d".

Table 1 and Table 2 are included on the following pages.

References (1) Methods of Paired Comparison, Psychometrica, Volu. 16, # 1, March 1951.

(2) North American Report, SID62-1225, 17 October 1962.

TABLE I:

| x → | .00 | .01 | .02 | .03 | .04 | .05 | .06 | .07 | .08 | .09 |
|---|---|---|---|---|---|---|---|---|---|---|
| ↓0.0 | .5000 | .4960 | .4920 | .4880 | .4840 | .4801 | .4761 | .4721 | .4681 | .4641 |
| 0.1 | .4602 | .4562 | .4522 | .4483 | .4443 | .4404 | .4364 | .4325 | .4286 | .4247 |
| 0.2 | .4207 | .4168 | .4129 | .4090 | .4052 | .4013 | .3974 | .3936 | .3897 | .3859 |
| 0.3 | .3821 | .3783 | .3745 | .3707 | .3669 | .3632 | .3594 | .3557 | .3520 | .3483 |
| 0.4 | .3446 | .3409 | .3372 | .3336 | .3300 | .3264 | .3228 | .3192 | .3156 | .3121 |
| 0.5 | .3085 | .3050 | .3015 | .2981 | .2946 | .2912 | .2877 | .2843 | .2810 | .2776 |
| 0.6 | .2743 | .2709 | .2676 | .2643 | .2611 | .2578 | .2546 | .2514 | .2483 | .2451 |
| 0.7 | .2420 | .2389 | .2358 | .2327 | .2296 | .2266 | .2236 | .2206 | .2177 | .2148 |
| 0.8 | .2119 | .2090 | .2061 | .2033 | .2005 | .1977 | .1949 | .1922 | .1894 | .1867 |
| 0.9 | .1841 | .1814 | .1788 | .1762 | .1736 | .1711 | .1685 | .1660 | .1635 | .1611 |
| 1.0 | .1587 | .1562 | .1539 | .1515 | .1492 | .1469 | .1446 | .1423 | .1401 | .1379 |
| 1.1 | .1357 | .1335 | .1314 | .1292 | .1271 | .1251 | .1230 | .1210 | .1190 | .1170 |
| 1.2 | .1151 | .1131 | .1112 | .1093 | .1075 | .1056 | .1038 | .1020 | .1003 | .0985 |
| 1.3 | .0968 | .0951 | .0934 | .0918 | .0901 | .0885 | .0869 | .0853 | .0838 | .0823 |
| 1.4 | .0808 | .0793 | .0778 | .0764 | .0749 | .0735 | .0721 | .0708 | .0694 | .0681 |
| 1.5 | .0668 | .0655 | .0643 | .0630 | .0618 | .0606 | .0594 | .0582 | .0571 | .0559 |
| 1.6 | .0548 | .0537 | .0526 | .0516 | .0505 | .0495 | .0485 | .0475 | .0465 | .0455 |
| 1.7 | .0446 | .0436 | .0427 | .0418 | .0409 | .0401 | .0392 | .0384 | .0375 | .0367 |
| 1.8 | .0359 | .0351 | .0344 | .0336 | .0329 | .0322 | .0314 | .0307 | .0301 | .0294 |
| 1.9 | .0287 | .0281 | .0274 | .0268 | .0262 | .0256 | .0250 | .0244 | .0239 | .0233 |
| 2.0 | .0228 | .0222 | .0217 | .0212 | .0207 | .0202 | .0197 | .0192 | .0188 | .0183 |
| 2.1 | .0179 | .0174 | .0170 | .0166 | .0162 | .0158 | .0154 | .0150 | .0146 | .0143 |
| 2.2 | .0139 | .0136 | .0132 | .0129 | .0125 | .0122 | .0119 | .0116 | .0113 | .0110 |
| 2.3 | .0107 | .0104 | .0102 | .0099 | .0096 | .0094 | .0091 | .0089 | .0087 | .0084 |
| 2.4 | .0082 | .0080 | .0078 | .0076 | .0073 | .0071 | .0070 | .0068 | .0066 | .0064 |
| 2.5 | .0062 | .0060 | .0059 | .0057 | .0055 | .0054 | .0052 | .0051 | .0050 | .0048 |
| 2.6 | .0047 | .0045 | .0044 | .0043 | .0042 | .0040 | .0039 | .0038 | .0037 | .0036 |
| 2.7 | .0035 | .0034 | .0033 | .0032 | .0031 | .0030 | .0029 | .0028 | .0027 | .0026+ |
| 2.8 | .0026- | .0025 | .0024 | .0023+ | .0023- | .0022 | .0021+ | .0021- | .0020 | .0019+ |
| 2.9 | .0019- | .0018 | .0018+ | .0017 | .0016+ | .0016- | .0015+ | .0015- | .0014+ | .0014- |

TABLE 2:

| z | .000 | .01 | .02 | .03 | .04 | .05 | .06 | .07 | .08 | .09 |
|---|---|---|---|---|---|---|---|---|---|---|
| .0 | .5000 | .5040 | .5080 | .5120 | .5160 | .5199 | .5239 | .5279 | .5319 | .5359 |
| .1 | .5398 | .5438 | .5478 | .5517 | .5557 | .5596 | .5636 | .5675 | .5714 | .5753 |
| .2 | .5793 | .5832 | .5871 | .5910 | .5948 | .5987 | .6026 | .6064 | .6103 | .6141 |
| .3 | .6179 | .6217 | .6255 | .6293 | .6331 | .6368 | .6406 | .6443 | .6480 | .6517 |
| .4 | .6554 | .6591 | .6628 | .6664 | .6700 | .6736 | .6772 | .6808 | .6844 | .6879 |
| .5 | .6915 | .6950 | .6985 | .7019 | .7054 | .7088 | .7123 | .7157 | .7190 | .7224 |
| .6 | .7257 | .7291 | .7324 | .7357 | .7389 | .7422 | .7454 | .7486 | .7517 | .7549 |
| .7 | .7580 | .7611 | .7642 | .7673 | .7704 | .7734 | .7764 | .7794 | .7823 | .7852 |
| .8 | .7881 | .7910 | .7939 | .7967 | .7995 | .8023 | .8051 | .8078 | .8106 | .8133 |
| .9 | .8159 | .8186 | .8212 | .8238 | .8264 | .8289 | .8315 | .8340 | .8365 | .8389 |
| 1.0 | .8413 | .8438 | .8461 | .8485 | .8508 | .8531 | .8554 | .8577 | .8599 | .8621 |
| 1.1 | .8643 | .8665 | .8686 | .8708 | .8729 | .8749 | .8770 | .8790 | .8810 | .8830 |
| 1.2 | .8849 | .8869 | .8888 | .8907 | .8925 | .8944 | .8962 | .8980 | .8997 | .9015 |
| 1.3 | .9032 | .9049 | .9066 | .9082 | .9099 | .9115 | .9131 | .9147 | .9162 | .9177 |
| 1.4 | .9192 | .9207 | .9222 | .9236 | .9251 | .9265 | .9279 | .9292 | .9306 | .9319 |
| 1.5 | .9332 | .9845 | .9357 | .9370 | .9882 | .9894 | .9406 | .9418 | .9429 | .9441 |
| 1.6 | .9452 | .9463 | .9474 | .9484 | .9495 | .9505 | .9515 | .9525 | .9535 | .9545 |
| 1.7 | .9554 | .9564 | .9573 | .9582 | .9591 | .9599 | .9608 | .9616 | .9625 | .9633 |
| 1.8 | .9641 | .9649 | .9656 | .9664 | .9671 | .9678 | .9686 | .9693 | .9699 | .9706 |
| 1.9 | .9713 | .9719 | .9726 | .9732 | .9738 | .9744 | .9750 | .9756 | .9761 | .9767 |
| 2.0 | .9772 | .9778 | .9783 | .9788 | .9793 | .9798 | .9803 | .9808 | .9812 | .9817 |
| 2.1 | .9821 | .9826 | .9830 | .9834 | .9838 | .9842 | .9846 | .9850 | .9854 | .9857 |
| 2.2 | .9861 | .9864 | .9868 | .9871 | .9875 | .9878 | .9881 | .9884 | .9887 | .9890 |
| 2.3 | .9893 | .9896 | .9898 | .9901 | .9904 | .9906 | .9909 | .9911 | .9913 | .9916 |
| 2.4 | .9918 | .9920 | .9922 | .9925 | .9927 | .9929 | .9931 | .9932 | .9934 | .9936 |
| 2.5 | .9938 | .9940 | .9941 | .9943 | .9945 | .9946 | .9948 | .9949 | .9951 | .9952 |
| 2.6 | .9953 | .9955 | .9956 | .9957 | .9959 | .9960 | .9961 | .9962 | .9963 | .9964 |
| 2.7 | .9965 | .9966 | .9967 | .9968 | .9969 | .9970 | .9971 | .9972 | .9973 | .9974 |
| 2.8 | .9974 | .9975 | .9976 | .9977 | .9977 | .9978 | .9979 | .9979 | .9980 | .9981 |
| 2.9 | .9981 | .9982 | .9982 | .9983 | .9984 | .9984 | .9985 | .9985 | .9986 | .9986 |
| 3.0 | .9987 | .9987 | .9987 | .9988 | .9988 | .9989 | .9989 | .9989 | .9990 | .9990 |
| 3.1 | .9990 | .9991 | .9991 | .9991 | .9992 | .9992 | .9992 | .9992 | .9993 | .9993 |
| 3.2 | .9993 | .9993 | .9994 | .9994 | .9994 | .9994 | .9994 | .9995 | .9995 | .9995 |
| 3.3 | .9995 | .9995 | .9995 | .9996 | .9996 | .9996 | .9996 | .9996 | .9996 | .9997 |
| 3.4 | .9997 | .9997 | .9997 | .9997 | .9997 | .9997 | .9997 | .9997 | .9997 | .9998 |

Beechcraft
Boulder Division

# Beech Aircraft Corporation

Boulder, Colorado

**Code Ident. No. 07399**

Descriptive Data 18024

## Summary Document
## Zero-Gravity Quantity Gaging Systems
## Trade Study

Issue Date: February 4, 1986

TABLE OF CONTENTS

## 1.0 INTRODUCTION

This descriptive data documents the results of the Trade Study efforts performed under NASA Contract NAS9-17378 Statement of Work Task 1. The work was performed by Beech Aircraft Corporation at the Boulder Division located in Boulder, Colorado.

Organization of the material contained in this document includes the actual Trade Study material presented at the Second Program Review held at Johnson Space Center on January 30, 1986, and an appendix which documents the preliminary concepts selected for analysis in the Trade Study effort.

## 2.0 TRADE STUDY PRESENTATION

The following pages reproduce the actual material presented to the NASA representatives to document the results of the Trade Study effort and to justify the conclusions and recommendations offered at the end of the presentation.

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# TRADE STUDY DISCUSSION
# AGENDA

(1) THE TRADE STUDY ACTIVITY

(2) RESULTS OF THE PRELIMINARY CONCEPT SCREENING

(3) CONCEPT EXPOSITIONS

(4) SELECTION CRITERIA EVALUATION APPROACHES

(5) MAJOR ATTRIBUTE ASSIGNED WEIGHTS

(6) DETERMINATION OF CROSS ATTRIBUTE TRADE-OFF WEIGHTS

(7) SCORING RESULTS FOR EACH MAJOR ATTRIBUTE
- OXYGEN SYSTEMS
- HYDROGEN SYSTEMS

(8) OVERALL CONCEPT SCORES
- OXYGEN SYSTEMS
- HYDROGEN SYSTEMS

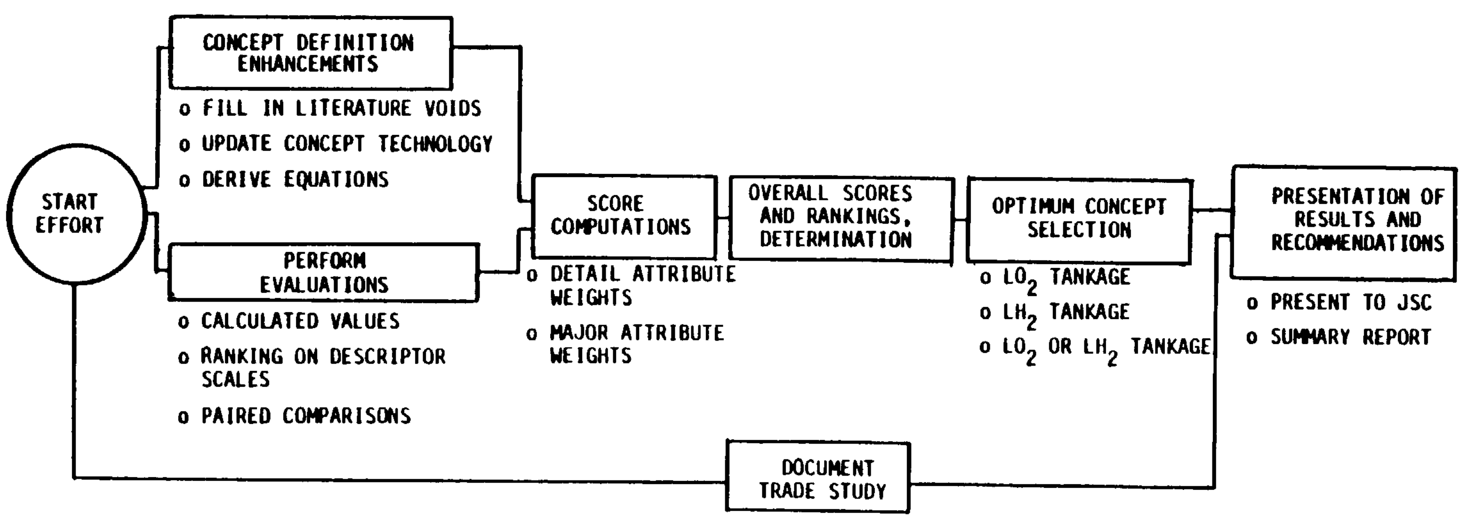
(9) RECOMMENDATIONS AND CONCLUSIONS

# THE TRADE STUDY EFFORT

BASIC OBJECTIVE: PERFORM THE ACTIVITIES REQUIRED TO ACCOMPLISH THE CONCEPT EVALUATIONS AS DELINIATED IN THE SELECTION CRITERIA AND SELECT THE OPTIMUM DIRECT GAGING CONCEPT(S) FOR:

(A) $LO_2$ PROPELLANT TANKAGE
(B) $LH_2$ PROPELLANT TANKAGE
(C) BOTH $LO_2$ AND $LH_2$ PROPELLANT TANKAGE

TRADE STUDY ACTIVITY FLOW CHART:



# RESULTS OF THE PRELIMINARY CONCEPT SCREENING

## OXYGEN SYSTEMS

INDIVIDUAL CONCEPTS:

1. CAPACITANCE MATRIX
2. RF MODE ANALYSIS
3. RESONANT INFRASONIC GAGING (RIGS)
4. PVT GAGING

INTEGRATED CONCEPTS:

1. CAPACITANCE - RIGS
2. CAPACITANCE - PVT GAGING
3. MICROWAVE - PVT GAGING

## HYDROGEN SYSTEMS

INDIVIDUAL CONCEPTS:

1. CAPACITANCE MATRIX
2. RF MODE ANALYSIS
3. GAMMA RADIATION ATTENUATION

INTEGRATED CONCEPTS:

1. RF MODE ANALYSIS - GAMMA RADIATION ATTENUATION

# GENERAL CHARACTERISTICS OF SELECTED CONCEPTS

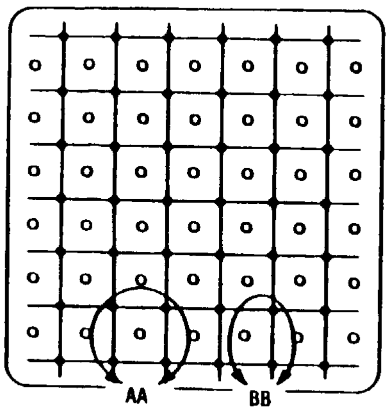
| CORE CONCEPTS | CLASSIFICATION | OPERATION BASIS | FLUID SUITABILITY OXYGEN | HYDROGEN |
|---|---|---|---|---|
| CAPACITANCE MATRIX | DISTRIBUTED PROPERTY SENSING | DIELECTRIC CONSTANT DENSITY RELATION | SUITABLE | SUITABLE |
| RF MODAL ANALYSIS | DISTRIBUTED PROPERTY SENSING | DIELECTRIC CONSTANT DENSITY RELATION | SUITABLE | SUITABLE |
| RESONANT INFRASONIC GAGING | VAPOR VOLUME SENSING | VAPOR SPRING RATE VAPOR VOLUME RELATION | SUITABLE | NOT SUITABLE[2] |
| PVT | VAPOR VOLUME SENSING | IDEAL GAS LAW IN COUPLED VOLUMES | SUITABLE | NOT SUITABLE[2] |
| MICROWAVE ATTENUATION | LINEAL PROPERTY SENSING | DIELECTRIC LOSS DENSITY RELATION | SUITABLE | NOT SUITABLE[3] |
| GAMMA RADIATION ATTEN | LINEAL PROPERTY SENSING | GAMMA ABSORPTION DENSITY RELATION | NOT SUITABLE[1] | SUITABLE |

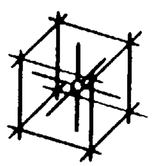
1 OXYGEN'S MUCH HIGHER MASS ATTENUATION COEFFICIENT RESULTS IN IMPRACTICAL NUMBERS OF SENSOR/DETECTOR PAIRS AND EXCESSIVE SOURCE STRENGTH REQUIRMENTS

2 RATIO OF SPECIFIC HEATS IS A STRONG FUNCTION OF TEMPERATURE AND LIQUID HYDROGEN IS SIGNIFICANTLY COMPRESSIBLE

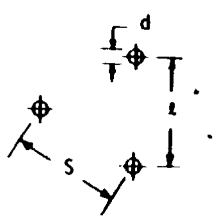
3 INSIGNIFICANT ATTENUATION OVER ANTICIPATED PATH LENGTHS

# CONCEPT EXPOSITION
## CAPACITANCE MATRIX
## PRINCIPLE OF OPERATION



ORTHOGRAPHIC A-A




DETAIL B-B

THE OPEN TANK VOLUME IS FILLED WITH 2 INTERSECTING BUT ELECTRICALLY ISOLATED LATTICES OF CUBICAL CELLS. THE CAPACITANCE BETWEEN THE EDGES OF THESE LATTICE ELEMENTS IS DEPENDENT ON THEIR DIAMETER AND SPACING AS WELL AS THE DIELECTRIC CONSTANT OF THE MEDIA BETWEEN THEM. THE GENERAL FORM OF THIS RELATION IS:

(1) $$C = \frac{8k\xi}{\text{Log}\left(\frac{2S}{d}\right)}$$

WHERE: k = CONSTANT OF PROPORTIONALITY
C = CAPACITANCE OF A GRID CELL
$\xi$ = DIELECTRIC CONSTANT OF FLUID
S = SPACING BETWEEN ELEMENTS
d = DIAMETER OF ELEMENT

THE CAPACITANCE OF A FULL MATRIX OF CUBICAL CELLS IS A FUNCTION OF THE NUMBER OF CELLS (N) OF SIDE ($\ell$) IN THE OPEN TANK VOLUME (V) AND THE AVERAGE DIELECTRIC CONSTANT ($\xi_{AVE}$) OF THE PROPELLANT IN THE OPEN VOLUME.

(2) $$C_{matrix} = \frac{8Nk\,\xi_{ave}}{\text{Log}\left(\frac{2S}{d}\right)}$$

WHERE: $N = V/\ell^3$

SINCE THE NONPOLAR PROPELLANTS, $O_2$ & $H_2$, OBEY THE CLAUSIUS-MOSSITTI RELATION:

(3) $$Z\rho_{ave} = \frac{\xi_{ave}-1}{\xi_{ave}+2}$$

WHERE: $\rho_{ave}$ = AVERAGE PROPELLANT DENSITY
$\xi_{ave}$ = AVERAGE PROPELLANT DIELECTRIC CONSTANT
$Z$ = CONSTANT OF PROPORTIONALITY

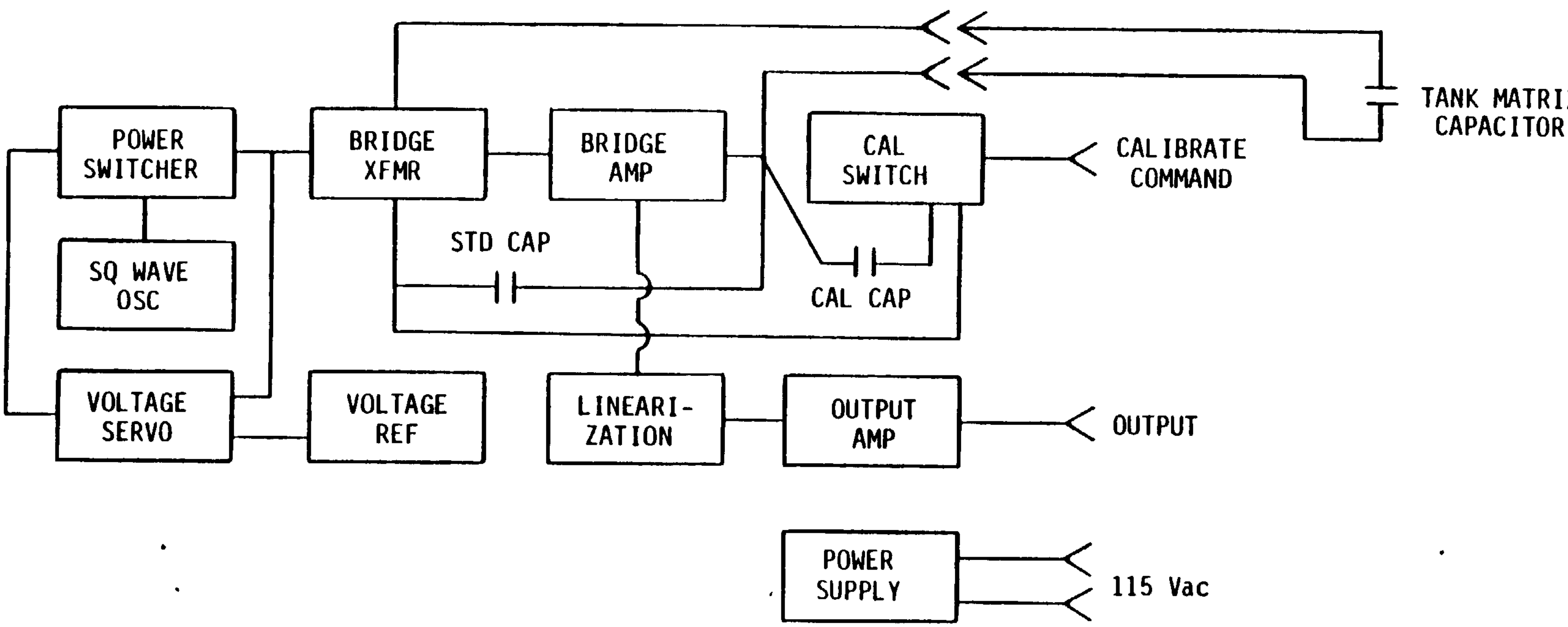
PROPELLANT MASS (M) IS EQUAL TO THE PRODUCT OF AVERAGE PROPELLANT DENSITY AND THE TOTAL OPEN TANK VOLUME, THE EQUATION FOR (M) IS:

(4) $$M = V\rho_{ave} = V\left(\frac{rC_m-1}{rC_m+2}\right)$$

WHERE: $$r = \left(\frac{\text{Log}\left(\frac{2S}{d}\right)}{8Nk}\right)$$

$C_m = C_{matrix}$

# CONCEPT EXPOSITION
# CAPACITANCE MATRIX
# BLOCK DIAGRAM



# CONCEPT EXPOSITION
# CAPACITANCE MATRIX
# CONCEPT APPLICATION

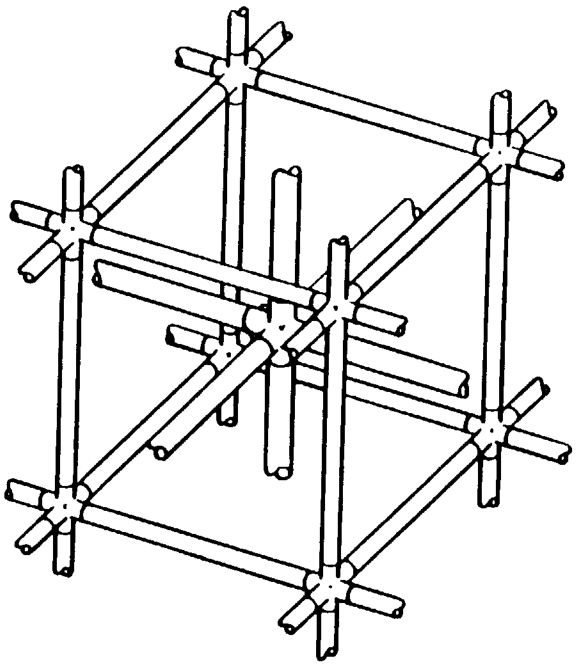
## APPLICATION ISSUES

- MATRIX GEOMETRY CAPABLE OF GIVING EQUAL WEIGHT CELLS IN FRINGING FIELDS AND WET WALL SITUATIONS
- FLUID LOSS BY WETTING MATRIX SURFACE IS TOLERABLE
- THE MATRIX CAN BE MADE STRUCTURALLY STABLE WITH TEMPERATURE

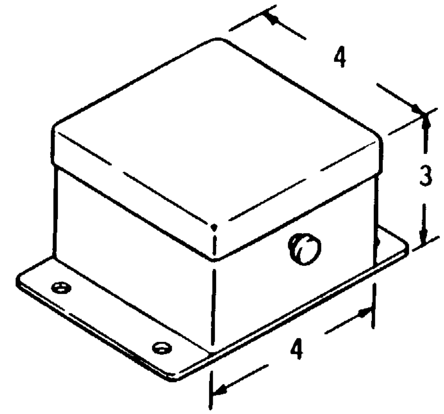
## APPLICATION ASSUMPTIONS

- THE PRESENCE OF A SECOND PRESSURANT GAS SPECIES HAS NOT BEEN CONSIDERED
- INTERNAL CONSTRUCT GEOMETRIES WILL NOT PRECLUDE A WORKABLE MATRIX DESIGN
- FLUID (INSIDE LINES, START BASKETS AND FLUID ACQUISITION CHANNELS) IS NOT AVAILABLE FOR MEASUREMENT

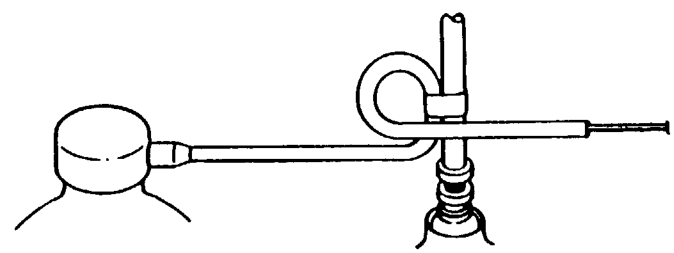
# CONCEPT EXPOSITION
# CAPACITANCE MATRIX
# APPROACH PICTORALS



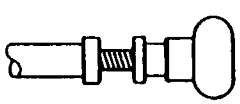
CUBICAL LATTICE ELEMENT



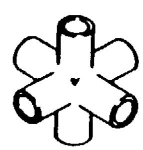

SIGNAL CONDITIONER



TANK WIRING PENETRATION

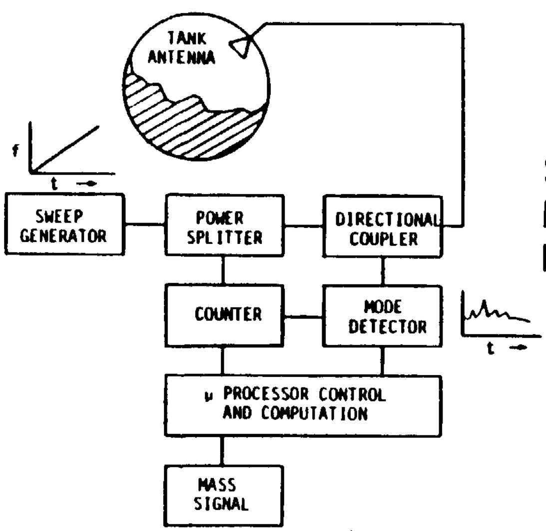


ADJ TERMINATOR



STAR CONNECTOR

# CONCEPT EXPOSITION
## RF MODAL ANALYSIS
## PRINCIPLE OF OPERATION




STANDING WAVE ELECTROMAGNETIC FIELD PATTERNS GENERATED BY AN ANTENNA INSIDE A CLOSED METAL CAVITY OCCUR AT RESONANT MODE FREQUENCIES WHICH ARE DEPENDENT ON THE CAVITY SIZE AND SHAPE AS WELL AS THE DIELECTRIC MEDIA IN THE CAVITY. FOR A SPHERICAL CAVITY:

(1) $$f_{ab} = \frac{U_{ab}}{2\pi R(\mu\varepsilon)^{1/2}}$$

WHERE:
- $f_{ab}$ = RESONANT FREQUENCY OF MODE ab
- $U_{ab}$ = EIGENVALUE FOR MODE ab
- $R$ = TANK RADIUS
- $\mu$ = MAGNETIC PERMEABILITY OF FLUID
- $\varepsilon$ = DIELECTRIC CONSTANT OF FLUID

SINCE THE NONPOLAR PROPELLANTS, OXYGEN AND HYDROGEN OBEY THE CLAUSIUS-MOSSITTI RELATION (2), THE MODAL RESONANT FREQUENCIES ARE RELATED TO PROPELLANT MASS.

(2) $$Z\rho = \frac{\varepsilon - 1}{\varepsilon + 2}$$

WHERE:
- $\rho$ = AVERAGE PROPELLANT DENSITY
- $\varepsilon$ = AVERAGE PROPELLANT DIELECTRIC CONSTANT
- $Z$ = CONSTANT OF PROPORTIONALITY

(NOTING THAT $\mu_o, \mu_n$ & $\varepsilon_o \approx 1$ WHERE: SUBSCRIPT o = EMPTY TANK
SUBSCRIPT n = NOT EMPTY TANK)

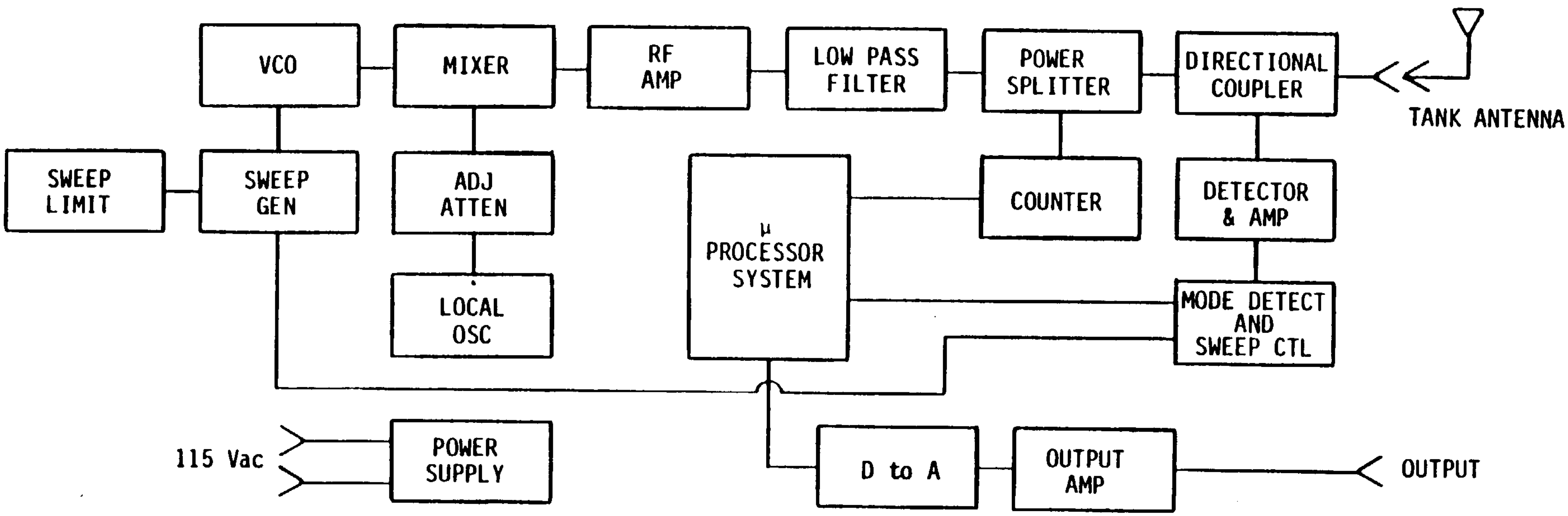
THE RATIO OF RESONANT FREQUENCIES FOR A GIVEN MODE WITH THE TANK EMPTY AND PARTIALLY FILLED CAN BE OBTAINED FROM (1) AS:

(3) $$\frac{f_o}{f_n} = (\varepsilon_n)^{1/2}$$

SINCE PROPELLANT MASS (M) IS EQUAL TO THE PRODUCT OF AVERAGE PROPELLANT DENSITY AND THE TOTAL TANK VOLUME, THE EQUATION FOR (M) IS:

(4) $$m = V\rho_n = V\,\frac{1}{Z}\left(\frac{\varepsilon_n - 1}{\varepsilon_n + 2}\right) = \frac{V}{Z}\left(\frac{f_o^2 - f_n^2}{f_o^2 + 2f_n^2}\right)$$

# CONCEPT EXPOSITION
# RF MODAL ANALYSIS
# BLOCK DIAGRAM



# CONCEPT EXPOSITION
# RF MODAL ANALYSIS
# CONCEPT APPLICATION

## APPLICATION ISSUES

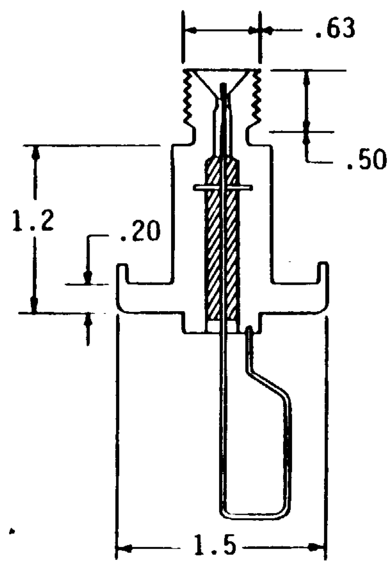
- ANTENNA(s) PLACEMENT CAN ACHIEVE RESONABLY COMPLETE ILLUMINATION OF THE INTERNAL TANK VOLUME
- THE SURFACE RESISTIVITY OF TANK WALL MATERIAL WILL NOT DEGRADE SUFFICIENTLY TO ADVERSELY AFFECT CAVITY Q

## APPLICATION ASSUMPTIONS

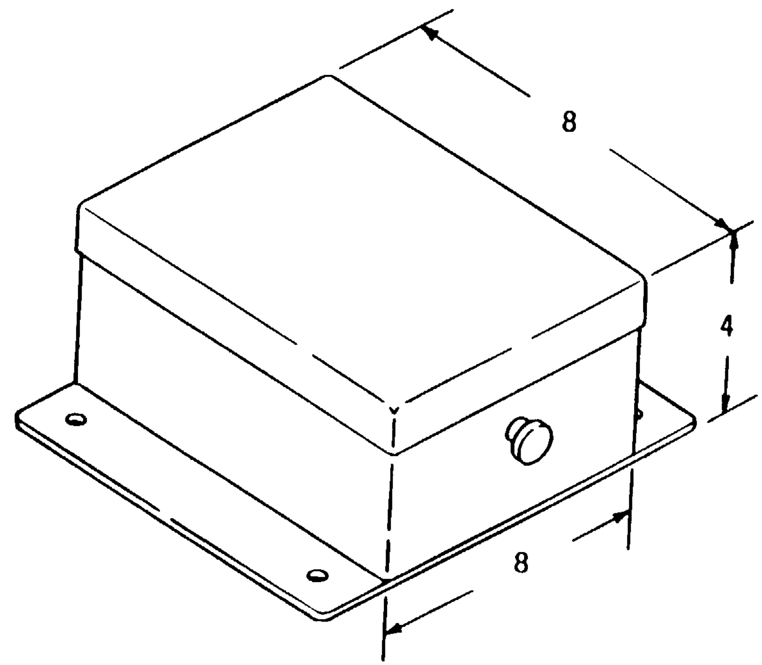
- THE PRESENCE OF A SECOND PRESSURANT GAS SPECIES HAS NOT BEEN CONSIDERED
- FLUID (INSIDE LINES, START BASKETS AND FLUID ACQUISITION CHANNELS) IS NOT AVAILABLE FOR MEASUREMENT

CONCEPT EXPOSITION
RF MODAL ANALYSIS
APPROACH PICTORALS



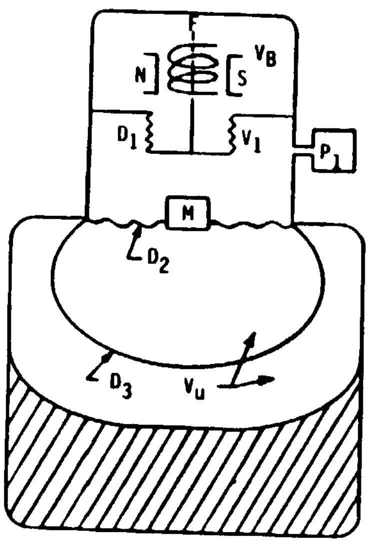



ANTENNA




SIGNAL CONDITIONER

# CONCEPT EXPOSITION
# RESONANT INFRASONIC GAGING
# PRINCIPAL OF OPERATION




$V_B$ = BACK VOLUME
$V_1$ = EXCITER VOLUME
$V_u$ = ULLAGE VOLUME
F = VARIABLE FREQUENCY PISTON DRIVER
M = KNOWN MASS
$D_1$ = DRIVER PISTON
$D_2$ = FOLLOWER PISTON
$D_3$ = ISOLATION DIAPHRAGM
$P_1$ = DYNAMIC PRESSURE SENSOR

A SIMPLE MASS SPRING SYSTEM, CONSISTING OF A SMALL KNOWN MASS AND THE ULLAGE VOLUME AS A GAS SPRING, ARE PLACED IN RESONANCE. AT RESONANCE, THE RELATIONSHIP BETWEEN THE RESONANT FREQUENCY ( $f_r$ ), THE KNOWN MASS (M), AND THE ULLAGE VOLUME SPRING RATE ($k_u$) IS GIVEN BY:

(1)
$$f_r = \frac{1}{2\pi}\left(\frac{k_u}{m}\right)^{1/2}$$

SINCE THE ULLAGE VOLUME GAS SPRING RATE IS GIVEN BY:

(2)
$$k_u = \gamma \frac{P A^2}{V_u}$$

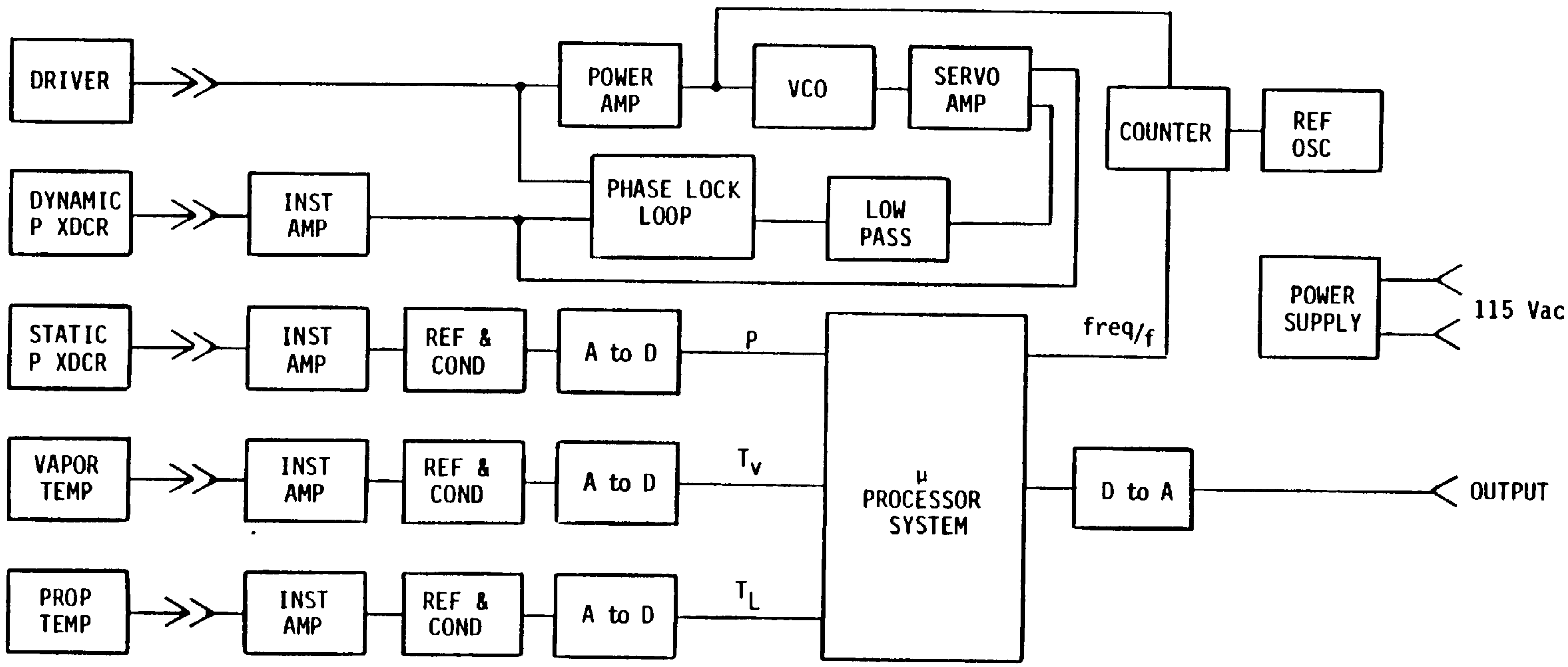
WHERE: $\gamma$ = RATIO OF GAS SPECIFIC HEATS
P = STATIC PRESSURE
A = PISTON AREA
$V_u$ = ULLAGE VOLUME

SUBSTITUTING (2) INTO (1) AND SOLVING FOR THE ULLAGE VOLUME GIVES:

(3)
$$V_u = \frac{A^2 \gamma P}{m\,(2\pi f_r)^2}$$

KNOWING THE TOTAL TANK VOLUME AND THE LIQUID AND VAPOR PROPELLANT DENSITIES (FROM PRESSURE AND TEMPERATURE MEASUREMENTS), THE TANK PROPELLANT MASS CAN BE DETERMINED.

# CONCEPT EXPOSITION
# RESONANT INFRASONIC GAGING
# BLOCK DIAGRAM



# CONCEPT EXPOSITION
# RESONANT INFRASONIC GAGING
# CONCEPT APPLICATION



## APPLICATION ISSUES

- ULLAGE VAPOR TEMPERATURE CAN BE ACCURATELY DETERMINED
- AVAILABILITY OF LOX COMPATIBLE FOLLOWER AND ISOLATION DIAPHRAGMS CAN BE RESOLVED

## APPLICATION ASSUMPTIONS

- THE PRESENCE OF A SECOND PRESSURANT GAS SPECIES HAS NOT BEEN CONSIDERED
- THE GAGING PROCESS IS ADIABATIC EVEN AT THE LOW OPERATING FREQUENCIES (0.05 Hz) REQUIRED TO MINIMIZE OTHER SOURCES OF ERROR
- FLUID (INSIDE LINES, START BASKETS AND FLUID ACQUISITION CHANNELS) IS NOT AVAILABLE FOR MEASUREMENT

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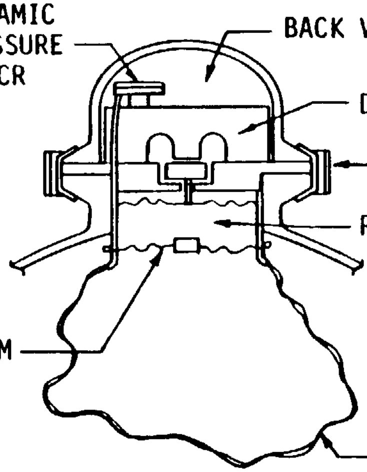
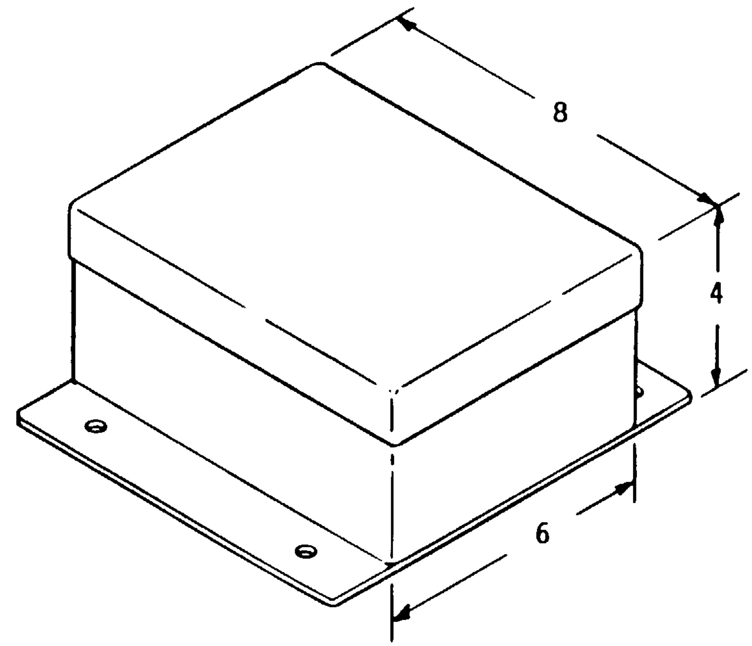
# CONCEPT EXPOSITION
# RESONANT INFRASONIC GAGING
# APPROACH PICTORIALS

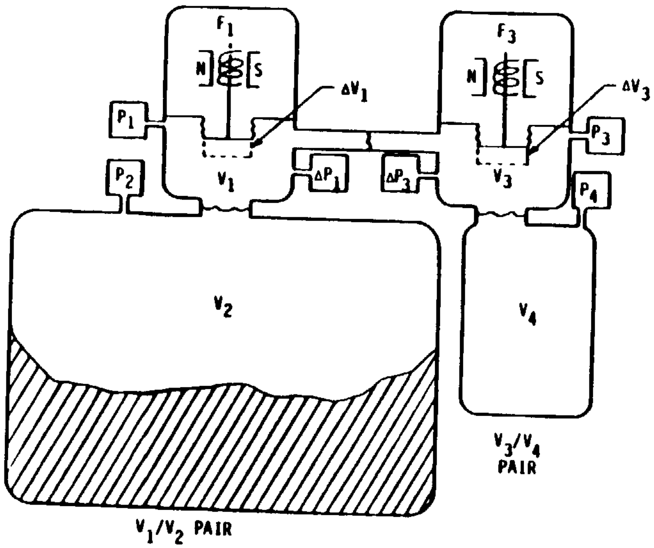



TANK SENSOR




SIGNAL CONDITIONER

# CONCEPT EXPOSITION
# PVT
# PRINCIPAL OF OPERATION




$V_1$ = EXCITER VOLUME - PROPELLANT
$V_3$ = EXCITER VOLUME - REFERENCE
$P_1$, $P_2$, $P_3$ & $P_4$ = STATIC PRESSURES
$\Delta P_1$ & $\Delta P_3$ = DYNAMIC PRESSURES
$F_1$ = FIXED AMPLITUDE DRIVER
$F_3$ = VARIABLE AMPLITUDE DRIVER
$V_2$ = PROPELLANT ULLAGE VOLUME
$V_4$ = REFERENCE VOLUME
~~ = ACOUSTIC RESISTANCE

THE PRESSURE CHANGE WHICH WOULD RESULT IN EACH OF THE TWO VOLUME PAIRS WHEN THE ASSOCIATED PISTONS WERE DISPLACED CAN BE REPRESENTED BY THE RELATIONS:

(1)
$$\Delta P_1 = \frac{P_1 \Delta V_1}{V_1 + V_2 - \Delta V_1}$$
AND (2)
$$\Delta P_3 = \frac{P_3 \Delta V_3}{V_3 + V_4 - \Delta V_3}$$

IF THE DISPLACEMENT OF THE $\Delta V_3$ PISTON WAS ADJUSTED SO THAT $\Delta P_1 = \Delta P_3$. THEN EQUATIONS (1) AND (2) COULD BE SET EQUAL AND SOLVED THE $V_2$, GIVING:

(3)
$$V_2 = \frac{\Delta V_1}{\Delta V_3}(V_3 + V_4) - V_1$$

SINCE THE PISTON DISPLACEMENT GIVING $\Delta V_1$ IS FIXED AND THE VOLUMES $V_1$, $V_3$ AND $V_4$ ARE KNOWN, THE VOLUME $V_2$ CAN BE DETERMINED WHEN THE $\Delta V_3$ PISTON DISPLACEMENT WHICH MAKES $\Delta P_1 = \Delta P_3$ IS ESTABLISHED.

THE ULLAGE VOLUME $V_2$, TOTAL TANK VOLUME $V_T$, AND THE PROPELLANT VAPOR AND LIQUID DENSITIES ARE THEN USED TO COMPUTE THE PROPELLANT MASS.

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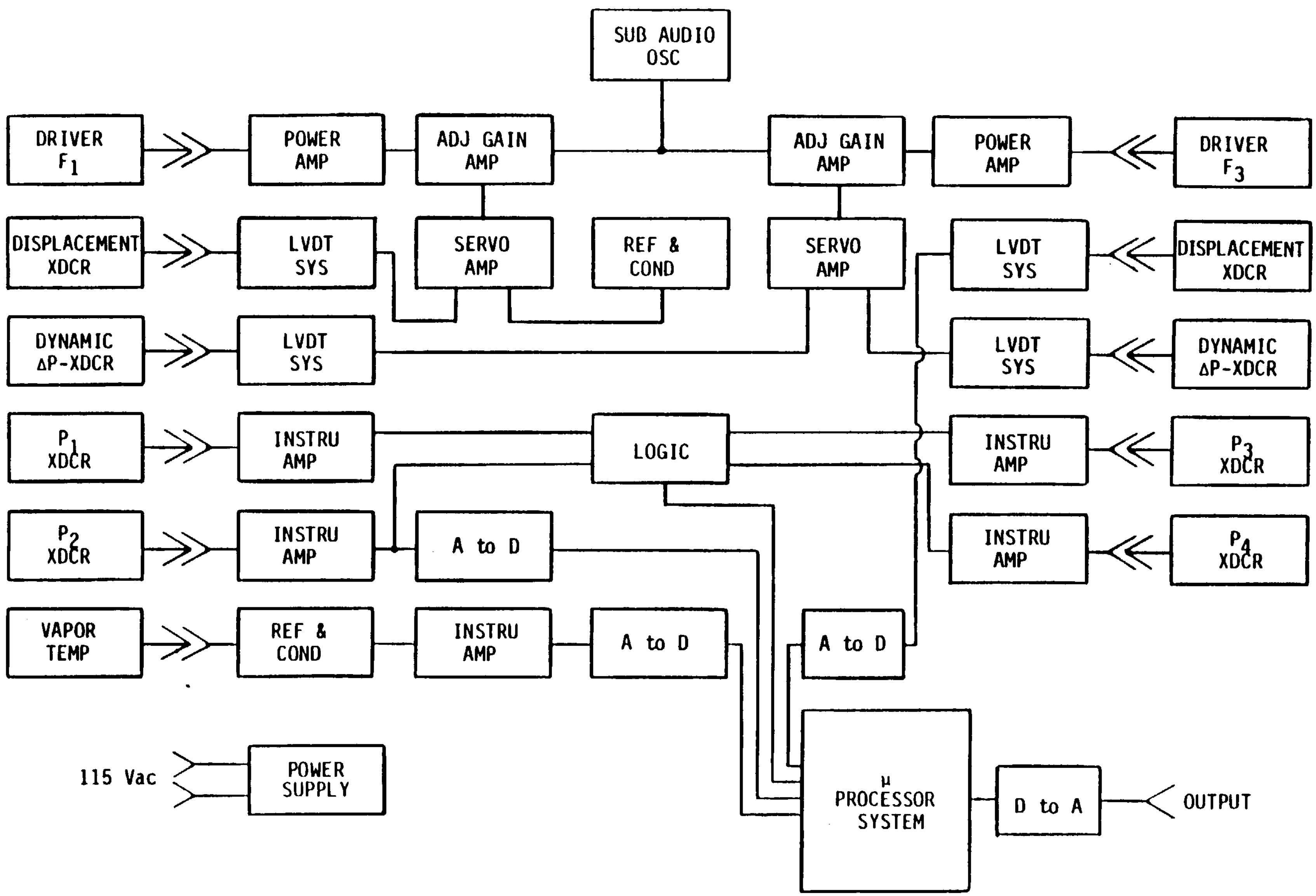
# CONCEPT EXPOSITION
# PVT
# BLOCK DIAGRAM



# CONCEPT EXPOSITION
# PVT
# CONCEPT APPLICATION

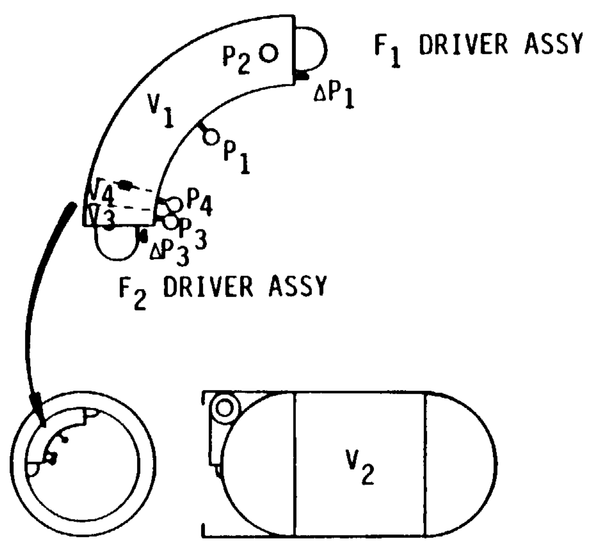
## APPLICATION ISSUES

- ULLAGE TEMPERATURE CAN BE ACCURATELY DETERMINED
- ISOLATION DIAPHRAGM MAY BE REQUIRED TO PREVENT LIQUID WETTING AND PLUGGING THE ACOUSTIC RESISTANCES

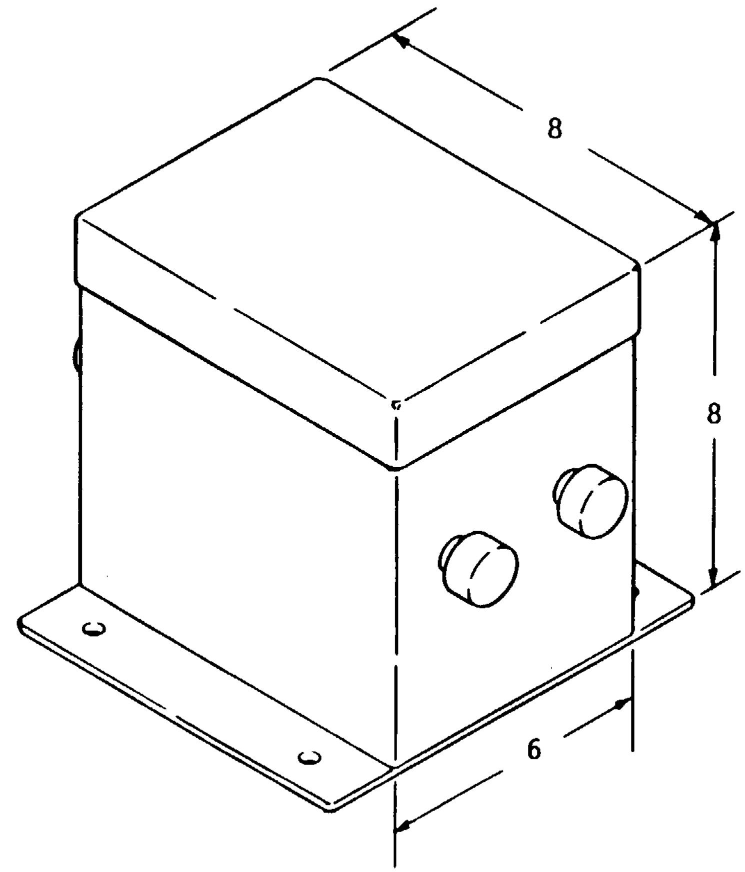
## APPLICATION ASSUMPTIONS

- THE PRESENCE OF A SECOND PRESSURANT GAS SPECIES HAS NOT BEEN CONSIDERED
- THE GAGING PROCESS IS ADIABATIC AT SUBAUDIO EXCITATION FREQUENCIES
- FLUID (INSIDE LINES, START BASKETS AND FLUID ACQUISITION CHANNELS) IS NOT AVAILABLE FOR MEASUREMENT

# CONCEPT EXPOSITION
# PVT
# APPROACH PICTORIALS

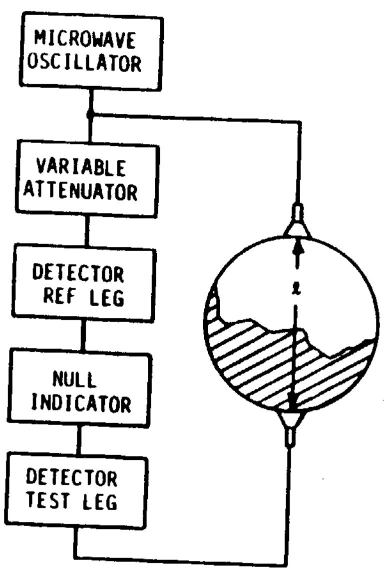



TANK SENSOR




SIGNAL CONDITIONER

# CONCEPT EXPOSITION
# MICROWAVE ATTENUATION
# PRINCIPAL OF OPERATION




THE ATTENUATION OF A MICROWAVE CARRIER BEING TRANSMITTED THROUGH A MEDIA WITH A DIELECTRIC CONSTANT OF $\xi$ AND A LOSS TANGENT OF $\tan\delta$ IS GIVEN BY EQUATION (1):

(1) $$A = \frac{k\ell\tan\delta\,(\varepsilon)^{1/2}}{\lambda_o}$$

WHERE:
- $A$ = MICROWAVE CARRIER ATTENUATION IN db
- $\ell$ = PATH LENGTH
- $\tan\delta$ = LOSS TANGENT OF FLUID
- $\varepsilon$ = DIELECTRIC CONSTANT OF FLUID
- $\lambda_o$ = FREE SPACE WAVELENGTH OF CARRIER
- $k$ = CONSTANT OF PROPORTIONALITY

SOLVING (1) FOR $\xi$ GIVES:

(2) $$\varepsilon = \left(\frac{A\lambda_o}{k\ell\tan\delta}\right)^2 = A^2 r$$

WHERE: $$r = \left(\frac{\lambda_o}{k\ell\tan\delta}\right)^2$$

SINCE THE NONPOLAR PROPELLANTS, OXYGEN AND HYDROGEN, OBEY THE CLAUSIUS-MOSSITTI RELATION:

(3) $$Z\rho_{ave} = \frac{\xi_{ave}-1}{\xi_{ave}+2}$$

WHERE:
- $\rho_{ave}$ = AVERAGE PROPELLANT DENSITY
- $\varepsilon_{ave}$ = AVERAGE DIELECTRIC CONSTANT
- $Z$ = CONSTANT OF PROPORTIONALITY

PROPELLANT MASS (M) IS EQUAL TO THE PRODUCT OF AVERAGE PROPELLANT DENSITY AND THE TANK VOLUME (V), THE EQUATION FOR (M) IS:

(4) $$m = V\rho_{ave} = V\,\frac{1}{Z}\left(\frac{\xi_{ave}-1}{\xi_{ave}+2}\right) = \frac{V}{Z}\left(\frac{A_{ave}^2 r-1}{A_{ave}^2 r+2}\right)$$

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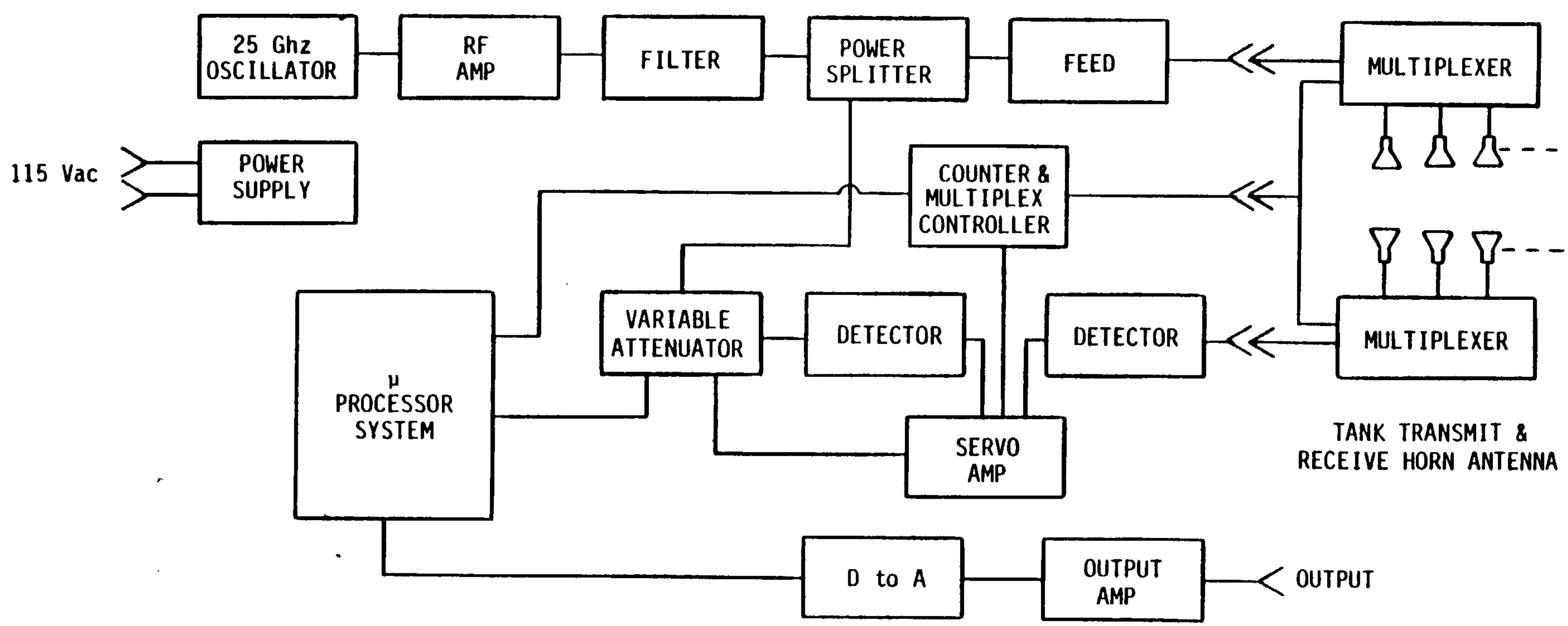
# CONCEPT EXPOSITION
# MICROWAVE ATTENUATION
# BLOCK DIAGRAM



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# CONCEPT EXPOSITION
# MICROWAVE ATTENUATION
# CONCEPT APPLICATION

## APPLICATION ISSUES

- ACCEPTABLE PRESSURE BARRIER WINDOWS FOR THE HORN ANTENNA CAN BE DEVELOPED
- HORN ANTENNA PATTERNS WILL NOT BE UNDULY DISTORTED OR REFRACTED BY A RANDOMLY CONFIGURED VAPOR-LIQUID INTERFACE PATTERN
- MULTIPLEX AND WAVE GUIDE ATTENUATIONS CAN BE STABILIZED

## APPLICATION ASSUMPTIONS

- THE PRESENCE OF A SECOND PRESSURANT GAS SPECIES HAS NOT BEEN CONSIDERED
- INTERNAL CONSTRUCT GEOMETRIES WILL NOT PREVENT AN ACCEPTABLE NUMBER OF CLEAR LINE OF SIGHT MICROWAVE TRANSMISSION PATHS
- FLUID (INSIDE LINES, START BASKETS AND FLUID ACQUISITION CHANNELS) IS NOT AVAILABLE FOR MEASUREMENT

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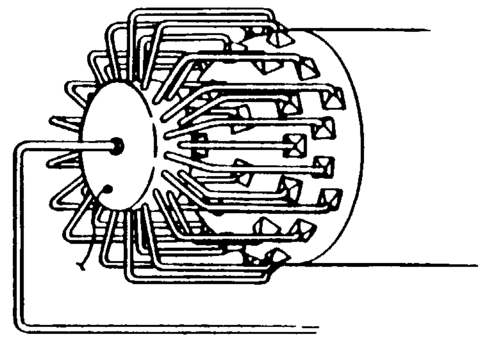
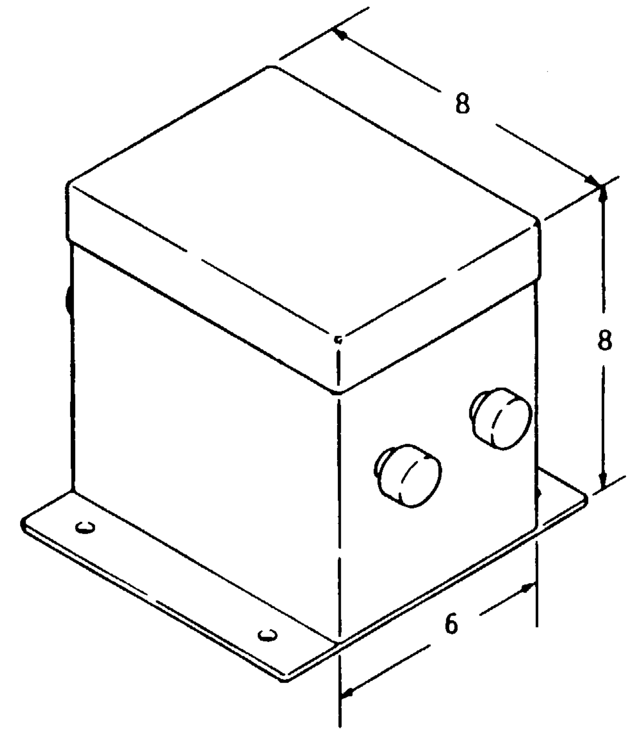
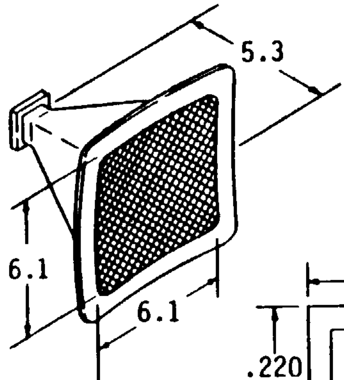
# CONCEPT EXPOSITION
# MICROWAVE ATTENUATION
# APPROACH PICTORIALS

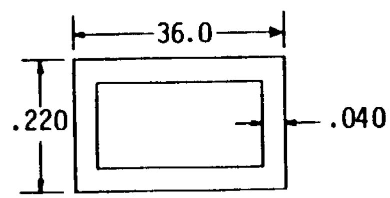


MULTIPLEXER/HORN INTERCONNECT

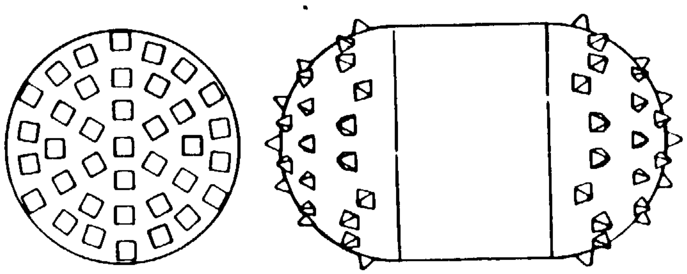



SIGNAL CONDITIONER

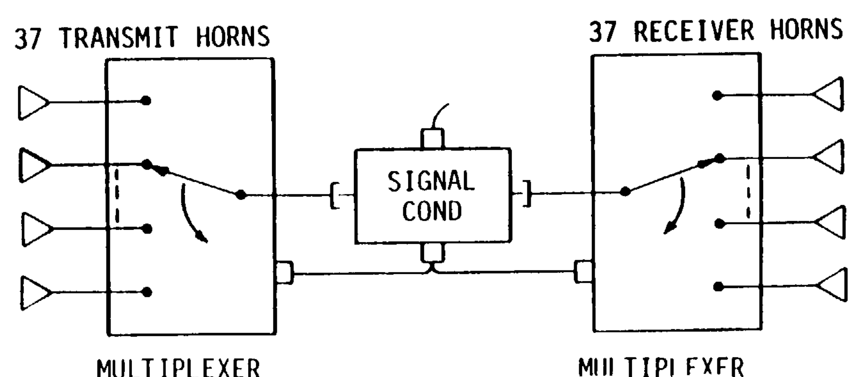


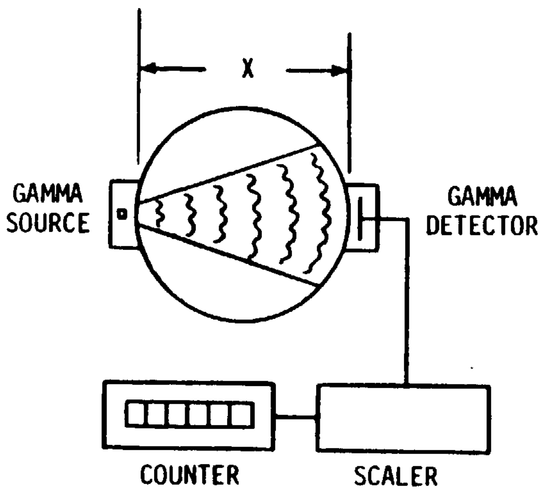

25 GHz WAVEGUIDE



HORN ANTENNA PATTERN



# CONCEPT EXPOSITION
# GAMMA RADIATION
# PRINCIPAL OF OPERATION




THE ABSORPTION OF THE RADIATION FROM A GAMMA RAY SOURCE BEING TRANSMITTED THROUGH A MEDIA WITH A MASS ABSORPTION COEFFICIENT ( $\theta$ ) AND A DENSITY ( $\rho$ ) IS GIVEN BY EQUATION (1):

(1) $$C = C_o \rho^{-\theta\rho x}$$

WHERE:
- $C$ = COUNT RATE AT A POINT $x$ DISTANCE FROM GAMMA SOURCE
- $\theta$ = MASS ABSORPTION COEFFICIENT OF FLUID
- $\rho$ = DENSITY OF FLUID
- $C_o$ = SOURCE COUNT RATE
- $x$ = PATH LENGTH

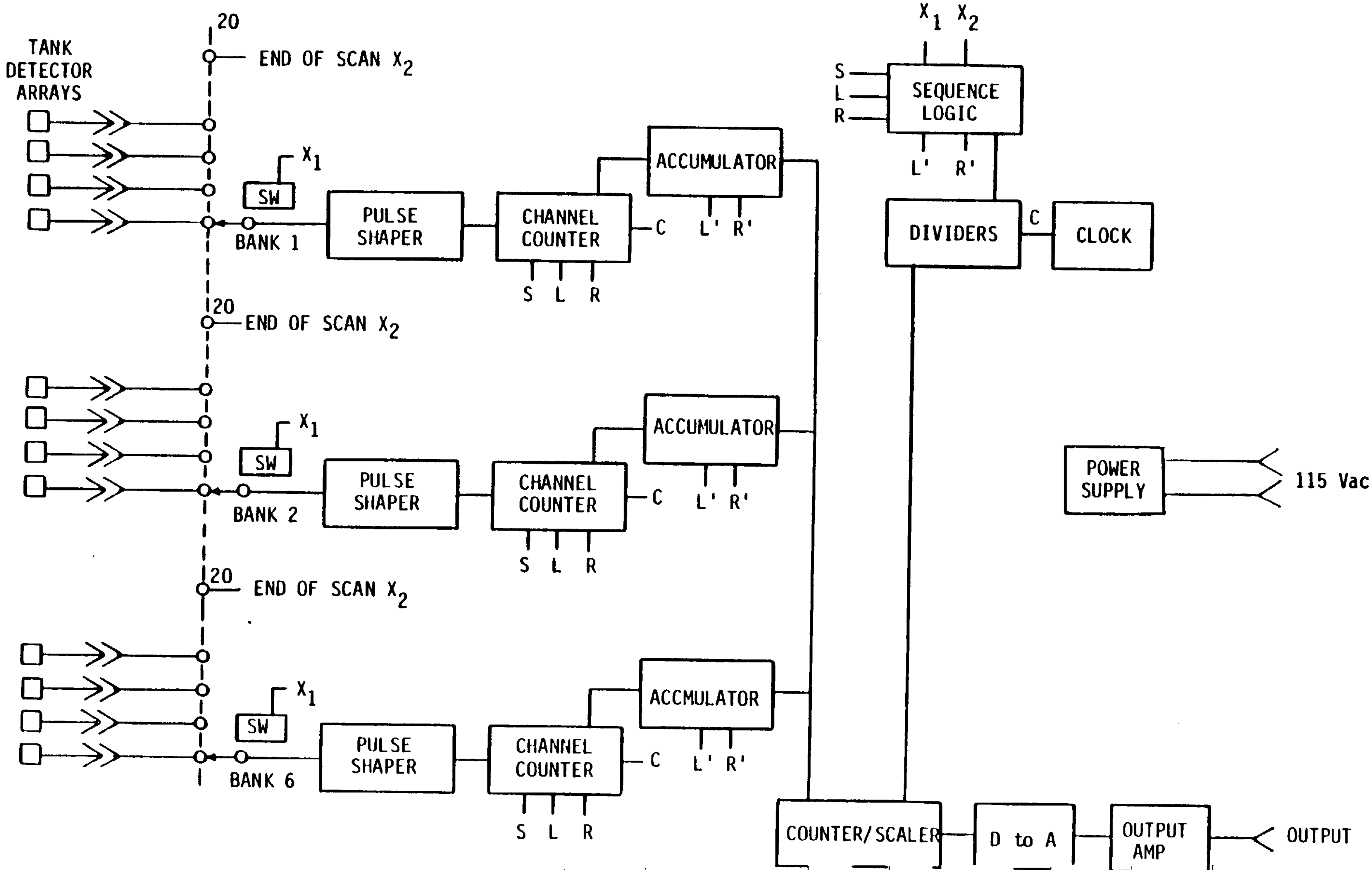
SOLVING (1) FOR $\rho$ GIVES:

(2) $$\rho = \frac{-1}{\theta x} Ln \frac{C}{C_o}$$

SINCE PROPELLANT MASS (M) IS EQUAL TO THE PRODUCT OF AVERAGE PROPELLANT DENSITY AND THE TANK VOLUME (V), THE EQUATION FOR (M) IS:

(3) $$m = V\rho_{ave} = \frac{-V}{\theta x} Ln \frac{C_{ave}}{C_o}$$

# CONCEPT EXPOSITION
# GAMMA RADIATION
# BLOCK DIAGRAM



# CONCEPT EXPOSITION
# GAMMA RADIATION
# CONCEPT APPLICATION

## APPLICATION ISSUES

- ACCEPTABLE HALF LIFE GAMMA RAY SOURCES AND OPERATIONAL PROCEDURES CAN BE FOUND
- A SAFE METHOD OF LOADING OF INTERNAL TANK SOURCES CAN BE FOUND
- THE INTERNAL MOUNTINGS FOR SOURCE'S AND DETECTORS CAN BE MADE LAUNCH CAPABLE AND THERMALLY STABLE
- INTERNAL DETECTORS WILL NOT SHIFT WITH CYCLING BETWEEN AMBIENT AND CRYOGENIC TEMPERATURES

## APPLICATION ASSUMPTIONS

- THE PRESENCE OF A SECOND PRESSURANT GAS SPECIES HAS NOT BEEN CONSIDERED
- THE TRW STUDY SOURCE/DETECTOR PAIR VS. ACCURACY RELATIONS ARE VALID
- INTERNAL CONSTRUCT GEOMETRIES WILL NOT PREVENT AND ACCEPTABLE NUMBER OF CLEAR LINE OF SIGHT SOURCE/ DETECTOR PAIRS
- FLUID (INSIDE LINES, START BASKETS AND FLUID ACQUISITION CHANNELS) IS NOT AVAILABLE FOR MEASUREMENT

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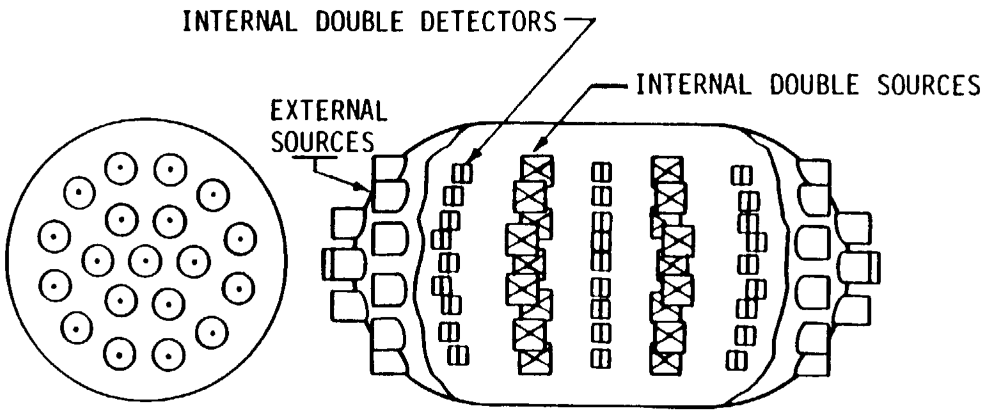
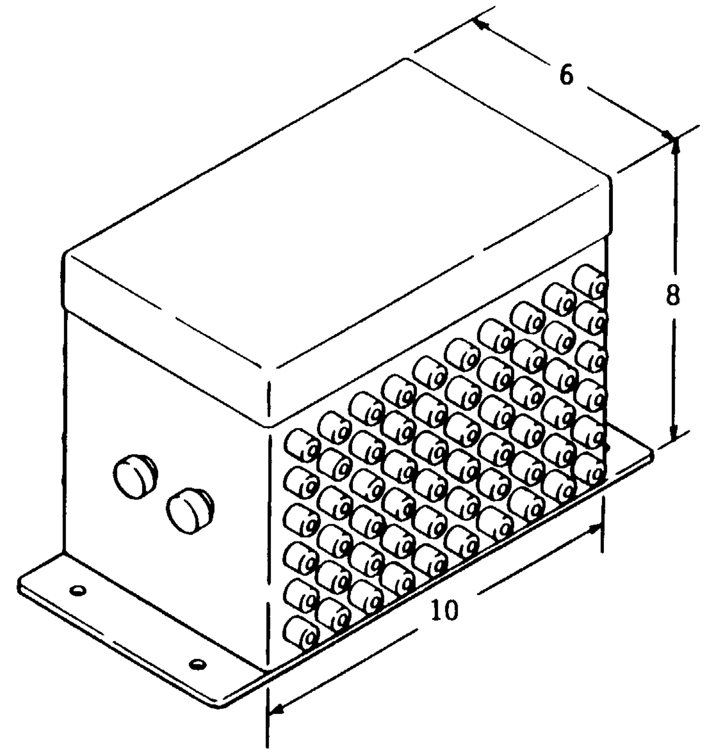
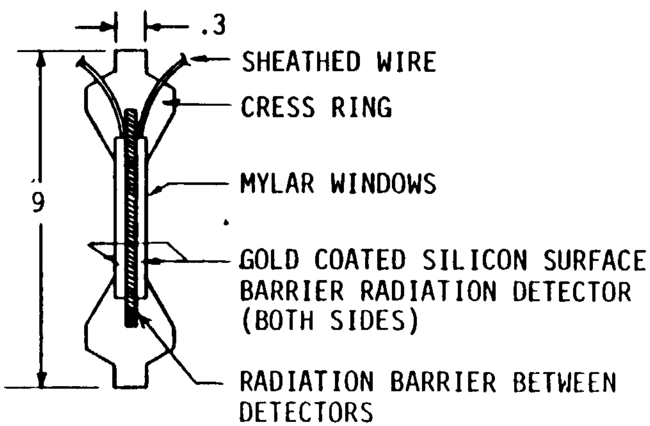
# CONCEPT EXPOSITION
# GAMMA RADIATION
# APPROACH PICTORIALS



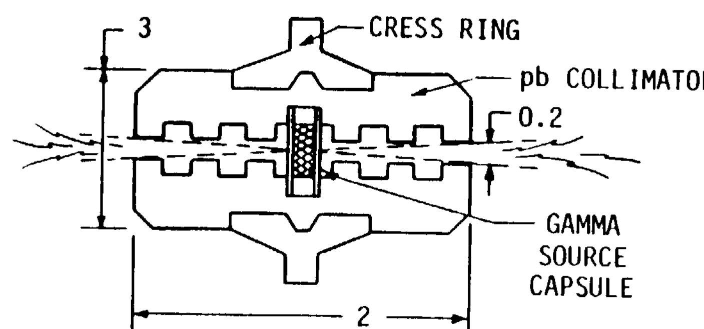

SOURCE / DETECTOR PATTERNS




SIGNAL CONDITIONER




DOUBLE INTERNAL DETECTOR

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# SELECTION CRITERIA
# EVALUATION APPROACHES

| MAJOR ATTRIBUTE | DETAIL ATTRIBUTES AND ISSUES | EVALUATION SCHEME |
|---|---|---|
| 1. ACCURACY | A) BASIC ACCURACY | COMPUTE & ASSESS VALUE |
| | B) SENSITIVITY TO TANK SIZE, SHAPE ... | SCORING TABLE |
| | C) RANGE | DESCRIPTOR SCALE |
| | D) EASE OF CALIBRATION | HIGH-MID-LOW SCALE |
| | E) MAINTENANCE OF CALIBRATION | HIGH-MID-LOW SCALE |
| 2. DESIGN FEATURES | A) SYSTEM WEIGHT | NATURAL VALUE |
| | B) SYSTEM ELECTRICAL POWER REQUIREMENT | NATURAL VALUE |
| | C) ENERGY INPUT TO FLUID | NATURAL VALUE |
| | D) NUMBER & COMPLEXITY OF FLUID CONTAINMENT PENETRATIONS | DESCRIPTOR SCALE |
| 3. DESIGN QUALITY | A) RELIABILITY | ESTIMATE, DESCRIPTOR & PAIRED |
| | B) REPAIRABILITY | PAIRED COMPARISON |
| | C) MAINTAINABILITY | HIGH-MID-LOW SCALE |
| | D) SAFETY | PAIRED & HIGH-MID-LOW SCALE |
| | E) COMPATIBILITY | HIGH-MID-LOW SCALE |
| 4. DESIGN STATE OF THE ART | A) MATERIALS | DESCRIPTOR SCALE |
| | B) CONSTRUCTION | DESCRIPTOR SCALE |
| | C) CIRCUITRY | DESCRIPTOR SCALE |
| | D) PERFORMANCE | DESCRIPTOR SCALE |
| | E) POTENTIAL FOR IMPROVEMENT | DESCRIPTOR SCALE |
| 5. FLIGHT HARDWARE DEVELOPMENT EFFORT | A) DEVELOPMENT HARDWARE EFFORT | DIRECT ESTIMATE |
| | B) FLIGHT PROTOTYPE HARDWARE EFFORT | DIRECT ESTIMATE |
| | C) FLIGHT HARDWARE EFFORT | DIRECT ESTIMATE |

# MAJOR ATTRIBUTE ASSIGNED WEIGHTS

| MAJOR ATTRIBUTE | ASSIGNED* WEIGHT |
|---|---|
| 1. ACCURACY | 0.35 |
| 2. DESIGN FEATURES | 0.20 |
| 3. DESIGN QUALITY | 0.25 |
| 4. DESIGN STATE OF THE ART | 0.10 |
| 5. FLIGHT HARDWARE DEVELOPMENT EFFORT | 0.10 |
| | 1.00 |

* WEIGHTS WERE ESTABLISHED IN CONJUNCTION WITH JSC DURING FIRST PROGRAM REVIEW OF THE SELECTION CRITERIA

# DETERMINATION OF CROSS ATTRIBUTE TRADE-OFF WEIGHTS

WHEN ALL GAGING CONCEPTS HAVE BEEN SCORED FOR EACH OF THE DETAIL ATTRIBUTES SUPPORTING A MAJOR ATTRIBUTE, THE FOLLOWING STEPS ARE FOLLOWED TO DETERMINE THE CROSS ATTRIBUTE TRADE OFF WEIGHTS:

(1) DETERMINE THE DIFFERENCE (DELTA) BETWEEN THE HIGHEST AND LOWEST SCORES FOR EACH DETAIL ATTRIBUTE

(2) PREPARE PARIED COMPARISON BALLOTS FOR EACH FUNCTIONAL PAIR OF DETAIL ATTRIBUTES, SUCH AS

> **Ballot**
>
> Which do you believe will provide the greatest benefit to Major Attribute "Maj":
>
> (1) 30 Scale Units Improvement in Detail Attribute a, or ☐
>
> (2) 20 Scale Units Improvement in Detail Attribute b? ☑
>
> How much benefit? About the same? ☐
>
> Moderately more? ☑
>
> Considerably more? ☐
>
> SCORE [- 1]

(3) HAVE THE BALLOTS VOTED, BY COGNIZANT BUT DIFFERENT TECHNICAL VIEWPOINTS.

(4) CALCULATE THE RELATIVE RANKING OF THE DETAIL ATTRIBUTES USING THE METHOD OF PAIRED COMPARISON

(5) OBTAIN THE CROSS TRADE WEIGHTS BY DIVIDING THE RELATIVE RANKING VALUES BY THE SUM OF THE RELATIVE RANKING VALUES

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# HIERARCHY OF MAJOR AND DETAIL ATTRIBUTE WEIGHTS

| | DETAIL ATTRIBUTE RELATIVE WEIGHT | MAJOR ATTRIBUTE RELATIVE WEIGHT |
|---|---|---|
| 1. ACCURACY | | 0.35 |
| A) BASIC ACCURACY | 0.273 | |
| B) SENSITIVITY TO TANK SIZE, SHAPE, INTERNAL GEOMETRY AND FLUID MASS | 0.182 | |
| C) RANGE | 0.136 | |
| D) EASE OF CALIBRATION | 0.182 | |
| E) MAINTENANCE OF CALIBRATION | 0.227 | |
| 2. DESIGN FEATURES | | 0.20 |
| A) SYSTEM WEIGHT | 0.187 | |
| B) SYSTEM ELECTRICAL POWER REQUIREMENTS | 0.250 | |
| C) ENERGY INPUT TO FLUID | 0.250 | |
| D) NUMBER & COMPLEXITY OF FLUID CONTAINMENT PENETRATIONS | 0.313 | |
| 3. DESIGN QUALITY | | 0.25 |
| A) RELIABILITY | 0.222 | |
| B) REPAIRABILITY | 0.186 | |
| C) MAINTAINABILITY | 0.111 | |
| D) SAFETY | 0.296 | |
| E) COMPATIBILITY | 0.185 | |
| 4. DESIGN STATE OF THE ART | | 0.10 |
| A) MATERIALS | 0.213 | |
| B) CONSTRUCTION | 0.204 | |
| C) CIRCUITRY | 0.280 | |
| D) PERFORMANCE | 0.101 | |
| E) POTENTIAL FOR IMPROVEMENT | 0.202 | |
| 5. FLIGHT HARDWARE DEVELOPMENT EFFORT | | 0.10 |
| A) DEVELOPMENT HARDWARE ESTIMATE TO COMPLETE (SPAN TIME, MANPOWER & DOLLARS, INCLUDING RISK) | 0.333 | |
| B) PROTOTYPE HARDWARE ESTIMATE TO COMPLETE (SPAN TIME, MANPOWER & DOLLARS, INCLUDING RISK) | 0.333 | |
| C) FLIGHT HARDWARE ESTIMATE TO COMPLETE (SPAN TIME, MANPOWER & DOLLARS, INCLUDING RISK) | 0.334 | |

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# ACCURACY
## SUMMARY OF CONCEPT SCORING
## STORAGE SIZE TANKS

OXYGEN SYSTEMS:

| GAGING SYSTEMS | BASIC ACCURACY SCORE (a) | CROSS TRADE (a)x.273 =1 | TANK SENSITIVITY SCORE (b) | CROSS TRADE (b)x .182 =2 | RANGE SCORE (c) | CROSS TRADE (c)x .136 =3 | EASE OF CALIBRATION SCORE (d) | CROSS TRADE (d)x .182 =4 | MAINTENANCE OF CALIB SCORE (e) | CROSS TRADE (e)x .227 =5 | UN-WEIGHTED MAJOR ATTRIBUTE SCORE 1+2+3+4+5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CAP MATRIX | 76.886 | 20.990 | 87.222 | 15.874 | 100.000 | 13.600 | 100.00 | 18.200 | 73.333 | 16.647 | 85.311 |
| RF MODE ANAL | 100.000 | 27.300 | 85.000 | 15.470 | 100.000 | 13.600 | 88.667 | 16.137 | 100.000 | 22.700 | 95.207 |
| RIGS | 63.038 | 17.209 | 72.777 | 13.245 | 100.000 | 13.600 | 60.000 | 10.920 | 33.333 | 7.567 | 62.541 |
| PVT | 76.886 | 20.990 | 72.222 | 13.144 | 100.000 | 13.600 | 73.333 | 13.347 | 46.667 | 10.593 | 71.674 |
| CAP/ RIGS | 69.962 | 19.100 | 79.999 | 14.560 | 100.000 | 13.600 | 37.500* | 6.825 | 23.056* | 5.233 | 59.318 |
| CAP/ PVT | 76.886 | 20.990 | 79.722 | 14.509 | 100.000 | 13.600 | 41.667* | 7.583 | 23.056* | 5.233 | 61.915 |
| MICRO/ PVT | 74.474 | 20.331 | 75.833 | 13.802 | 91.000 | 12.376 | 22.500* | 4.095 | 15.000* | 3.405 | 54.009 |

* = PRODUCT/SUM

HYDROGEN SYSTEMS:

| GAGING SYSTEMS | BASIC ACCURACY SCORE (a) | CROSS TRADE (a)x .273 =1 | TANK SENSITIVITY SCORE (b) | CROSS TRADE (b)x .182 =2 | RANGE SCORE (c) | CROSS TRADE (c)x .136 =3 | EASE OF CALIBRATION SCORE (d) | CROSS TRADE (d)x .182 =4 | MAINTENANCE OF CALIB SCORE (e) | CROSS TRADE (e)x .227 =5 | UN-WEIGHTED MAJOR ATTRIBUTE SCORE 1+2+3+4+5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CAP MATRIX | 76.886 | 20.990 | 87.222 | 15.874 | 100.000 | 13.600 | 100.000 | 18.200 | 73.333 | 16.647 | 85.311 |
| RF MODE ANAL | 100.000 | 27.300 | 85.000 | 15.470 | 100.000 | 13.600 | 88.667 | 16.137 | 100.000 | 22.700 | 95.207 |
| GAMMA RAD | 110.952 | 30.290 | 76.111 | 13.852 | 91.000 | 12.376 | 46.667 | 8.493 | 33.333 | 7.567 | 72.578 |
| RF/ GAMMA | 105.476 | 28.795 | 80.556 | 14.661 | 95.500 | 12.988 | 28.056* | 5.106 | 23.611 | 5.360 | 66.910 |

* = PRODUCT/SUM

# DESIGN FEATURES
# SUMMARY OF CONCEPT SCORING
# STORAGE SIZE TANKS

OXYGEN SYSTEMS:

| GAGING SYSTEMS | WEIGHT SCORE (a) | CROSS TRADE (a)x.187 =1 | ELECT POWER SCORE (b) | CROSS TRADE (b)x.250 =2 | ENERGY INPUT SCORE (c) | CROSS TRADE (c)x.250 =3 | SENSOR COMPLEXITY SCORE (d) | CROSS TRADE (d)x.313 =4 | UN-WEIGHTED MAJOR ATTRIBUTE SCORE 1+2+3+4+5 |
|---|---|---|---|---|---|---|---|---|---|
| CAP MATRIX | 0.108 | 0.020 | 100.000 | 25.000 | 0.478 | 0.120 | 5.000 | 1.565 | 26.705 |
| RF MODE ANAL | 100.000 | 18.700 | 66.666 | 16.667 | 100.000 | 25.000 | 90.500 | 28.327 | 88.694 |
| RIGS | 47.847 | 8.947 | 63.492 | 15.873 | 0.245 | 0.061 | 62.000 | 19.406 | 44.287 |
| PVT | 4.850 | 0.907 | 48.193 | 12.048 | 0.098 | 0.025 | 52.500 | 16.433 | 29.413 |
| CAP/ RIGS | 0.108 | 0.020 | 38.835 | 9.709 | 0.162 | 0.041 | 4.600* | 1.440 | 11.210 |
| CAP/ PVT | 0.106 | 0.020 | 32.520 | 8.130 | 0.081 | 0.020 | 4.560* | 1.424 | 9.594 |
| MICRO/ PVT | 1.774 | 0.332 | 25.654 | 6.414 | 0.000 | 0.000 | 23.200* | 7.262 | 14.008 |

* = PRODUCT/SUM

HYDROGEN SYSTEMS:

| GAGING SYSTEMS | WEIGHT SCORE (a) | CROSS TRADE (a)x.187 =1 | ELECT POWER SCORE (b) | CROSS TRADE (b)x.250 =2 | ENERGY INPUT SCORE (c) | CROSS TRADE (c)x.250 =3 | SENSOR COMPLEXITY SCORE (d) | CROSS TRADE (d)x.313 =4 | UN-WEIGHTED MAJOR ATTRIBUTE SCORE 1+2+3+4+5 |
|---|---|---|---|---|---|---|---|---|---|
| CAP MATRIX | 0.117 | 0.022 | 100.000 | 25.000 | 0.048 | 0.012 | 5.000 | 1.565 | 26.599 |
| RF MODE ANAL | 100.000 | 18.700 | 66.666 | 16.667 | 0.296 | 0.074 | 90.500 | 28.327 | 63.771 |
| GAMMA RAD | 1.145 | 0.214 | 25.530 | 6.383 | 100.000 | 25.000 | 24.000 | 7.512 | 39.109 |
| RF/ GAMMA | 1.132 | 0.212 | 18.460 | 4.615 | 0.296 | 0.074 | 16.000* | 5.008 | 9.909 |

* = PRODUCT/SUM

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# DESIGN QUALITY
## SUMMARY OF CONCEPT SCORING

OXYGEN SYSTEMS:

| GAGING SYSTEMS | RELI-ABILITY SCORE (a) | CROSS TRADE (a)x .222 =1 | REPAIR-ABILITY SCORE (b) | CROSS TRADE (b)x .186 =2 | MAINTAIN-ABILITY SCORE (c) | CROSS TRADE (c)x .111 =3 | SAFETY SCORE (d) | CROSS TRADE (d)x .296 =4 | COMPAT-IBILITY SCORE (e) | CROSS TRADE (e)x .185 =5 | UN-WEIGHTED MAJOR ATTRIBUTE SCORE 1+2+3+4+5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CAP MATRIX | 78 | 17.316 | 93 | 17.298 | 53 | 5.883 | 74 | 21.904 | 71 | 13.135 | 75.536 |
| RF MODE ANAL | 60 | 13.320 | 96 | 17.856 | 68 | 7.548 | 85 | 25.160 | 89 | 16.465 | 80.349 |
| RIGS | 40 | 8.880 | 62 | 11.532 | 46 | 5.106 | 40 | 11.840 | 29 | 5.365 | 42.723 |
| PVT | 58 | 12.876 | 66 | 12.276 | 47 | 5.217 | 63 | 18.648 | 43 | 7.995 | 56.972 |
| CAP/ RIGS | 26* | 5.772 | 37* | 6.882 | 25* | 2.775 | 26* | 7.696 | 21* | 3.885 | 27.010 |
| CAP/ PVT | 33* | 7.326 | 39* | 7.254 | 25* | 2.775 | 34* | 10.064 | 27* | 4.995 | 32.414 |
| MICRO/ PVT | 20* | 4.440 | 15* | 2.790 | 25* | 2.775 | 24* | 7.104 | 26* | 4.810 | 21.919 |

* = PRODUCT/SUM

HYDROGEN SYSTEMS:

| GAGING SYSTEMS | RELI-ABILITY SCORE (a) | CROSS TRADE (a)x .222=1 | REPAIR-ABILITY SCORE (b) | CROSS TRADE (b)x.186 =2 | MAINTAIN-ABILITY SCORE (c) | CROSS TRADE (c)x.111 =3 | SAFETY SCORE (d) | CROSS TRADE (d)x .296=4 | COMPAT-IBILITY SCORE (e) | CROSS TRADE (e)x.185 =5 | UN-WEIGHTED MAJOR ATTRIBUTE SCORE 1+2+3+4+5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CAP MATRIX | 86 | 19.092 | 93 | 17.298 | 53 | 5.883 | 74 | 21.904 | 72 | 13.320 | 77.497 |
| RF MODE ANAL | 67 | 14.874 | 96 | 17.856 | 68 | 7.548 | 85 | 25.160 | 84 | 15.540 | 80.960 |
| GAMMA RAD | 54 | 11.988 | 65 | 12.090 | 39 | 4.329 | 34 | 10.064 | 39 | 7.215 | 45.686 |
| RF/ GAMMA | 30* | 6.660 | 39* | 7.254 | 25* | 2.775 | 24* | 7.104 | 27* | 4.995 | 28.788 |

* = PRODUCT/SUM

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# DESIGN STATE OF THE ART
# SUMMARY OF CONCEPT SCORING
# STORAGE SIZE TANKS

OXYGEN SYSTEMS:

| GAGING SYSTEMS | MATERIALS SCORE (a) | CROSS TRADE (a)x.213 =1 | CONSTRUCTION SCORE (b) | CROSS TRADE (b)x.204 =2 | CIRCUITRY SCORE (c) | CROSS TRADE (c)x.280 =3 | PERFORMANCE SCORE (d) | CROSS TRADE (d)x.101 =4 | POTENTIAL SCORE (e) | CROSS TRADE (e)x.202 =5 | UN-WEIGHTED MAJOR ATTRIBUTE SCORE 1+2+3+4+5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CAP MATRIX | 49.000 | 10.437 | 38.500 | 7.854 | 54.250 | 15.190 | 100.000 | 10.100 | 73.750 | 14.898 | 58.479 |
| RF MODE ANAL | 59.500 | 12.674 | 59.500 | 12.138 | 38.500 | 10.780 | 100.000 | 10.100 | 73.750 | 14.898 | 60.590 |
| RIGS | 22.000 | 4.686 | 28.000 | 5.712 | 22.000 | 6.160 | 100.000 | 10.100 | 55.000 | 11.110 | 37.768 |
| PVT | 22.000 | 4.686 | 28.000 | 5.712 | 22.000 | 6.160 | 100.000 | 10.100 | 55.000 | 11.110 | 37.768 |
| CAP/ RIGS | 7.700 | 1.640 | 8.050 | 1.642 | 8.043 | 2.252 | 100.000 | 10.100 | 43.250 | 8.737 | 24.371 |
| CAP/ PVT | 7.700 | 1.640 | 8.050 | 1.642 | 8.043 | 2.252 | 100.000 | 10.100 | 43.250 | 8.737 | 24.371 |
| MICRO/ PVT | 5.500 | 1.172 | 7.000 | 1.428 | 5.098 | 1.427 | 100.000 | 10.100 | 40.000 | 8.080 | 22.207 |

HYDROGEN SYSTEMS:

| GAGING SYSTEMS | MATERIALS SCORE (a) | CROSS TRADE (a)x.213 =1 | CONSTRUCTION SCORE (b) | CROSS TRADE (b)x.204 =2 | CIRCUITRY SCORE (c) | CROSS TRADE (c)x.280 =3 | PERFORMANCE SCORE (d) | CROSS TRADE (d)x .101 =4 | POTENTIAL SCORE (e) | CROSS TRADE (e)x .202 =5 | UN-WEIGHTED MAJOR ATTRIBUTE SCORE 1+2+3+4+5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CAP MATRIX | 49.000 | 10.437 | 38.500 | 7.854 | 54.250 | 15.190 | 100.000 | 10.100 | 73.750 | 14.898 | 58.479 |
| RF MODE ANAL | 59.500 | 12.674 | 59.500 | 12.138 | 38.500 | 10.780 | 100.000 | 10.100 | 73.750 | 14.898 | 60.590 |
| GAMMA RAD | 28.000 | 5.964 | 16.500 | 3.366 | 4.750 | 1.330 | 100.000 | 10.100 | 45.000 | 9.090 | 29.850 |
| RF/ GAMMA | 9.597 | 2.044 | 7.013 | 1.431 | 2.264 | 0.634 | 100.000 | 10.100 | 38.500 | 7.777 | 21.986 |

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# FLIGHT HARDWARE DEVELOPMENT EFFORT
## SUMMARY OF CONCEPT SCORING

OXYGEN SYSTEMS:

| GAGING SYSTEMS | DEV HDWR SCORE (a) | CROSS TRADE (a)x.333 =1 | PROTO HDWR SCORE (b) | CROSS TRADE (b)x.333 =2 | FLIGHT HARDWARE SCORE (c) | CROSS TRADE (c)x.333 =3 | UN-WEIGHTED MAJOR ATTRIBUTE SCORE 1+2+3+4+5 |
|---|---|---|---|---|---|---|---|
| CAP MATRIX | 100.000 | 33.333 | 86.133 | 28.711 | 87.489 | 29.163 | 91.207 |
| RF MODE ANAL | 89.928 | 29.976 | 100.000 | 33.333 | 100.000 | 33.333 | 96.642 |
| RIGS | 70.472 | 23.491 | 30.285 | 10.095 | 41.894 | 13.965 | 47.551 |
| PVT | 90.498 | 30.166 | 45.455 | 15.152 | 49.407 | 16.469 | 61.787 |
| CAP/ RIGS | 29.163 | 9.721 | 19.451 | 6.484 | 25.543 | 8.514 | 24.719 |
| CAP/ PVT | 42.790 | 14.263 | 24.950 | 8.317 | 28.506 | 9.502 | 32.082 |
| MICRO/ PVT | 34.807 | 11.602 | 19.712 | 6.571 | 22.031 | 7.344 | 25.517 |

HYDROGEN SYSTEMS:

| GAGING SYSTEMS | DEV HDWR SCORE (a) | CROSS TRADE (a)x.333 =1 | PROTO HDWR SCORE (b) | CROSS TRADE (b)x.333 =2 | FLIGHT HARDWARE SCORE (c) | CROSS TRADE (c)x.333 =3 | UN-WEIGHTED MAJOR ATTRIBUTE SCORE 1+2+3+4+5 |
|---|---|---|---|---|---|---|---|
| CAP MATRIX | 100.000 | 33.333 | 86.133 | 28.711 | 87.489 | 29.163 | 91.207 |
| RF MODE ANAL | 89.928 | 29.976 | 100.000 | 33.333 | 100.000 | 33.333 | 96.642 |
| GAMMA RAD | 82.919 | 27.640 | 34.916 | 11.639 | 45.641 | 15.214 | 54.493 |
| RF/ GAMMA | 35.562 | 11.854 | 22.007 | 7.336 | 28.257 | 9.419 | 28.609 |

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# MAJOR ATTRIBUTE
# SUMMARY OF CONCEPT SCORING
# STORAGE SIZE TANKS

OXYGEN SYSTEMS:

| GAGING SYSTEMS | ACCURACY SCORE (a) | WEIGHT (a)x .35 =1 | DESIGN FEATURES SCORE (b) | WEIGHT (b)x .20 =2 | DESIGN QUALITY SCORE (c) | WEIGHT (c)x .25 =3 | STATE OF ART SCORE (d) | WEIGHT (d)x .10 =4 | FLITE HOWR EFFORT SCORE (e) | WEIGHT (e)x .10 =5 | OVERALL SCORE 1+2+3+4+5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CAP MATRIX | 85.311 | 29.86 | 26.705 | 5.34 | 75.536 | 18.88 | 58.479 | 5.85 | 91.207 | 9.12 | 69.05 |
| RF MODE ANAL | 95.207 | 33.32 | 88.694 | 17.74 | 80.349 | 20.09 | 60.590 | 6.06 | 96.642 | 9.66 | 86.87 |
| RIGS | 62.541 | 21.89 | 44.287 | 8.86 | 42.723 | 9.54 | 37.768 | 3.78 | 47.551 | 4.76 | 47.83 |
| PVT | 71.674 | 25.09 | 29.413 | 5.58 | 56.972 | 11.39 | 37.768 | 3.78 | 61.787 | 6.18 | 52.32 |
| CAP/ RIGS | 59.318 | 20.76 | 11.210 | 2.24 | 27.010 | 5.40 | 24.371 | 2.44 | 24.719 | 2.47 | 33.31 |
| CAP/ PVT | 61.915 | 21.67 | 9.594 | 1.92 | 32.414 | 8.10 | 24.371 | 2.44 | 32.082 | 3.21 | 37.34 |
| MICRO/ PVT | 54.009 | 18.90 | 14.008 | 2.80 | 21.919 | 4.38 | 22.207 | 2.22 | 25.517 | 2.55 | 30.85 |

HYDROGEN SYSTEMS:

| GAGING SYSTEMS | ACCURACY SCORE (a) | WEIGHT (a)x .35 =1 | DESIGN FEATURES SCORE (b) | WEIGHT (b)x .20 =2 | DESIGN QUALITY SCORE (c) | WEIGHT (c)x .25 =3 | STATE OF ART SCORE (d) | WEIGHT (d)x .10 =4 | FLITE HOWR EFFORT SCORE (e) | WEIGHT (e)x .10 =5 | OVERALL SCORE 1+2+3+4+5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CAP MATRIX | 85.311 | 29.86 | 26.599 | 5.32 | 77.497 | 19.37 | 58.479 | 5.85 | 91.207 | 9.12 | 69.52 |
| RF MODE ANAL | 95.207 | 33.32 | 63.771 | 12.75 | 80.960 | 20.24 | 60.590 | 6.06 | 96.642 | 9.66 | 82.03 |
| GAMMA RAD | 72.578 | 25.40 | 39.109 | 7.82 | 45.686 | 11.42 | 29.850 | 2.99 | 54.493 | 5.45 | 53.08 |
| RF/ GAMMA | 66.910 | 23.42 | 9.909 | 1.98 | 28.788 | 7.20 | 21.986 | 2.20 | 28.609 | 2.86 | 37.66 |

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# EFFECTS OF TANK SIZE ON CONCEPT OVERALL SCORES

## $O_2$ SYSTEMS

| CONCEPTS | STORAGE SIZE OVERALL SCORE | OTV SIZE OVERALL SCORE | SMALL SIZE OVERALL SIZE |
|---|---|---|---|
| CAP MATRIX | 69.05 | 69.06 | 69.95 |
| RF MODE ANA | 86.87 | 86.87 | 86.87 |
| RIGS | 47.83 | 47.81 | 47.83 |
| PVT | 52.32 | 54.15 | 51.85 |
| CAP/RIGS | 33.31 | 33.65 | 33.80 |
| CAP/PVT | 37.34 | 37.67 | 37.20 |
| MICRO/PVT | 30.85 | 31.23 | 30.60 |

## $H_2$ SYSTEMS

| CONCEPTS | STORAGE SIZE OVERALL SCORE | OTV SIZE OVERALL SCORE | CFMF SIZE OVERALL SCORE |
|---|---|---|---|
| CAP MATRIX | 69.52 | 69.53 | 70.07 |
| RF MODE ANA | 82.03 | 82.02 | 82.02 |
| GAMMA RAD | 53.08 | 53.08 | 53.63 |
| RF/GAMMA | 37.66 | 37.65 | 37.92 |

## SUMMARY REMARKS

- TANK SIZE EFFECTS PRIMARILY AFFECTED THE SCORING OF MAJOR ATTRIBUTE "DESIGN FEATURES"

- TANK SIZE EFFECTS WHICH WERE A NORMAL CONSEQUENCE OF DESIGNING A SYSTEM FOR A PARTICULAR TANK CONFIGURATION WERE CONSIDERED A MINIMAL ACCURACY SENSITIVITY ISSUE WHOSE SPECIFIC CONSEQUENCE WOULD BE MORE EXACTLY ASSESSED IN THE DESIGN FEATURE ATTRIBUTE AREA

- THE NON-DIGITAL IMPLEMENTATION OF THE CAPACITANCE MATRIX CONCEPT WAS RETAINED SO THAT THE HIGH DESIGN MATURITY FOR THIS APPROACH COULD BE USED TO ITS BEST ADVANTAGE IN THE SCORING

- RF MODAL ANALYSIS SCORED BEST IN ALL OF THE MAJOR ATTRIBUTE CATEGORIES. THIS INDICATES THAT THIS APPROACH WOULD HAVE BEEN THE OPTIMUM CHOICE REGARDLESS OF THE MAJOR ATTRIBUTE WEIGHING FACTORS.

# TRADE STUDY RESULT

CONCLUSION: CANDIDATE CONCEPT SCORING RESULTS OBTAINED UNDER THE DISCIPLINE OF THE SECTION CRITERIA HAVE INDICATED THAT THE OPTIMUM DIRECT GAGING APPROACH FOR EITHER OR BOTH OXYGEN AND HYDROGEN ZERO-GRAVITY PROPELLANT TANKAGE IS THE RF MODAL ANALYSIS SYSTEM.

RECOMMENDATION: THAT NASA-JSC APPROVE CARRYING THE RF MODAL ANALYSIS SYSTEM INTO DEVELOPMENT.

Appendix C

Beechcraft
Boulder Division

# Beech Aircraft Corporation

Boulder, Colorado

**Code Ident. No. 07399**

Descriptive Data 18003

Revision A

# ZERO G QUANTITY GAGING SYSTEM: TEST PLAN FOR FEASIBILITY TESTING IN SUPPORT OF TRADES

October 11, 1985

Revision A issued October 11, 1985

REVISION SHEET

| REV | BY | PAGE AFFECTED | DESCRIPTION OF REVISION | APPROVAL | DATE |
|---|---|---|---|---|---|
| A | R PEDERSON | 8 | Added reference to Dewar Insulation | | |
| | | 12 | Paragraph 4.3 - $LN_2$ was $LH_2$ | | |
| | | 13 | Added Paragraph 4.3.1 "RF Gaging System Equipment" | | |
| | | 14 | Figure 7. Test Procedure completion date was October 14 | | |

# TABLE OF CONTENTS

## 1.0 INTRODUCTION

Comprehensive screening of candidate quantity gaging systems has resulted in the selection of RF mode analysis as the most promising technique. Testing of the selected system will be required to support assumptions made during the trade studies. The purpose of this document is to describe what testing will be required and how it will be conducted.

A universal test fixture has been designed as a part of the Task 2 activities. The test fixture will be used to evaluate the sensitivity of the proposed gaging system to stored fluid mass and orientation, and tank internal geometry (e.g.: slosh baffles, screen acquisition devices, thermodynamic vents, etc). Other areas to be investigated will include the type and extent of signal processing required, the accuracy of the gaging system (with cryogens and their simulants), and different antenna configurations. This test plan also describes the additional test hardware required to accomplish the testing of an RF mode analysis gaging system.

## 2.0 OBJECTIVES

The intent of this test plan is to validate the selection of the most promising quantity gaging system. In support of that goal, the tests proposed herein will:

A. Establish the applicability of cryo simulant fluids for evaluation of quantity gaging system performance in KC-135 zero-g flight tests.

B. Determine the performance (accuracy, repeatability and hysteresis) of a lab equipment based RF gaging system.

C. Establish the raw data analysis techniques required to convert an RF model response of the tank cavity into a representative fluid quantity.

D. Identify any unforseen problem areas which would preclude the use or further development of an RF gaging system.

E. Establish the sensitivity of the RF gaging system output to variations in tank orientation, internal components, and fluid movement.

F. Prove out the test setup in advance of its required use in support of the design trades (Task 2.2.2).

G. Identify any problems with data acquisition or reduction, the test setup or test procedure that will need to be addressed in the design trades.

H. Define the Q of the tank cavity and verify it is within an acceptable range for RF gaging.

## 3.0 APPROACH

The objectives noted above will be accomplished through an orderly series of tests designed to expand on work done by the National Bureau of Standards as reported in document NBSIR73-318 dated June 1973. The referenced work involved testing an RF mode analysis gaging system with liquid nitrogen and liquid oxygen in a spherical dewar. The NBS testing used a dewar that was free of internal components except for three RF antennas, a somewhat ideal case but necessary to develop the basic RF system design and data analysis techniques. The testing done for this task will initially parallel the work at NBS. A nearly spherical test dewar, Figure 1, has been designed which will allow testing with $LH_2$ and $LO_2$. The dewar is designed such that it can be separated at the equator. This feature will allow specially designed dummy components such as start baskets and fluid acquisition channels to be installed for comparison of RF resonance mode signatures to an empty dewar. More detailed descriptions of the test dewar and dummy components are presented in Appendix A.

The RF gaging system itself will be assembled from discrete, laboratory sweep frequency generators, oscilloscopes, time bases, directional couplers, detectors, antennas, reference cavity, and signal multiplexer. Figure 2 shows a block diagram of the anticipated equipment configuration. Actual frequency bands to be swept and number of modes to be investigated will be selected in the trade studies. Initial results of the gaging tests will be used to refine those selections.

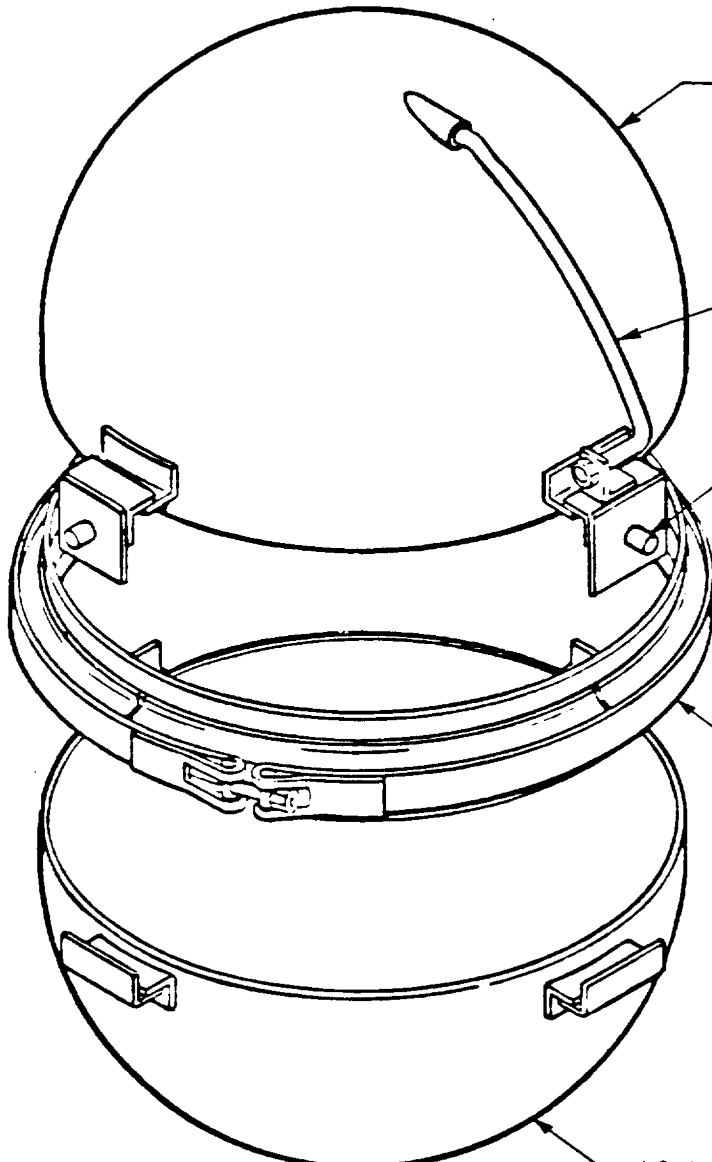



Figure 1. P/N 561438 PRESSURE VESSEL ASSEMBLY.

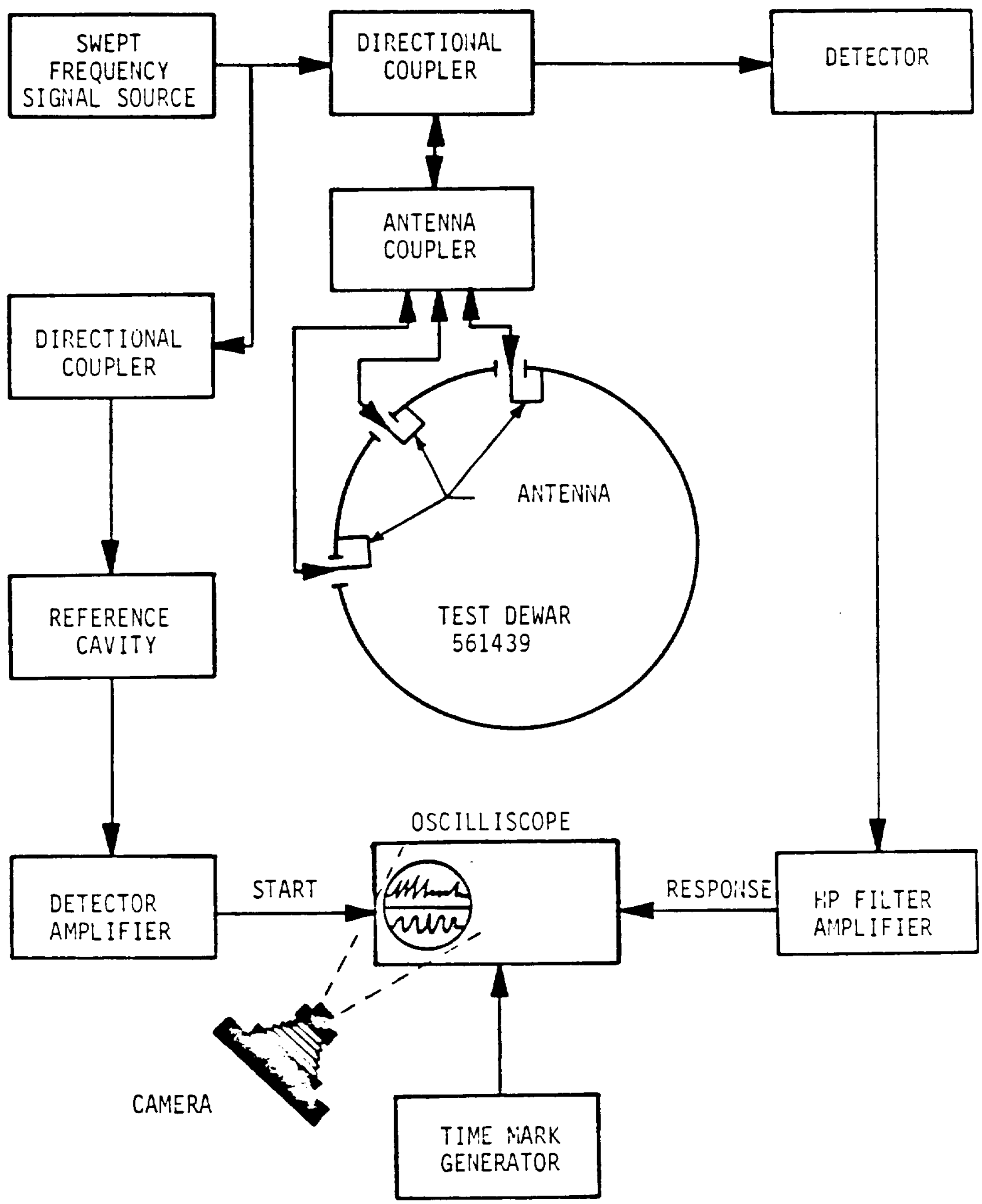



Figure 2. RF GAGING SYSTEM BREADBOARD COMPONENTS.

Three series of gaging tests will be required to support the selection of the RF mode analysis system. The first series of tests will be run with the dewar empty of any interior components. This will establish a baseline frequency response signature of the dewar. The following fluids will be tested:

A. Simulation Fluid(s)
B. Liquid Hydrogen
C. Liquid Oxygen

During the cryogenic test phase, the dewar will be insulated with a multi-layer insulation (MLI) blanket. The blanket will be sewn up by the Manufacturing Department and installed on the dewar by the Test Department. Specific details of the MLI blanket are to be determined.

The fluid(s) used to simulate $LH_2$ and $LO_2$ will be determined in the trade studies. The ability of the simulation fluids to accurately represent the performance of cryogens will be investigated in these tests. Any adjustments which may be required in the simulation fluid will be made at this point and additional tests may be run to validate their performance.

The second series of tests involves separating the dewar at its equator and installing a scaled replica of a start basket, thermodynamic vent, and screened-channel fluid acquisition device. These components will be non-functional. They will, however, have the correct dimensional proportions for the dewar size and shape. They also will behave in the RF environment similarly to a functional unit. Only the cryogen simulation fluid(s) will be used for this and succeeding tests.

The third series of tests will add a slosh baffle system to the dewar. As before, it appears to the RF gaging system as a correctly sized and operating unit.

For each series of test, the performance of the RF gaging system will be determined for:

A. Dewar orientation (ie: angle from vertical of 0 to 360° at 45° intervals)
B. Fill level - full, 3/4, 1/2, 1/4, empty
C. Antenna location - polar top, equator sidewall and 45° latitude sidewall, as a minimum

Figure 3 depicts these test conditions in more detail.

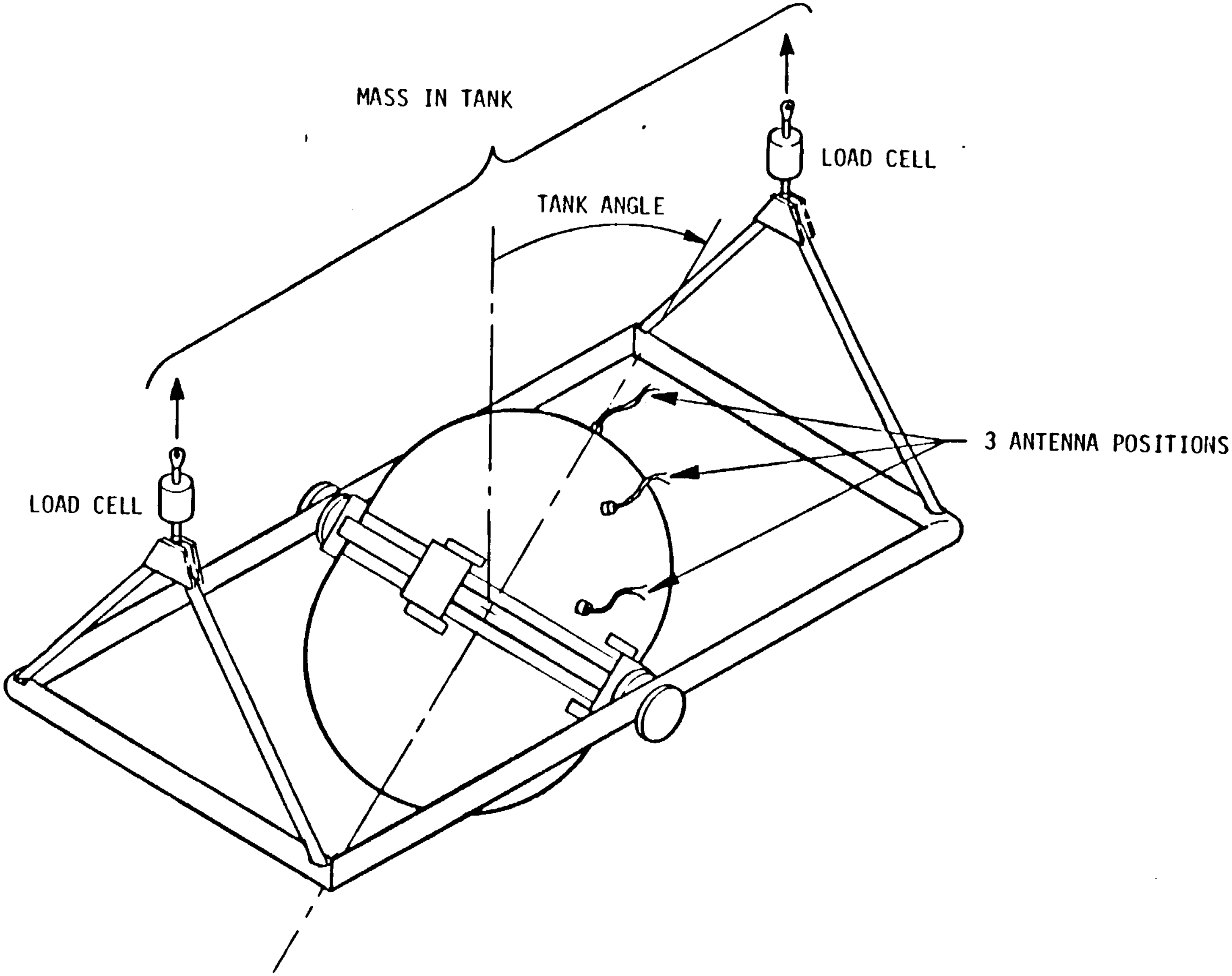



Figure 3. THE PERFORMANCE OF THE GAGING SYSTEM WILL BE DETERMINED FOR THREE PARAMETERS.

Data from these tests will be evaluated as soon as each test is completed. In that way, any change in test strategy dictated by the data will be immediately incorporated into a revised test plan. In order to maintain the compressed work schedule proposed for this effort, all formal reporting for these tests will be postponed until after the trade studies are complete. In this way, maximum resource will be made available to transfer significant results obtained from the test directly and immediately to the trade study effort.

4.0 GENERAL TEST PROCEDURE

4.1 Test Setup. Figure 4 illustrates the general test configuration. The universal test dewar will be installed in a support/rotating fixture (Code D934/TCO 26659, S/N 69751) which will hang from a rail inside the CVC vacuum chamber located at Beech's Test Department. The test dewar will be instrumented to allow recording of dewar temperature, pressure, angle from vertical and suspended weight on the support fixture. Any additional instrumentation required to control the test (ie: vacuum level of the CVC chamber, status of fluid control system, etc.) will be determined and supplied by the Beech Test Department. The universal test dewar will incorporate, as a minimum, three available locations for RF antennas (reference Appendix A). This will allow sequential testing of different antenna configurations and locations. Each antenna will be individually selectable from outside the chamber. This will require that three coax, type tbd, passthroughs be installed in the CVC chamber.

The universal test dewar is designed to withstand 40 psia internal pressure. Prior to its installation in the test setup, it will be cold-shocked, proof tested to 60 psia and leak tested. All other hardware exposed to the test environment will be similarily tested.

4.2 System Tests.

4.2.1 Characterization Tests. Once the test setup has been completed and checked out, a system characterization series of tests will be run. These tests will be run essentially "freehand"; that is, without a specific procedure. This will allow the Test and Engineering departments to get a feel for the operation of the system. A minimum of data will be recorded. The dewar will be tested empty to determine the "Q" of the cavity for confirmation of analytical results developed during the trade studies. The

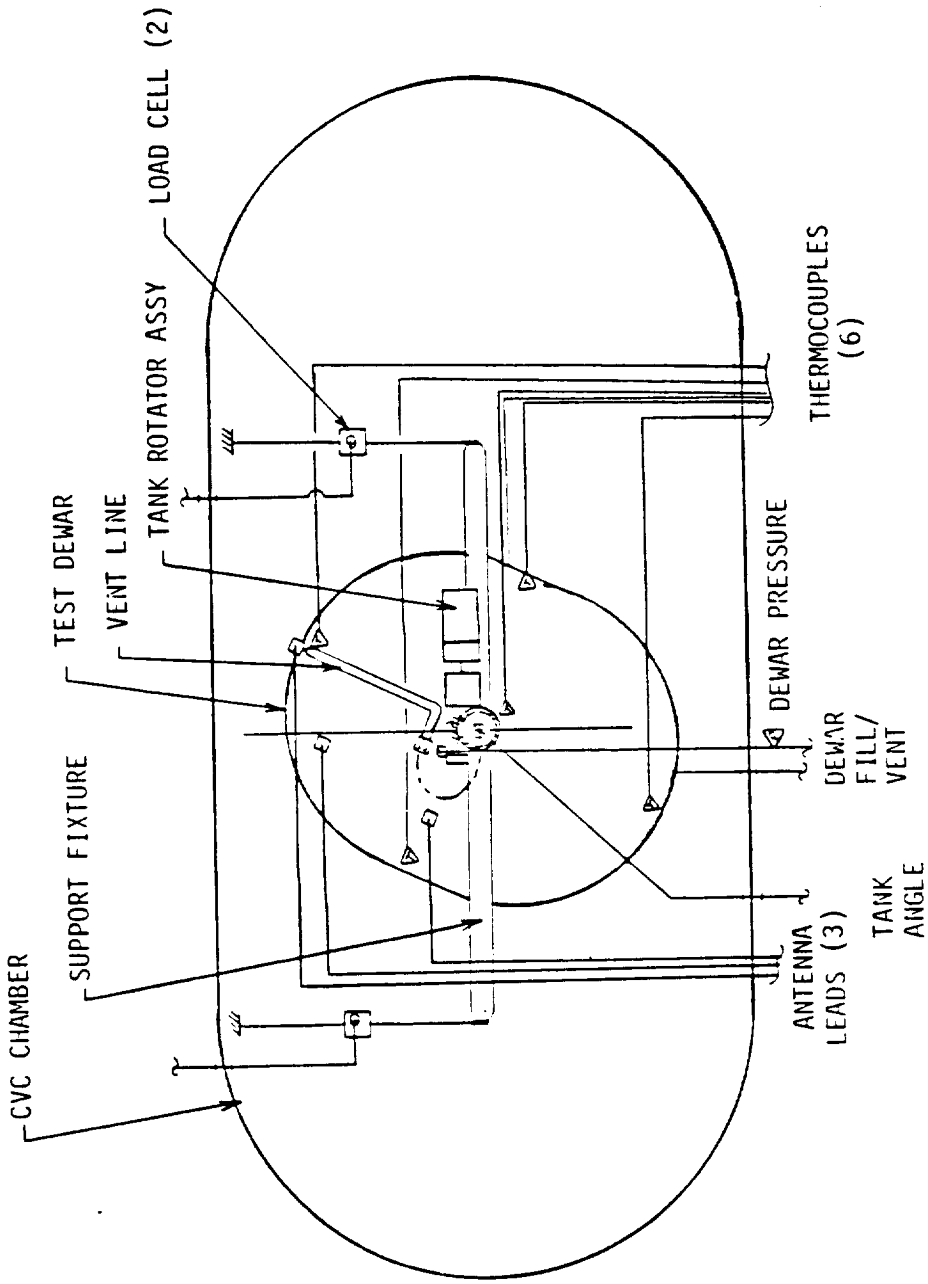



Figure 4. THE TEST DEWAR WILL BE SET UP IN THE CVC CHAMBER.

dewar will be rotated on its support fixture in the empty and full conditions to determine the dynamic response of the dewar and damping time of fluid oscillations. Fluids to be used for this test are to be determined. These initial tests will establish the raw data analysis techniques required to convert an RF modal response of the tank cavity into a representative fluid quantity. This, in turn, will highlight any areas where a change in instrumentation accuracy, recording rate, type, etc., may be desirable. Specific operating procedures will be developed at this point which will be used for all subsequent tests.

4.2.2 Baseline Tests. Dewar configuration for these tests will be per Beech Layout Drawing 561439-1. A series of baseline tests will be run using $LO_2$, $LH_2$ and one or possibly two other fluids which will simulate the performance of the cryogens. These simulation fluids will have been selected in the trade studies, and their ability to accurately reflect the performance of the cryogens in subsequent flight tests will be verified. For these tests, the dewar will be empty of all interior constructs except for antennas and temperature/pressure instrumentation. A test matrix has been developed, Figure 5, which describes a full range of test conditions for the RF gaging system. The system will be tested for a range of fill levels from full to empty, tank orientation from vertical to inverted and back, three different antenna locations, and at least three different fluids. It should be noted that a significant percentage of the test combinations will likely not be run. As the baseline tests progress, information gained from the tests will be used to eliminate test combinations which have limited value for supporting the trade studies. The number of dewar orientations, or fill levels may be reduced based on the consistency of data acquired in previous tests. Antenna locations may be eliminated from consideration due to poor performance. The matrix in Figure 5 simply presents the total array of tests from which Engineering may choose.

4.2.3. Phase I Component Tests. After the baseline tests have established the capabilities of the RF gaging system, the universal test dewar will be removed from the CVC vacuum chamber for modifications. The dewar will be split at its equator and modified per Beech layout drawing 561439 into the -3 configuration. The modifications include installing a thermodynamic vapor only vent, a set of four screened fluid acquisition channels, and a start basket. Figure 6 illustrates the components and shows their installation in the dewar. The components are nonfunctional and are not connected together fluidically. They are fastened to the dewar and to each other with tack welds

## 1.0 BASELINE TESTS

| TEST NO. | TANK ANGLE 0 | 45 | 90 | 135 | 180 | 225 | 270 | 315 | 360 | FILL LEVEL F | 3/4 | 1/2 | 1/4 | E | ANT LOC 1 | 2 | 3 | FLUID LO2 | LH2 | S* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.1 | X | X | X | X | X | X | X | X | X | X | | | | | X | | | X | | |
| 1.2 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | X | | | | | | X | | ¦ | | |
| 1.3 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | X | | | | | | | X | ¦ | | |
| 1.4 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | X | | | | X | | | ¦ | | |
| 1.5 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | X | | | | | X | | ¦ | | |
| 1.6 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | X | | | | | | X | ¦ | | |
| 1.7 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | X | | | X | | | ¦ | | |
| 1.8 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | X | | | | X | | ¦ | | |
| 1.9 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | X | | | | | X | ¦ | | |
| 1.10 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | X | | X | | | ¦ | | |
| 1.11 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | X | | | X | | ¦ | | |
| 1.12 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | X | | | | X | ¦ | | |
| 1.13 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | | X | X | | | ¦ | | |
| 1.14 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | | X | | X | | ¦ | | |
| 1.15 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | | X | | | X | X | | |
| 1.16 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | X | | | | | X | | | | X | |
| 1.17 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | X | | | | | | X | | | ¦ | |
| 1.18 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | X | | | | | | | X | | ¦ | |
| 1.19 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | X | | | | X | | | | ¦ | |
| 1.20 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | X | | | | | X | | | ¦ | |
| 1.21 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | X | | | | | | X | | ¦ | |
| 1.22 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | X | | | X | | | | ¦ | |
| 1.23 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | X | | | | X | | | ¦ | |
| 1.24 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | X | | | | | X | | ¦ | |
| 1.25 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | X | | X | | | | ¦ | |
| 1.26 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | X | | | X | | | ¦ | |
| 1.27 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | X | | | | X | | ¦ | |
| 1.28 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | | X | X | | | | ¦ | |
| 1.29 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | | X | | X | | | ¦ | |
| 1.30 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | | X | | | X | | X | |
| 1.31 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | X | | | | | X | | | | | X |
| 1.32 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | X | | | | | | X | | | | ¦ |
| 1.33 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | X | | | | | | | X | | | ¦ |
| 1.34 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | X | | | | X | | | | | ¦ |
| 1.35 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | X | | | | | X | | | | ¦ |
| 1.36 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | X | | | | | | X | | | ¦ |
| 1.37 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | X | | | X | | | | | ¦ |
| 1.38 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | X | | | | X | | | | ¦ |
| 1.39 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | X | | | | | X | | | ¦ |
| 1.40 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | X | | X | | | | | ¦ |
| 1.41 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | X | | | X | | | | ¦ |
| 1.42 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | X | | | | X | | | ¦ |
| 1.43 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | | X | X | | | | | ¦ |
| 1.44 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | | X | | X | | | | ¦ |
| 1.45 | X | X | X | X | X | X | X | X | X | | | | | X | | | X | | | X |

* CRYOGEN SIMULATION FLUID

## 2.0 PHASE I COMPONENT TESTS

| TEST NO. | TANK ANGLE 0 | 45 | 90 | 135 | 180 | 225 | 270 | 315 | 360 | FILL LEVEL F | 3/4 | 1/2 | 1/4 | E | ANT LOC 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.1 | X | X | X | X | X | X | X | X | X | X | | | | | X | | |
| 2.2 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | X | | | | | | X | |
| 2.3 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | X | | | | | | | X |
| 2.4 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | X | | | | X | | |
| 2.5 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | X | | | | | X | |
| 2.6 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | X | | | | | | X |
| 2.7 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | X | | | X | | |
| 2.8 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | X | | | | X | |
| 2.9 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | X | | | | | X |
| 2.10 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | X | | X | | |
| 2.11 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | X | | | X | |
| 2.12 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | X | | | | X |
| 2.13 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | | X | X | | |
| 2.14 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | | X | | X | |
| 2.15 | X | X | X | X | X | X | X | X | X | | | | | X | | | X |

## 3.0 PHASE 2 COMPONENT TESTS

| TEST NO. | TANK ANGLE 0 | 45 | 90 | 135 | 180 | 225 | 270 | 315 | 360 | FILL LEVEL F | 3/4 | 1/2 | 1/4 | E | ANT LOC 1 | 2 | 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3.1 | X | X | X | X | X | X | X | X | X | X | | | | | X | | |
| 3.2 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | X | | | | | | X | |
| 3.3 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | X | | | | | | | X |
| 3.4 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | X | | | | X | | |
| 3.5 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | X | | | | | X | |
| 3.6 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | X | | | | | | X |
| 3.7 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | X | | | X | | |
| 3.8 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | X | | | | X | |
| 3.9 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | X | | | | | X |
| 3.10 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | X | | X | | |
| 3.11 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | X | | | X | |
| 3.12 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | X | | | | X |
| 3.13 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | | X | X | | |
| 3.14 | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | ¦ | | | | | X | | X | |
| 3.15 | X | X | X | X | X | X | X | X | X | | | | | X | | | X |

Figure 5. TEST MATRICES.

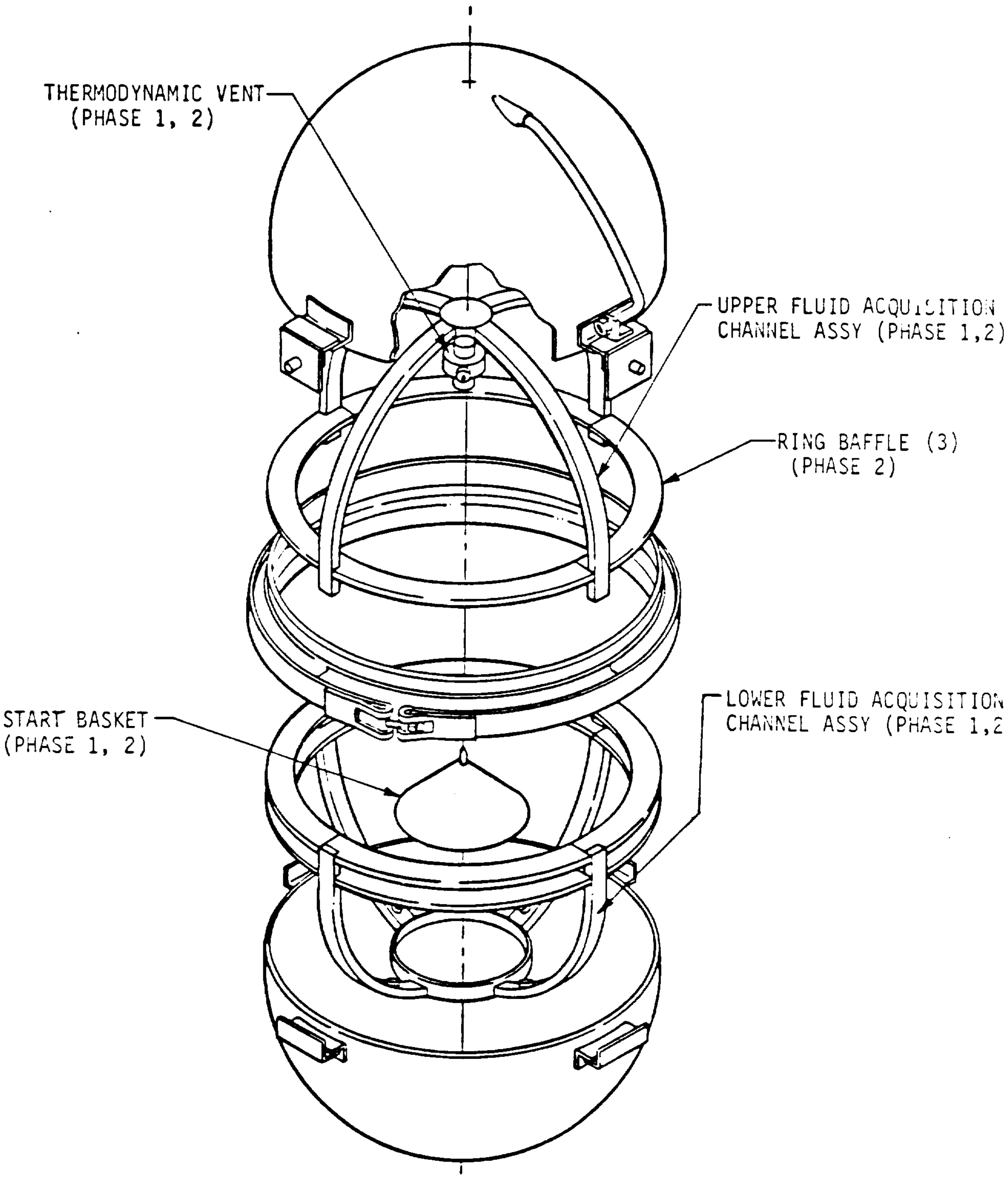



Figure 6. PHASE I AND PHASE 2 TEST HARDWARE INSTALLATION.

and mechanical fasteners in order to maintain their relative positions in the dewar. Dimensions of the components were scaled from similar equipment designed for larger $LH_2/LO_2$ dewars as described in NASA CR-165150. Materials of construction were selected on the basis of compatability for the intended use. In this case, stainless steel was used exclusively due to its compatability with $LO_2$, $LH_2$, and all of the potential simulation fluids. The dewar will be reassembled, seal welded and leak tested prior to reinstallation into the CVC chamber.

Testing for Phase I will proceed along the same lines as the baseline tests. Critical test conditions will be selected from the test matrix and test results will be compared to results obtained for similar conditions with an empty dewar. These tests will determine the effect interior constructs have on the performance of RF gaging systems.

4.2.4 Phase 2 Component Tests. In this phase, the dewar will again be removed from the CVC and modified to add a set of three ring-shaped slosh baffles (reference 561439-5 configuration). The dewar will be reassembled, seal welded, leak tested, and reinstalled into the CVC. Testing will again follow the pattern used for Phase I and the baseline tests.

4.3 Test Facilities. The following test facilities and materials will be required to be supplied by the Test Deparment:

- Test area compatible with $LH_2$, $LO_2$, Kerosene (not concurrently)
- Protected area for Test and Engineering personnel
- Fluids:

| | |
|---|---|
| $GN_2$ | 0-150 psia |
| $LN_2$ | Low pressure |
| $GH_2$ | Low pressure |
| $LH_2$ | Low pressure |
| GHe | 0-60 psig |
| $LO_2$ | Low pressure |

- CVC vacuum chamber
- Electrical power for valve and test equipment operation: 110 VAC, excitation voltage/current for temperature/pressure sensors

- o Vacuum system for vacuum purging of condensible or reactive gases from test system plumbing and dewar hardware.
- o Data Acquisition and control system: HP 9836/3497 acceptable.
- o Test control and monitor panel for centralized control of test fixture
- o Instrumentation:

| | |
|---|---|
| Dewar pressure | 0-60 psia ± 1 psia |
| Dewar temperature | 6 places on outer surface of dewar (range 36°R to 510°R ± 1°) |
| Fixture weighing system | Load cell or equivalent (capable of weighing the dewar and support fixture to an accuracy of ± .2% |

Dewar orientation gaging system capable of displaying the angle of the dewar from vertical at any time to an accuracy of ± 1°

- o Dewar fill and drain system which will allow the dewar fill level to be controlled while the dewar is in the vacuum chamber

4.3.1 <u>RF Gaging System Equipment.</u> The equipment required to generate and process the RF signals to and from the dewar will be supplied by the Test Department (reference Figure 2). The detailed specifications list for the test equipment will be generated in consultation with the Engineering Department. This consultation will provide the frequencies to be swept, sweep rate, power levels, detector sensitivities and data collection rates, etc. Wherever possible, existing test equipment will be used or adapted to perform the gaging system function. The Test Department will be consulted for determination of existing equipment capabilities.

4.4 <u>Reporting.</u> A daily operating log will be kept and made available to the Engineering Department. Daily test results will be compiled and provided to Engineering for analysis. In this way, any changes in test direction dictated by the test results can be quickly implemented. A final test report will be written by Engineering after the trade studies have been completed.

4.5 <u>Schedule.</u> Figure 7 describes the primary tasks and their scheduled duration/completion.

# MASTER TASK SCHEDULE

Work Order No. 22885

Date: 09/23/85
Revision: A
10/11/85

△ Scheduled Event
▲ Complete Event

Program Title: Task 2.1
Feasibility Testing in Support of Trade Studies

Beechcraft
Boulder Division

1985: SEPT 1 8 15 22 29 | OCT 6 13 20 27 | NOV 3 10 17 24 | DEC 1 8 15 22 29
1986: JAN 5 12 19 26 | FEB 2 9 16 23

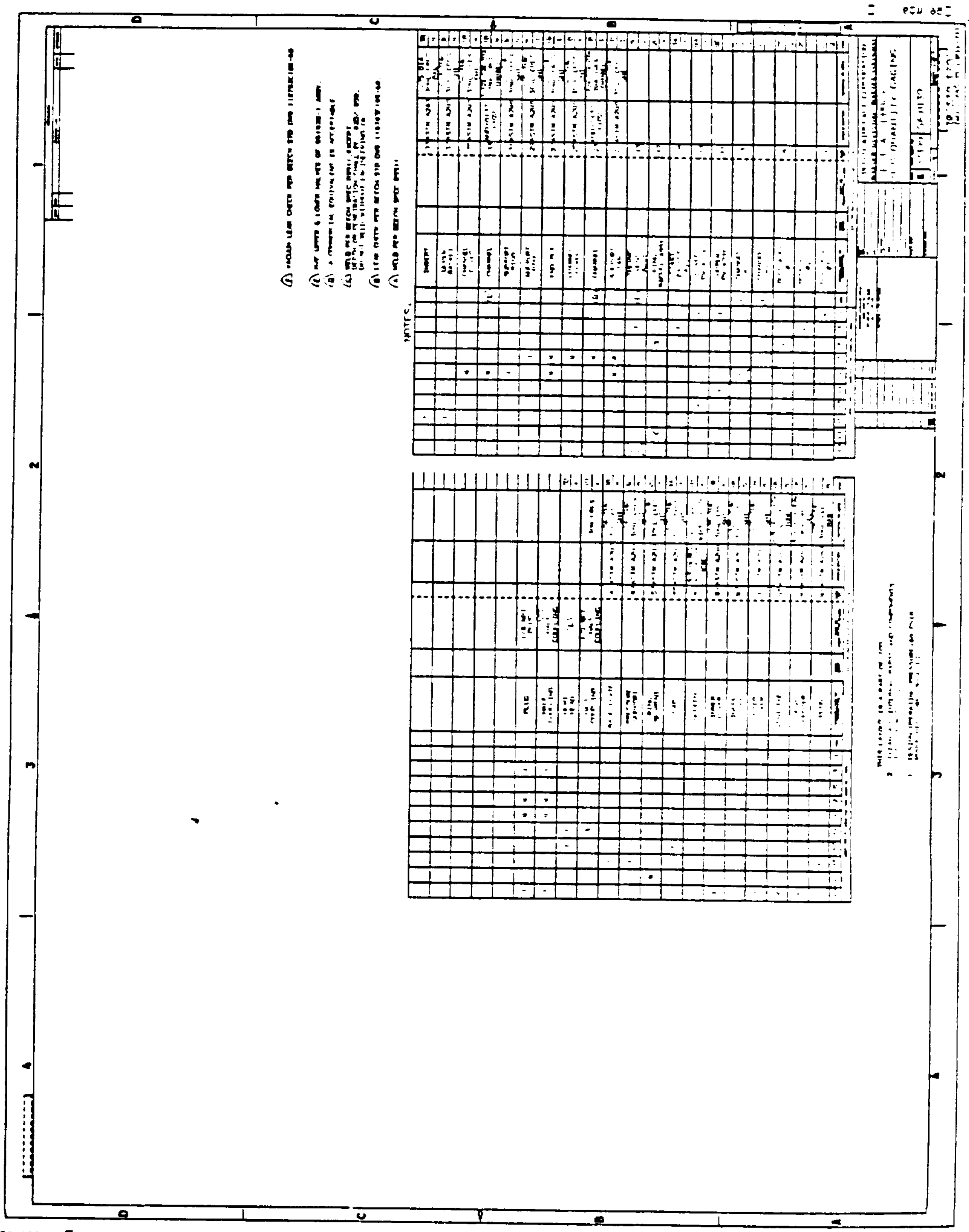
| Task Description | DEPT |
|---|---|
| ENGINEERING TEST REQUEST | ENGR |
| TEST PROCEDURE | TEST |
| TEST HARDWARE DRAWINGS | ENGR |
| TOOLING DRAWINGS | MFG |
| PROCUREMENT | PROC |
| TEST HARDWARE: BUILD | MFG |
| TEST HARDWARE: COLD SHOCK PROOF/LEAK | TEST |
| TEST SETUP | TEST |
| CHARACTERIZATION TESTS | TEST |
| BASELINE TESTS | TEST |
| MOD FOR PHASE I TESTS | MFG |
| PHASE 1 TESTS | TEST |
| MOD FOR PHASE 2 TESTS | TEST |
| PHASE 2 TESTS | TEST |
| REPORTING | ENGR |

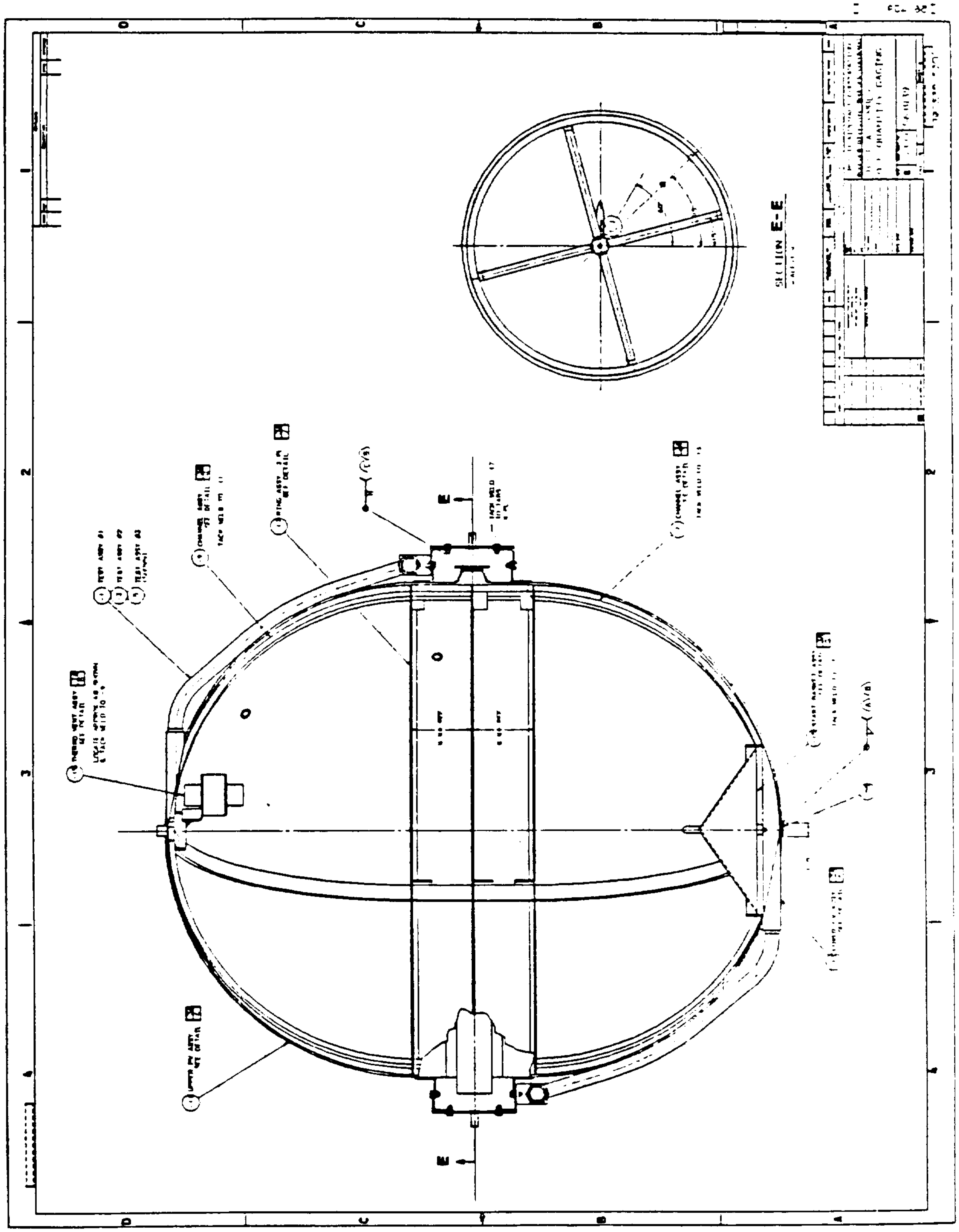
| Schedule Status Evaluation | Ahead of Sched. On Schedule Behind Sched. |
|---|---|

Descriptive Data 18003
October 11, 1985
Revision A - 10/11/85

APPENDIX A

TEST ASSEMBLY 561439





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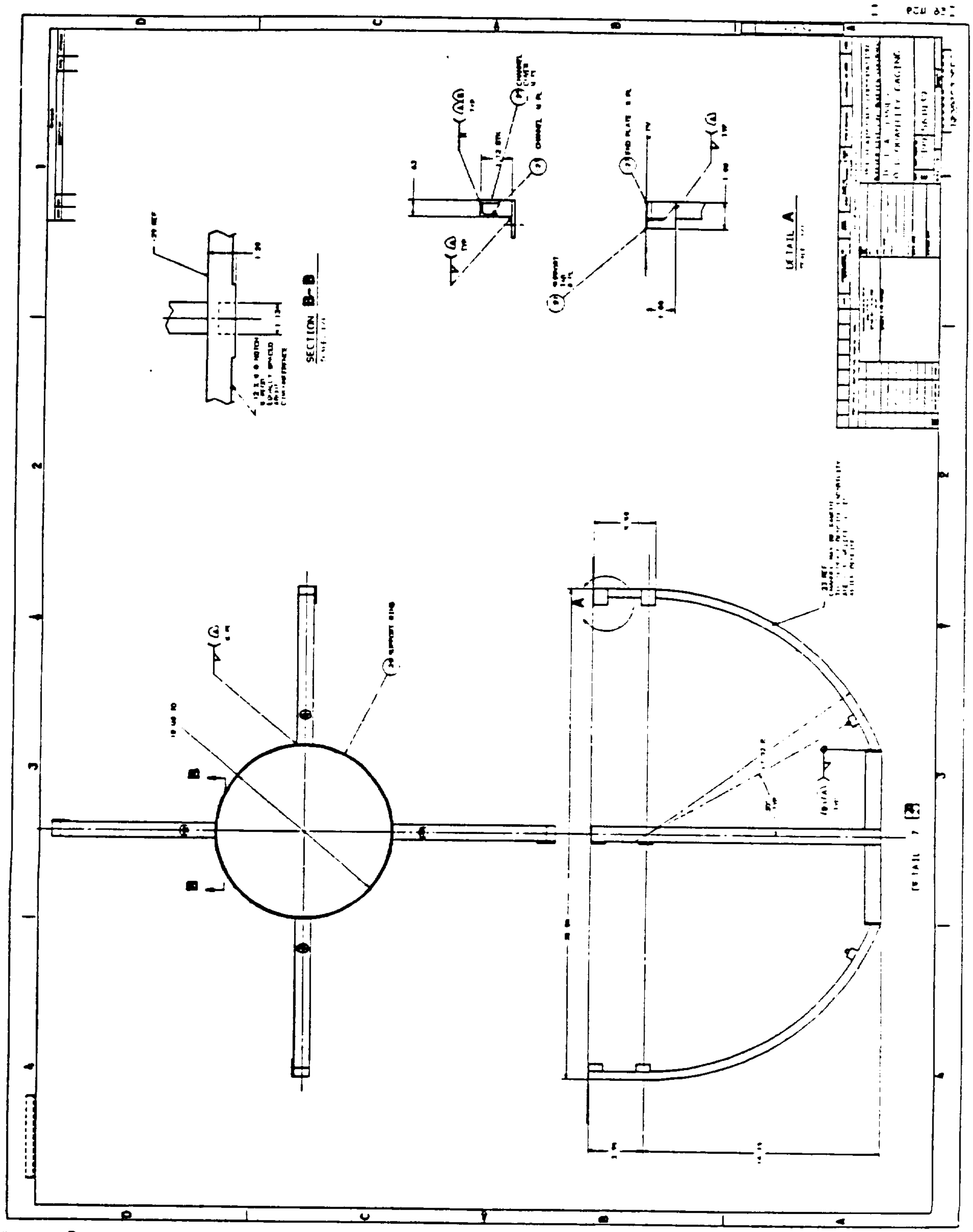
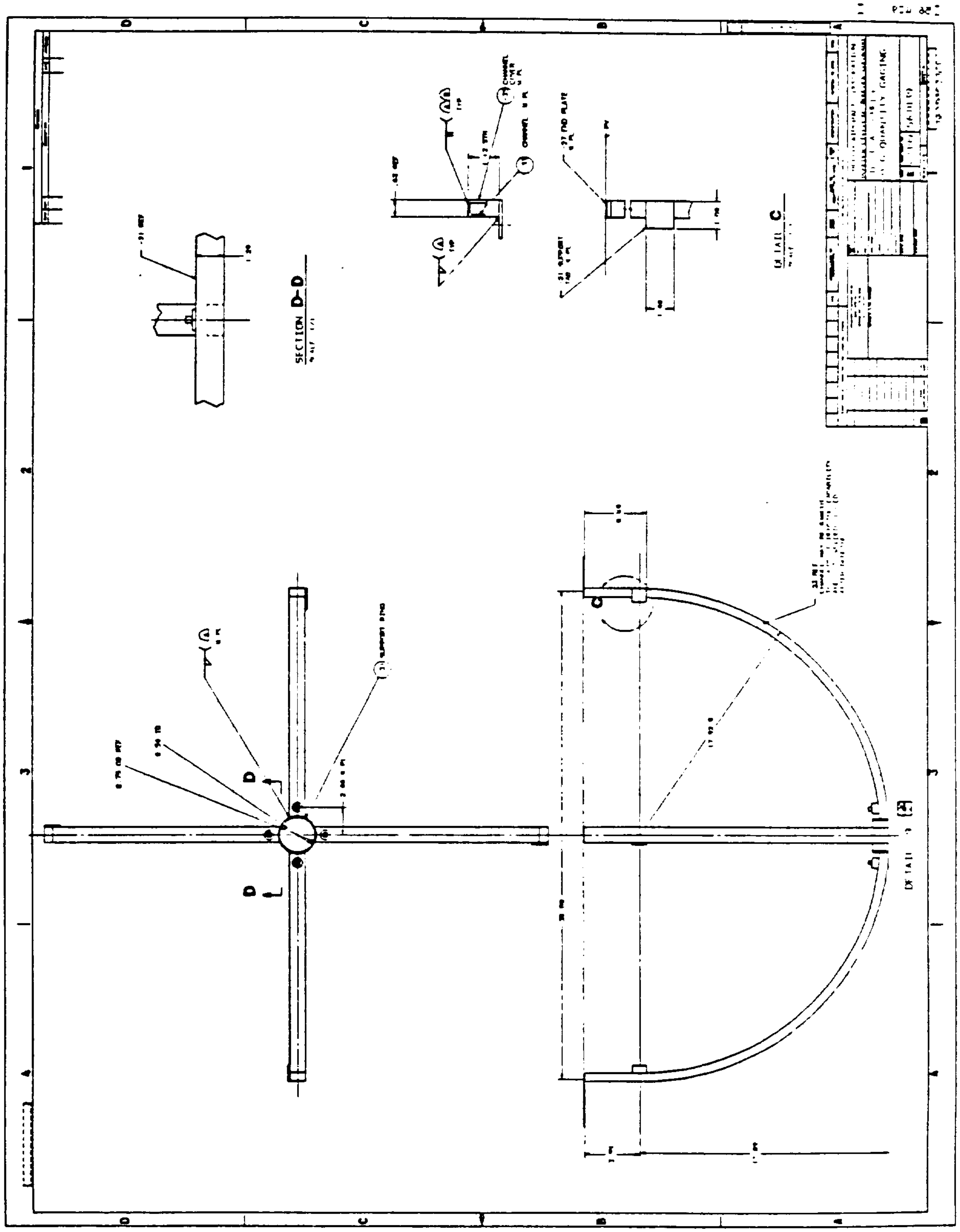



A-4

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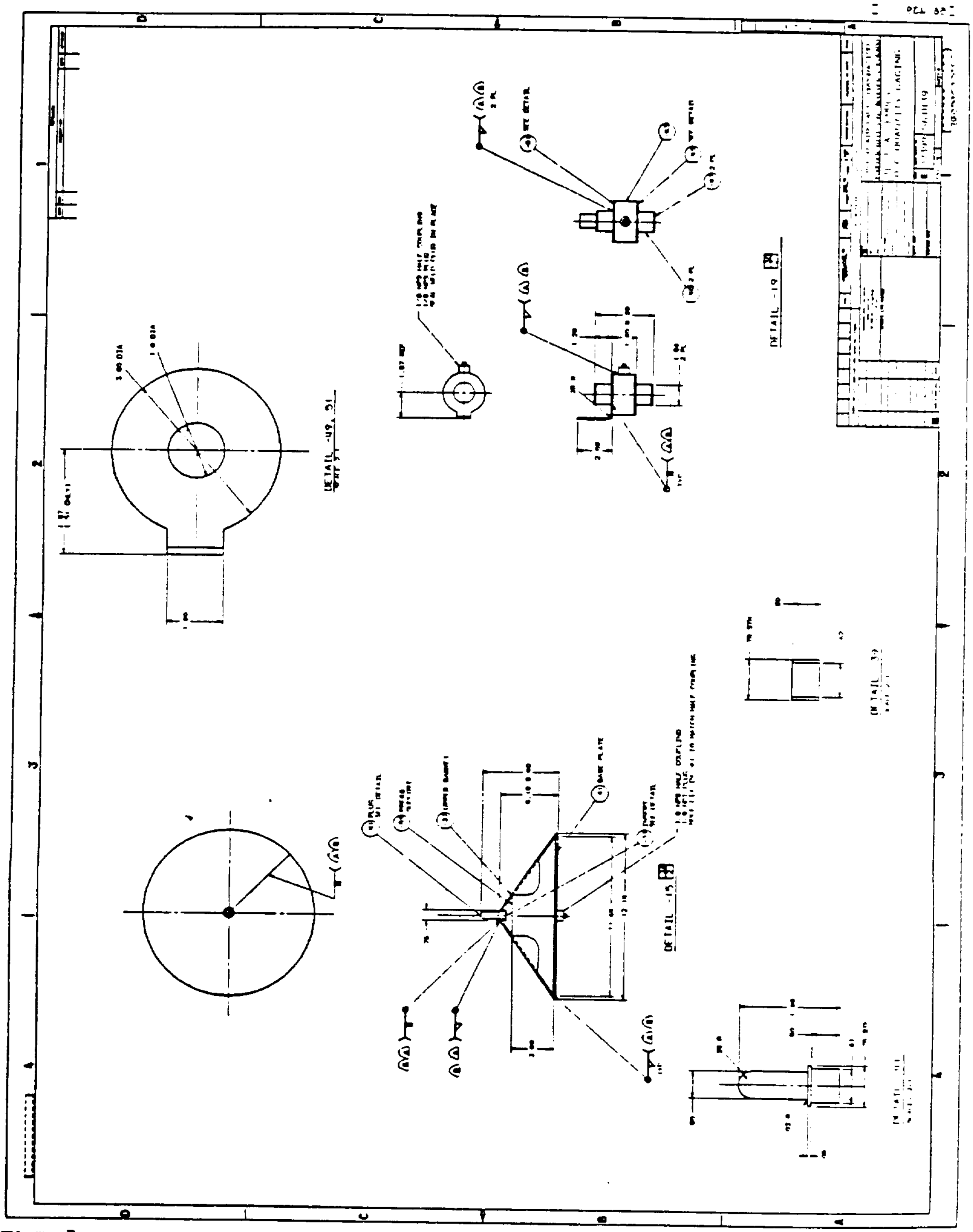
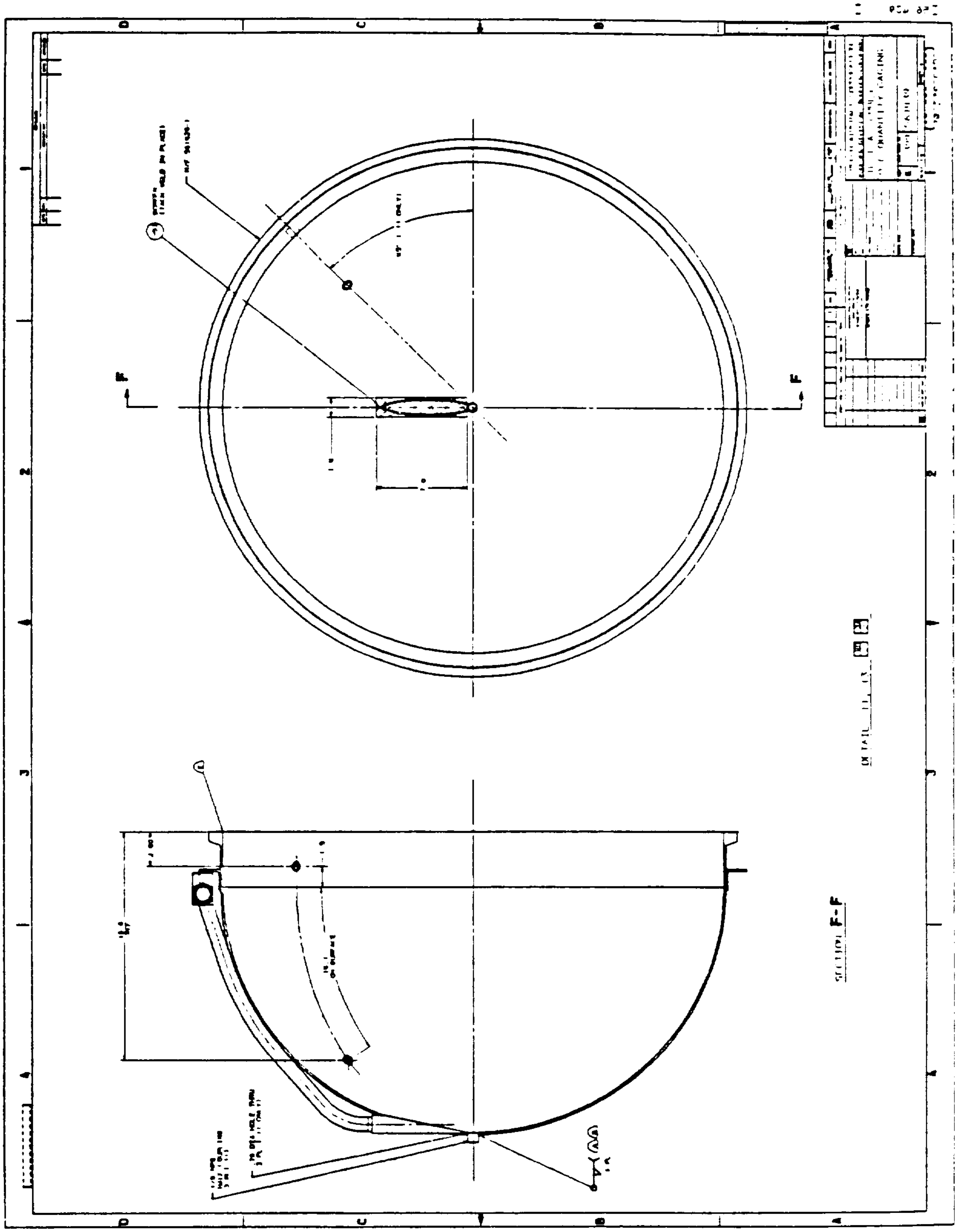
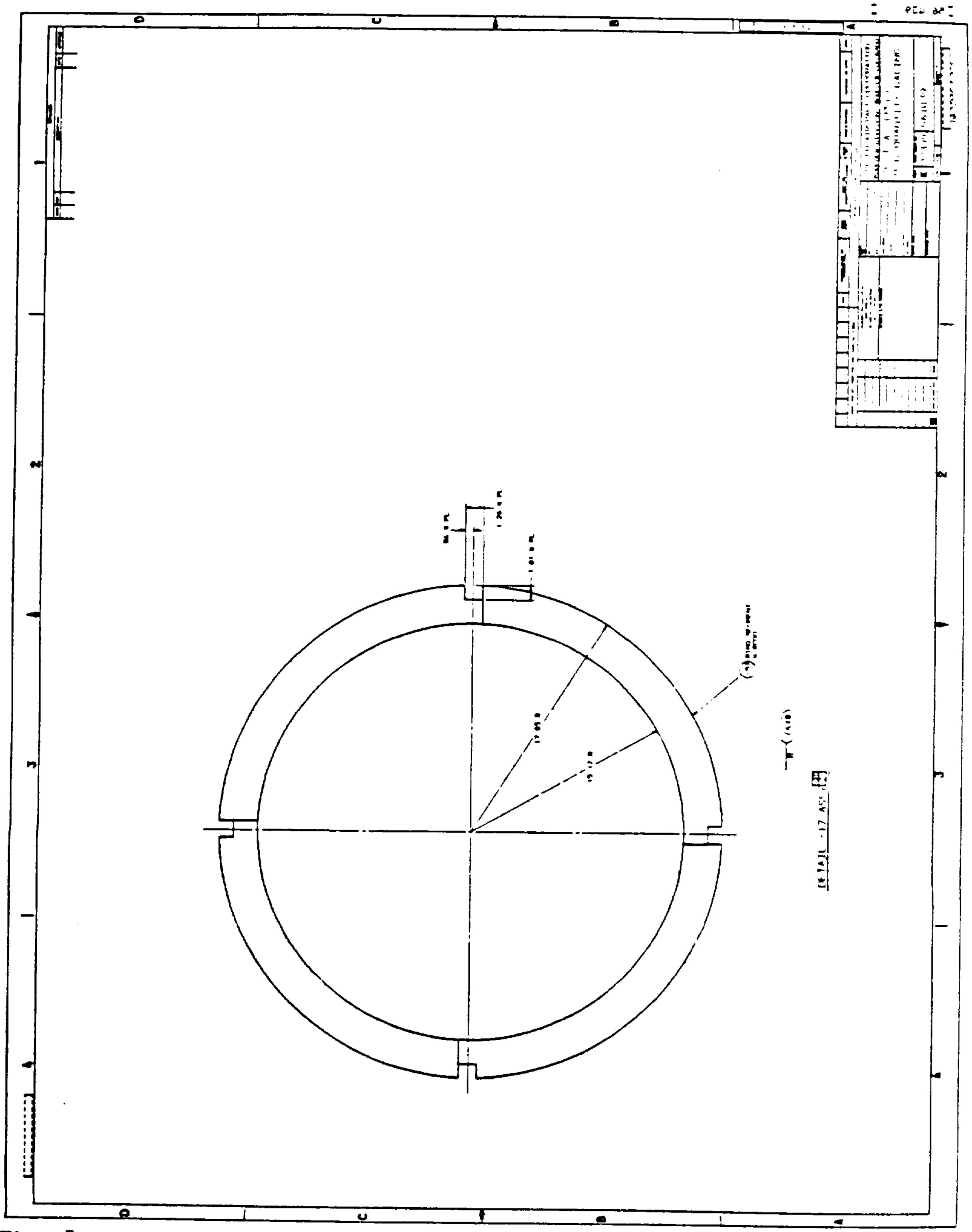




A-7



# BEECH AIRCRAFT CORPORATION
## BOULDER DIVISION

# TEST ENGINEERING DEPARTMENT

# TEST PROCEDURE

ZERO "G" QUANTITY GAUGING
SYSTEM TESTING

Procedure No. TED-127 Issue Date ____________

PREPARED BY: R. E. Webber

REVIEWED BY: J. E. Lewis

APPROVED BY: ____________

PROJECT ENGINEER: ____________

TED NO. 127

NO. OF PAGES: ________

1.0 GENERAL.

1.1 Scope. This document outlines the methods and requirements to perform characterization tests on a dewar using cryogens or fluids which will simulate the performance of the cryogens.

1.1.1 Purpose. The intent of this procedure is to validate the selection of the most promising quantity gauging system.

1.2 Document Precedence. Where the contents of this document and the documents referenced herein disagree, this document shall govern.

1.3 Applicable Documents. The following documents of the current issue form a part of this document to the extent specified herein.

1.3.1 Beech Aircraft Corporation.

| | |
|---|---|
| BS-11983 | General Solution Handling, Cleaning, and Sealing |
| BS-16102 | PRSA Product Cleanliness Requirements |
| BS-16104 | Special Handling, Marking and Packaging of Fracture Critical Parts and Assemblies |
| SOP-22 | Safety Manual |
| SOP-30 | Pre-Test Safety Control Hazardous Testing Operation |
| SOP-111 | Leak Check Procedure |

1.3.2 Military Documents.

| | |
|---|---|
| MIL-C-45662A | Calibration System Requirements |
| MIL-P-27201B | Propellant, Hydrogen |
| MIL-P-27407(1) | Propellant Pressurizing Agent, Helium |

1.3.3 National Aeronautics and Space Administration.

| | |
|---|---|
| MSFC-234A | Nitrogen, Space Vehicle |
| MSFC-Spec-399(1) | Oxygen, Grade A, Specification for |

1.4 Test Reports.

1.4.1 Final Test Report. The final test report shall consist of, but not be limited to the following:

a. All test data and inspection records.

b. A log of maintenance repair or adjustments to the test specimen, if any.

1.5 Test Surveillance.

1.5.1 Witnessing of Tests. All tests performed per this document that require Quality Assurance shall be witnessed by a Beech Quality Assurance Representative. Engineering representatives shall witness all testing.

1.5.2 Signing Data. Data taken during this test shall be certified by the signature and/or stamp of the Test Conductor. This signature shall constitute verification that the data was obtained in accordance with this document. The signature shall not necessarily indicate concurrence with the conclusions presented in the final report.

1.6 Changes. Any deviations or variations from the requirements specified herein shall require approval of Beech Engineering.

Any changes to this procedure after its approval may be initiated by change in the form of a Daily Operational Log sheet to this procedure, which shall be approved by the Beech Project Engineer and Test Department.

2.0 TEST CONDITIONS.

2.1 Test Responsibility. All testing shall be conducted under the authority of the assigned test conductor. It shall be the responsibility of the test conductor to conduct the test in accordance with the methods and requirements as outlined in this document. The test conductor shall be responsible for the safety of all personnel, test specimens, test facility and equipment. He shall have the authority to suspend testing or take any appropriate action as he deems necessary to assure the continued safety of all personnel, test specimens, test facility and equipment. Safety will be controlled by SOP-22 and SOP-30.

2.2 Atmospheric Conditions. Unless otherwise specified herein, all testing shall be performed at test site ambient pressure and temperature. Data from tests performed at other than test site ambient conditions shall reflect the imposed conditions. Ambient conditions will be recorded as specified in this procedure.

2.4 Temperature Stabilization. Temperature stabilization is assumed when the component has been subjected to the specified environmental temperature for a period of one (1) hour or such time as specified for the specific test.

2.5 Test Instrumentation Accuracy. All test measurements shall be made with instruments of the laboratory precision type. All instruments which are subjected to periodic calibration per MIL-C-45662 and are used to measure a test parameter, shall have certified accuracies traceable to the National Bureau of Standards and shall bear a current calibration decal at the time of implementation. Calibration due date shall be included on the test data equipment list. Where applicable, the following measurements shall be made as required in Section 6.0 of the accuracy specified below:

NOTE: a. The following list is a general listing of test instrumentation, all of which are not necessarily required for this test.

b. Instruments which meet the test instrumentation accuracy specified herein shall be selected so that all normal readings fall within the upper half of the dial or scale.

(1) The pressure gauge accuracy shall be ± 0.1% F.S. (critical).

(2) The recorder system accuracy shall be ± 1%.

(3) The temperature measuring system accuracy shall be ±5 °F.

(4) AC voltage and current measuring accuracy shall be ± 0.01% FS ± 1 count.

(5) DC voltage and current measuring accuracies shll be ± 0.01% FS ± 1 count.

(6) The flow rate accuracy shall be ± 2.0% FS.

(7) Elapsed time ± 0.2 seconds up to 60 minutes; ± 2 minutes over 60 minutes.

(8) $LO_2$ weight ± 0.5 lbs. from 0 to 900 lbs.
$LH_2$ weight ± 0.5 lbs. from 0 - 100 lbs.

(9) Dielectric strength measuring accuracy shall be ± 5% on both current and voltage readings.

2.5.1 Data Recording. In cases where there is a redundancy of readout, the most accurate results shall be used for entry into the data sheets.

2.6 Adjustments and Repairs. No maintenance, repair or adjustments on the test specimen other than those specifically stated in this document shall be allowed unless a failure is encountered. A detailed record of all maintenance repair or adjustments shall be included in the final test report. During test, adjustments, repairs, and recalibrations can be made to the test equipment so long as test integrity is maintained and can be verified.

2.7 Cleanliness of Test Equipment. Prior to start of testing, all test equipment, plumbing, instrumentation, etc., which could possible contaminate the test specimen, shall be verified to be as clean or cleaner than the test specimen.

2.8 Calibration. Prior to the start of testing, conduct a step calibration of all recorder systems for each test parameter being recorded. Identify recording system, and retain data for reference, if required.

3.0 TEST SPECIMEN.

3.1 Identification and Designation. The specimen, recording system charts, and data sheets shall be identified as follows:

a. Part Name

b. Beech Part Number

c. Beech Serial Number

3.2 Status of Test Specimen. Before being subjected to the test of Section 6.0 of this document, inspection shall be accomplished to determine that the test unit meets the requirements for quantity gauging verification tests.

4.0 GENERAL TEST INSTRUCTIONS.

4.1 Test Sequence. Testing will normally proceed as directed by this document. Sequential changes deemed advisable by the Test Conductor and/or the Engineering Department may be initiated, if noted and approved, on a Daily Operational Log sheet. Prior to testing the following shall have been accomplished:

a. Verification of specimen status per Para. 3.2.

b. Visually inspect test item for damage. Note any damage on the Daily Operational Log sheet of this document. The Test Conductor shall notify the principal engineer immediately.

4.2 Instrumentation and Installation of the Test Specimen. The test specimen shall be mechanically installed and instrumented equal to or in accordance with figures as designated in specific test per Section 6.0 of this document.

4.3 Instrumentation Monitoring.

4.3.1 Monitoring Procedure. All data records shall be identified at the time of the test as to the time, run number, test name, and test specime serial number. Identify each record at the beginning and end of each test.

4.4 Test Data.

a. Whenever test specimen performance data is obtained at an imposed environment, the performance and environmental data shall be recorded simulatneously.

4.4 Test Data. (continued)

b. All original data entered on data sheets shall be legible annotated using reproducible black ink.

c. Legible copies of the original test data sheets shall be included in the final test report per Para. 1.4.1.

5.0 DESIGN AND PERFORMANCE REQUIREMENTS.

5.1 Define the "Q" of the tank cavity and verify it is within an applicable range for RF gauging.

5.2 Determine the performance (accuracy, repeatability and hysteresis) of a lab equipment based RF gauging system.

5.3 Identify any unforseen problem areas which would preclude the use or further development of an RF gauging system.

6.0 TEST OUTLINE.

NOTE: The first tests will be run using this document as a guideline to establish a specific procedure.

6.1 Characterization Tests. The dewar will be tested empty to determine the "Q" of the tank. The dewar will then be filled with a fluid (to be determined) and rotated to determine the dynamic response of the dewar and damping time of fluid oscillations. Specific operating procedures will also be developed at this time, which will be used for subsequent tests.

6.2 Baseline Tests. A series of tests will be run using $LO_2$, $LH_2$, and possibly other fluids which will simulate the performance of cryogenics. For these tests, the dewar will be empty of all interior constructs except for antennas and temperature/pressure instrumentation. The system will be tested for a range of fill levels from full to empty, tank orientation from vertical to inverted and back, three different antenna locations, and at least three different fluids. The Test Matrix (Reference Figure 3) presents a total array of tests from which to choose.

6.3 Phase I Component Tests. After the baseline tests have established the capabilities of the RF quantity gauging system, the universal test dewar will be removed for modification. The dewar will be reassembled and leak tested prior to reinstallation in CVC. Testing for Phase I will be along the same lines as the baseline tests. Critical test conditions will be selected from the test matrix and test results will be compared to results obtained for similar conditions with an empty dewar.

6.4 Phase II Component Tests. In this phase, the dewar will again be modified. The dewar will be reassembled, leak tested, and reinstalled into the CVC. Testing will follow the pattern used for Phase I and the baseline tests.

# BEECH TEST DATA

Beech Aircraft Corporation — Environmental Test Laboratories

Please PRINT – Use BLACK INK

| Report Number | Page No. |
|---|---|
| | |

| Test Description | Test Procedure Reference | Start Date | Sheet No. |
|---|---|---|---|
| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ____ of ____ |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6.1 CHARACTERIZATION TESTS | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 1 | Verify all plumbing connected per Figure 1. | Verify | | |
| 2 | Verify all electrical connected per Figure 2. | Verify | | |
| 3 | Verify all data channels and control channels operational prior to starting any testing. | Verify | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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# BEECH TEST DATA

Beech Aircraft Corporation — Environmental Test Laboratories

| Test Description | Test Procedure Reference | Start Date | Sheet No. | Report Number | Page No. |
|---|---|---|---|---|---|
| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ___ of ___ | | |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6.1 CHARACTERIZATION TESTS | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 4 | With CVC at ambient conditions: | | | |
| | a. Dewar installed in CVC and pressurized to 35 ± 2 psia with $GN_2$. All instrumentation connected and operational. | Verify | | |
| | b. Rotate dewar from 0° to 360° in 45° steps. | Verify | | |
| | (1) Read RF quantity gauging at each 45° step on each antenna (1, 2, & 3). | | | |
| | 0° | 0° | o | |
| | Antenna 1 | *Time | | |
| | 2 | | | |
| | 3 | | | |
| | 45° | 45° | o | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 90° | 90° | o | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | *Record computer real time for each antenna throughout test. | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

# BEECH TEST DATA

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| Report Number | Page No. |
|---|---|
| | |

| Test Description | Test Procedure Reference | Start Date | Sheet No. |
|---|---|---|---|
| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ____ of ____ |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6.1 CHARACTERIZATION TESTS | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 4 | (continued) | | | |
| | 135° | 135° | ° | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 180° | 180° | ° | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 225° | 225° | ° | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 270° | 270° | ° | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 315° | 315° | ° | |
| | Antenna 1 | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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# BEECH TEST DATA

Beech Aircraft Corporation — Environmental Test Laboratories

| Report Number | Page No. |
|---|---|
| | |

| Test Description | Test Procedure Reference | Start Date | Sheet No. |
|---|---|---|---|
| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ____ of ____ |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6.1 CHARACTERIZATION TESTS | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 4 | (continued) | | | |
| | Antenna 2 | | | |
| | 3 | | | |
| | $360^{\circ}$ | $360^{\circ}$ | ° | |
| | Antenna 1 | | | |
| | 2 | | | |
| | c. Rotate back to $0^{\circ}$. 3 | | | |
| 5 | With CVC at maximum vacuum and the temperature at $-120^{\circ}F$, all instrumentation connected and operational: | Verify | | |
| | a. Fill test dewar (tank)$^{\Delta}$with $LN_2$. Record load cell weight. Pressure regulated at ______psia. | Load Cell | lbs | |
| | | Pressure | psia | |
| | b. Rotate dewar from $0^{\circ}$ to $360^{\circ}$ in $45^{\circ}$ steps: | | | |
| | (1) Read RF quantity gauging and weight at each $45^{\circ}$ step. Quantity gauging to be read on each antenna. | | | |
| | $0^{\circ}$ | $0^{\circ}$ | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | ° | |
| | Δ Use Fill Procedure. 2 | | ° | |
| | 3 | | ° | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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# BEECH TEST DATA

Beech Aircraft Corporation — Environmental Test Laboratories

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| Test Description | Test Procedure Reference | Start Date | Sheet No. |
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| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ____ of ____ |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6.1 CHARACTERIZATION TESTS | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 5 | (Continued) 45° | 45° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 90° | 90° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 135° | 135° | ° | |
| | Weight | Load ell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 180° | 180° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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| Test Description | Test Procedure Reference | Start Date | Sheet No. |
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| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ___ of ___ |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6.1 CHARACTERIZATION TESTS | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 5 | (Continued) | | | |
| | $225^0$ | $225^0$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $270^0$ | $270^0$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $360^0$ | $360^0$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | c. Rotate dewar back to $0^0$ and reduce dewar quantity to 75%* of full as required on load cells and pressure regulated at _______psia. | Verify<br>$0^0$ | o | |
| | *Use Deplete Procedure. | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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| Test Description | Test Procedure Reference | Start Date | Sheet No. |
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| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ____ of ____ |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6.1 CHARACTERIZATION TESTS | | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|---|
| 5 | (Continued) | | | | |
| | | | Load Cell | ____ lbs | |
| | | | Pressure | ____ psia | |
| | d. Rotate dewar from 0° to 360° in 45° steps. | | Verify | | |
| | (1) Read RF quantity gauging and weight at each 45° step. Quantity gauging to be read on each antenna. | | Verify | | |
| | | 0° | 0° | ____ ° | |
| | | Weight | Load Cell | ____ lbs | |
| | | Antenna 1 | | | |
| | | 2 | | | |
| | | 3 | | | |
| | | 45° | 45° | ____ ° | |
| | | Weight | Load Cell | ____ lbs | |
| | | Antenna 1 | | | |
| | | 2 | | | |
| | | 3 | | | |
| | | 90° | 90° | ____ ° | |
| | | Weight | Load Cell | ____ lbs | |

| | Beech QC | Test Engineer |
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| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ___ of ___ |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6.1 CHARACTERIZATION TESTS | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 5 | (Continued) | | | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 135° | 135° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 180° | 180° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 225° | 225° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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# BEECH TEST DATA

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| Test Description | Test Procedure Reference | Start Date | Sheet No. |
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| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ___ of ___ |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
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| PRESSURE VESSEL ASSY | 561438 | | | |

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| STEP | PARA. 6.1 CHARACTERIZATION TESTS | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 5 | (Continued) | | | |
| | $225^0$ | $225^0$ | 0 | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $270^0$ | $270^0$ | 0 | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $315^0$ | $315^0$ | 0 | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $360^0$ | $360^0$ | 0 | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |

| | Beech QC | Test Engineer |
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| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ____ of ____ |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6.1 CHARACTERIZATION TESTS | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 5 | (Continued) | | | |
| | Antenna 2 | | | |
| | 3 | | | |
| | e. Rotate dewar back to $0^0$ and reduce dewar quantity to 50%*of full as read on the load cells and pressure regulated at ____psia. | Verify | | |
| | | $0^0$ | o | |
| | | Load Cell | lbs | |
| | | Pressure | psia | |
| | f. Rotate dewar from $0^0$ to $360^0$ in $45^0$ steps. | Verify | | |
| | (1) Read RF quantity gauging and weight at each $45^0$ step. Quantity gauging to be read on each antenna. | | | |
| | $0^0$ | $0^0$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $45^0$ | $45^0$ | o | |
| | Weight | Load Cell | lbs | |
| | *Use Deplete Procedure. | | | |

| | Beech QC | Test Engineer |
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| | | |

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| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6.1 CHARACTERIZATION TESTS | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 5 | (Continued) | | | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 45° | 45° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 90° | 90° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 135° | 135° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6.1 CHARACTERIZATION TESTS | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 5 | (Continued) | | | |
| | $180^{0}$ | $180^{0}$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $225^{0}$ | $225^{0}$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $270^{0}$ | $270^{0}$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $315^{0}$ | $315^{0}$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |

| | Beech QC | Test Engineer |
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| | | |

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| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6.1 CHARACTERIZATION TESTS | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 5 | (Continued) | | | |
| | Antenna 3 | | | |
| | $360^0$ | $360^0$ | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | g. Rotate dewar back to $0^0$ and reduce dewar quantity to 25% *of full as read on load cells and pressure regulated at _____ psia. | Verify | | |
| | | $0^0$ | ° | |
| | | Load Cell | lbs | |
| | | Pressure | psia | |
| | h. Rotate dewar from $0^0$ to $360^0$ in $45^0$ steps. | Verify | | |
| | (1) Read RF quantity gauging and weight at each $45^0$ step. Quantity gauging to be read on each antenna. | | | |
| | $0^0$ | $0^0$ | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |

*Use Deplete Procedure.

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6.1 CHARACTERIZATION TESTS | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 5 | (Continued) | | | |
| | $45^o$ | $45^o$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $90^o$ | $90^o$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $135^o$ | $135^o$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $180^o$ | $180^o$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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| **Item Name** | **Part Number** | **Serial Number** | **Start Time** | **Beech W.O.** | | |
| PRESSURE VESSEL ASSY | 561438 | | | | | |

| STEP | PARA. 6.1 CHARACTERIZATION TESTS | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 5 | (Continued) | | | |
| | Antenna 3 | | | |
| | 225° | 225° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 270° | 270° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 315° | 315° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6.1 CHARACTERIZATION TESTS | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 5 | (Continued) | | | |
| | $360^o$ | $360^o$ | ____ $^o$ | |
| | Weight | Load Cell | ____ lbs | |
| | Antenna 1 | ____ | ____ | |
| | 2 | ____ | ____ | |
| | 3 | ____ | ____ | |
| | i. Rotate dewar back to $0^o$ and empty dewar.* Purge with $GN_2$ at 25 psia for 15 minutes. | Verify | | |
| | | $0^o$ | ____ $^o$ | |
| | | Verify Purged | | |
| | j. Rotate dewar from $0^o$ to $360^o$ in $45^o$ steps. | Verify | | |
| | (1) Read RF quantity gauging and weight at each $45^o$ step. Quantity gauging to be read on each antenna. | | | |
| | $0^o$ | $0^o$ | ____ $^o$ | |
| | Weight | Load Cell | ____ lbs | |
| | Antenna 1 | ____ | ____ | |
| | 2 | ____ | ____ | |
| | 3 | ____ | ____ | |
| | *Use Deplete Procedure. | | | |

| | Beech QC | Test Engineer |
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| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6.1 CHARACTERIZATION TESTS | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 5 | (Continued) | | | |
| | $45^0$ | $45^0$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $90^0$ | $90^0$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $135^0$ | $135^0$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |

| | Beech QC | Test Engineer |
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| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6.1 CHARACTERIZATION TESTS | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 5 | (Continued) | | | |
| | 180° | 180° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 225° | 225° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 270° | 270° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 315° | 315° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |

| | Beech QC | Test Engineer |
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| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6.1 CHARACTERIZATION TESTS | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 5 | (Continued) | | | |
| | $360^o$ | $360^o$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | k. Rotate dewar back to $0^o$. | $0^o$ | o | |

| | Beech QC | Test Engineer |
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| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6_.1 FILL PROCEDURE | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| | NOTE: This fill is to be accomplished with test dewar in upright position (0°), CVC at maximum vacuum and specimen (test dewar) at -120°F. | | | |
| 1 | Close or verify closed MV-1, MV-2, MV-3, and MV-4. | Verify | | |
| 2 | Verify fluid supply connected to fill line (MV-1, Reference Figure 1). | Verify | | |
| 3 | Verify vent (MV-4, Reference Figure 1) connected to proper vent system ($LO_2$ to oxygen vent, etc.) | Verify | | |
| 4 | Vent supply dewar to site ambient for minimum of 2 hours prior to starting fill. | Verify<br>≥ 2 hours | | |
| 5 | Raise supply dewar pressure to 35 psia. Open MV-511 (dewar supply valve) Open MV-1, then open MV-4 (this will start fill). | Verify | | |
| 6 | When test dewar is full (vent sound, PG-1 indication), close MV-1. | Verify | | |
| 7 | Verify computer on line and pressure control set at desired pressure | Verify | | |
| 8 | Open MV-3 and then close MV-4. | Verify | | |
| | (Refer to Deplete Procedure NOTE) | | | |

| | Beech QC | Test Engineer |
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| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6_.2 DEPLETE PROCEDURE | | | |
|---|---|---|---|---|
| 1 | Connect MV-1 Fill Line to Vent Stack (Reference Figure 1) | Verify | | |
| 2 | Verify MV-2 and MV-3 closed. | Verify | | |
| 3 | Slowly open MV-1 and watch load cell readings to reach desired quantity. When quantity is reached, close MV-1. | Verify | | |
| 4 | Open MV-3 and proceed with test. | Verify | | |

NOTE

To prevent unintentional loss of fluid from the dewar, valves MV-2 and MV-3 must be set to allow venting of gas only. The required valve settings will be a function of fluid quantity and tank rotation. The list below may be used as a guide. Valve settings during the test shall be as directed by the Test Conductor.

VALVE POSITIONS

| Rotation | 100% MV-2 | 100% MV-3 | 75% MV-2 | 75% MV-3 | 50% MV-2 | 50% MV-3 | 25% MV-2 | 25% MV-3 |
|---|---|---|---|---|---|---|---|---|
| 0 | C | 0 | C | 0 | C | 0 | C | 0 |
| 45 | C | C | C | 0 | C | 0 | C | 0 |
| 90 | C | C | C | C | C | C | 0 | 0 |
| 135 | C | C | 0 | C | 0 | C | 0 | C |
| 180 | 0 | C | 0 | C | 0 | C | 0 | C |
| 225 | C | C | 0 | C | 0 | C | 0 | C |
| 270 | C | C | C | C | C | C | 0 | 0 |
| 315 | C | C | C | 0 | C | 0 | C | 0 |
| 360 | C | 0 | C | 0 | C | 0 | C | 0 |

Legend: C = Closed, 0 = Open

| | Beech QC | Test Engineer |
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| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
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| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6._ | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 1 | Verify all plumbing connected per Figure 1. | Verify | | |
| 2 | Verify all electrical connected per Figure 2. | Verify | | |
| 3 | Verify all data channels and control channels operational prior to starting any testing. | Verify | | |
| 4 | With CVC at maximum vacuum and the temperature at -120°F, all instrumentation operational. | Verify | | |
| | a. Fill test dewar (tank)Δ with and record load cell weight. Pressure regulated at psia. | Load Cell | lbs | |
| | | Pressure | psia | |
| | 0° | 0° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | Δ Use Fill Procedure. | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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# BEECH TEST DATA

Beech Aircraft Corporation — Environmental Test Laboratories

| Report Number | Page No. |
|---|---|
| | |

| Test Description | Test Procedure Reference | Start Date | Sheet No. |
|---|---|---|---|
| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ___ of ___ |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6._ | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 4 | (Continued) | | | |
| | 45° | 45° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 90° | 90° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 135° | 135° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 180° | 180° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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# BEECH TEST DATA

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| | |

| Test Description | | Test Procedure Reference | Start Date | Sheet No. |
|---|---|---|---|---|
| ZERO "G" QUANTITY GAUGING SYSTEM | | TED-127 | | ____ of ____ |
| **Item Name** | **Part Number** | **Serial Number** | **Start Time** | **Beech W.O.** |
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6._ | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 4 | (Continued) | | | |
| | Antenna 2 | | | |
| | 3 | | | |
| | 225° | 225° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 270° | 270° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 315° | 315° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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# BEECH TEST DATA

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| Test Description | Test Procedure Reference | Start Date | Sheet No. |
|---|---|---|---|
| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ____ of ____ |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6._ | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 4 | (Continued) | | | |
| | $360^0$ | $360^0$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | c. Rotate dewar back to $0^0$ and reduce dewar quantity to 75%* of full as read on load cells and pressure regulated at ____ psia. | Verify | | |
| | | $0^0$ | o | |
| | | Load Cell | lbs | |
| | | Pressure | psia | |
| | d. Rotate dewar from $0^0$ to $360^0$ in $45^0$ steps. | | | |
| | (1) Read RF quantity gauging and weight at each $45^0$ step. Quantity gauging to be read on each antenna. | | | |
| | $0^0$ | $0^0$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |

*Use Deplete Procedure.

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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# BEECH TEST DATA

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| Test Description | Test Procedure Reference | Start Date | Sheet No. |
|---|---|---|---|
| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ____ of ____ |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6._ | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 4 | (Continued) | | | |
| | $45^{0}$ | $45^{0}$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $90^{0}$ | $90^{0}$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $135^{0}$ | $135^{0}$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $180^{0}$ | $180^{0}$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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# BEECH TEST DATA

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| Test Description | Test Procedure Reference | Start Date | Sheet No. |
|---|---|---|---|
| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ____ of ____ |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA 6._ | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 4 | (Continued) | | | |
| | Antenna 3 | | | |
| | $225^{o}$ | $225^{o}$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $270^{o}$ | $270^{o}$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $315^{o}$ | $315^{o}$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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# BEECH TEST DATA

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| Report Number | Page No. |
|---|---|
| | |

| Test Description | Test Procedure Reference | Start Date | Sheet No. |
|---|---|---|---|
| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ____ of ____ |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6._ | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 4 | (Continued) | | | |
| | $360^0$ | $360^0$ | ____ $^0$ | |
| | Weight | Load Cell | ____ lbs | |
| | Antenna 1 | ____ | ____ | |
| | 2 | ____ | ____ | |
| | 3 | ____ | ____ | |
| | e. Rotate dewar back to $0^0$ and reduce dewar quantity to 50%* of full as read on the load cells and pressure regulated at psia. | Verify | | |
| | $0^0$ | $0^0$ | ____ $^0$ | |
| | Weight | Load Cell | ____ lbs | |
| | Pressure | Pressure | ____ psia | |
| | f. Rotate dewar from $0^0$ to $360^0$ in $45^0$ steps. | | | |
| | (1) Read RF quantity gauging and weight at each $45^0$ step. Quantity gauging to be read on each antenna. | | | |
| | $0^0$ | $0^0$ | ____ $^0$ | |
| | Weight | Load Cell | ____ lbs | |
| | Antenna 1 | ____ | ____ | |
| | *Use Deplete Procedure. | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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# BEECH TEST DATA

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| | |

| Test Description | Test Procedure Reference | Start Date | Sheet No. |
|---|---|---|---|
| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ____ of ____ |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6._ | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 4 | (Continued) | | | |
| | Antenna 2 | | | |
| | 3 | | | |
| | 45° | 45° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 90° | 90° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 135° | 135° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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| Test Description | Test Procedure Reference | Start Date | Sheet No. | Report Number | Page No. |
|---|---|---|---|---|---|
| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ____ of ____ | | |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6._ | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 4 | (Continued) | | | |
| | 180° | 180° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 225° | 225° | ° | |
| | Weight | | | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 270° | 270° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 315° | 315° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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| Report Number | Page No. |
|---|---|
| | |

| Test Description | Test Procedure Reference | Start Date | Sheet No. |
|---|---|---|---|
| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ___ of ___ |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6._ | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 4 | (Continued) | | | |
| | Antenna 2 | | | |
| | 3 | | | |
| | $360^0$ | $360^0$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | g. Rotate dewar back to $0^0$ and reduce dewar quantity to 25%*of full as read on load cells and pressure regulated at psia. | | | |
| | $0^0$ | $0^0$ | o | |
| | Weight | Load Cell | lbs | |
| | Pressure | Pressure | psia | |
| | h. Rotate dewar from $0^0$ to $360^0$ in $45^0$ steps. | | | |
| | (1) Read RF quantity gauging and weight at each $45^0$ step. Quantity gauging to be read on each antenna. | | | |
| | $0^0$ | $0^0$ | o | |
| | Weight | Load Cell | lbs | |
| | *Use Deplete Procedure. | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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| | |

| Test Description | Test Procedure Reference | Start Date | Sheet No. |
|---|---|---|---|
| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ___ of ___ |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6·_ | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 4 | (Continued) | | | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $45^{0}$ | $45^{0}$ | $^{0}$ | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $90^{0}$ | $90^{0}$ | $^{0}$ | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $135^{0}$ | $135^{0}$ | $^{0}$ | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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| | |

| Test Description | Test Procedure Reference | Start Date | Sheet No. |
|---|---|---|---|
| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ____ of ____ |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6._ | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 4 | (Continued) | | | |
| | $180^{\circ}$ | $180^{\circ}$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $225^{\circ}$ | $225^{\circ}$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $270^{\circ}$ | $270^{\circ}$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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| Test Description | Test Procedure Reference | Start Date | Sheet No. |
|---|---|---|---|
| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ____ of ____ |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6._ | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 4 | (Continued) | | | |
| | $315^0$ | $315^0$ | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $360^0$ | $360^0$ | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | i. Rotate dewar back to $0^0$ and empty dewar.* Purge with $GN_2$ at 25 psia for 15 minutes. | $0^0$ | ° | |
| | | Verify Purged | | |
| | *Use Deplete Procedure. | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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| ZERO "G" QUANTITY GAUGING SYSTEM | TED-127 | | ____ of ____ |

| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6._ | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 4 | (Continued) | | | |
| | j. Rotate dewar from $0^o$ to $360^o$ in $45^o$ steps. | | | |
| | (1) Read RF quantity gauging and weight at each $45^o$ step. Quantity gauging to be read on each antenna. | | | |
| | $0^o$ | $0^o$ | ____ o | |
| | Weight | Load Cell | ____ lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $45^o$ | $45^o$ | ____ o | |
| | Weight | Load Cell | ____ lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | $90^o$ | $90^o$ | ____ o | |
| | Weight | Load Cell | ____ lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6._ | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 4 | (Continued) | | | |
| | 135° | 135° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 180° | 180° | ° | |
| | Weight | Load Cell | | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 225° | 225° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | 315° | 315° | ° | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

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| Item Name | Part Number | Serial Number | Start Time | Beech W.O. |
|---|---|---|---|---|
| PRESSURE VESSEL ASSY | 561438 | | | |

| STEP | PARA. 6._ | REQUIRED | OBSERVED | TEST |
|---|---|---|---|---|
| 4 | (Continued) | | | |
| | Antenna 2 | | | |
| | 3 | | | |
| | $360^{o}$ | $360^{o}$ | o | |
| | Weight | Load Cell | lbs | |
| | Antenna 1 | | | |
| | 2 | | | |
| | 3 | | | |
| | k. Rotate dewar back to $0^{o}$. | $0^{o}$ | o | |

| | Beech QC | Test Engineer |
|---|---|---|
| | | |

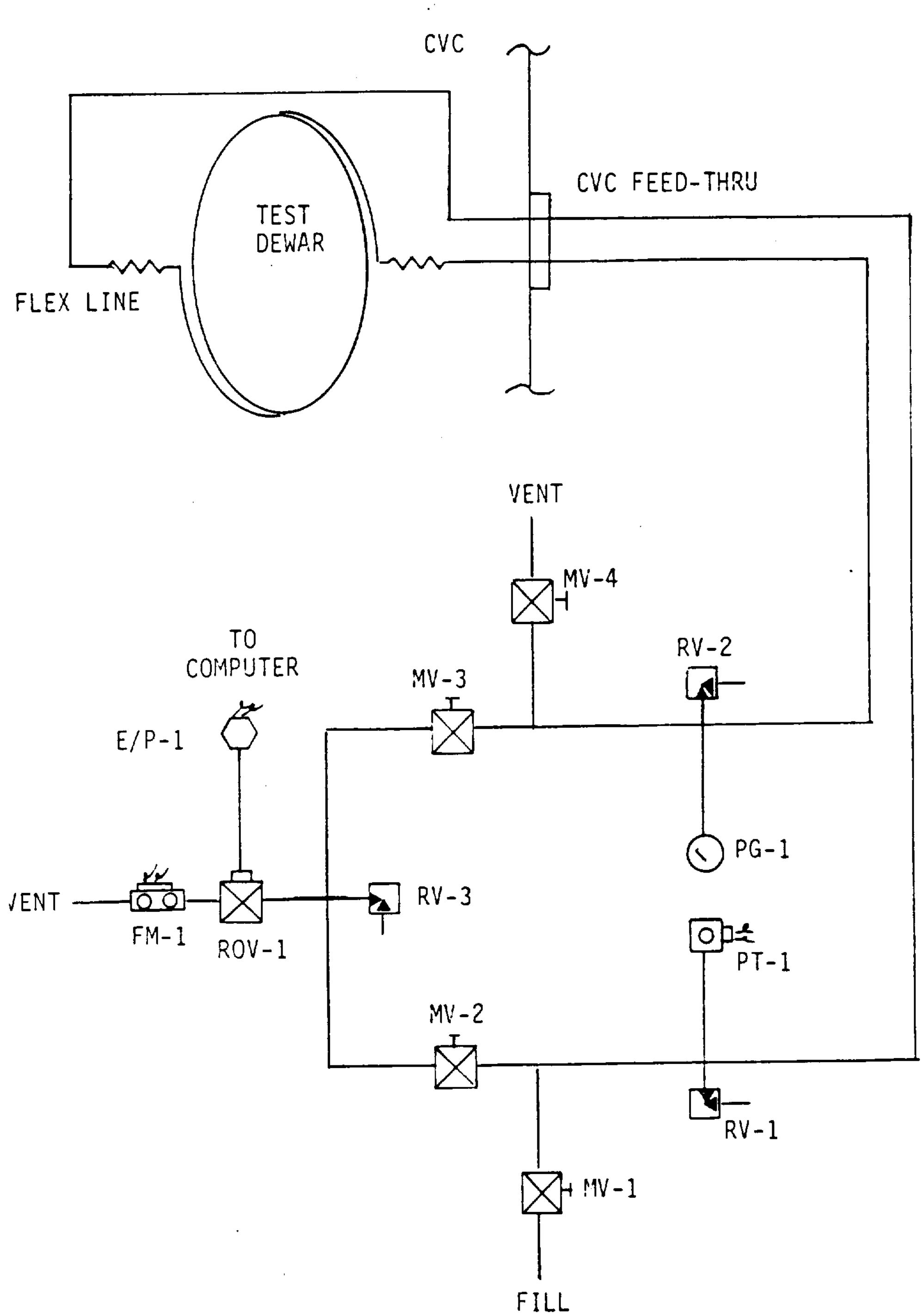


FIGURE 1
FLUIDS SCHEMATIC

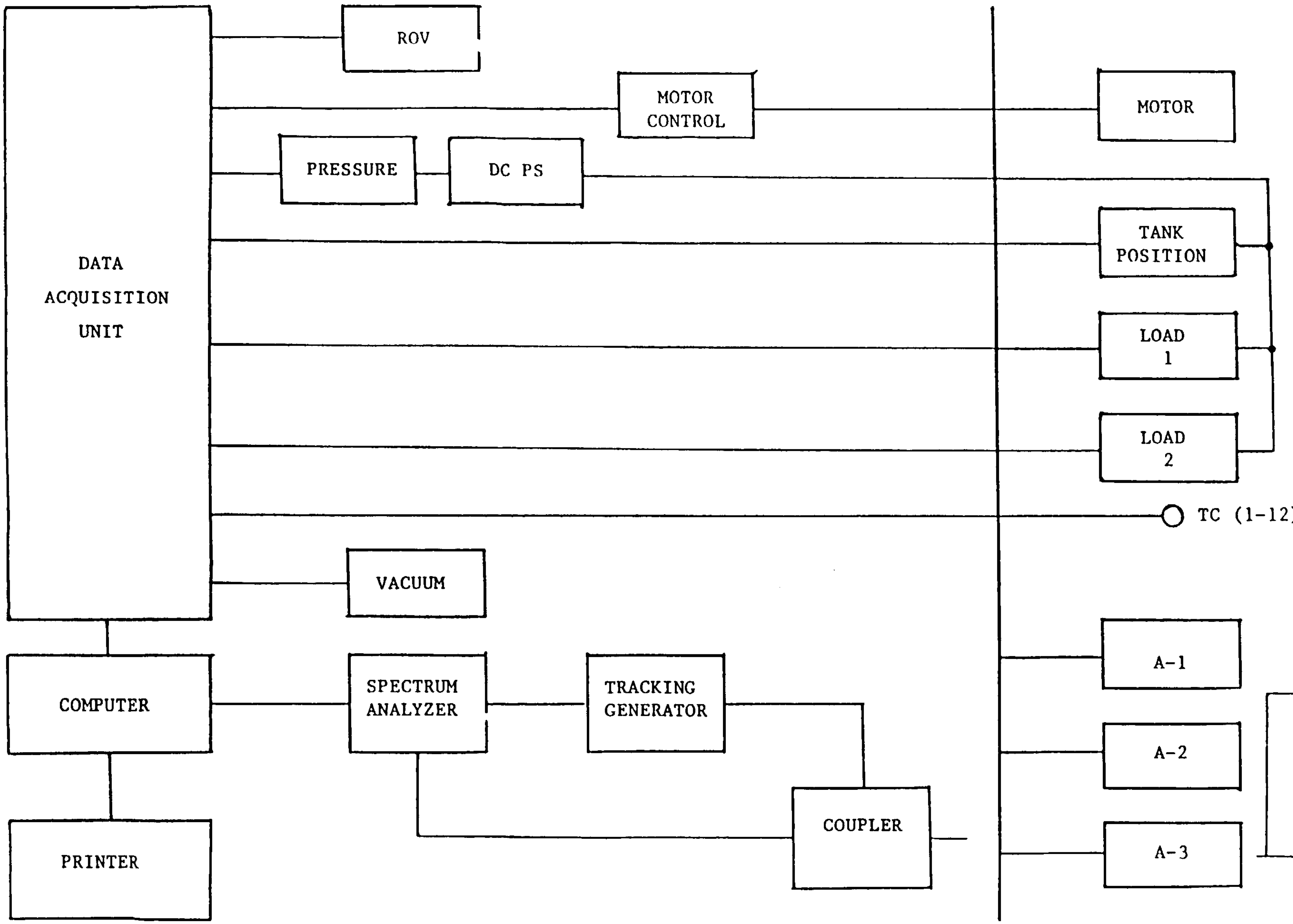


FIGURE 2

INSTRUMENTATION SETUP DIAGRAM

## 1.0 BASELINE TESTS

| TEST | TANK ANGLE | | | | | | | | | FILL LEVEL | | | | | ANT LOC | | | FLUID | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NO. | 0 | 45 | 90 | 135 | 180 | 225 | 270 | 315 | 360 | F | 3/4 | 1/2 | 1/4 | E | 1 | 2 | 3 | LO2 | LH2 | S* |
| 1.1 | X | X | X | X | X | X | X | X | X | X | | | | | X | | | X | | |
| 1.2 | | | | | | | | | | X | | | | | | X | | | | |
| 1.3 | | | | | | | | | | X | | | | | | | X | | | |
| 1.4 | | | | | | | | | | | X | | | | X | | | | | |
| 1.5 | | | | | | | | | | | X | | | | | X | | | | |
| 1.6 | | | | | | | | | | | X | | | | | | X | | | |
| 1.7 | | | | | | | | | | | | X | | | X | | | | | |
| 1.8 | | | | | | | | | | | | X | | | | X | | | | |
| 1.9 | | | | | | | | | | | | X | | | | | X | | | |
| 1.10 | | | | | | | | | | | | | X | | X | | | | | |
| 1.11 | | | | | | | | | | | | | X | | | X | | | | |
| 1.12 | | | | | | | | | | | | | X | | | | X | | | |
| 1.13 | | | | | | | | | | | | | | X | X | | | | | |
| 1.14 | | | | | | | | | | | | | | X | | X | | | | |
| 1.15 | | | | | | | | | | | | | | X | | | X | X | | |
| 1.16 | | | | | | | | | | X | | | | | X | | | | X | |
| 1.17 | | | | | | | | | | X | | | | | | X | | | | |
| 1.18 | | | | | | | | | | X | | | | | | | X | | | |
| 1.19 | | | | | | | | | | | X | | | | X | | | | | |
| 1.20 | | | | | | | | | | | X | | | | | X | | | | |
| 1.21 | | | | | | | | | | | X | | | | | | X | | | |
| 1.22 | | | | | | | | | | | | X | | | X | | | | | |
| 1.23 | | | | | | | | | | | | X | | | | X | | | | |
| 1.24 | | | | | | | | | | | | X | | | | | X | | | |
| 1.25 | | | | | | | | | | | | | X | | X | | | | | |
| 1.26 | | | | | | | | | | | | | X | | | X | | | | |
| 1.27 | | | | | | | | | | | | | X | | | | X | | | |
| 1.28 | | | | | | | | | | | | | | X | X | | | | | |
| 1.29 | | | | | | | | | | | | | | X | | X | | | | |
| 1.30 | | | | | | | | | | | | | | X | | | X | | X | |
| 1.31 | | | | | | | | | | X | | | | | X | | | | | X |
| 1.32 | | | | | | | | | | X | | | | | | X | | | | |
| 1.33 | | | | | | | | | | X | | | | | | | X | | | |
| 1.34 | | | | | | | | | | | X | | | | X | | | | | |
| 1.35 | | | | | | | | | | | X | | | | | X | | | | |
| 1.36 | | | | | | | | | | | X | | | | | | X | | | |
| 1.37 | | | | | | | | | | | | X | | | X | | | | | |
| 1.38 | | | | | | | | | | | | X | | | | X | | | | |
| 1.39 | | | | | | | | | | | | X | | | | | X | | | |
| 1.40 | | | | | | | | | | | | | X | | X | | | | | |
| 1.41 | | | | | | | | | | | | | X | | | X | | | | |
| 1.42 | | | | | | | | | | | | | X | | | | X | | | |
| 1.43 | | | | | | | | | | | | | | X | X | | | | | |
| 1.44 | | | | | | | | | | | | | | X | | X | | | | |
| 1.45 | X | X | X | X | X | X | X | X | X | | | | | X | | | X | | | X |

• CRYOGEN SIMULATION FLUID

## 2.0 PHASE I COMPONENT TESTS

| TEST | TANK ANGLE | | | | | | | | | FILL LEVEL | | | | | ANT LOC | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NO. | 0 | 45 | 90 | 135 | 180 | 225 | 270 | 315 | 360 | F | 3/4 | 1/2 | 1/4 | E | 1 | 2 | 3 |
| 2.1 | X | X | X | X | X | X | X | X | X | X | | | | | X | | |
| 2.2 | | | | | | | | | | X | | | | | | X | |
| 2.3 | | | | | | | | | | X | | | | | | | X |
| 2.4 | | | | | | | | | | | X | | | | X | | |
| 2.5 | | | | | | | | | | | X | | | | | X | |
| 2.6 | | | | | | | | | | | X | | | | | | X |
| 2.7 | | | | | | | | | | | | X | | | X | | |
| 2.8 | | | | | | | | | | | | X | | | | X | |
| 2.9 | | | | | | | | | | | | X | | | | | X |
| 2.10 | | | | | | | | | | | | | X | | X | | |
| 2.11 | | | | | | | | | | | | | X | | | X | |
| 2.12 | | | | | | | | | | | | | X | | | | X |
| 2.13 | | | | | | | | | | | | | | X | X | | |
| 2.14 | | | | | | | | | | | | | | X | | X | |
| 2.15 | X | X | X | X | X | X | X | X | X | | | | | X | | | X |

## 3.0 PHASE 2 COMPONENT TESTS

| TEST | TANK ANGLE | | | | | | | | | FILL LEVEL | | | | | ANT LOC | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NO. | 0 | 45 | 90 | 135 | 180 | 225 | 270 | 315 | 360 | F | 3/4 | 1/2 | 1/4 | E | 1 | 2 | 3 |
| 3.1 | X | X | X | X | X | X | X | X | X | X | | | | | X | | |
| 3.2 | | | | | | | | | | X | | | | | | X | |
| 3.3 | | | | | | | | | | X | | | | | | | X |
| 3.4 | | | | | | | | | | | X | | | | X | | |
| 3.5 | | | | | | | | | | | X | | | | | X | |
| 3.6 | | | | | | | | | | | X | | | | | | X |
| 3.7 | | | | | | | | | | | | X | | | X | | |
| 3.8 | | | | | | | | | | | | X | | | | X | |
| 3.9 | | | | | | | | | | | | X | | | | | X |
| 3.10 | | | | | | | | | | | | | X | | X | | |
| 3.11 | | | | | | | | | | | | | X | | | X | |
| 3.12 | | | | | | | | | | | | | X | | | | X |
| 3.13 | | | | | | | | | | | | | | X | X | | |
| 3.14 | | | | | | | | | | | | | | X | | X | |
| 3.15 | X | X | X | X | X | X | X | X | X | | | | | X | | | X |

FIGURE 3
TEST MATRIXES

# Appendix D

Beechcraft
Boulder Division

# Beech Aircraft Corporation

Boulder, Colorado

**Code Ident. No. 07399**

## ZERO-G QUANTITY GAGING SYSTEM
## TEST PLAN
## FOR
## FEASIBILITY TESTING IN SUPPORT OF DESIGN

Descriptive Data 18031

Date Issued: March 7, 1986

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## LIST OF FIGURES

## 1.0 INTRODUCTION

Feasibility testing in support of the trade studies has confirmed the suitability of the RF Modal Analysis Quantity Gaging Concepts. Further testing of this approach will be required to obtain specific application-oriented data to support the design of a development Quantity Gaging System. The purpose of this document is to describe what testing will be required and how it will be conducted.

The universal test tank/fixture used during the feasibility testing in support of trades will again be used in the design feasibility testing. The design tests will be conducted using DIALA-AX simulant fluid, so the tank multilayer insulation blankets will not be required. The internal configuration of the universal tank will be the last configuration tested in the trades feasibility test (i.e., Test Assembly 3). This configuration includes dummy screen acquisition devices, start basket, thermodynamic vent, slosh baffles, and a cylindrical mast along the longitudinal axis. The external tank configuration will include ISO-KF flanged antenna port(s) for mounting developmental antenna designs. Cryogenic mechanical performance of the antenna/mount design will be verified in the vacuum chamber using a simple fixture.

## 2.0 OBJECTIVES

The intent of this test plan is to provide application-specific data and design approach verification for the design of an RF Modal Analysis Zero-Gravity Quantity Gaging System. In support of that goal, the tests proposed herein will:

A. Identify modal characteristics suitable for use in modal search and identification techniques.

B. Verify modal search and identification schemes for design implementation.

C. Verify computational algorithms to be used in the determination of tank fluid mass from the modal frequencies.

D. Tune the electrical performance of the tank antenna.

E. Verify the mechanical design and sealing capability of the ISO-KF flanged development antenna.

F. Identify any unforeseen problem areas which would impact the design of the development RF modal gaging system.

## 3.0 APPROACH

The objectives of the test plan will be realized through an orderly series of tests which will make use of the universal test tank/fixture and a laboratory equipment breadboard of the RF modal gaging system. The configuration of the test tank is as shown in Figure 1, while the fixture is illustrated in Figure 2. A block diagram of the RF modal gaging system is shown in Figure 3.

RF system operating paramaters will be as established during the trades feasibility testing. In addition, all testing except for antenna mechanical design and sealing capability tests will be conducted at room temperature using DIALA-AX simulant fluid. The antenna sealing capability tests will be conducted at cryogenic temperatures.

Three series of tests will be required to support the test objectives. The first series will concentrate on investigating the electrical performance of the tank antenna(s) and verifying their mechanical design. This will result in test antenna with performance and design features essentially congruent with the antenna(s) that will be provided to NASA as part of the development gaging system.

The second series of tests will undertake the detection of modal response characteristics suitable for modal search and identification techniques which can be implemented into the quantity gaging system signal conditioner. The most promising techniques will be verified at various tank fill levels and attitudes using the test control computer.

The third series of tests will use the test control computer to investigate application of the selected mode search and identification techniques as well as computational algorithms for converting modal responses to tank mass quantity. This will verify the computational approach to be implemented in the signal conditioner design.

Data from these tests will be evaluated as the tests progress and the results will be used to modify, if required, the test plan in order to efficiently achieve the test objectives.

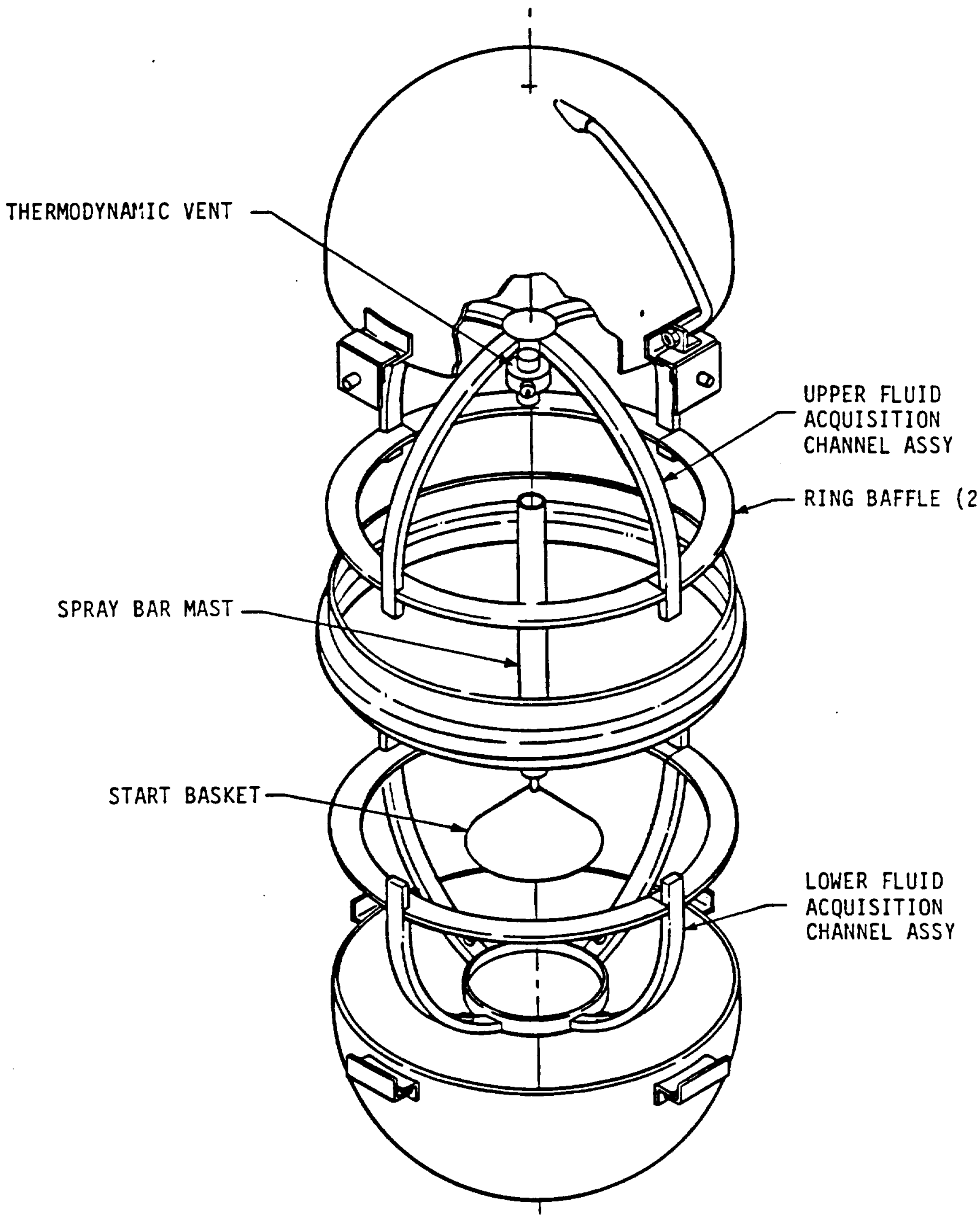


Figure 1. TEST TANK CONFIGURATION

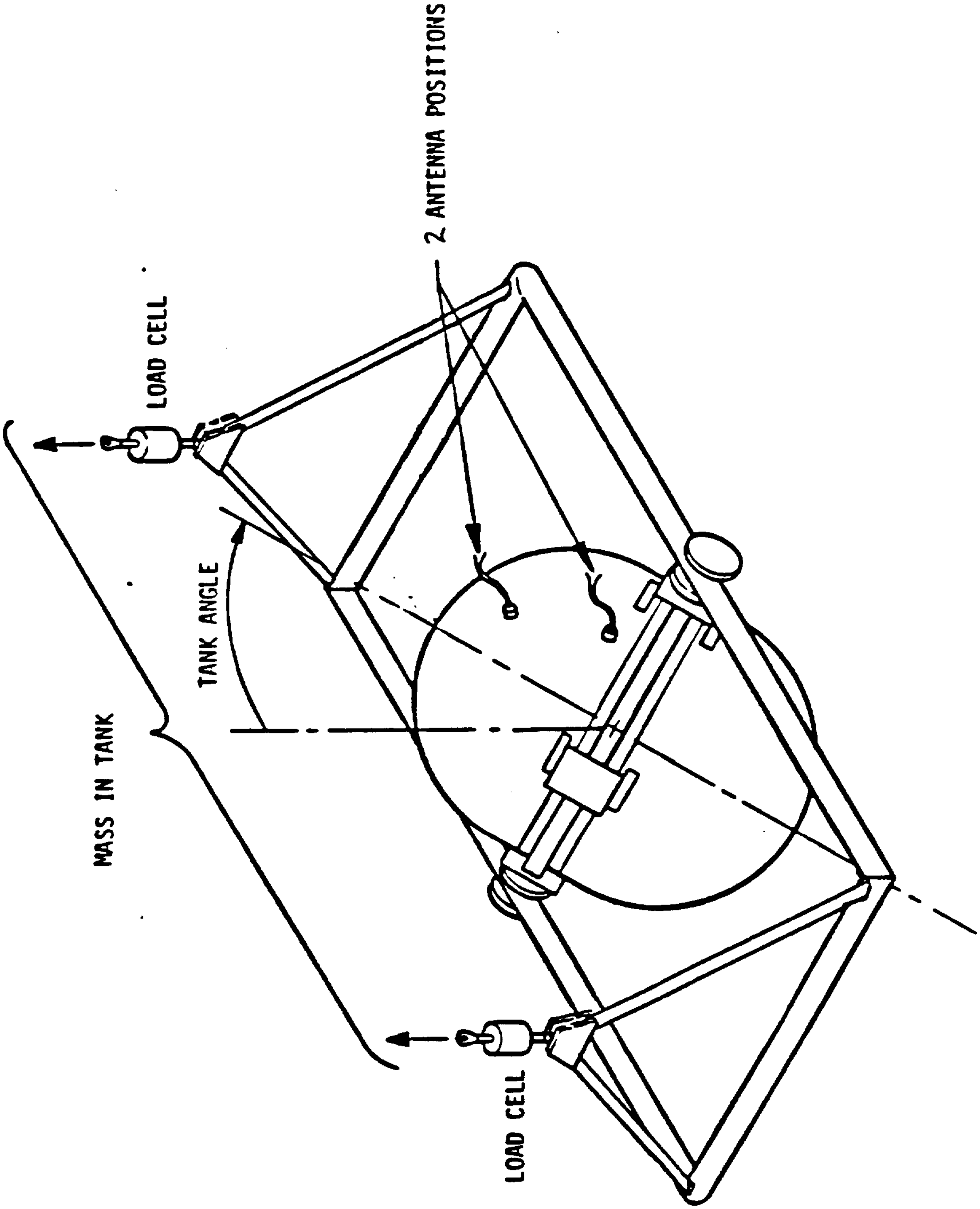


Figure 2. TANK TEST FIXTURE

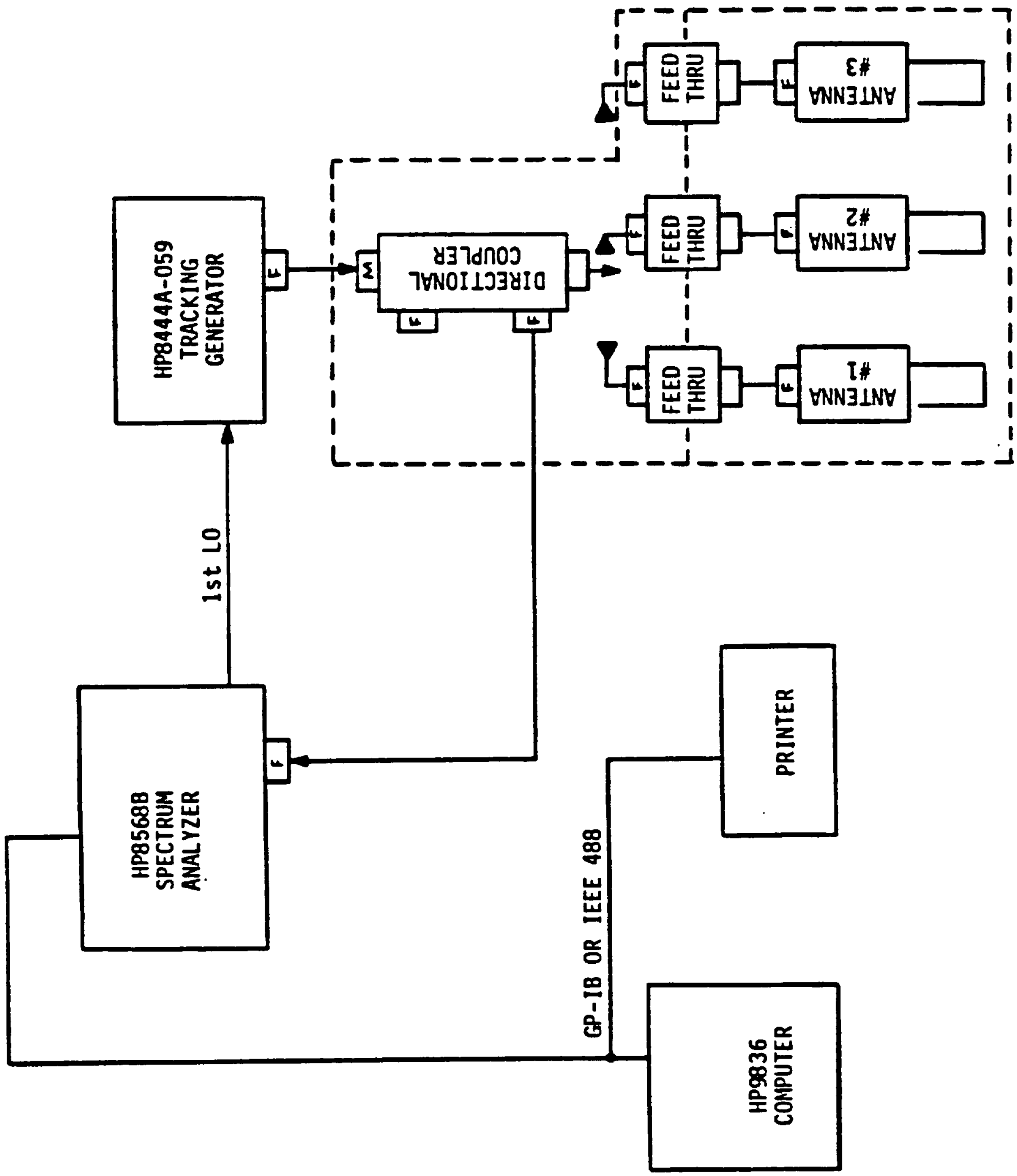


Figure 3. BLOCK DIAGRAM - RF MODAL GAGING SYSTEM

4.0 GENERAL TEST PROCEDURE

4.1 Test Setup. Figure 4 illustrates the general test configuration. The universal test dewar will be installed in a support/rotating fixture (Code D934/TCO 26659, S/N 69751) which will hang from a rail inside the CVC vacuum chamber located at Beech's Test Department. The test dewar will not be operated at cryogenic temperatures so the chamber vacuum system will not be required. The test setup will utilize the same instrumentation and operational system as was used during the simulant fluid portion of the trades-feasibility testing. The antenna installations will be the only test dewar configuration changes to be made during this test series.

The universal test dewar is designed to withstand 40 psia internal pressure. The only source of internal pressure expected in these tests is the pumping pressure required to fill and drain the dewar with DIALA-AX simulant fluid.

4.2 System Tests.

4.2.1 Antenna Tests. Antenna testing consists of two separate test sequences; the electrical performance investigative sequence and the verification of mechanical design sequence. These two sequences can be performed independently, so parallel testing is possible to reduce span time.

4.2.1.1 Electrical Tests. Antenna electrical performance tests will evaluate two antenna designs in two test dewar antenna positions. Initially, the antenna orientation at each dewar position will be varied to find the best empty tank response. Once this has been established, the dewar will be filled and plots of the four primary modes will be made at each 45 degree increment from zero to 180 degrees. Data will be obtained for each of the two dewar antenna positions at each angular increment. The sequence will be repeated for tank fill levels of full, 3/4 full, 1/2 full, 1/4 full, and empty. When the sequence has been completed, the second antenna design will be installed in each of the two dewar positions and the entire test sequence repeated. Test Matrix 1.0 in Figure 5 outlines the maximum extent of the tests. It is anticipated that the maximum number of tests will not be required to accomplish the test objectives of:

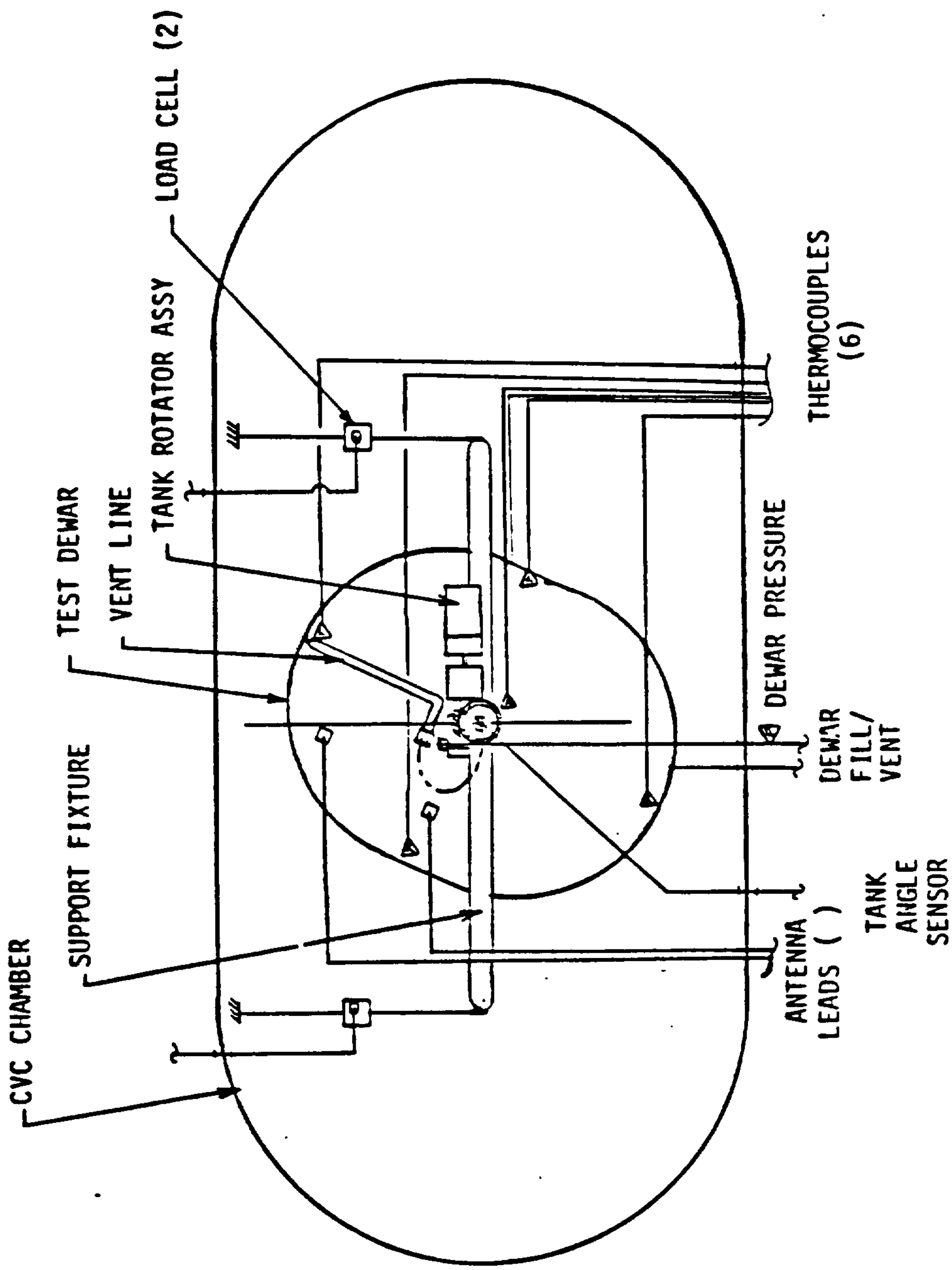


Figure 4. GENERAL TEST SETUP

**1.0 TEST MATRIX**

| Ant. Design 1 | Ant. Design 2 | Mount Position 1 | Mount Position 2 | Tank Angle 0 | 45 | 90 | 135 | 180 | Fill Level P | 3/4 | 1/2 | 1/4 | E |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | | X | | P | P | P | P | P | X | | | | |
| X | | | X | P | P | P | P | P | X | | | | |
| X | | X | | P | P | P | P | P | | X | | | |
| X | | | X | P | P | P | P | P | | X | | | |
| X | | X | | P | P | P | P | P | | | X | | |
| X | | | X | P | P | P | P | P | | | X | | |
| X | | X | | P | P | P | P | P | | | | X | |
| X | | | X | P | P | P | P | P | | | | X | |
| X | | X | | P | P | P | P | P | | | | | X |
| X | | | X | P | P | P | P | P | | | | | X |
| | X | X | | P | P | P | P | P | X | | | | |
| | X | | X | P | P | P | P | P | X | | | | |
| | X | X | | P | P | P | P | P | | X | | | |
| | X | | X | P | P | P | P | P | | X | | | |
| | X | X | | P | P | P | P | P | | | X | | |
| | X | | X | P | P | P | P | P | | | X | | |
| | X | X | | P | P | P | P | P | | | | X | |
| | X | | X | P | P | P | P | P | | | | X | |
| | X | X | | P | P | P | P | P | | | | | X |
| | X | | X | P | P | P | P | P | | | | | X |

P = 4 ea. mode plots

**2.0 TEST MATRIX**

| Ant. Design 1 | Ant. Design 2 | Mount Position 1 | Mount Position 2 | Tank Angle 0 | 45 | 90 | 135 | 180 | 225 | 270 | 315 | 360 | Fill Level P | 3/4 | 1/2 | 1/4 | E |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X | | X | | P | P | P | P | P | P | P | P | P | X | | | | |
| X | | | X | P | P | P | P | P | P | P | P | P | X | | | | |
| | X | X | | P | P | P | P | P | P | P | P | P | X | | | | |
| | X | | X | P | P | P | P | P | P | P | P | P | X | | | | |
| X | | X | | P | P | P | P | P | P | P | P | P | | X | | | |
| X | | | X | P | P | P | P | P | P | P | P | P | | X | | | |
| | X | X | | P | P | P | P | P | P | P | P | P | | X | | | |
| | X | | X | P | P | P | P | P | P | P | P | P | | X | | | |
| X | | X | | P | P | P | P | P | P | P | P | P | | | X | | |
| X | | | X | P | P | P | P | P | P | P | P | P | | | X | | |
| | X | X | | P | P | P | P | P | P | P | P | P | | | X | | |
| | X | | X | P | P | P | P | P | P | P | P | P | | | X | | |
| X | | X | | P | P | P | P | P | P | P | P | P | | | | X | |
| X | | | X | P | P | P | P | P | P | P | P | P | | | | X | |
| | X | X | | P | P | P | P | P | P | P | P | P | | | | X | |
| | X | | X | P | P | P | P | P | P | P | P | P | | | | X | |
| X | | X | | P | P | P | P | P | P | P | P | P | | | | | X |
| X | | | X | P | P | P | P | P | P | P | P | P | | | | | X |
| | X | X | | P | P | P | P | P | P | P | P | P | | | | | X |
| | X | | X | P | P | P | P | P | P | P | P | P | | | | | X |

P = 4 ea. mode plots

Figure 5. TEST MATRIX

(A) Selecting a design with the most level impedance over the operating range,

(B) Determining the best antenna orientation, and

(C) Peaking the antenna response to the selected modes.

The selected antenna design response plots obtained in the best orientation(s) and dewar position(s) will also form the baseline data set for the modal response characteristics test series.

4.2.1.2 Mechanical Tests. Mechanical design verification tests will subject a test antenna to the following::

(A) Cold shock to $LH_2$ temperature,
(B) Proof pressure to 80 psia, and
(C) Helium leak rate measurement while:
- at $LH_2$ temperature,
- 40 psia He pressure on the antenna side, and
- Vacuum on the connector side.

The tests will be accomplished using a test fixture as shown in Figure 6.

4.2.2 Modal Response Characteristics Tests. At first, any additional tests required to fill gaps or obtain more detail for the baseline data set obtained during the antenna electrical performance tests will be completed. Then, with the tank in the zero degree position, the four primary modes will be continuously tracked (one at a time) as the dewar is filled and then emptied. Video records of this data from the spectrum analyzer screen will be required.

The test setup will be identical to the Paragraph 4.2.1.1 tests with the best antenna design and orientation installed in the two dewar mount positions. The mode characteristic data obtained will be used by engineering to define no more than two mode search and identification approaches which are to be implemented by the test control computer. Once implemented, the approaches will be evaluated by verifying their performance using the test sequence shown in Test Matrix 2.0 of Figure 5.

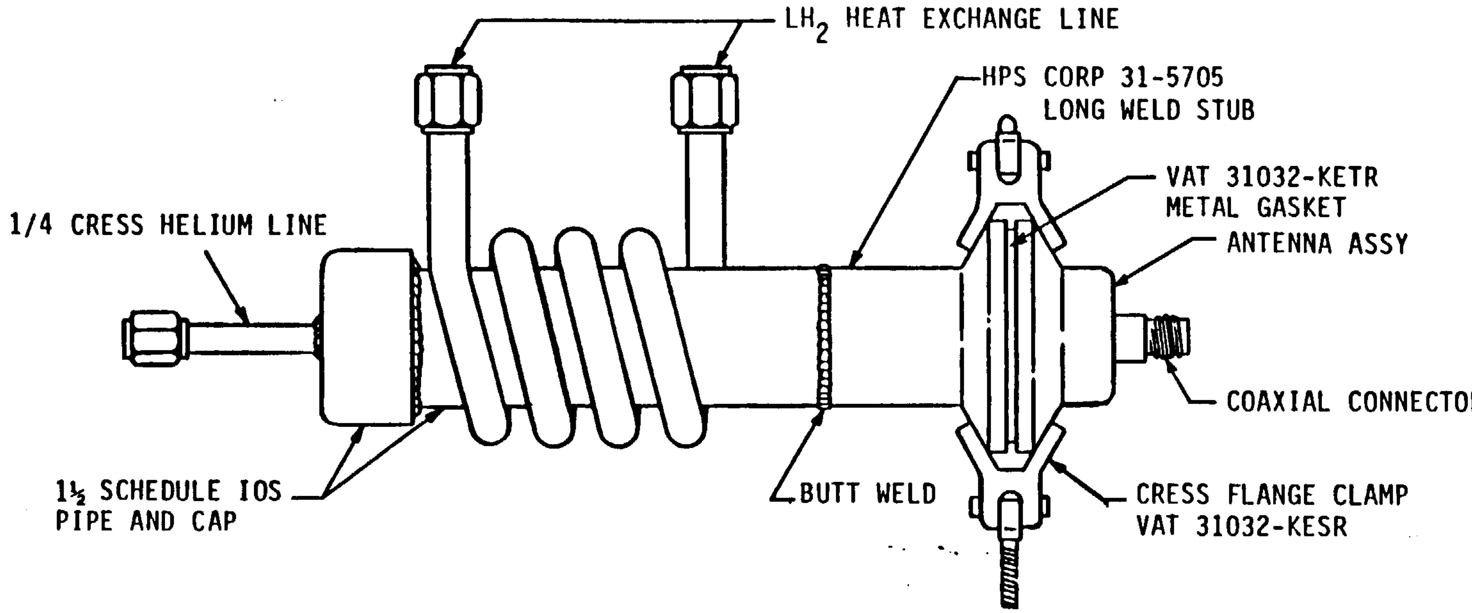


Figure 6. ANTENNA SEAL TEST FIXTURE

4.2.3 Mass Computation Algorithm Tests. The test control computer program will be expanded from the version used to implement the best mode search and identification approach found during the testing of 4.2.2 to include computational algorithms for converting modal responses to tank mass quantity. The computational algorithms will be evaluated by verifying their performance using the test sequence shown in Test Matrix 2.0 of Figure 5 and the test setup of 4.2.2.

4.3.3 Test Facilities. The following test facilities and materials will be required to be supplied by the Test Department.

- Test area compatible with DIALA-AX simulant fluid.
- Test setup as developed from Trades Feasibility Testing including:
  - HP 9836/3497 Data Acquisition and Control System
  - HP 8568B Spectrum Analyzer, HP 8444A-059 Tracking Generator and Directional Coupler.
  - Test control and monitor panels for centralized control of the test fixture.
  - Instrumentation:

    | | |
    |---|---|
    | Dewar pressure | (Same as trades test setup) |
    | Dewar temperature | (Same as trades test setup) |
    | Fixture weighing system | (Same as trades test setup) |
    | Dewar angle | (Same as trades test setup) |

  - Protected area for test and engineering personnel
  - CVC vacuum chamber
  - Electrical power
  - Dewar fill and drain system which will allow the dewar fill level of DIALA-AX simulant to be controlled while the dewar is in the vacuum chamber. (Note: The DIALA-AX fill system is a closed loop to prevent loss of the simulant fluid).
- Fluids: $GN_2$ 0-150 psia; GHe 0-60 psia; DIALA-AX simulant fluid

4.4 Reporting. A daily operating log will be kept and made available to the Engineering Department. Daily test results will be compiled and provided to Engineering for analysis. In this way, any changes in test direction dictated by the test results can be quickly implemented. A final test report will be written by Engineering after the trade studies have been completed.

4.5 Schedule. Figure 7 describes the primary tasks and their scheduled duration/completion.

# MASTER TASK SCHEDULE

Work Order No. 22885

Date: 3/5/86
Revision: -

△ Scheduled Event
▲ Complete Event

Program Title: ZERO GRAVITY DESIGN FEASIBILITY TEST

1986 — MARCH: 2, 9, 16, 23, 30; APRIL: 6, 13, 20, 27; MAY: 4, 11, 18, 25

| | Task Description | Dept. |
|---|---|---|
| 3/10 | Engineering Test Request | Engr. |
| 3/10-4/4 | Test Procedure | Test |
| 3/10-3/14 | Test Hardware Drawings | Engr. |
| 3/10-3/14 | TCO's | Engr. |
| 3/17-4/4 | Test Hardware Build | Mfg. |
| 4/4-4/9 | Test Tank Mod. | Mfg. |
| 4/9-4/11 | Test Tank Cold Shock Proof, Leak | Test |
| 3/17-4/11 | Test Setup | Test |
| 4/13-4/16 | Antenna Tests - Electrical | Test |
| 4/13-4/16 | Antenna Tests - Mechanical | Test |
| 4/17-4/23 | Modal Response Characteristics Tests | Test |
| 4/24-4/29 | Mass Computation Algorithm Tests | Test |
| 4/30-5/7 | Reporting | Engr. |

| Schedule Status Evaluation | |
|---|---|
| | Ahead of Sched. |
| | On Schedule |
| | Behind Sched. |

Figure 7. MASTER TASK SCHEDULE

# BEECH AIRCRAFT CORPORATION
## BOULDER DIVISION

# TEST ENGINEERING DEPARTMENT

# TEST PROCEDURE

ZERO G QUANTITY GAGING SYSTEM
FEASIBILITY TESTING
IN SUPPORT OF DESIGN

**Procedure No.** TED-131 **Issue Date** 4/9/86

PREPARED BY: [signature]

REVIEWED BY: C M Anderson

APPROVED BY: J E Lewis

PROJECT ENGINEER: [signature]

TED NO. 131

NO. OF PAGES:

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1.0 SCOPE

1.1 General. This document establishes the test methods and procedures to perform Zero-G Quantity Gaging System feasibility testing in support of design as specified in the Test Plan, DD 18031, and the Engineering Test Request, ETR ZGQG-002.

1.2 Purpose. It is the intent of this procedure to provide development test data and design verification for an RF modal analysis Zero-G Quantity Gaging System. The specific test objectives are:

1. Identify modal characteristics suitable for use in modal search and identification techniques.

2. Verify modal search and identification schemes for design implementation.

3. Verify computational algorithms to be used in the determination of tank fluid mass from the modal frequencies.

4. Tune the electrical performance of the tank antenna.

5. Verify the mechanical design and sealing capability of the ISO-KF flanged development antenna.

6. Identify any unforeseen problem areas which would impact the design of the development RF modal gaging system.

1.3 Classification. The tests specified in this procedure are classified as development.

2.0 REFERENCE DOCUMENTS

2.1 Beech Aircraft. The following documents form a part of this procedure to the extent specified herein.

| | |
|---|---|
| DD 18031 | Zero-G Quantity Gaging System Test Plan for Feasibility Testing in Support of Design |
| ETR ZGQG-002 | Engineering Test Request |
| SOP 008 | CVC Operating Procedure |

3.0 GENERAL REQUIREMENTS

3.1 Tests. Three series of tests will be required. The first series will evaluate the electrical performance of the antenna and verify its mechanical design. The second will detect modal response characteristics suitable for modal search and identification techniques which can be implemented into a quantity gaging system signal conditioner. The third will use the test data acquisition and control computer to investigate application of the selected mode search and identification technique, and to evaluate computational algorithms for converting modal responses to tank mass quantity.

3.2 Deviations and Changes. The procedures described in this document may be changed or deviations may be incorporated when approved by the Test Conductor and the cognizant Design Engineer. All approved changes and deviations shall be recorded in the Test Operations Log and red-lined into the as-run copy of the procedure.

3.3 Test Sequence. Tests specified herein will be performed in the order listed. This order may be changed when approved by the Test Conductor and the Design Engineer. A change in a specified sequence shall be indicated by a red-line notation in the as-run copy of the procedure.

3.4 Test Equipment. All standard test equipment specified and used in this procedure shall be identified on the Equipment List and verified to be in Calibration. Test setups will be documented by photographs whenever possible.

3.5 Data. Test data will consist of the information manually recorded on the data sheets of this procedure, video tapes, and the measurements made and recorded by the data acquisition and control computer. The manually recorded information indicates test sequence and operation completion. These are used primarily to track and document test progress. The computer generated data are periodic measurements of test parameters on the Measurements List and printouts of antenna mode scans measured by the spectrum analyzer. The video data documents the display of a targeted modal response on the spectrum analyzer screen during the fill and depletion of the tank. A Test Operations Log will also be maintained throughout the testing period.

Two copies of all test data, including photographs, will be made. One set will be sent to the responsible Design Engineer and the other retained in the Test Department files. The Test Conductor is responsible for the control of all test data. These data include test software (the application program disk and the calibration disk) and all recorded data disks.

4.0 PROCEDURES

4.1 Antenna Performance Tests. The tests of the antenna assembly will consist of a mechanical design verification test and an electrical performance test.

4.1.1 Antenna Mechanical Design Verification. The mechanical test sequence will subject the antenna assembly to a cold shock, proof pressure, and leak check, all at liquid hydrogen temperatures. The antenna seal test fixture shown by Figure 1 will be used for these tests.

1. Install the antenna and test fixture in accordance with the setup diagram of Figure 2. T/C ________
2. Cold shock the antenna by flowing $LH_2$ through the cooling coil. T/C ________
3. While holding the assembly at approximately $LH_2$ temperature, pressurize the fixture to 80 psia GHe for at least 5 minutes. T/C ________
4. Reduce the pressure to 40 psia GHe and direct the leak detector to the antenna coax connector and the flange seal area. There shall be no leak detected greater than $1 \times 10^{-8}$ SCC/S He. T/C ________
5. Reduce the GHe pressure to ambient, vent the fixture, discontinue the $LH_2$ flow, secure the leak detector, and allow the test fixture to warm to ambient temperature. T/C ________
6. Remove the antenna from the fixture and record the test information on the Antenna Mechanical Test Data sheet. T/C ________

4.1.2 Antenna Electrical Performance Test. Antenna electrical tests will evaluate two antenna designs in two tank antenna positions. Initially, the antenna orientation will be varied to find the best empty tank response. Then the tank will be filled and plots of the four primary modes will be made at each 45 degree tank rotation increment from 0 to 180 degrees. Data will be obtained for each of the two tank antenna positions. The sequence will be repeated for tank fill levels of 3/4, 1/2, 1/4, and empty. The entire test sequence will then be repeated for the second antenna design installed in the two tank positions.

1. Install the tank in the CVC chamber in accordance with the fluids schematic of Figure 3, the instrumentation setup diagram of Figure 4, and the instrument list of Table I.
T/C ________

2. With a design 1 antenna installed in each antenna position, measure the empty tank response. T/C ________

3. Change the orientation of each antenna, as directed by the Design Engineer, to obtain the best empty tank response. Record this orientation on the Antenna Orientation Diagram by sketching the antenna angular position relative to a plane passing through the antenna mounting hole and tank center.
T/C ________

4. Place the chamber in operation as specified by SOP 008 and stabilize to a shroud temperature of -120°F. T/C ________

5. Fill the tank with $LN_2$ as directed by the Test Conductor T/C ________

6. Perform the spectrum analyzer measurements of the four primary modes for each antenna as specified by the Design Engineer. For each tank position and fill level indicated on the Antenna Electrical Test Data sheets, enter the date and the time of the measurements
T/C ________

7. Empty and purge the tank, return the chamber to ambient conditions, and install a design 2 type antenna into the two tank antenna positions. T/C ________

8. Perform Steps 2 through 6 for the design 2 type antenna. T/C ________

9. Empty and purge the tank, and return the chamber to ambient conditions.
T/C ________

4.2 Modal Response Characteristic Tests. This series of tests will measure the four primary modal responses as the tank is filled, rotated, and emptied. Data from these tests will be analyzed and no more than two mode search and identification approaches will be defined for implementation using the test data acquisition and control computer. Once implemented, the appraoches will be evaluated by performing the tests listed on the Modal Response Characteristic Data sheet.

1. Install the selected antenna design in the tank mounting positions T/C ________

2. Place the chamber in operation as specified by SOP 008 and stabilize to a shroud temperature of -120°F. T/C ________

3. Set the video camera to monitor the spectrum analyzer display. Start recording with the camera elapsed time indication set to ON T/C ________

4. Set the spectrum analyzer to monitor the first selected primary mode. T/C ________

5. Fill the tank with $LN_2$ as directed by the Test Conductor. T/C ________

6. Deplete the tank to 1/2 full.
T/C ________

7. Rotate the tank forward to 360 degrees and then back to zero degrees.
T/C ________

8. Empty the tank as directed by the Test Conductor. T/C ________

9. Set the spectrum analyzer to monitor the second selected primary mode, and perform Steps 5, 6, and 7. T/C ________

10. Set the spectrum analyser to monitor the third selected primary mode, and perform Steps 5, 6, and 7. T/C ________

11. Set the spectrum analyzer to monitor the fourth selected primary mode, and perform Steps 5, 6, and 7. T/C ________

12. Secure the video equipment and retain the tape as part of the test data. T/C ________

13. Load the Mode Search and Identification routines, specified by the Design Engineer, into the test data acquisition and control computer. T/C ________

14. Perform the test sequence indicated by the Modal Response Characteristics Data sheet. T/C ________

15. Empty and purge the tank, and return the chamber to ambient conditions. T/C ________

4.3 Mass Computational Algorithm Test. This test series will utilize the test data acquisition and control computer with the developed computational algorithms for converting modal responses to tank mass quantity. The algorithms will be evaluated by performing the test sequence specified on the Mass Computation Algorithm Data sheet.

1. Conduct the measurements at the tank fill levels and rotation listed on the data sheet. T/C ________

2. Empty and purge the tank, and return the chamber to ambient conditions. T/C ________

3. Secure all test systems.

## ANTENNA MECHANICAL TEST DATA

| Antenna S/N | Cold Shock ($LH_2$) | Proof Press (psia) | Leak Rate (SCC/S He) |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

## ANTENNA ORIENTATION DIAGRAMS

| Design 1 | |
|---|---|
| | |

| Design 2 | |
|---|---|
| | |

Data Sheet #1

ANTENNA ELECTRICAL TEST DATA

Tank Fill Level - F

Tank Weight ____ lbs

| Antenna Design | Antenna Position | Tank Angle 0 | 45 | 90 | 135 | 180 |
|---|---|---|---|---|---|---|
| 1 | 1 | | | | | |
| 1 | 2 | | | | | |

Tank Fill Level - 3/4

Tank Weight ____ lbs

| Antenna Design | Antenna Position | Tank Angle 0 | 45 | 90 | 135 | 180 |
|---|---|---|---|---|---|---|
| 1 | 1 | | | | | |
| 1 | 2 | | | | | |

Tank Fill Level - 1/2

Tank Weight ____ lbs

| Antenna Design | Antenna Position | Tank Angle 0 | 45 | 90 | 135 | 180 |
|---|---|---|---|---|---|---|
| 1 | 1 | | | | | |
| 1 | 2 | | | | | |

Tank Fill Level - 1/4

Tank Weight ____ lbs

| Antenna Design | Antenna Position | Tank Angle 0 | 45 | 90 | 135 | 180 |
|---|---|---|---|---|---|---|
| 1 | 1 | | | | | |
| 1 | 2 | | | | | |

Tank Fill Level - E

Tank Weight ____ lbs

| Antenna Design | Antenna Position | Tank Angle 0 | 45 | 90 | 135 | 180 |
|---|---|---|---|---|---|---|
| 1 | 1 | | | | | |
| 1 | 2 | | | | | |

Data Sheet #2

Tank Fill Level - F

Tank Weight ____ lbs

| Antenna Design | Antenna Position | Tank Angle 0 | 45 | 90 | 135 | 180 |
|---|---|---|---|---|---|---|
| 1 | 1 | | | | | |
| 1 | 2 | | | | | |

Tank Fill Level - 3/4

Tank Weight ____ lbs

| Antenna Design | Antenna Position | Tank Angle 0 | 45 | 90 | 135 | 180 |
|---|---|---|---|---|---|---|
| 1 | 1 | | | | | |
| 1 | 2 | | | | | |

Tank Fill Level - 1/2

Tank Weight ____ lbs

| Antenna Design | Antenna Position | Tank Angle 0 | 45 | 90 | 135 | 180 |
|---|---|---|---|---|---|---|
| 1 | 1 | | | | | |
| 1 | 2 | | | | | |

Tank Fill Level - 1/4

Tank Weight ____ lbs

| Antenna Design | Antenna Position | Tank Angle 0 | 45 | 90 | 135 | 180 |
|---|---|---|---|---|---|---|
| 1 | 1 | | | | | |
| 1 | 2 | | | | | |

Tank Fill Level - E

Tank Weight ____ lbs

| Antenna Design | Antenna Position | Tank Angle 0 | 45 | 90 | 135 | 180 |
|---|---|---|---|---|---|---|
| 1 | 1 | | | | | |
| 1 | 2 | | | | | |

Data Sheet #3

MODAL RESPONSE CHARACTERISTICS DATA

Tank Fill Level - F        Tank Weight ____ lbs

| Antenna Design | Position | 0 | 45 | 90 | 135 | 180 | 225 | 270 | 315 | 360 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| | | | | | | | | | | |

Tank Fill Level - 3/4        Tank Weight ____ lbs

| Antenna Design | Position | 0 | 45 | 90 | 135 | 180 | 225 | 270 | 315 | 360 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| | | | | | | | | | | |

Tank Fill Level - 1/2        Tank Weight ____ lbs

| Antenna Design | Position | 0 | 45 | 90 | 135 | 180 | 225 | 270 | 315 | 360 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| | | | | | | | | | | |

Tank Fill Level - 1/4        Tank Weight ____ lbs

| Antenna Design | Position | 0 | 45 | 90 | 135 | 180 | 225 | 270 | 315 | 360 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| | | | | | | | | | | |

Tank Fill Level - E        Tank Weight ____ lbs

| Antenna Design | Position | 0 | 45 | 90 | 135 | 180 | 225 | 270 | 315 | 360 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| | | | | | | | | | | |

Data Sheet #4

MASS COMPUTATION ALGORITHM DATA

Tank Fill Level - F　　　　Tank Weight _____ lbs

| Antenna Design | Position | 0 | 45 | 90 | 135 | 180 | 225 | 270 | 315 | 360 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| | | | | | | | | | | |

Tank Fill Level - 3/4　　　　Tank Weight _____ lbs

| Antenna Design | Position | 0 | 45 | 90 | 135 | 180 | 225 | 270 | 315 | 360 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| | | | | | | | | | | |

Tank Fill Level - 1/2　　　　Tank Weight _____ lbs

| Antenna Design | Position | 0 | 45 | 90 | 135 | 180 | 225 | 270 | 315 | 360 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| | | | | | | | | | | |

Tank Fill Level - 1/4　　　　Tank Weight _____ lbs

| Antenna Design | Position | 0 | 45 | 90 | 135 | 180 | 225 | 270 | 315 | 360 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| | | | | | | | | | | |

Tank Fill Level - E　　　　Tank Weight _____ lbs

| Antenna Design | Position | 0 | 45 | 90 | 135 | 180 | 225 | 270 | 315 | 360 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| | | | | | | | | | | |

Data Sheet #5

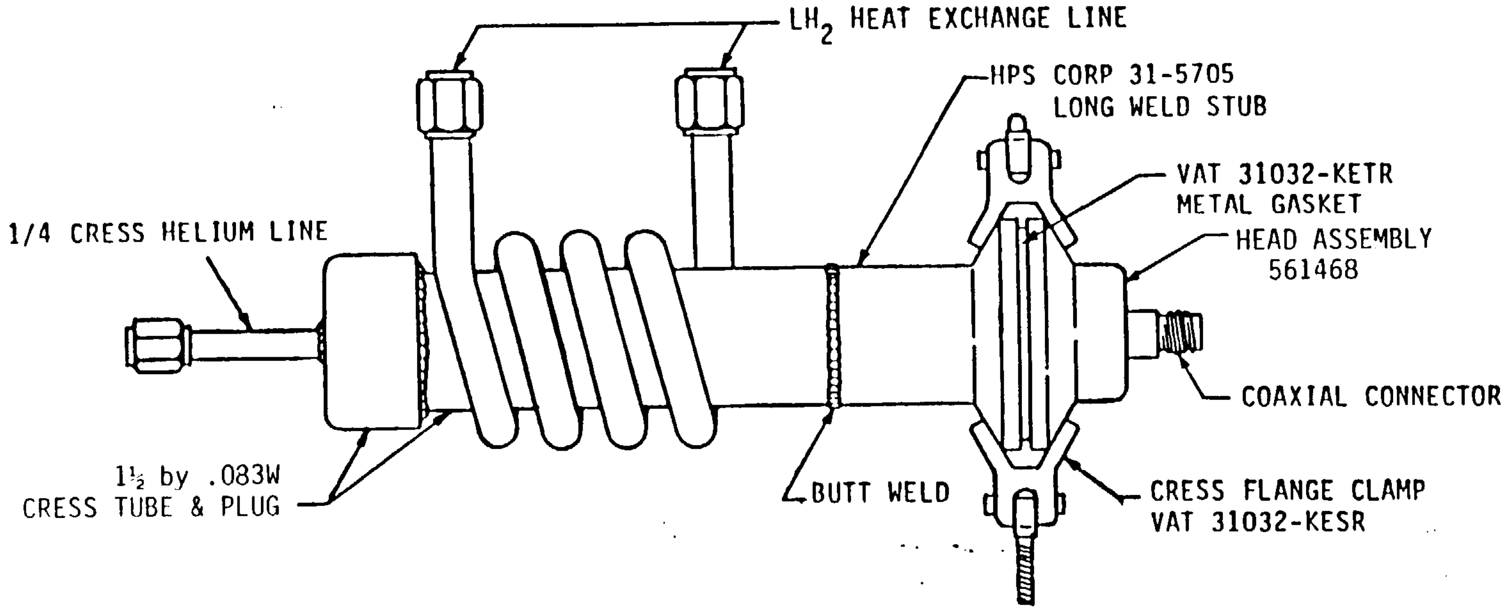


Figure 1

ANTENNA SEAL TEST FIXTURE

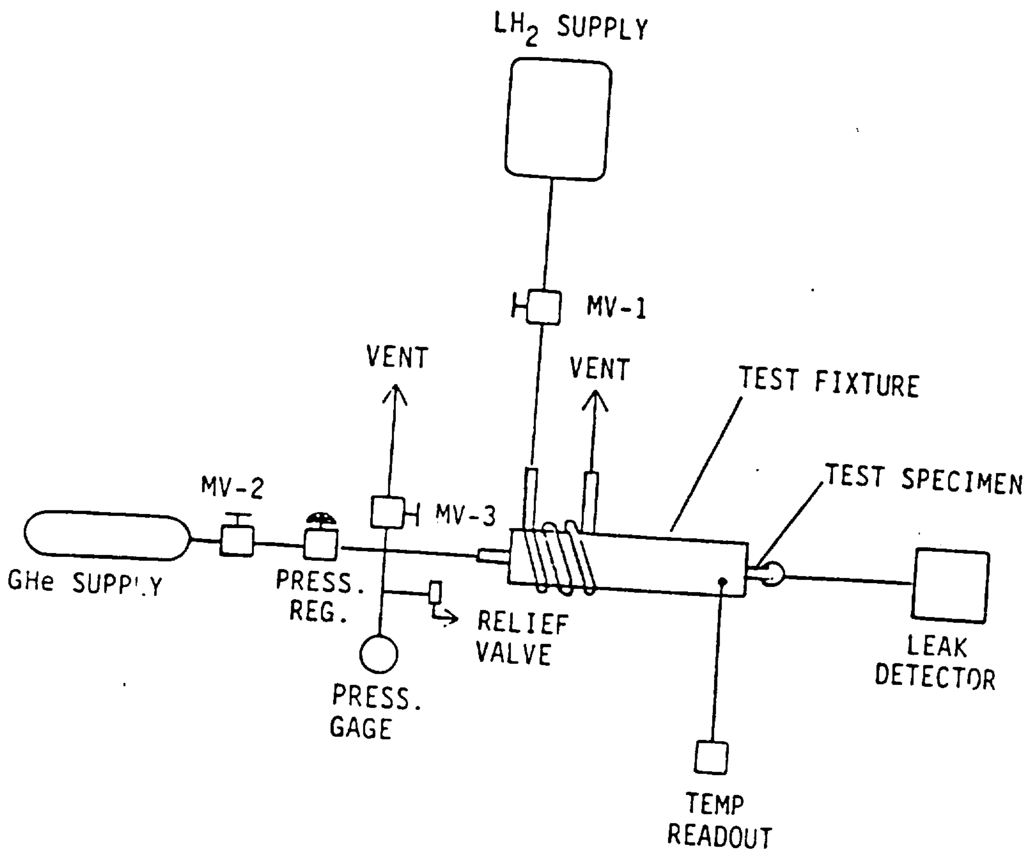


Figure 2

ANTENNA MECHANICAL TEST SETUP

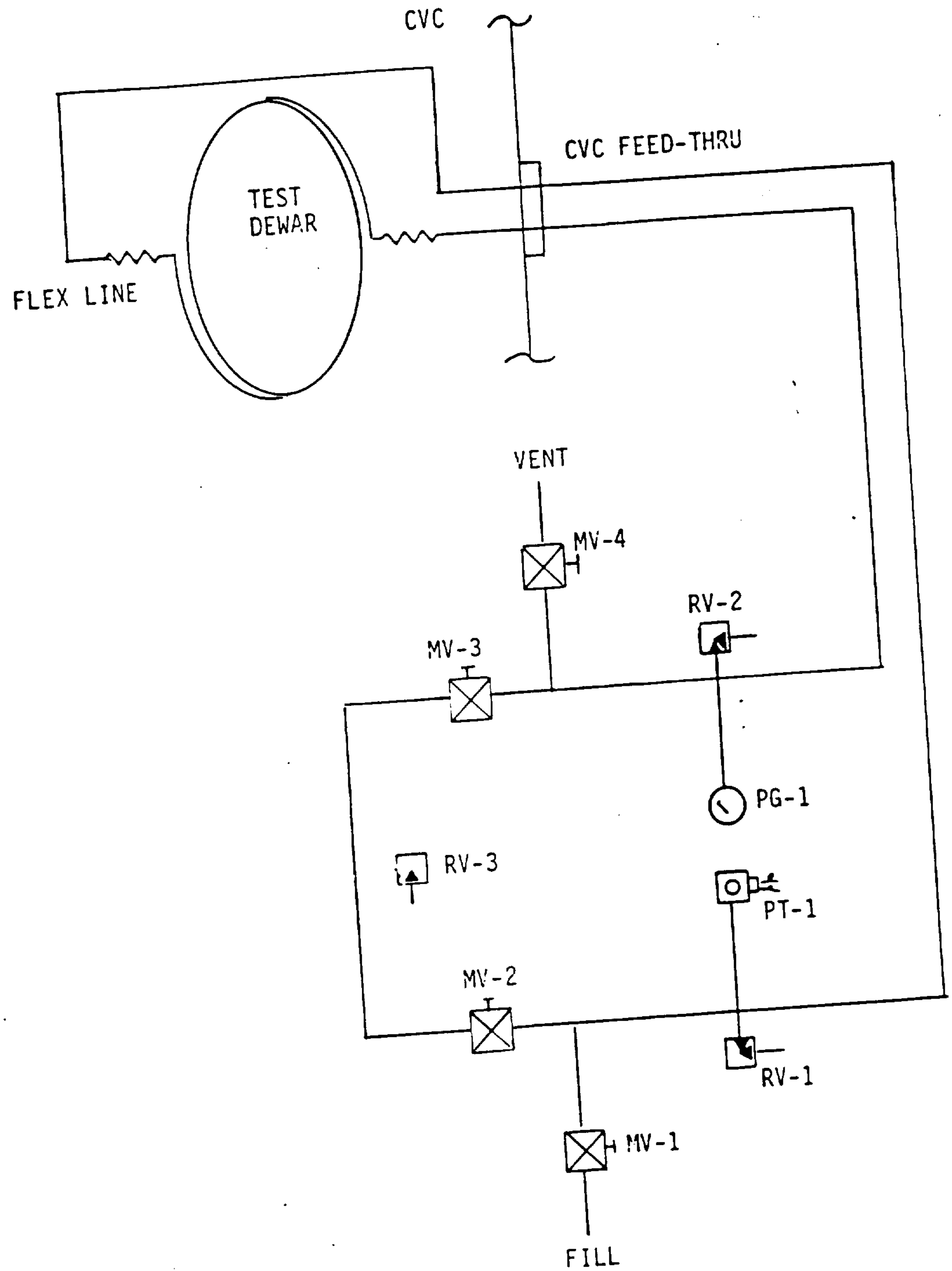


Figure 3

FLUIDS SCHEMATIC

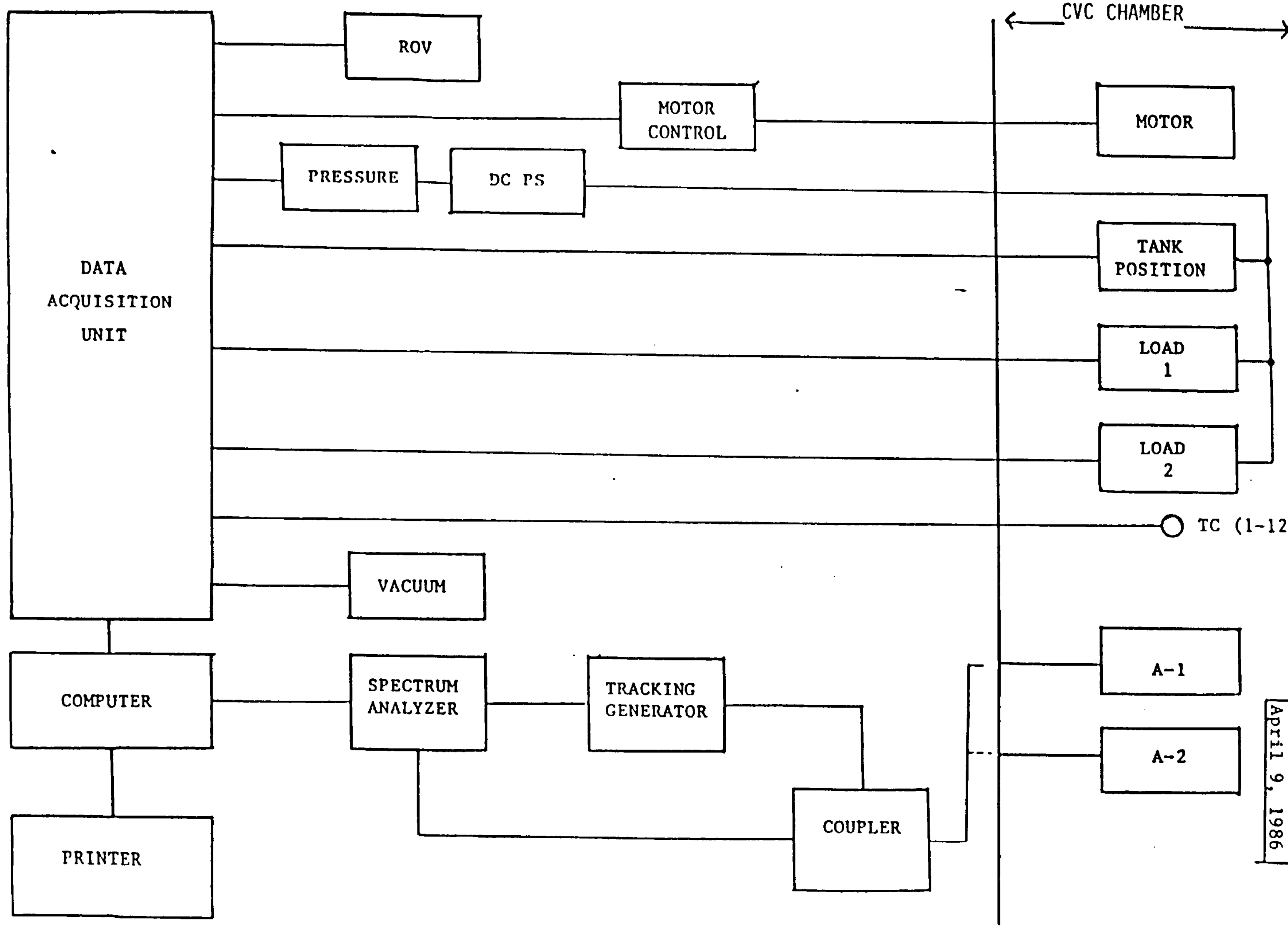


Figure 4

INSTRUMENTATION SET UP DIAGRAM

Appendix E

Beechcraft
Boulder Division

# Beech Aircraft Corporation

Boulder, Colorado

**Code Ident. No. 07399**

## INTERFACE REQUIREMENTS

## ZERO-GRAVITY QUANTITY GAGING SYSTEM

Beech Specification
BS 18029

Issue Date: March 7, 1986

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# LIST OF FIGURES



# LIST OF TABLES

1.0 INTRODUCTION

This Interface Requirements document has been prepared by the Boulder Division of Beech Aircraft Corporation in compliance with NASA Contract NAS9-17378 Statement of Work Task 3.0.

1.1 Purpose. Interface Requirements mutually established by Beech, the JSC TTA Project Engineer, and the JSC Technical Manager are formally documented in this Requirement to form the basis for assuring compatibility and control of all interfaces between Beech supplied gaging system hardware and the NASA test facilities.

1.2 Scope. Interface issues covered by this Requirement include both quantity gaging system ground testing at the JSC TTA facility and flight testing in the JSC KC-135 Reduced Gravity Aircraft. Ground testing will involve cryogenic propellants ($LO_2$ and $LH_2$) as well as ambient temperature tests using a simulant fluid. Flight testing will use the simulant fluid only.

2.0 APPLICABLE DOCUMENTS

The following documents form a part of this Requirement to the extent noted.

| | | |
|---|---|---|
| NASA | JSC-17385<br>May 1981 | JSC Reduced Gravity Aircraft User's Guide (in entirity) |
| MILITARY | MIL-B-5087B<br>Dec 1984 | Bonding, Electrical, and Lightning Protection, for Aerospace Systems (Bonding requirements structure and antenna) |

3.0 INTERFACE REQUIREMENTS

This section develops the specific interface details and definitions required to coordinate NASA testing of a Beech-supplied Development Zero-Gravity Quantity Gaging System. The NASA test program consists of ground test and KC-135 flight test phases. The interface requirements developed in this section cover both of these test phases. Interface areas addressed include:

(1) Test Tank Configuration
(2) Quantity Gaging System Signal Conditioner
(3) Quantity Gaging System Antenna(s)
(4) Antenna/Signal Conditioner Interconnection
(5) Simulant Test Fluid

3.1 Test Tankage Definitions. The following paragraphs provide the necessary NASA/Beech interface details related to both the ground test and KC-135 test tankage. The interface issues covered include:

(1) Test Tankage Configurations
(2) Tank Dimensional Data
(3) Tank Internal Components
(4) Gaging Antenna Locations

3.1.1 Ground Test Tank Configurations. Three configurations of ground test tankage will be used. These will allow testing of a spherical and two different aspect ratio cylindrical tanks. The hemispherical heads will be common to all three configurations. This will allow all three configurations to be realized with two flanged hemispherical heads, two different lengths of flanged cylindrical spool sections with integral trunnions, and one set of bolt-on trunnions for the spherical configuration. The flanged construction is required to:

(1) Allow make-up of the various configuration, and
(2) Permit installation of dummy internal tank components.

Electrical continuity between the tank elements is required and shall meet the appropriate sections of MIL-B-5087 to achieve a bonding resistance between elements of no more than 0.02 ohm.

Illustrations of the ground test tank configurations are shown in Figure 3.1.1.

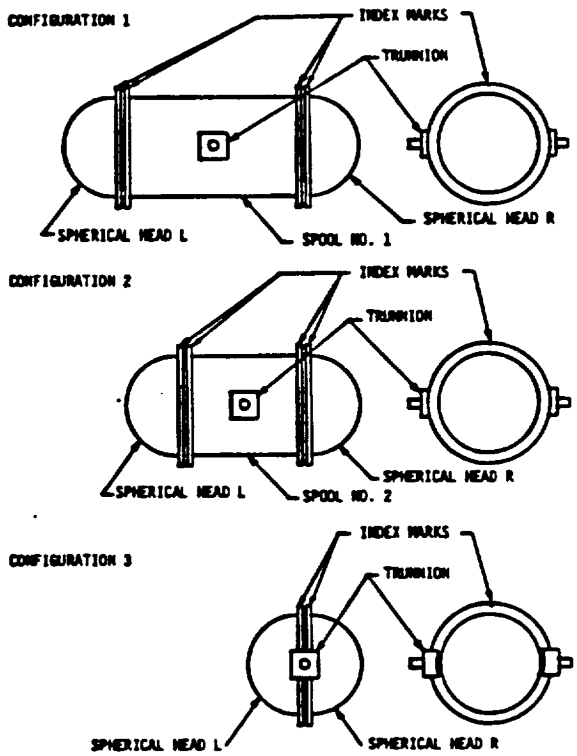



Figure 3.1.1. GROUND TEST TANK CONFIGURATIONS.

3.1.1.1 Ground Test Tank Dimensional Data. The dimensioning conventions and data describing the elements making up all three configurations of the ground test tank are detailed in Figure 3.1.1.1 and Tables 3-I and 3-II.

3.1.1.2 Ground Test Tank Internal Components. The location, size, configuration and materials of dummy internal tank components which will be installed in the three ground test tank configurations are fully detailed on the following NASA drawings which are included in Appendix A of this Interface Requirements document.

Configuration 1 Internal Components (see NASA Drawing NASA TBD in Appendix A)
Configuration 2 Internal Components (see NASA Drawing NASA TBD in Appendix A)
Configuration 3 Internal Components (see NASA Drawing NASA TBD in Appendix A)

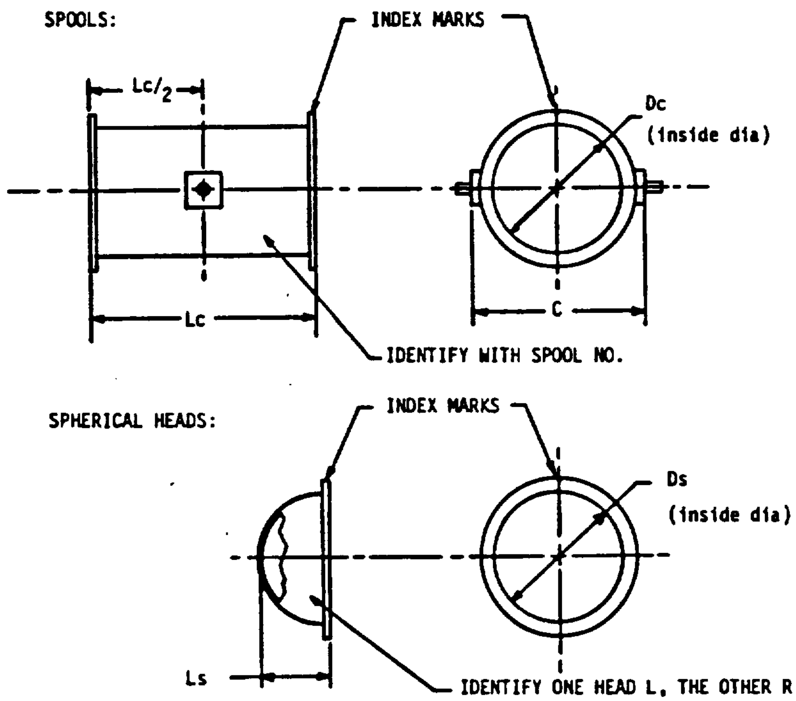



Figure 3.1.1.1. DIMENSIONING CONVENTIONS.

Table 3-I.
SPOOL DIMENSIONS.

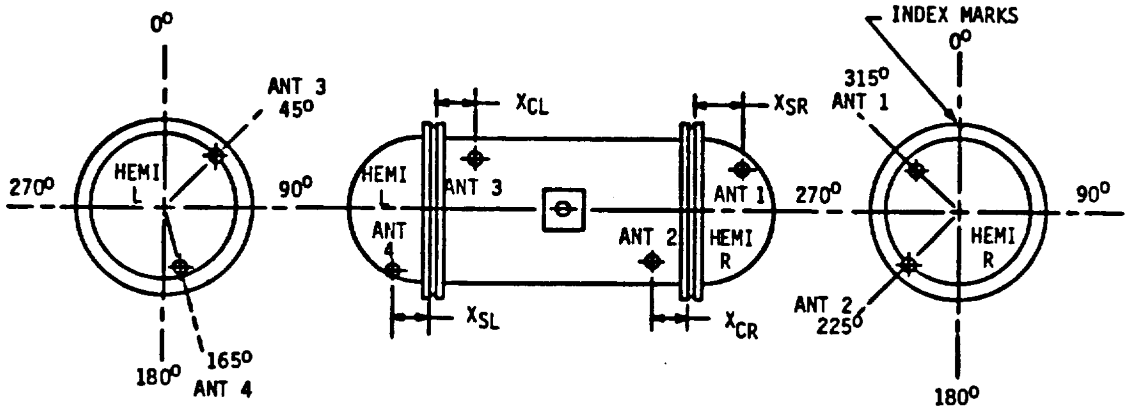
| SPOOL NO. | Dc INCHES | Lc INCHES | C INCHES |
|---|---|---|---|
| NO. 1 | (NASA TBD) | (NASA TBD) | (NASA TBD) |
| NO. 2 | (NASA TBD) | (NASA TBD) | (NASA TBD) |

Table 3-II.
SPHERICAL HEAD DIMENSIONS.

| SPHERICAL HEAD | Ds INCHES | Ls INCHES |
|---|---|---|
| L | (NASA TBD) | (NASA TBD) |
| R | (NASA TBD) | (NASA TBD) |

NOTE: COMPRESSED GASKET HEIGHTS ARE (NASA TBD) INCHES.

3.1.1.3 Ground Test Tank Antenna Locations. The coordinate system for locating ground test tank antenna installation center points on the outside surface of the tank elements is detailed in Figure 3.1.1.3. The antenna locations for each of the three ground test tank configurations are detailed in Tables 3-III, 3-IV and 3-V.




NOTE: ANTENNAS SHOWN ARE ONLY FOR ILLUSTRATION OF THE COORDINATE SYSTEM. LOCATIONS ARE TABULATED BELOW FOR THESE EXAMPLES.

| ANTENNA NO. | LINEAL COORDINATE | RADIAL COORDINATE |
|---|---|---|
| 1 | $X_{SR}$ | 315° |
| 2 | $X_{CR}$ | 225° |
| 3 | $X_{CL}$ | 45° |
| 4 | $X_{SL}$ | 165° |

FIGURE 3.1.1.3. ANTENNA COORDINATES.

Table 3-III.
CONFIGURATION 1 ANTENNA LOCATIONS.

| ANTENNA LOCATION-TANK CONFIGURATION 1 | | |
|---|---|---|
| ANTENNA NO. | LINEAL COORDINATE-in | RADIAL COORDINATE-deg |
| (BAC TBD) | (BAC TBD) | (BAC TBD) |
| (BAC TBD) | (BAC TBD) | (BAC TBD) |
| (BAC TBD) | (BAC TBD) | (BAC TBD) |
| (BAC TBD) | (BAC TBD) | (BAC TBD) |

Table 3-IV.
CONFIGURATION 2 ANTENNA LOCATIONS.

| ANTENNA LOCATION-TANK CONFIGURATION 2 | | |
|---|---|---|
| ANTENNA NO. | LINEAL COORDINATE-in | RADIAL COORDINATE-deg |
| (BAC TBD) | (BAC TBD) | (BAC TBD) |
| (BAC TBD) | (BAC TBD) | (BAC TBD) |
| (BAC TBD) | (BAC TBD) | (BAC TBD) |
| (BAC TBD) | (BAC TBD) | (BAC TBD) |

Table 3-V.
CONFIGURATION 3 ANTENNA LOCATIONS.

| ANTENNA LOCATION-TANK CONFIGURATION 3 | | |
|---|---|---|
| ANTENNA NO. | LINEAL COORDINATE-in | RADIAL COORDINATE-deg |
| (BAC TBD) | (BAC TBD) | (BAC TBD) |
| (BAC TBD) | (BAC TBD) | (BAC TBD) |
| (BAC TBD) | (BAC TBD) | (BAC TBD) |
| (BAC TBD) | (BAC TBD) | (BAC TBD) |

3.1.2 Flight Test Tank Configuration. A single "gaged tank" configuration will be used for KC-135 zero-gravity tests. This tank will be capable of tethered operation only during periods of near zero gravity. The simulant fluid level in the "gaged tank" will be capable of variation during normal KC-135 flight by means of a supporting sump tank and pumping system. Fluid connections between the sump tank system and the gaged tank will only be in place during fluid transfer operations. The connection method will be self-sealing quick disconnects.

An illustration of the flight test tank configuration is shown in Figure 3.1.2.

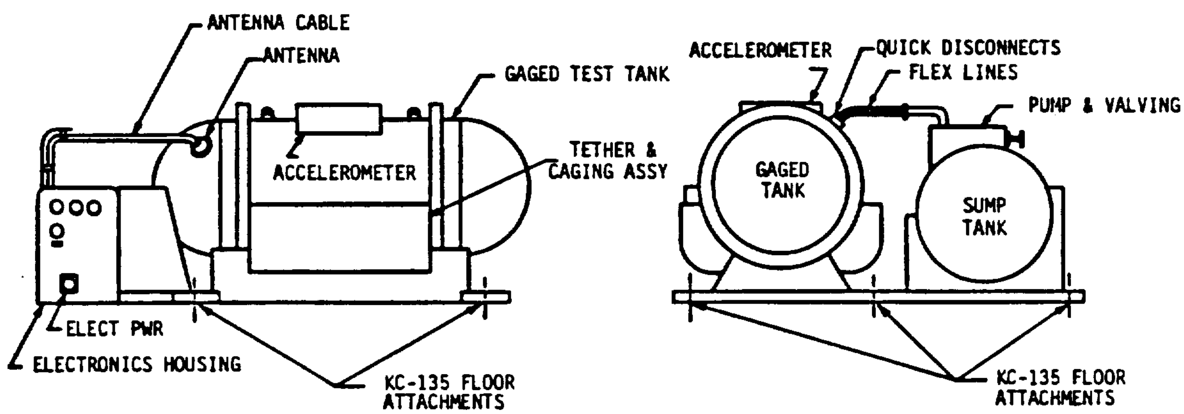



Figure 3.1.2. FLIGHT TEST TANK CONFIGURATION.

NOTE: THIS FIGURE IS A BEECH CONCEPTUALIZATION OF A POSSIBLE KC-135 TEST BED. THE ACTUAL ILLUSTRATION WILL BE PROVIDED BY NASA.

3.1.2.1 Flight Test Tank Dimensional Data. The dimensioning conventions and data describing the flight test tank are shown in Figure 3.1.2.1 and Table 3-VI. The test tank utilizes hemispherical heads.

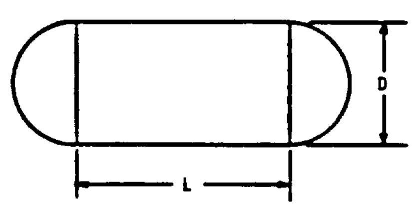



Figure 3.1.2.1. DIMENSIONING CONVENTION.

Table 3-VI. FLIGHT TEST TANK DIMENSIONS.

| DIAMETER D-inches | HEAD THICKNESS-in | CYLINDER THICKNESS-in | LENGTH L-inches |
|---|---|---|---|
| (NASA TBD) | (NASA TBD) | (NASA TBD) | (NASA TBD) |

3.1.2.2 Flight Test Tank Internal Components. The location, size, configuration and materials of dummy internal tank components, which will be installed in the KC-135 flight test tank are fully detailed on the following NASA drawing which is included in Appendix A.

Flight Tank Internal Components (see NASA drawing NASA TBD in Appendix A.

3.1.2.3 Flight Test Tank Antenna Locations. The coordinate system for locating flight test tank antenna installation center points on the outside surface of the tank is detailed in Figure 3.1.2.3. The antenna locations are detailed in Table 3-VII.

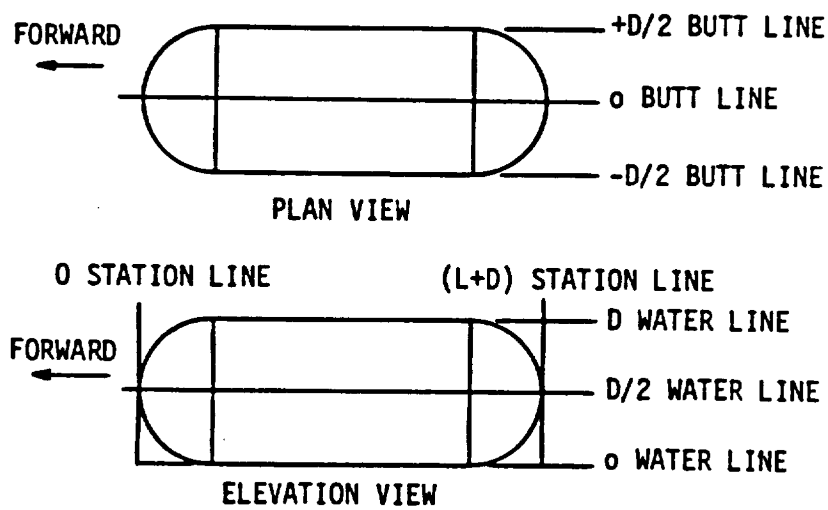



Figure 3.1.2.3. ANTENNA COORDINATES.

Table 3-VII. FLIGHT TANK ANTENNA LOCATIONS.

| ANTENNA LOCATION - KC135 TEST TANK | | | |
|---|---|---|---|
| ANTENNA NO. | BUTTLINE | STATION LINE | WATER LINE |
| (BAC TBD)<br>(BAC TBD)<br>(BAC TBD) | (BAC TBD)<br>(BAC TBD)<br>(BAC TBD) | (BAC TBD)<br>(BAC TBD)<br>(BAC TBD) | (BAC TBD)<br>(BAC TBD)<br>(BAC TBD) |

3.2 Quantity Gaging System Signal Conditioner. The following paragraphs provide the necessary NASA/Beech interface details related to both the ground test and KC-135 test gaging system signal conditioner. The interface issues covered include:

(1) Electrical Interface Requirements
(2) Mechanical Interface Requirements
(3) Environmental Capability

3.2.1 Electrical Interface Requirements. The quantity gaging signal conditioner electrical interface characteristics are described below.

3.2.1.1 Electrical Power:

(1) Mains Requirements. Electrical power to operate the quantity gaging signal conditioner will be 110 to 115 volt AC, 60 Hz at 20 watts. The signal conditioner will incorporate an appropriate circuit breaker to protect the mains source from electrical shorts.

(2) Power Cord. The quantity gaging signal conditioner will be supplied by Beech with an eight foot electrical power cord terminated in a standard NEMA 5-15P grounding plug. This cord can be re-terminated, if required, by NASA to conform to mains connection procedures at the test site. Wiring details of the power cord are as follows:

- Conductors are stranded 18 AWG with vinyl insulation.
- Color coding and conductor connections meet standard practice (live - black, neutral - white, ground - green)
- The power cord is vinyl jacketed
- The power cord ground is connected to the signal conditioner case

3.2.1.2 Output Signal:

(1) Electrical Characteristics. The output signal from the quantity gaging signal conditioner will be linear DC voltage related to the mass quantity of fluid in the test tank. The output voltage will range from

zero volts corresponding to an empty tank to five volts corresponding to a full tank. The output impedance of the output signal will not exceed 100 ohms at any signal level in the zero to five volt range.

(2) Output Connection. The output signal will be available at a three pin MR0214S-1S receptacle on the signal conditioner case. A mating straight plug MS3106R14S-1P will be supplied by Beech for connection to the NASA data acquisition wiring. Pin assignments for the output signal are:

- Pin A Output positive
- Pin B Output return
- Pin C Shield

3.2.1.3 Antenna Drive:

(1) Electrical Characteristics. The antenna drive output from the quantity gaging signal conditioner will be swept frequency UHF signal of 1.0 dbm maximum level. The output impedance of the drive output will be a nominal 50 ohms.

(2) Output Connection. The antenna drive signal(s) will be available at one or more type N coaxial connections on the signal conditioner case (also see Paragraph 3.4).

3.2.1.4 Bonding. A bonding stud meeting the requirements of MIL-B-5087 will be available on the signal conditioner case.

3.2.2 Mechanical Interface Requirments. The quantity gaging signal conditioner mechanical interface characteristics are described below.

3.2.2.1 Envelope Dimensions and Interface Locations. The overall dimensions of the quantity gaging signal conditioner are shown in Figure 3.2.2.1. Dimensions are in inches. Key interface locations are as noted.

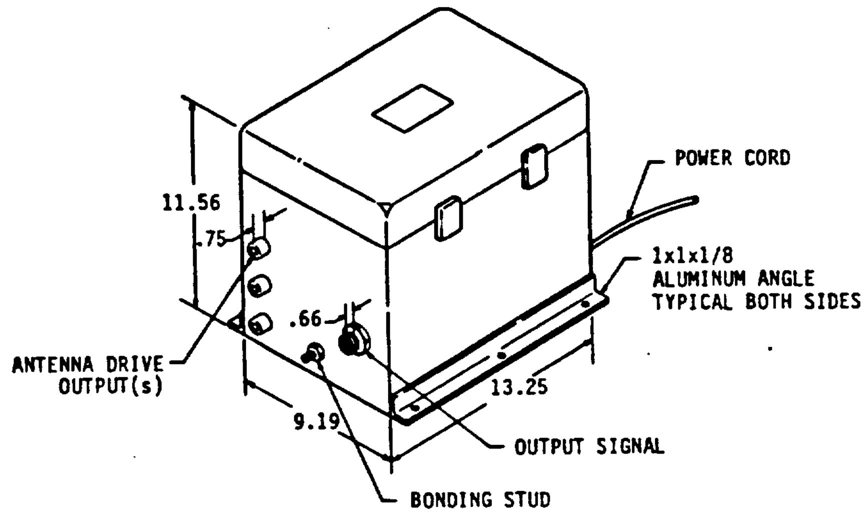



Figure 3.2.2.1. SIGNAL CONDITIONER ENVELOPE.

3.2.2.2 Weight and Center of Gravity. The weight of the quantity gaging signal conditioner will not exceed twenty pounds including the eight foot power cord and plug.

The signal conditioner center of gravity exclusive of the power cord is as indicated in Figure 3.2.2.2.

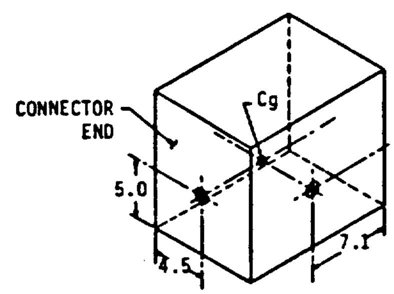



Figure 3.2.2.2. CENTER OF GRAVITY.

3.2.2.3 Mounting Provisions. The signal conditioner case incorporates two mounting angles drilled to clear number 10 mounting hardware. The bolt pattern is as shown in Figure 3.2.2.3.

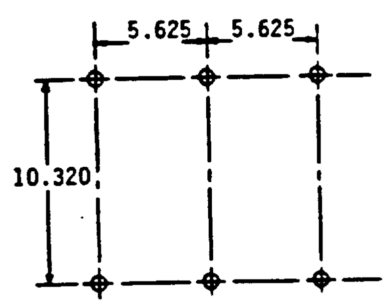



Figure 3.2.2.3. MOUNTING BOLT PATTERN.

3.2.2.4 Signal Conditioner Access. The top of the signal conditioner is hinged so that access to initial set-up controls, diagnostic test points and adjustments can be made. Access clearances required to permit insitu check out, etc., are illustrated in Figure 3.2.2.4.

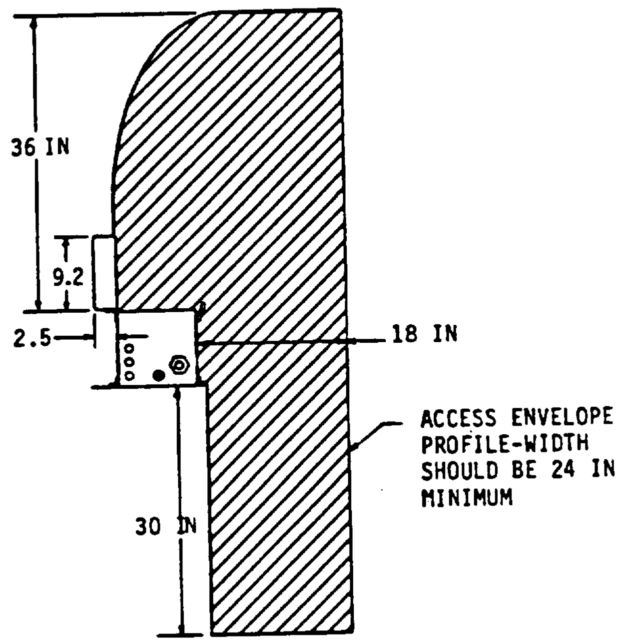



Figure 3.2.2.4. ACCESS ENVELOPE.

3.2.3 Environmental Capability. The quantity gaging signal conditioner environmental capability is detailed below.

3.2.3.1 Temperature Extremes. The signal conditioner will be capable of full accuracy operation over a temperature range of 50°F to 80°F. In addition, the signal conditioner will be capable of non-operating exposure to temperatures over the range of -40°F to +131°F without damage or degradation.

3.2.3.2 Acceleration. The signal conditioner will be capable of accelerations of 9 g's along any axis while in the non-operating mode without damage or degradation. In addition, the signal conditioner will be capable of accelerations of 3 g's along any axis while operating at full accuracy. Mounting provisions of the signal conditioner will be capable of sustaining forward crash loads of 30 g's with damage to the signal conditioner but without failure of the mounting structure.

3.2.3.3 Pressure Extremes. The signal conditioner will be capable of full accuracy operation over an ambient pressure range of 15 psia to 9 psia. In addition, the signal conditioner will be capable of sustaining sudden pressure reductions to 2.7 psia without damage but operation will not necessarily be at full accuracy.

3.2.3.4 Vibration. The signal conditioner will be capable of full accuracy operation while exposed to random vibration levels of 0.0005 $g^2$/Hz over the frequency range of 15 to 2000 Hz.

3.2.3.5 Humidity. The signal conditioner will be capable of full accuracy operation while exposed to up to 100% relative humidity conditions with condensing on the external surfaces of the signal conditioner.

3.3 Quantity Gaging System Antenna(s). The following paragraphs provide the necessary NASA/Beech interface details related to both the ground test and KC-135 test antenna(s). The interface issues covered include:

(1) Electrical Interface Requirements
(2) Mechanical Interface Requirements
(3) Environmental Capability

3.3.1 Electrical Interface Requirements. The gaging system antenna electrical interface characteristics are described below.

3.3.1.1 Antenna Drive Input. The swept frequency UHF signal from the signal conditioner is connected to the antenna at its integral type N coaxial jack. The maximum rf power level delivered to the antenna will not exceed 1 dbm. Figure 3.3.2.1 illustrates the location of the coaxial connection.

3.3.1.2 Bonding. The antenna assemblies must be electrically bonded to the test tank pressure vessels. This bonding will meet the appropriate sections of MIL-B-5087 to achieve a bonding resistance of no more than 0.02 ohm.

3.3.2 Mechanical Interface Requirements. The gaging system antenna mechanical interface characteristics are described below.

3.3.2.1 Envelope Dimensions and Interface Locations. The overall dimensions of a gaging system antenna are as shown in Figure 3.3.2.1. Dimensions are in inches. Key interface locations are as noted.

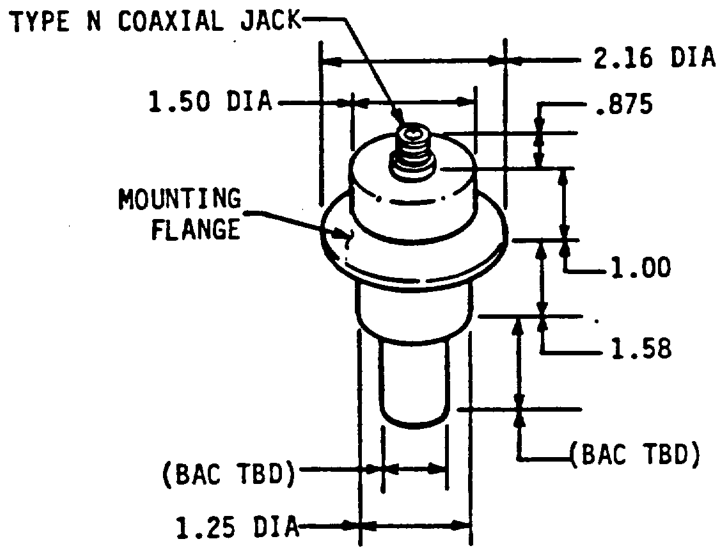



Figure 3.3.2.1. ANTENNA ENVELOPE.

3.3.2.2 Weight and Center of Gravity. The weight of a gaging system antenna will not exceed 1.6 pounds. The center of gravity is as indicated in Figure 3.3.2.2. The weight does not include the tank flange or the flange clamp.

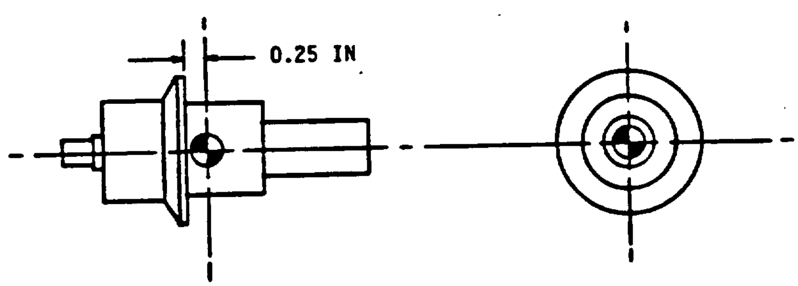



Figure 3.3.2.2. CENTER OF GRAVITY.

3.3.2.3 Mounting Provisions. The gaging system antenna(s) are mounted on the test tanks using HPS Corporation ISO-KF Corporation components as shown in Figure 3.3.2.3. Beech will provide the following mounting components in addition to the antenna(s).

(1) Stainless Steel Clamp HPS Corp P/N 31-3005
(2) Indium T-Ring Seal HPS Corp P/N 31-3805

NASA will provide and install on the test tanks in the appropriate antenna location(s) a flanged long weld stub conforming to HPS Part Number 31-5705. Address and phone number of the HPS Corporation is as follows:

HPS Corporation
1898 S. Flatiron Court
Boulder, CO 80301
(303) 449-9861

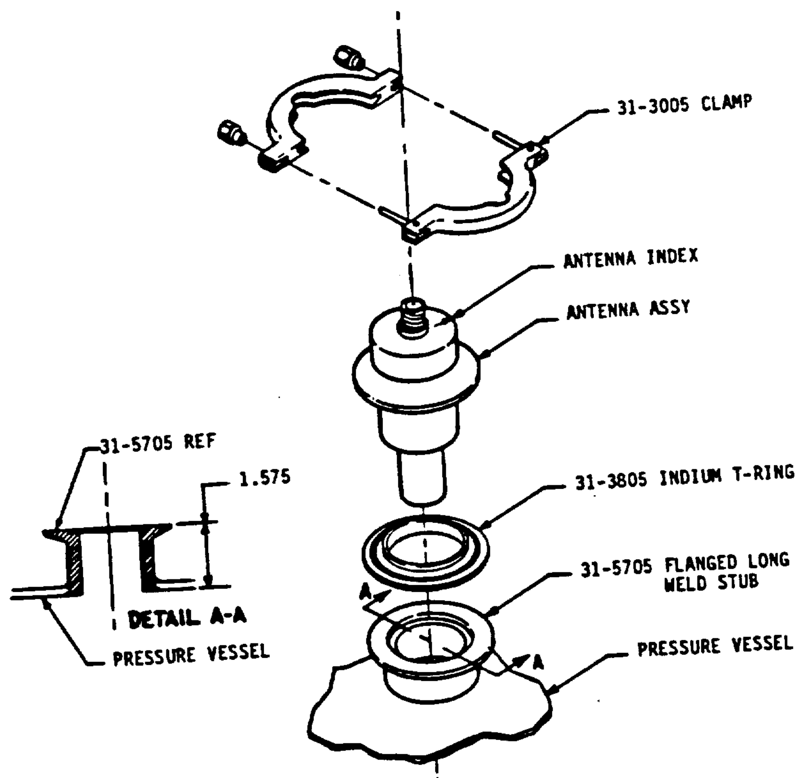



Figure 3.3.2.3. ANTENNA MOUNTING.

3.3.2.4 Antenna Indexing. If required, an index mark will be stamped into the antenna housing near the coaxial connector (see Figure 3.3.2.3). The location of this index with respect to the major test tank axes will be specifically coordinated with NASA and incorporated into this paragraph.

3.3.3 Environmental Capability. The gaging system antenna(s) environmental capability is detailed below.

3.3.3.1 Temperature Extremes. The antenna will be able to operate at full capability over the temperature range of -425°F to +80°F. In addition, the highest non-operating temperature is +131°F.

3.3.3.2 Acceleration. The antenna will be capable of accelerations of 9 g's along any axis while in the non-operating mode without damage or degradation. In addition, the antenna will be capable of accelerations of 3 g's in any axis while operating at full capability. The antenna mounting provisions are capable of sustaining forward crash loads of 30 g's without failure.

3.3.3.3 Pressure Extremes. The antenna will be capable of withstanding pressures of 15 psia to $1 \times 10^{-9}$ Torr on the connector side while experiencing pressures of $1 \times 10^{-9}$ Torr to 40 psia on the antenna side while operating at full capability.

3.3.3.4 Vibration. The antenna will be capable of full operating ability while exposed to random vibration levels of 0.0005 $g^2$/Hz over the frequency range of 15 to 2000 Hz.

3.3.3.5 Humidity. The antenna will, when properly connected, be capable of full operating ability while exposed to up to 100% relative humidity conditions with condensing on the connector side surfaces.

3.4 Antenna/Signal Conditioner Interconnections. The following paragraphs provide the necessary NASA/Beech interface details related to both the ground test and KC-135 test antenna/signal conditioner interconnections. The interface issues covered include:

(1) Interface Cabling Configurations

(2) Interface Cabling Major Components

3.4.1 Ground Test Antenna/Signal Conditioner Interconnections. The interconnecting antenna cable routing is illustrated in Figure 3.4.1, while the major cable components are identified in Table 3-VIII and Figure 3.4.1.

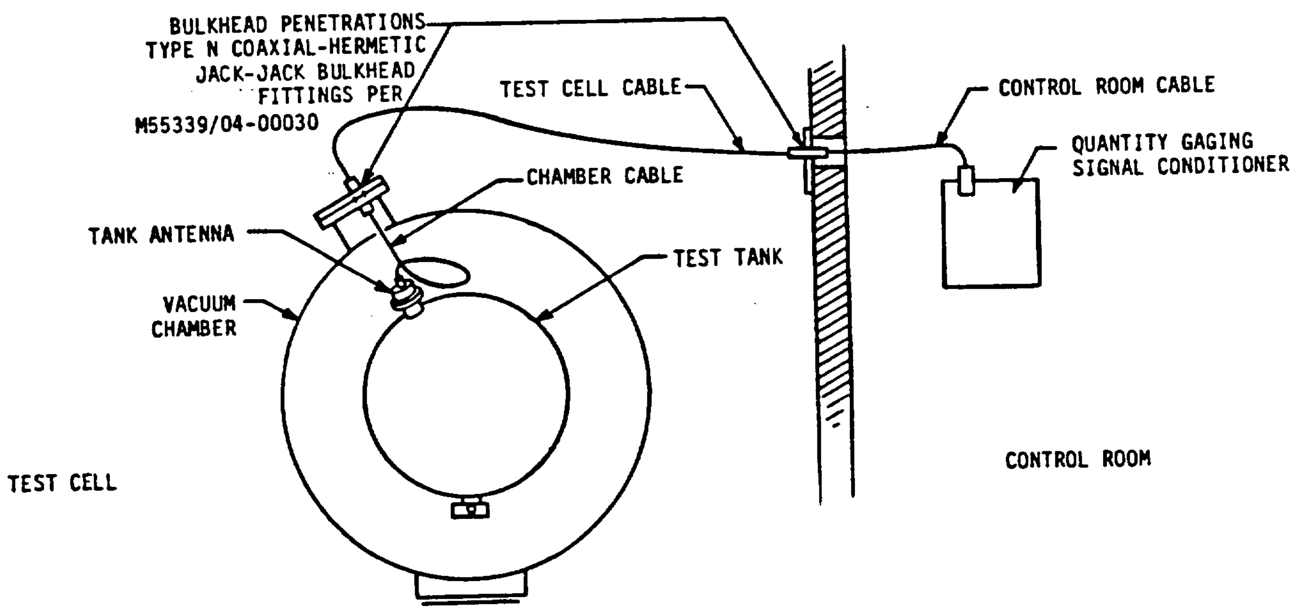



Figure 3.4.1. ANTENNA CABLE ROUTING - GROUND TEST.

Table 3-VIII. CABLE COMPONENTS.

| INTERCONNECTING CABLE REQUIREMENTS PER TANK ANTENNA | | | |
|---|---|---|---|
| CABLE IDENTIFICATION | COAXIAL CABLE | END FITTINGS-BOTH ENDS | LENGTH-IN |
| Control Room | RG142 B/U | Type N Coaxial Plug (male) | (NASA TBD) |
| Test Cell | RG142 B/U | Type N Coaxial Plug (male) | (NASA TBD) |
| Vacuum Chamber | RG142 B/U | Type N Coaxial Plug (male) | (NASA TBD) |
| | | TOTAL LENGTH NOT TO EXCEED 300 INCHES | |

3.4.2 KC-135 Antenna/Signal Conditioner Interconnections. The interconnecting antenna cable routing is illustrated in Figure 3.4.2, while the major cable components are identified in Table 3-VIV.

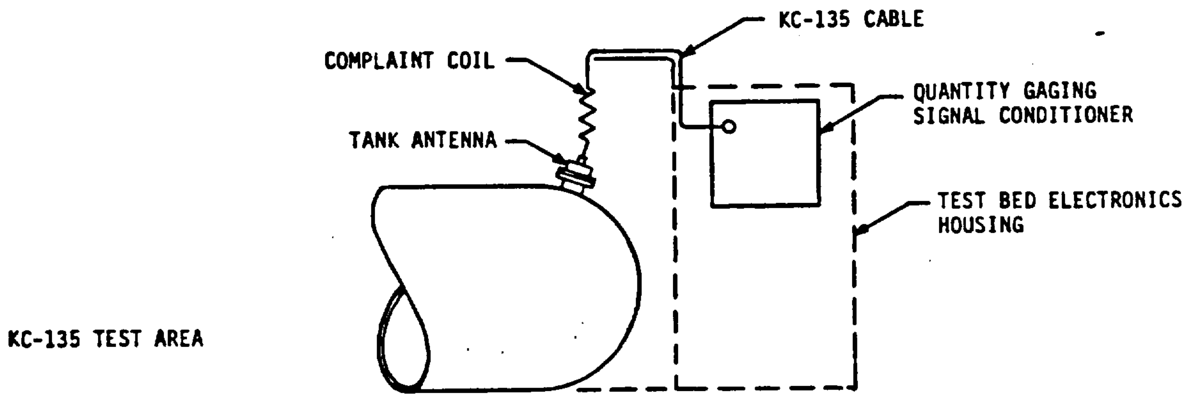



Figure 3.4.2. ANTENNA CABLE ROUTING - KC-135 TEST.

Table 3-VIV. CABLE COMPONENTS.

| INTERCONNECTING CABLE REQUIREMENTS PER TANK ANTENNA | | | |
|---|---|---|---|
| CABLE IDENTIFICATION | COAXIAL CABLE | END FITTINGS-BOTH ENDS | LENGTH-IN |
| KC-135 | RG142 B/U | Type N Coaxial Plug (male) | *(NASA TBD) |
| *TOTAL LENGTH NOT TO EXCEED 300 INCHES | | | |

3.5 Simulant Test Fluid. The simulant fluid which will be used for both ground and KC-135 tests is DIALA-AX oil. This fluid has been judged to have suitable electrical and physical properties as well as acceptably low hazard ratings for health, fire and reactivity. The manufacturer's Technical Bulletin and Safety Data Sheets are included in Appendix B.

# APPENDIX A

## NASA DRAWINGS

NASA DRAWINGS TBD

The NASA Drawings
will be incorporated
upon receipt by
Beech Aircraft Corporation.

# APPENDIX B

## DIALA-AX OIL

Technical Bulletin
and
Material Safety Data Sheets

SOC:39-85
(Supersedes SOC:39-82)

# Technical Bulletin
# Shell Oil Company

# DIALA® A OIL, DIALA AX OIL

## Electrical insulating oils for rapid heat transmission with high oxidation stability

### Meet ANSI/ASTM/NEMA standards

**Product description**

Shell's *Diala®* Oils meet the ANSI/ASTM D 3487 and the NEMA TR-P8-1975 Specifications.

Two oils (designated Type I and Type II) are covered in these specifications. Type I oil is intended for use where normal oxidation resistance is required. Type II oil is for more severe service applications requiring greater oxidation resistance.

*Diala* A Oil meets the ANSI/ASTM/NEMA Type I requirements without addition of oxidation inhibitor. *Diala* AX Oil meets Type II requirements and contains approximately 0.2%w of oxidation inhibitor. Anti-oxidant concentration is varied to meet Rotating Bomb Oxidation Test requirements, but does not exceed the 0.3%w maximum of Type II requirements.

*Diala* A Oil is approved under G.E.'s Specification A13A3A1 (10C) and Westinghouse's PD 55822 AG Rev. G-WEMCO C. *Diala* AX Oil has G.E. A13A3A2 (10CA) and Westinghouse PD 55822 AV Rev. T-WEMCO CI approvals.

*Diala* base oils are well-refined from low pour point naphthenic stocks.

**Applications**

Shell's *Diala* Oils are excellent for use in transformers, circuit breakers, oil-filled switches and in X-ray equipment. These oils provide electrical insulation and heat transfer in such electrical devices. *Diala* Oils have the oxidation stability required to resist the formation of acids that might attack construction materials and the formation of other oxidation products that can reduce the oil's ability to insulate and cool electrical windings.

**Availability**

*Diala* A and AX Oils are available nationwide for domestic use or export. Contact your Shell Oil Sales Office for your requirements.

**Handling & safety information**

*Diala* Oil is formulated with refined petroleum oil and a lubricant additive. Their inherent toxicity is quite low. However, prolonged or repeated contact requires the observation of good industrial hygiene practices.

On ingestion, get medical attention. On eye contact, flush with water for at least 15 minutes, get medical attention. Frequent or prolonged skin contact should be avoided. Inhalation of vapors or oil mist may irritate the lungs.

Good industrial hygiene practice requires the use of effective ventiliation to remove oil vapors and mist. Skin contact is minimized by the use of rubber gloves and oil resistant, non-absorbent clothing. After working with lubricants, wash thoroughly with soap and water before eating or smoking. Change clothing soaked with oil, reuse only after laundering.

If more detailed information is required, *Material Safety Data Sheets* are available on *Diala* Oil at your request.

## Typical Properties Diala® Oils

| | ASTM Test method | ANSI/ASTM/ NEMA limits Type I & Type II | | Diala A/AX Oils Typical values | |
|---|---|---|---|---|---|
| **Physical properties** | | | | | |
| Aniline point, °C | D 611 | 63-78 | | 74 | |
| Color | D 1500 | 0.5 max | | <0.5 | |
| Flash point, °C | D 92 | 145 min | | 148 | |
| Interfacial tension, 25°C, dynes/centimeter | D 971 | 40 min | | 45 | |
| Pour Point °C | D 97 | −40 max | | −60 | |
| Specific gravity, 15/15°C | D 1298 | 0.91 max | | 0.886 | |
| Viscosity, cSt/SUS at: 100°C | D 445/D 88 | 3.0/36 max | | 2.34/34.3 | |
| 40°C | D 445/D 88 | 12.0/66 max | | 8.37/56.7 | |
| 0°C | D 445/D 88 | 76.0/350 max | | 66/304 | |
| Visual examination | D 1524 | Clear & bright | | Clear & bright | |
| **Electrical properties** | | | | | |
| Dielectric breakdown voltage at 60 hertz. | | | | | |
| Disc electrodes, Kv | D 877 | 30 min | | 35 | |
| VDE electrodes, Kv, either: 0.040 inch (1.02mm) gap | D 1816[1] | 28 min | | >28 | |
| 0.080 inch (2.04mm) gap | | 56 | | >56 | |
| Dielectric breakdown voltage impulse, 25°C, needle-to-sphere grounded, 1-inch (25.4mm) gap, Kv | D 3300 | 145 min | | 176 | |
| Power factor, 60 hertz, % at: 25°C | D 924 | 0.05 max | | 0.01 | |
| 100°C | D 924 | 0.30 max | | 0.07 | |
| **Chemical properties** | | Type I | Type II | Diala A Oil | Diala AX Oil |
| Oxidation inhibitor content, %w 2,6-ditertuary butyl paracresol | D 2668 or D 1473 | 0.08 max | 0.3 max | None | 0.19 |
| Corrosive sulfur | D 1275 | Non-corrosive | | Non-corrosive | |
| Water, ppm | D 1533 or D 1315 | 35 max | | 30 | |
| Neutralization no., mg KOH/g of oil | D 974 | 0.03 max | | 0.01 | |
| Oxidation stability at: | | | | | |
| 72 hrs | D 2440 | | | | |
| Sludge, %w | | 0.15 max | 0.10 max | 0.04 | 0.03 |
| TAN-C, mg KOH/g of oil | | 0.50 max | 0.30 max | 0.27 | 0.21 |
| 164 hrs | | | | | |
| Sludge, %w | | 0.30 max | 0.20 max | 0.15 | 0.05 |
| TAN-C, mg KOH/g of oil | | 0.60 max | 0.40 max | 0.35 | 0.26 |
| Oxidation stability, rotating bomb, minutes | D 2112 | | 195 min | | 250 |

[1] D 1816 applies only to new, filtered, dehydrated and degassed oil.

**Supplemental Information Diala® Oils**

| | ASTM Test method | ANSI/ASTM NEMA Oils Typical values | Diala A/AX Oils Typical values |
|---|---|---|---|
| Gassing tendency, µl/min. | D 2300 | Report | 16 |
| Coefficient of expansion, ml/°C/ml | D 1903 | 0.0007-0.0008 | 0.00075 |
| Dielectric constant at 25°C | D 924 | 2.2-2.3 | 2.2-2.3 |
| Specific heat, gm-cal/gm at 20°C | D 2766 | 0.44 | 0.445 |
| Thermal conductivity, cal/cm/sec/°C | D 2717 | 0.0003-0.0004 | 0.0003 |
| API gravity, 60/60°F | D 287 | | 28.1 |
| Color, Saybolt | D 156 | | 20 |
| Viscosity, SUS at 100°F | D 445/D 2161 | | 58.8 |
| 210°F | D 445/D 2161 | | 34.1 |
| Viscosity, cSt at 100°F | D 445 | | 10.0 |
| 210°F | D 445 | | 2.38 |
| Viscosity index | D 2270 | | 45 |
| Steam emulsion no. | D 1935 | | 15 |
| Sulfur, %w | D 2622 | | 0.07 |
| Molecular weight | D 2503 | | 261 |
| Refractive index | D 1218 | | 1.4815 |
| Viscosity-gravity constant | D 2140 | | 0.865 |
| Carbon type composition: % $C_A$ | D 2140 | | 7 |
| % $C_N$ | | | 47 |
| % $C_P$ | | | 46 |

**Shell Oil Company Lubricants Sales Offices**

| | |
|---|---|
| East Coast<br>(201) 325-5450 | 100 Executive Drive<br>West Orange, New Jersey 07052 |
| Chicago<br>(312) 887-5706<br>(800) 323-3405 | 1415 West 22nd Street<br>Oak Brook, Illinois 60521 |
| Cleveland<br>(216) 842-4000 | 7123 Pearl Road<br>Middleburg Heights, Ohio 44130 |
| Houston<br>(713) 439-1000 | 24 Greenway Plaza, Suite 711<br>Houston, Texas 77046 |
| West Coast<br>(714) 991-9200 | 511 N. Brookhurst Street<br>Anaheim, California 92803 |

**Shell Oil Company Head Office Sales**

| | |
|---|---|
| Houston<br>(713) 241-4201 | One Shell Plaza<br>P.O. Box 2463<br>Houston, Texas 77001 |

**Warranty**

All products purchased from Shell are subject to terms and conditions set out in the contract, order acknowledgement and/or bill of lading. Shell warrants only that its product will meet those specifications designated as such herein or in other publications. All other information supplied by Shell is considered accurate but is furnished upon the express condition that the customer shall make its own assessment to determine the product's suitability for a particular purpose. No warranty is expressed or implied regarding such other information, the data upon which the same is based, or the results to be obtained from the use thereof; that any product shall be merchantable or fit for any particular purpose; or that the use of such other information or product will not infringe any patent.

June 1985

Shell

# MATERIAL SAFETY DATA SHEET

MSDS NUMBER ▶ 60,030-5 PAGE 1

97307 (4-85)

| 24 HOUR EMERGENCY ASSISTANCE | GENERAL MSDS ASSISTANCE |
|---|---|
| SHELL: 713-473-9461 CHEMTREC: 800-424-9300 | SHELL: 713-241-4819 |

| ACUTE HEALTH * | FIRE | REACTIVITY | HAZARD RATING ▶ |
|---|---|---|---|
| 1 | 1 | 0 | LEAST - 0 SLIGHT - 1 MODERATE - 2 HIGH - 3 EXTREME - 4 |

*For acute and chronic health effects refer to the discussion in Section III

BE SAFE
READ OUR PRODUCT SAFETY INFORMATION ...AND PASS IT ON
(PRODUCT LIABILITY LAW REQUIRES IT)

| SECTION I | NAME |
|---|---|
| PRODUCT ▶ | SHELL DIALA(R) OIL AX |
| CHEMICAL NAME ▶ | MIXTURE (SEE SEC II-A) |
| CHEMICAL FAMILY ▶ | PETROLEUM HYDROCARBON: INDUSTRIAL OIL |
| SHELL CODE ▶ | 68702 69702 63702 63722 |

## SECTION II-A PRODUCT/INGREDIENT

| NO. | COMPOSITION | CAS NUMBER | PERCENT |
|---|---|---|---|
| P | SHELL DIALA OIL AX | MIXTURE | 100 |
| 1 | SOLVENT REFINED HYDROTREATED MIDDLE DISTILLATE | 64742-46-7 | 60-100 |
| 2 | SEVERELY HYDROTREATED LIGHT NAPHTHENIC DISTILLATE | 64742-53-6 | 0-40 |
| 3 | BUTYLATED HYDROXY TOLUENE | 128-37-0 | <0.2 |

## SECTION II-B ACUTE TOXICITY DATA

| NO. | ACUTE ORAL LD50 | ACUTE DERMAL LD50 | ACUTE INHALATION LC50 |
|---|---|---|---|
| P | >10 ML/KG. RAT | >2 ML/KG. RAT | NOT AVAILABLE |

BASED UPON DATA AVAILABLE TO SHELL, COMPONENT 3 IN THIS PRODUCT IS NOT HAZARDOUS UNDER OSHA HAZARD COMMUNICTION (29 CFR 1910.1200).

## SECTION III HEALTH INFORMATION

THE HEALTH EFFECTS NOTED BELOW ARE CONSISTENT WITH REQUIREMENTS UNDER THE OSHA HAZARD COMMUNICATION STANDARD (29 CFR 1910.1200).

**EYE CONTACT**
BASED ON ESSENTIALLY SIMILAR PRODUCT TESTING PRODUCT IS PRESUMED TO BE NONIRRITATING TO THE EYES.

**SKIN CONTACT**
BASED ON ESSENTIALLY SIMILAR PRODUCT TESTING PRODUCT IS PRESUMED TO BE SLIGHTLY IRRITATING TO THE SKIN. PROLONGED AND REPEATED CONTACT MAY RESULT IN VARIOUS SKIN DISORDERS SUCH AS DERMATITIS. FOLLICULITIS OR OIL ACNE.

**INHALATION**
INHALATION OF VAPORS (GENERATED AT HIGH TEMPERATURES ONLY) OR OIL MIST MAY CAUSE A MILD IRRITATION OF THE MUCOUS MEMBRANES OF THE UPPER RESPIRATORY TRACT.

**INGESTION**
INGESTION OF PRODUCT MAY RESULT IN VOMITING; ASPIRATION (BREATHING OF VOMITUS INTO THE LUNGS) MUST BE AVOIDED AS EVEN SMALL QUANTITIES MAY RESULT IN ASPIRATION PNEUMONITIS.

PRODUCT NAME: SHELL DIALA(R) OIL AX

MSDS 80,030-5
PAGE 2

SIGNS AND SYMPTOMS
IRRITATION AS NOTED ABOVE. ASPIRATION PNEUMONITIS MAY BE EVIDENCED BY COUGHING, LABORED BREATHING AND CYANOSIS (BLUISH SKIN); IN SEVERE CASES DEATH MAY OCCUR.

AGGRAVATED MEDICAL CONDITIONS
PREEXISTING SKIN AND RESPIRATORY DISORDERS MAY BE AGGRAVATED BY EXPOSURE TO THIS PRODUCT.

SECTION IV — OCCUPATIONAL EXPOSURE LIMITS

| | OSHA | | ACGIH | | OTHER |
|---|---|---|---|---|---|
| NO. | PEL/TWA | PEL/CEILING | TLV/TWA | TLV/STEL | |
| P | 5 MG/M3* | NONE | 5 MG/M3* | 10 MG/M3* | NONE |

*OIL MIST, MINERAL

SECTION V — EMERGENCY AND FIRST AID PROCEDURES

EYE CONTACT
FLUSH EYES WITH WATER. IF IRRITATION OCCURS, GET MEDICAL ATTENTION.

SKIN CONTACT
REMOVE CONTAMINATED CLOTHING/SHOES AND WIPE EXCESS FROM SKIN. FLUSH SKIN WITH WATER. FOLLOW BY WASHING WITH SOAP AND WATER. IF IRRITATION OCCURS, GET MEDICAL ATTENTION.

INHALATION
REMOVE VICTIM TO FRESH AIR AND PROVIDE OXYGEN IF BREATHING IS DIFFICULT. GET MEDICAL ATTENTION.

INGESTION
DO NOT INDUCE VOMITING. IF VOMITING OCCURS SPONTANEOUSLY, KEEP HEAD BELOW HIPS TO PREVENT ASPIRATION OF LIQUID INTO THE LUNGS. GET MEDICAL ATTENTION.

NOTE TO PHYSICIAN
IF MORE THAN 2.0 ML PER KG HAS BEEN INGESTED AND VOMITING HAS NOT OCCURRED, EMESIS SHOULD BE INDUCED WITH SUPERVISION. KEEP VICTIM'S HEAD BELOW HIPS TO PREVENT ASPIRATION. IF SYMPTOMS SUCH AS LOSS OF GAG REFLEX, CONVULSIONS OR UNCONSCIOUSNESS OCCUR BEFORE EMESIS, GASTRIC LAVAGE USING A CUFFED ENDOTRACHEAL TUBE SHOULD BE CONSIDERED.

SECTION VI — SUPPLEMENTAL HEALTH INFORMATION

NONE IDENTIFIED.

SECTION VII — PHYSICAL DATA

BOILING POINT: >300 (DEG F)

SPECIFIC GRAVITY: 0.883 (H2O=1)

VAPOR PRESSURE: NOT AVAILABLE (MM HG)

MELTING POINT: -60 (POUR POINT) (DEG F)

SOLUBILITY: NEGLIGIBLE (IN WATER)

VAPOR DENSITY: NOT AVAILABLE (AIR=1)

EVAPORATION RATE (N-BUTYL ACETATE = 1): NOT AVAILABLE

VIS CS (40 DEG C) 9.07-9.3

PRODUCT NAME: SHELL DIALA(R) OIL AX

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PAGE 3

APPEARANCE AND ODOR: WHITE LIQUID. SLIGHT HYDROCARBON ODOR.

## SECTION VIII FIRE AND EXPLOSION HAZARDS

FLASH POINT AND METHOD:
285-310 DEG F (COC)

FLAMMABLE LIMITS /% VOLUME IN AIR
LOWER: N/AVA UPPER: N/AVA

EXTINGUISHING MEDIA
USE WATER FOG, FOAM, DRY CHEMICAL OR CO2. DO NOT USE A SIRECT STREAM OF WATER. PRODUCT WILL FLOAT AND CAN BE REIGNITED ON SURFACE OF WATER.

SPECIAL FIRE FIGHTING PROCEDURES AND PRECAUTIONS
MATERIAL WILL NOT BURN UNLESS PREHEATED. DO NOT ENTER CONFINED FIRE-SPACE WITHOUT FULL BUNKER GEAR (HELMET WITH FACE SHIELD, BUNKER COATS, GLOVES AND RUBBER BOOTS), INCLUDING A POSITIVE-PRESSURE NIOSH-APPROVED SELF-CONTAINED BREATHING APPARATUS. COOL FIRE EXPOSED CONTAINERS WITH WATER.

## SECTION IX REACTIVITY

STABILITY: STABLE

HAZARDOUS POLYMERIZATION: WILL NOT OCCUR

CONDITIONS AND MATERIALS TO AVOID:
AVOID HEAT, OPEN FLAMES, AND OXIDIZING MATERIALS.

HAZARDOUS DECOMPOSITION PRODUCTS
THERMAL DECOMPOSITION PRODUCTS ARE HIGHLY DEPENDENT ON THE COMBUSTION CONDITIONS. A COMPLEX MIXTURE OF AIRBORNE SOLID, LIQUID, PARTICULATES AND GASES WILL EVOLVE WHEN THIS MATERIAL UNDERGOES PYROLYSIS OR COMBUSTION. CARBON MONOXIDE AND OTHER UNIDENTIFIED ORGANIC COMPOUNDS MAY BE FORMED UPON COMBUSTION.

## SECTION X EMPLOYEE PROTECTION

RESPIRATORY PROTECTION
IF EXPOSURE MAY OR DOES EXCEED OCCUPATIONAL EXPOSURE LIMITS (SECTION IV) USE A NIOSH-APPROVED RESPIRATOR TO PREVENT OVEREXPOSURE. IN ACCORD WITH 29 CFR 1910.134 USE EITHER AN ATMOSPHERE-SUPPLYING RESPIRATOR OR AN AIR-PURIFYING RESPIRATOR FOR ORGANIC VAPORS AND PARTICULATES.

PROTECTIVE CLOTHING
WEAR CHEMICAL-RESISTANT GLOVES AND OTHER PROTECTIVE CLOTHING AS REQUIRED TO MINIMIZE SKIN CONTACT. NO SPECIAL EYE PROTECTION IS ROUTINELY NECESSARY. TEST DATA FROM PUBLISHED LITERATURE AND/OR GLOVE AND CLOTHING MANUFACTURERS INDICATE THE BEST PROTECTION IS PROVIDED BY NITRILE GLOVES.

## SECTION XI ENVIRONMENTAL PROTECTION

SPILL OR LEAK PROCEDURES
MAY BURN ALTHOUGH NOT READILY IGNITABLE. USE CAUTIOUS JUDGMENT WHEN CLEANING UP LARGE SPILLS. *** LARGE SPILLS *** WEAR RESPIRATOR AND PROTECTIVE CLOTHING AS APPROPRIATE. SHUT OFF SOURCE OF LEAK IF SAFE TO DO SO. DIKE AND CONTAIN. REMOVE WITH VACUUM TRUCKS OR PUMP TO STORAGE SALVAGE VESSELS. SOAK UP RESIDUE WITH AN ADSORBENT SUCH AS CLAY, SAND, OR OTHER SUITABLE MATERIALS: DISPOSE OF PROPERLY. FLUSH AREA WITH WATER TO REMOVE TRACE RESIDUE. *** SMALL SPILLS *** TAKE UP WITH AN ABSORBENT MATERIAL AND DISPOSE OF PROPERLY.

WASTE DISPOSAL
PLACE IN AN APPROPRIATE DISPOSAL FACILITY IN COMPLIANCE WITH LOCAL REGULATIONS.

ENVIRONMENTAL HAZARDS
THIS PRODUCT IS CLASSIFIED AS AN OIL UNDER SECTION 311 OF THE CLEAN WATER ACT. SPILLS ENTERING (A) SURFACE WATERS OR (B) ANY WATER COURSES OR SEWERS ENTERING/LEADING TO SURFACE WATERS THAT CAUSE A SHEEN MUST BE REPORTED TO THE NATIONAL RESPONSE CENTER. 800-424-8602.

PRODUCT NAME: SHELL DIALA(R) OIL AX

MSDS 60,030-5
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SECTION XII SPECIAL PRECAUTIONS

---

MINIMIZE SKIN CONTACT. WASH WITH SOAP AND WATER BEFORE EATING, DRINKING, SMOKING OR USING TOILET FACILITIES. LAUNDER CONTAMINATED CLOTHING BEFORE REUSE. PROPERLY DISPOSE OF CONTAMINATED LEATHER ARTICLES, INCLUDING SHOES, THAT CANNOT BE DECONTAMINATED.

---

SECTION XIII TRANSPORTATION REQUIREMENTS

---

DEPARTMENT OF TRANSPORTATION CLASSIFICATION: NOT HAZARDOUS BY D.O.T. REGULATIONS

---

SECTION XIV OTHER REGULATORY CONTROLS

---

THE COMPONENTS OF THIS PRODUCT ARE LISTED ON THE EPA/TSCA INVENTORY OF CHEMICAL SUBSTANCES.

---



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DATE PREPARED: JULY 25, 1985

JOHN P. SEPESI

BE SAFE
READ OUR PRODUCT
SAFETY INFORMATION ...AND PASS IT ON
(PRODUCT LIABILITY LAW
REQUIRES IT)

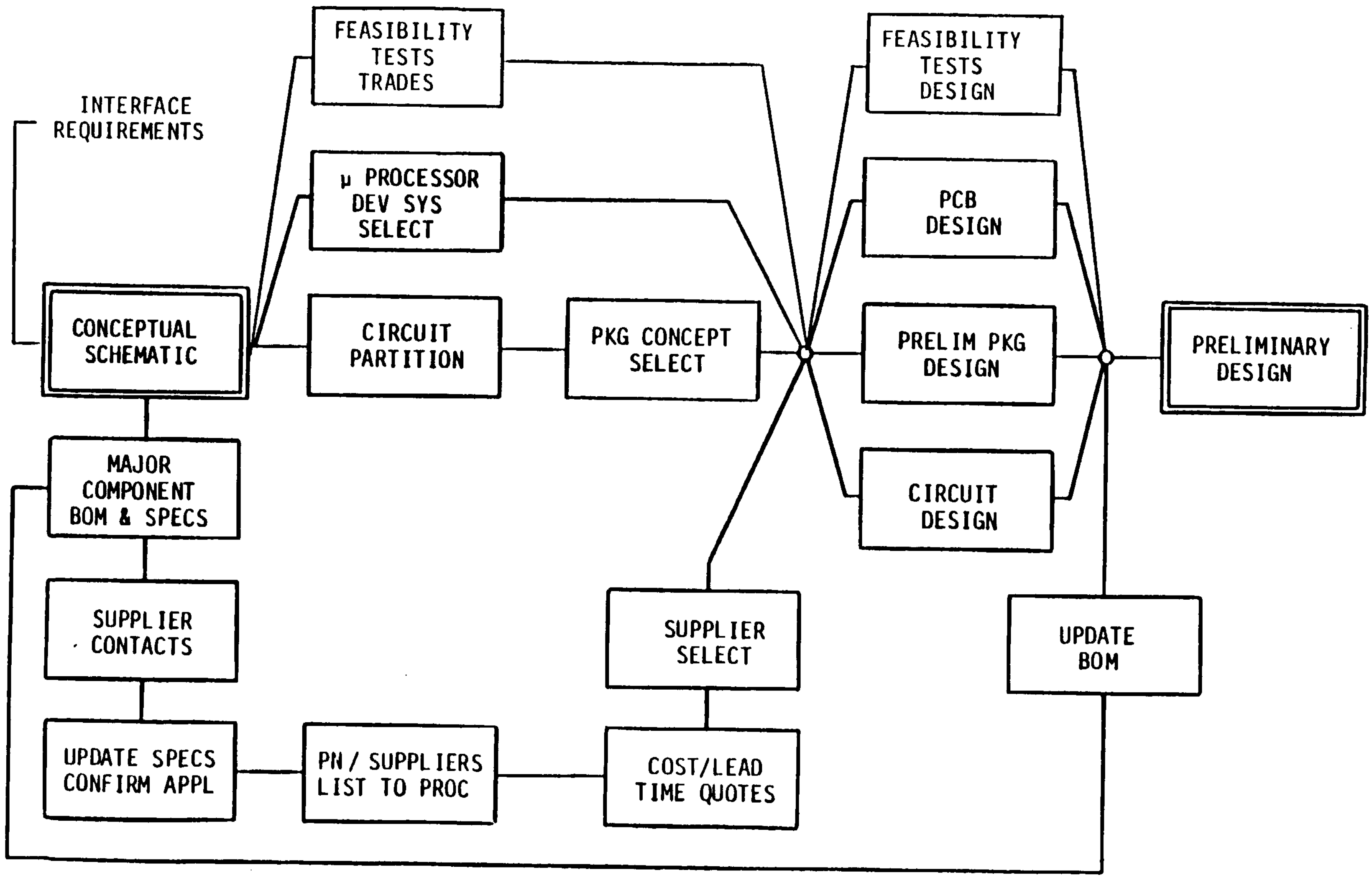
SHELL OIL COMPANY
PRODUCT SAFETY AND COMPLIANCE
P. O. BOX 4320
HOUSTON, TX 77210

# Appendix F

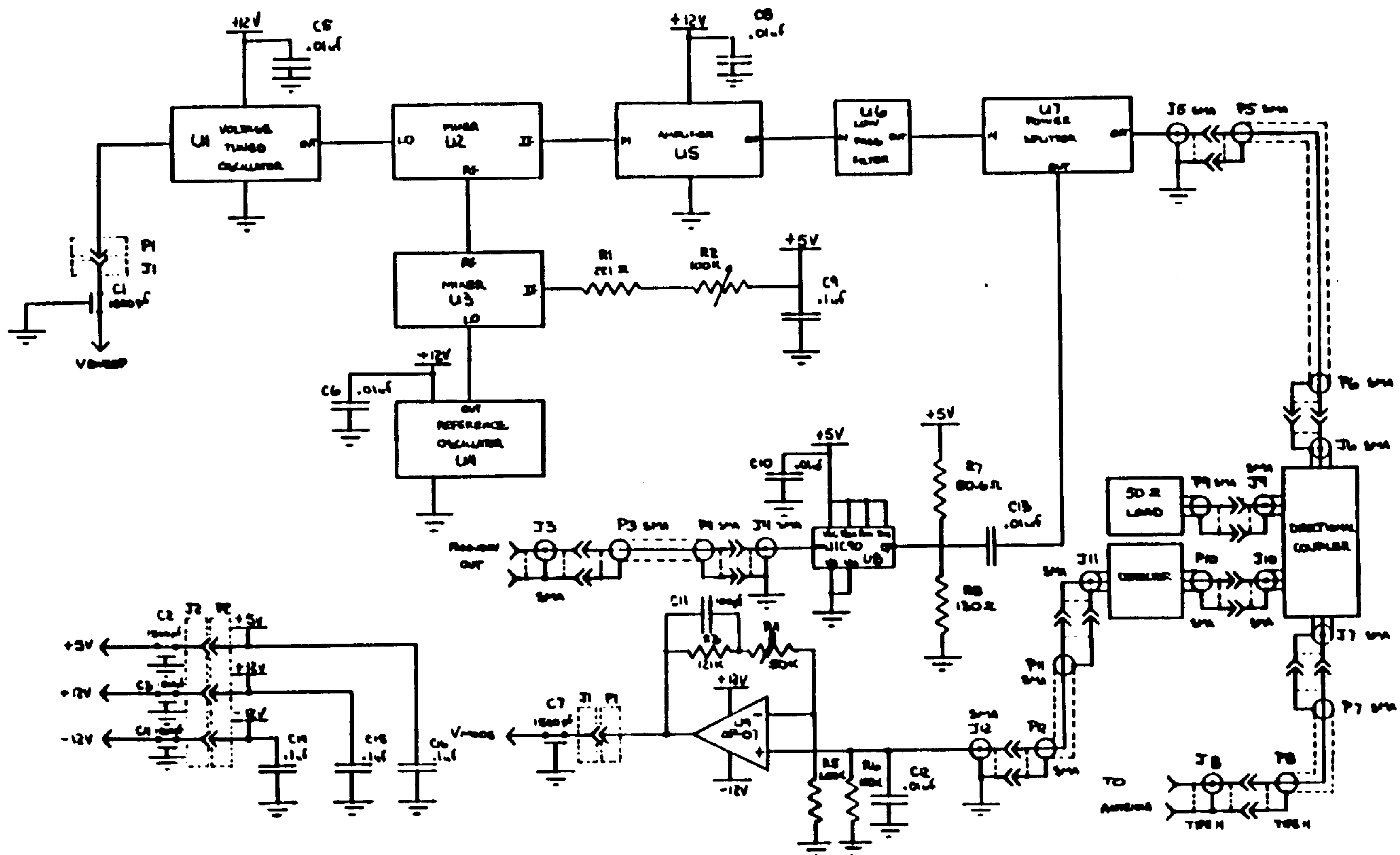
Beechcraft
Boulder Division

# CURRENT GAGING SYSTEM DESIGN ACTIVITIES

(SIGNAL CONDITIONER)

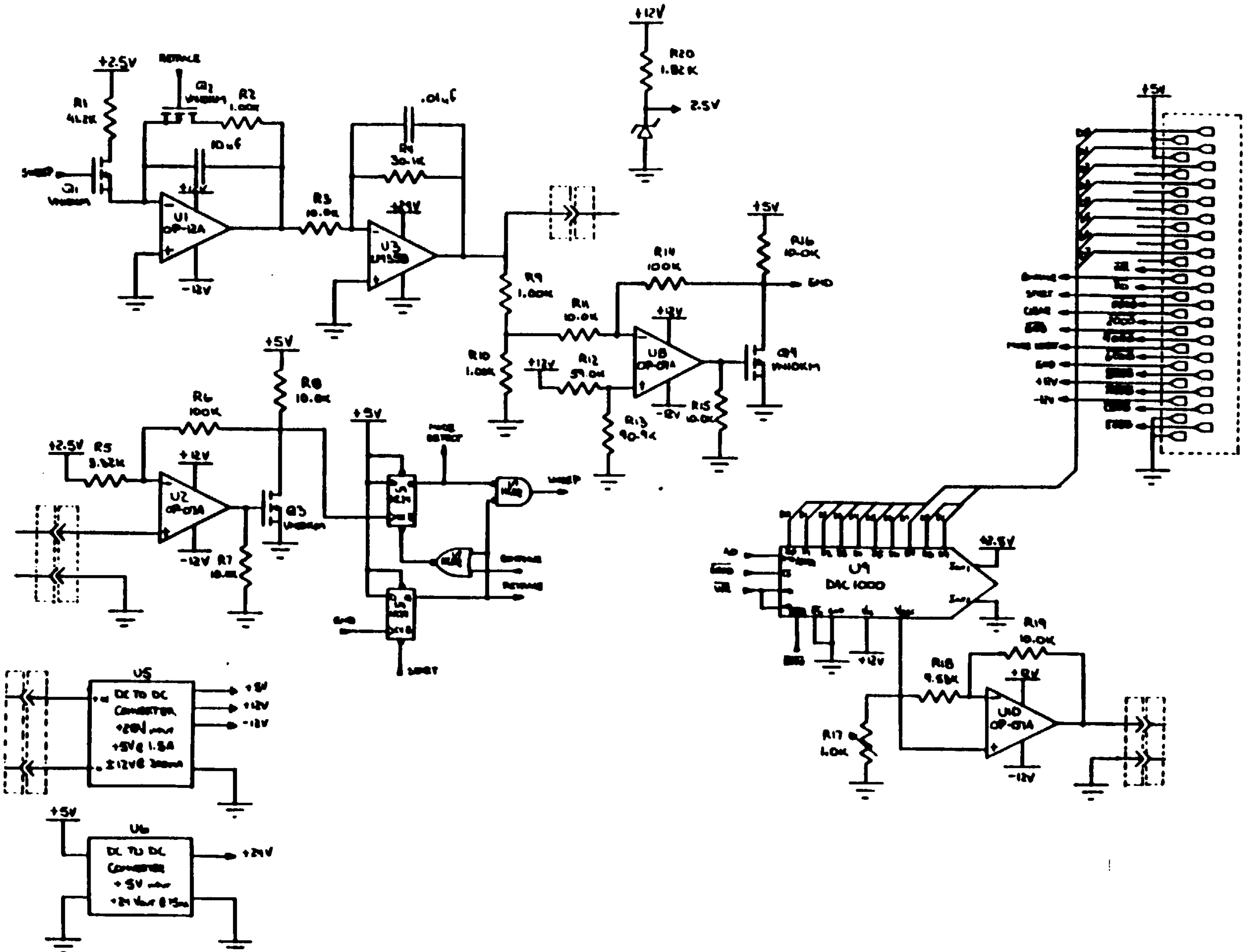


# CIRCUIT PARTITION - RF SECTION



Beechcraft
Boulder Division

# CIRCUIT PARTITION
## SWEEP CONTROL/ANALOG OUTPUT & SECONDARY POWER



| VENDOR | PART NUMBER | DESCRIPTION | COMMENTS |
|---|---|---|---|
| | | | 1-24 PCS |
| AVANTEK, INC. | HTO-0900 | VARACTOR TUNED OSCILLATOR | $368 4 WEEKS |
| 14261 E. 4th AVE SUITE 38 | | 900 MHz TO 1600 MHz | |
| AURORA, CO 80011 | | TO-8V PACKAGE | |
| 303-367-1000 | | | |
| (HARVEY HUFFMAN) | | | |
| | | | |
| VARI-L COMPANY, INC | VCO-108 | VOLTAGE CONTROLLED OSCILLATOR | 1-9 PCS 275.00 |
| 11101 EAST 51ST AVE | | 800 TO 1600 MHz | 14 WKS AR |
| DENVER, CO 80239 | | TO-8 PACKAGE | |
| 303-371-1560 | | | |
| Denise | VCO-109 | VOLTAGE CONTROLLED OSCILLATOR | 1-9 PCS 275.00 |
| | | 900 TO 1800 MHz | 14 wks a |
| | | TO-8 PACKAGE | |
| MAGNUM MICROWAVE CORP. | xxxxx | VOLTAGE CONTROLLED OSCILLATOR | 1-9 120.00 |
| 4575 CUSHING PKWY | V56-T1 | 900 TO 1600 MHz | 10-49 110.00 |
| FREMONT, CA 94538 | | TO-8 PACKAGE | 6 WKS ARO |
| 415-968-9281 (GORDON GRAM) | | | |
| | | | |
| MERRIMAC INDUSTRIES, INC | DMF-2C-2500 | LOW LEVEL DOUBLE BALANCED | 1-9 PCS 190.00 |
| P.O. BOX 986 | | MIXER | 44 STK) 8-10 WKS |
| 41 FAIRFIELD PLACE | | FLATPACK PACKAGE | aro |
| WEST CALDWELL, NJ 07007 | | | |
| 201-575-1300 | DMF-6A-1500 | MEDIUM LEVEL DOUBLE BALANCED | 1-9 PCS 135.00 |
| amy | | MIXER | 16 STK) 8-10 wks |
| | | FLATPACK PACKAGE | aro |
| | | | |
| ADAM-RUSSELL COMPANY, INC. | MD-123 | HIGH PERFORMANCE DOUBLE BALANCED | 1-9 pcs 145.00 |
| ANZAC DIVISION | | MIXER | gold Sur/Chg 1.31 |
| 80 CAMBRIDGE STREET | | FLATPACK PACKAGE | STK 146.31 |
| BURLINGTON, MA 01803 | | | |
| 617-273-3333 | MD-154 | BROADBAND DOUBLE-BALANCED | 1-9 PCS 180.00 |
| Items normally | | MIXER | gold Sur/Chg 2.01 |
| STK - if not | | FLATPACK PACKAGE | STK 182.01 |
| 10 wks lead time. | | | |
| | MD-157 | DOUBLE-BALANCED MIXER | 1-9 PCS 155.00 |
| | | FLATPACK PACKAGE | gold Sur/Chg 1.31 |
| | | | STK 156.3 |
| VARI-L COMPANY, INC. | DBM-183 | HIGH LEVEL DOUBLE-BALANCED | 1-9 pcs 135.00 |
| 11101 EAST 51ST AVE | | MIXER | 14 WKS ar |
| DENVER, CO 80239 | | FLATPACK PACKAGE | |
| 303-371-1560 | | | |
| Denise | DBM-184 | DOUBLE-BALANCED MIXER | 1-9 pcs 155.00 |
| | | FLATPACK PACKAGE | 14 WKS a |
| | | | |
| | DBM-600 | DOUBLE-BALANCED MIXER | 1-9 pcs 180.00 |
| | | FLATPACK PACKAGE | 14 WKS a |

| VENDOR | PART NUMBER | DESCRIPTION | COMMENTS | |
|---|---|---|---|---|
| WATKINS-JOHNSON | WJ-A66 | 10 TO 1200 MHz CASCADABLE | 1-9 pcs | 208.00 |
| 3333 HILLVIEW AVE. | | AMPLIFIER | | 16 wkD |
| STANFORD INDUSTRIAL PARK | | TO-8 PACKAGE | | |
| PALO ALTO, CA 94304 | | | | |
| 415-493-4141 | WJ-RA26 | 10 TO 1500 MHz CASCADABLE | 1-9 pcs | 252.00 |
| Boleen | | AMPLIFIER | 10 STK | 16-18 wk |
| | | TO-8B PACKAGE | | if not S |
| | WJ-A66-1 | 10 TO 1000 MHz CASCADABLE | 1-9 pcs | 208.00 |
| | | AMPLIFIER | | 14 wkD |
| | | TO-8 PACKAGE | | |
| AVANTEK, INC. | UTO-1021 | 2 TO 1000 MHz HIGH PERFORMANCE | 1-9 pcs | 170.00 |
| 14261 E. 4TH AVE SUITE 38 | | AMPLIFIER | | 3 wk |
| AURORA, CO 80011 | | TO-8 PACKAGE | | |
| 303-367-1000 | | | | |
| (LARVEY HUFFMAN) | UTO-1056 | 2 TO 1000 MHz HIGH PERFORMANCE | 1-9 pcs | 150.00 |
| Kathy | | AMPLIFIER | | 3 wk |
| | | TO-8 PACKAGE | | |
| MERRIMAC INDUSTRIES, INC. | DMF-8A-500 | HIGH LEVEL DOUBLE BALANCED | 1-9 pcs | 125.00 |
| P.O. BOX 986 | | MIXER | 10 STK | 8-10 wk |
| 41 FAIRFIELD PLACE | | FLATPACK PACKAGE | | aro |
| WEST CALDWELL, NJ 07007 | | | | |
| 201-575-1300 | | | | |
| Amy | | | | |
| VARI-L COMPANY, INC | DBM-178 | HIGH LEVEL DOUBLE BALANCED | 1-9 pcs | 120.00 |
| 1101 EAST 51ST AVE | | MIXER | | 14 wkD C |
| DENVER, CO 80239 | | FLAT PACK PACKAGE | | |
| 303-371-1560 | | | | |
| Denise | | | | |
| LARK ENGINEERING CO | LTC-650-4MM | LOW PASS FILTER $f_c$ = 650 MHz | 1-4 | 253.00 |
| 26401 CALLE ROLANDO | | TO-8 PACKAGE | 5-9 | 198.00 |
| SAN JUAN CAPISTRANO, CA 92675 | | | 10-14 | 175.00 |
| 714-493-9501 | | | | |
| Debbie | | | | 8-10 wk |

| VENDOR | PART NUMBER | DESCRIPTION | COMMENTS |
|---|---|---|---|
| WAVETEK INDIANA, INC.<br>5808 CHURCHMAN<br>P.O. BOX 190<br>BEECH GROVE, IN<br>317-787-3332<br>Martin | T8L4PP-650 | LOW PASS FILTER fc=650MHz<br>TO-8 PACKAGE | 1-5 pcs 202.00<br>6-10 141.00<br>8-10 wk |
| ADAM-RUSSELL Company, Inc<br>ANZAC DIVISION<br>80 CAMBRIDGE STREET<br>BURLINGTON MA 01803<br>617-273-3333 | DS-327 | TWO-WAY POWER DIVIDER<br>FLATPACK PACKAGE | 1-9 pcs 70.00<br>10 wks |
| OLEKTRON CORP.<br>61 SUTTON ROAD<br>WEBSTER, MA 01570<br>617-943-7440<br>JoAnn | FP-HJ-220<br>OBSOLETE * | TWO-WAY POWER DIVIDER<br>FLATPACK PACKAGE | FP-HJ-302G<br>1-9 pcs 69.00<br>8-10 wks |
| | FP-HJ-402G<br>FP8-HJ-402G | TWO-WAY POWER DIVIDER<br>FLATPACK PACKAGE | 1-9 pcs 111.00<br>8-10 |
| VARI-L COMPANY, INC.<br>11101 EAST 51ST AVE<br>DENVER, CO 80239<br>303-371-1560<br>Denise | PS-2-1000F. | TWO-WAY POWER DIVIDER<br>FLAT PACK PACKAGE | 1-9 pcs 100.00<br>14 wk<br>ar |
| MERRIMAC INDUSTRIES<br>P.O. BOX 986<br>41 FAIRFIELD PLACE<br>WEST CALDWELL, NJ 07007<br>201-575-1300<br>amy | BCM-10-500 | 10dB DIRECTIONAL COUPLER<br>CONNECTORIZED PACKAGE<br>SMA CONNECTORS | 1-9 pcs 195.00<br>8-10 [illegible]<br>10 stk)<br>ar |
| OLEKTRON<br>61 SUTTON ROAD<br>WEBSTER, MA 01570<br>617-943-7440<br>JoAnn | O-D4-10G | 10dB DIRECTIONAL COUPLER<br>CONNECTORIZED PACKAGE<br>SMA CONNECTORS | 1-9 pcs 131.00<br>8-10 |

| Vendor | Part Number | Description | Qty | Comment |
|---|---|---|---|---|
| | | | | DISTRIBUTORS |
| PMI, INTERSIL, TI | OP-07A-P | ULTRA-LOW OFFSET OP-AMP | 4 | A, B, W |
| PMI, INTERSIL, TI | OP-12E-P | LOW-INPUT-CURRENT OP-AMP | 1 | A, B, W |
| MOTOROLA, TI, NATIONAL | LM 358N | DUAL OP-AMP | 1 | A, B, H |
| LINEAR TECHNOLOGY | LT 1004-2.5CZ | MICROPOWER VOLTAGE REF. | 1 | D, M, W |
| NATIONAL | DAC 1000 LCD | DOUBLE-BUFFERED D/A CONV. | 1 | B, H |
| MOTOROLA, FAIRCHILD, SIGNETICS | MC 1488 P | RS-232- QUAD LINE DRIVER | 1 | A, B, H |
| MOTOROLA, FAIRCHILD, SIGNETICS | MC 1489 P | RS-232 QUAD LINE RECEIVER | 1 | A, B, H |
| SILICONIX, INTERSIL | VN10KM | VMOS FET | 4 | B, H, W |
| MOTOROLA | IN5540 B | 20V LOW VOLTAGE AVALANCHE DIODE | 1 | B, K, H |
| FAIRCHILD | 11C90DC | 650 MHz PRESCALER | 1 | A, B, H |
| MOTOROLA, FAIRCHILD, SIGNETICS | 74F02PC | QUAD 2-INPUT NOR (FAST) | 1 | A, B, H |
| MOTOROLA, FAIRCHILD, SIGNETICS | 74F161PC | 4 BIT BINARY COUNTER (FAST) | 1 | A, B, H |
| MOTOROLA, FAIRCHILD, SIGNETICS | 74HC32N | QUAD 2-INPUT OR (CMOS) | 1 | A, B, H |
| " " " | 74HC42N | 4-LINE TO 10-LINE DECODER (CMOS) | 1 | ↓ |
| " " " | 74HC74N | DUAL D-TYPE FLIP-FLOP (CMOS) | 1 | ↓ |
| " " " | 74HC244N | OCTAL BUFFER 3-STATE (CMOS) | 3 | ↓ |
| " " " | 74HC373N | OCTAL D-TYPE LATCH (CMOS) | 1 | ↓ |
| " " " | 74HC393N | DUAL 4-BIT BINARY COUNTER (CMOS) | 2 | ↓ |
| INTEL, OKI, SIGNETICS | 80C31BH | 8 BIT MICROCONTROLLER (CMOS) | 1 | A, H, W |
| INTEL, HITACHI, SIGNETICS | 27C64-20 | 8K×8 UV EPROM 200ns (CMOS) | 1 | A, H, W |
| INTEL, XICOR, NCR | X2004-3 | 512×8 5VOLT NOVRAM | 1 | A, M, W |

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| VENDOR | PART NUMBER | DESCRIPTION | | COMMENT |
|---|---|---|---|---|
| DALE, MEPCO, ALLEN-BRADLEY | RN55C80R6F | 80.6 Ω | 1 | A, N, S |
| | RN55C1300F | 130 Ω | 1 | |
| | RN55C1500F | 150 Ω | 1 | |
| | RN55C1001F | 1.00K | 4 | |
| | RN55C1211F | 1.21K | 1 | |
| | RN55C3321F | 3.32K | 1 | |
| | RN55C8251F | 8.25K | 1 | |
| | RN55C9531F | 9.53K | 1 | |
| | RN55C1002F | 10.0K | 9 | |
| | RN55C3012F | 30.1K | 1 | |
| | RN55C4122F | 41.2K | 1 | |
| | RN55C5902F | 59.0K | 1 | |
| | RN55C6652F | 66.5K | 1 | |
| | RN55C9092F | 90.9K | 1 | |
| | RN55C1003F | 100K | 3 | |
| MEPCO, BECKMAN, VRN, ALLEN-B WESTON, SPECTROL, BOURNS | 8024EKW102 (MEPCO) | 1.0K (MIL RJ24FW) | 1 | |
| | 8024EKW503 (MEPCO) | 50K (MIL RJ24FW) | 1 | |
| | 8024EKW104 (MEPCO) | 100K (MIL RJ24FW) | 1 | |
| MURATA ERIE, MALLORY, AVX | CK05BX103K | .01 uf MONOLITHIC CAP. | 11 | |
| " " " " | CK05BX104K | .1 uf MONOLITHIC CAP | 9 | |
| " " " | CK06BX105K | 1 uf MONOLITHIC CAP | 5 | |
| MEPCO, MALLORY, SPRAGUE, AVX, | MALLORY PART OR EQUIV. TDC106K020NLF | 10 uf 20 VDC EPOXY DIPPED SOLID TANTALUM | 1 | |
| AMP, ALCOSWITCH, C&K, GRAYHILL | DT-04 | 4 POSITION DIP SWITCH (ALCO) | 1 | |

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| VENDOR | PART NUMBER | DESCRIPTION | QTY | COMMENT |
|---|---|---|---|---|
| COMPUTER PRODUCTS INC<br>STEVEN-ARNOLD DIVISION<br>7 ELKINS STREET<br>SOUTH BOSTON, MA 02127<br>607-268-1170 | ES24T12/310X | +5@1.5A & ±12@ ±310MA | 1 | POWER SUPPLY DC TO DC |
| CALEX MFG Co., INC.<br>3355 VINCENT Rd.<br>PLEASANT HILL, CA 94523-4389<br>415-932-3911 | 24T5.12SW | +5@1.5A & ±12@ ±310MA | 1 | POWER SUPPLY DC TO DC |
| COMPUTER PRODUCTS INC.<br>POWER PRODUCTS DIV<br>2981 GATEWAY DRIVE<br>POMPANO BEACH, FL 33069<br>305-975-7660 | PM671 | +5V INPUT ±12V OUT @ ±40MA | 1 | POWER SUPPLY DC TO DC |
| CALEX MFG Co., INC<br>3355 VINCENT Rd.<br>PLEASANT HILL, CA 94523-4389<br>415-932-3911 | 5D12.040 | +5V INPUT ±12V OUT @ ±40MA | 1 | POWER SUPPLY DC TO DC |
| INTEGRATED CIRCUITS INC<br>10301 WILLOWS Rd.<br>REDMOND, WA 98052<br>206-882-3100 | DIP512DT | +5V INPUT ±12V OUT @ ±42 MA | 1 | POWER SUPPLY DC TO DC |
| POWER GENERAL<br>152 WILL DR<br>CANTON, MA 02021<br>617 828-6216 | 407 | 5V INPUT ±12V OUT @ ±40MA | 1 | POWER SUPPLY DC TO DC |
| CONNOR-WINFIELD CORP<br>109 TURNER Ct.<br>POB L<br>WEST CHICAGO, IL 60185<br>312-231-5270 | C24C @12MHz | 12MHz TCXO 5VOLTS TTL | 1 | |
| CTS CORPORATION<br>KNIGHTS DIVISION<br>400E REIMANN AVE<br>SANDWICH, IL 60548<br>815 786-8411 | JKXO-16E @12MHz | 12MHz TCXO 5VOLTS TTL | 1 | |

81-30564

| VENDOR | PART NUMBER | DESCRIPTION | | COMMENT |
|---|---|---|---|---|
| McCOY ELECTRONIC CO.<br>100 WATTS St.<br>POB B<br>MT HOLLY SPRINGS, PA 17065<br>717-486-3411 | MC163X2 @ 12MHz | 12MHz TCXO 5Volts TTL | 1 | |
| MONITOR PRODUCTS<br>P.O. BOX 1966<br>502 VIA DEL MONTE<br>OCEANSIDE CA 92054<br>619-433-4510 | 7149 @12MHz | 12MHz TCXO 5Volts TTL | 1 | |
| ELPAC COMPONENTS | C5A106 | 10uf METALLIZED POLYCARBONATE | 1 | 50VDC L 1.17 W .59 T .42 |
| KEMET (UNION CARBIDE) | F241M1005J030A | 10uf METALLIZED POLYCARBONATE | 1 | 30VDC 1.38 .56 |
| | F141M1005J050A | 10uf METALLIZED POLYCARBONATE | 1 | 50VDC 1.31 .67 |
| ELECTROCUBE | 650B1A106J | 10uf METALLIZED POLYCARBONATE | 1 | 50VDC 1.15 .56 .39 |
| | 650C1A106J | 10uf METALLIZED POLYCARBONATE | 1 | 50VDC 1.15 .67 .27 |
| MALLORY | 106KP5RWD1250 | 10uf METALLIZED POLYCARBONATE | 1 | 50VDC 1.25 .49 |
| | 106JP5WD1250 | 10uf METALLIZED POLYCARBONATE | 1 | 50VDC 1.25 .53 .41 |
| MEPCO/ELECTRA, INC. | 708B1BN106J101AX | 10uf METALLIZED POLYCARBONATE | 1 | 100V 1.88 .93 .56 |
| | | | | A, N, S |

E1-30564

# DISTRIBUTORS

A — ARROW ELECTRONICS INC.
1390 S. POTOMAC ST. SUITE 136
AURORA, CO 80012
303-696-1111

T — TTI

DALLAS/FT WORTH, TX
817-429-1440

B — BELL INDUSTRIES
8155W 48 AVE.
DENEVER, CO 80033
303-424-1985

W — WYLE DISTRIBUTION
451 E 124TH AVE
THORNTON, CO 80241
303-457-9953

D — DIPLOMAT ELECTRONICS INC.
96 INVERNESS DR. E.
DENVER CO
303-799-8300

H — HAMILTON/AVNET
8765E ORCHARD Rd.
DENVER CO
303-779-9998

K — KIERULFF ELECTRONICS
7060 S TUCSON Wy

303-790-4444

M — MARSHALL IND.
7000 N. BROADWAY
80221
303-427-1818

N — NEWARK ELECTRONICS
8141 W I-70
80002
303-423-7941

S — SHELLEY-RAGON INC.
1212 S. BROADWAY
DENEVER, CO 80210
303-744-3601

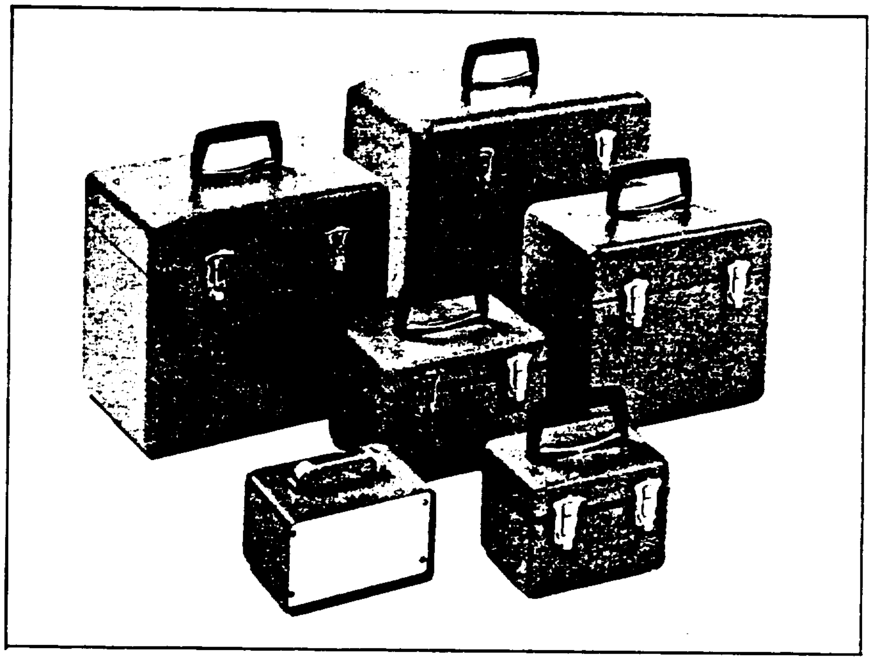
81-30564

# ZERO CENTURION VALULINE CARRYING CASES

Choose from three distinct styles. The Zero Valuline Series provides you with a variety of options in selecting the case which best satisfies your needs.

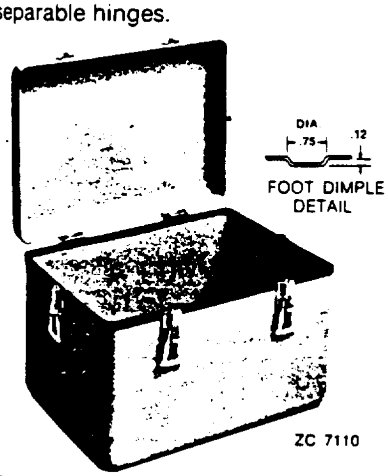
Constructed of deep drawn aluminum shells, they are seamless and draft free. Three closure options, along with variations in internal panel mounting, give you added versatility in the packaging of your electronic, electro-mechanical, or instrumentation equipment.

In addition to the standard sizes listed on the following pages, you may select from the 40,000 standard sizes of deep drawn enclosures listed in this catalog as a basis for your "special case". You can obtain all these sizes without a tooling charge.



## ZC 7000 SERIES ALUMINUM CARRYING CASES

Most economical of the Valuline cases, the ZC 7000 Series cases are available in 11 off-the-shelf sizes. All cases feature fully gasketed, bonded closures which fit over the edge of the lower shell. ZC 7000 cases have separable hinges.




ZC 7110

FOOT DIMPLE DETAIL

### ZC 7000 Series Cases

Measurements shown in inches.

| CASE NO. With Separable Hinges | W | L | $H_1$ | $H_2$ | T | ALLOY | $R_1$ | $R_2$ | LATCHES FRONT | LATCHES SIDE |
|---|---|---|---|---|---|---|---|---|---|---|
| ZC 7010 | 4.00 | 7.00 | 1.25 | 2.90 | .06 | 1100-0 | .31 | .31 | 2 | — |
| ZC 7020 | 4.00 | 8.75 | 1.25 | 2.90 | .06 | 1100-0 | .19 | .25 | 2 | — |
| ZC 7030 | 5.00 | 7.00 | 1.25 | 3.65 | .06 | 1100-0 | .31 | .31 | 2 | — |
| ZC 7040 | 5.50 | 8.00 | 1.25 | 3.65 | .06 | 1100-0 | .25 | .25 | 2 | — |
| ZC 7050 | 5.68 | 10.00 | 1.25 | 4.65 | .06 | 1100-0 | .25 | .25 | 2 | — |
| ZC 7060 | 6.00 | 9.00 | 1.25 | 4.65 | .06 | 1100-0 | .31 | .31 | 2 | — |
| ZC 7070 | 6.00 | 14.50 | 1.37 | 4.53 | .06 | 1100-0 | .44 | .50 | 2 | — |
| ZC 7080 | 7.00 | 11.00 | 1.50 | 5.40 | .06 | 6061-0 | .50 | .31 | 2 | — |
| ZC 7090 | 8.00 | 14.00 | 1.87 | 6.03 | .06 | 6061-0 | .87 | .87 | 2 | — |
| ZC 7100 | 9.00 | 9.00 | 1.50 | 6.40 | .06 | 6061-0 | .50 | .50 | 2 | — |
| ZC 7110 | 9.19 | 13.25 | 1.62 | 7.28 | .06 | 6061-0 | .59 | .59 | 2 | 1 |

Note: W, L and H are outside dimensions. $R_1$, and $R_2$ are inside dimensions.

**ORDERING INFORMATION**

**Standards**
Order by part number.

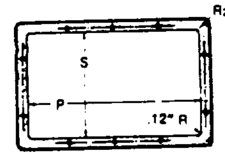
ZC -☐-☐

**Case/Series Number** ____
**Add S for Special Sizes** ____

**Special Sizes —**
Order by Series Number and attach detail information. Secondary operations available.

Example on "Specials"
ZC-7000-S 12" x 12"
$H_1$ = 4" $H_2$ = 7"

# ZERO CENTURION VALULINE CARRYING CASES




## ZIC 600 SERIES ALUMINUM CARRYING CASES

Strongest of the Valuline cases, this series features a spot-welded, pre-drilled panel flange, with threaded inserts installed to accept a full-size, primed panel, which is included with the basic case.

### ORDERING INFORMATION

**Standards**
Order by part number.

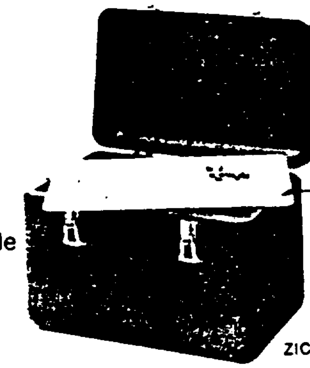
## ZIC

Case/Series Number

Add S for Special Sizes

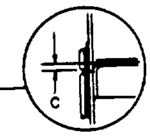
Special Sizes — Order by Series Number and attach detail information. Secondary operations available

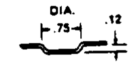
Example on "Specials"
ZIC 600-S
20.12" x 32.12"
$H_1$ = 5" $H_2$ = 10"



ZIC 613

Latch Assembly Reference




FOOT DIMPLE DETAIL

Measurements shown in inches.

**ZIC 600 Series Cases**

| CASE NUMBER | W | L | $H_1$ | $H_2$ | T | ALLOY | $R_1$ | $R_2$ | C | S | P | SIZE PANEL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ZIC 608 | 7.00 | 8.00 | 2.50 | 6.00 | .06 | 1100-0 | .31 | .31 | .25 | 5.37 | 6.37 | 6.50 x 7.50 |
| ZIC 609 | 9.00 | 9.00 | 2.50 | 8.00 | .06 | 6061-0 | .50 | .50 | .25 | 7.37 | 7.37 | 8.50 x 8.50 |
| ZIC 610 | 6.69 | 10.69 | 2.50 | 6.00 | .09 | 6061-0 | .50 | .50 | .21 | 5.00 | 9.00 | 6.18 x 10.18 |
| ZIC 611 | 7.00 | 11.00 | 2.50 | 6.00 | .06 | 6061-0 | .50 | .31 | 34 | 5.37 | 9.37 | 6.31 x 10.31 |
| ZIC 612 | 8.37 | 11.50 | 2.50 | 7.00 | .06 | 6061-0 | .50 | .56 | .25 | 6.75 | 9.87 | 7.87 x 11.00 |
| ZIC 613 | 9.19 | 13.25 | 2.50 | 9.00 | .09 | 6061-0 | .56 | .56 | .28 | 7.50 | 11.56 | 8.56 x 12.62 |
| ZIC 616 | 10.00 | 16.00 | 2.50 | 9.00 | .09 | 6061-0 | 1.00 | 1.00 | .28 | 8.31 | 14.31 | 9.50 x 15.50 |

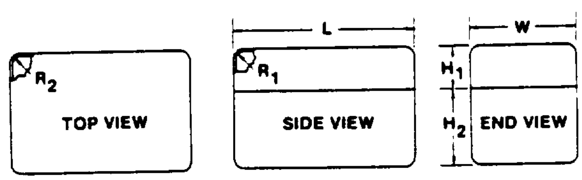
Note: W, L and H are outside dimensions; $R_1$, $R_2$, P and S are inside dimensions.

## ZIP 800 SERIES ALUMINUM CARRYING CASES

Most versatile series of the Valuline cases, which feature a fully gasketed closure of extruded aluminum, spot-welded to the interior case shell, to permit installation of optional panel support brackets and full size primed panel. (Order separately.) An O-ring gasket provides additional environmental protection.

### DELIVERY

All cases listed in the Valuline Series are in stock and available for two-week delivery.




Case dimensions are always shown in the following order:

WIDTH — the narrowest measurement, looking down on the case.

LENGTH — the longest measurement, looking down on the case.

HEIGHT — measured from base to top. The "upper" shell is designated $H_1$. The "lower" shell is designated $H_2$

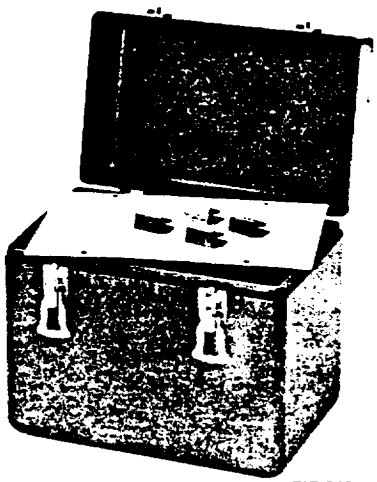
Measurements shown in inches

**ZIP 800 Series Cases**

| CASE NUMBER | W | L | $H_1$ | $H_2$ | T | ALLOY | $R_1$ | $R_2$ | LATCHES FRONT | LATCHES SIDE | HINGES | PANEL NO. | STD. NO MTG. BRKTS. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ZIP 805 | 6.00 | 9.00 | 2.50 | 5.00 | .06 | 1100-0 | .31 | .31 | 2 | — | 2 | ZP 9178-05 | 4 |
| ZIP 810 | 7.00 | 11.00 | 2.50 | 7.00 | .06 | 6061-0 | .50 | .31 | 2 | — | 2 | ZP 9178-10 | 4 |
| ZIP 820 | 8.00 | 14.00 | 2.50 | 7.00 | .06 | 6061-0 | .87 | .87 | 2 | — | 2 | ZP 9178-20 | 6 |
| ZIP 830 | 8.75 | 12.00 | 2.50 | 8.00 | .06 | 6061-0 | .50 | .75 | 2 | — | 2 | ZP 9178-30 | 6 |
| ZIP 840 | 9.19 | 13.25 | 2.50 | 9.00 | .06 | 6061-0 | .59 | .59 | 2 | — | 2 | ZP 9178-40 | 6 |
| ZIP 850 | 10.00 | 16.00 | 2.50 | 9.00 | .09 | 6061-0 | 1.00 | 1.00 | 2 | 1 | 3 | ZP 9178-50 | 8 |

Note: W, L and H are outside dimensions; $R_1$ and $R_2$ are inside dimensions.

# ZERO CENTURION VALULINE CARRYING CASES



ZIP 840

## ZIP 800 SERIES ALUMINUM CARRYING CASES

**ORDERING INFORMATION**
**Standards**
Order by part number.

*Suffix "B" must always be followed by a number.

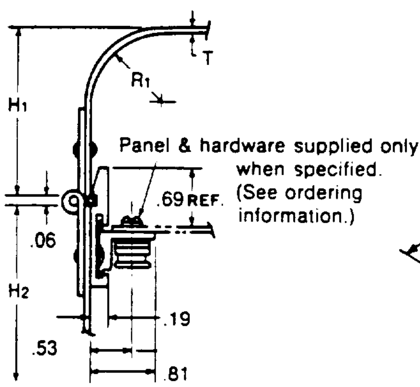
ZIP -☐-☐-☐

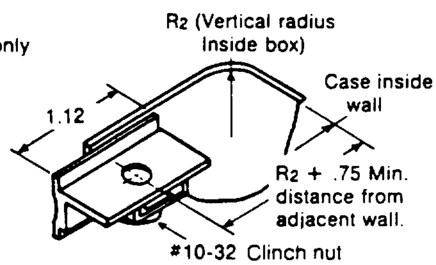
- Add S for Special Sizes
- **A** = Basic Case Assembly with no panel or panel support brackets
- **B*** = Basic Case assembly less standard panel and retention screws, but including any specified quantity of panel support brackets (unassembled). Insert number following suffix B for quantity, such as B6.
- **C** = Basic case assembly with standard panel and appropriate number of panel support brackets and retention screws (unassembled).

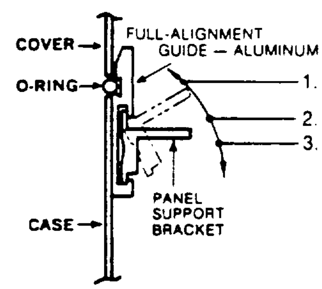
**Specials:** Order by Series number and attach detail information. Secondary operations available.

Example on "Specials"
ZIP 800-C-S 12" x 12"
$H_1$ = 3" $H_2$ = 7"

Measurements shown in Inches



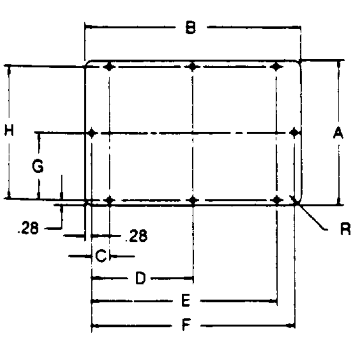




### ADJUSTABLE PANEL SUPPORT BRACKET
ZSP 9-014

The adjustable panel support bracket shown is an accessory. If desired, specify quantity required for interface with equipment panel. (See ordering information.) Install per instructions shown at right.

### PANEL SUPPORT BRACKET INSTALLATION

1. Apply room temperature cure epoxy to contact surface of support bracket and insert bracket into extrusion slot, as shown.
2. Rotate downward, as shown, until support bracket is seated.
3. Slide bracket laterally as required to align bracket with panel hole location.
4. Allow epoxy to cure prior to further handling. (Note: Epoxy can be obtained locally at most hardware or industrial supply houses.)




### ZIP 800 Series Panel Dimensions

Measurements shown in inches.

| PANEL NUMBER | A | B | C | D | E | F | G | H | R | NO. OF HOLES |
|---|---|---|---|---|---|---|---|---|---|---|
| ZP 9178-05 | 5.37 | 8.37 | 1.50 | — | 6.31 | — | — | 4.81 | .18 | 4 |
| ZP 9178-10 | 6.37 | 10.37 | 2.00 | — | 7.81 | — | — | 5.81 | .18 | 4 |
| ZP 9178-20 | 7.37 | 13.37 | 2.87 | — | 9.93 | 12.81 | 3.40 | 6.81 | .62 | 6 |
| ZP 9178-30 | 8.12 | 11.37 | 2.00 | — | 8.81 | 10.81 | 3.78 | 7.56 | .50 | 6 |
| ZP 9178-40 | 8.56 | 12.62 | 2.50 | — | 9.56 | 12.06 | 4.00 | 8.00 | .43 | 6 |
| ZP 9178-50 | 9.31 | 15.31 | 2.50 | 7.37 | 12.25 | 14.75 | 4.37 | 8.75 | .75 | 8 |

# MICROPROCESSOR DEVELOPMENT SYSTEMS FOR THE 80C31

| INTEL | | PRICE |
|---|---|---|
| PMDX431A SERIES IV DEVELOPMENT SYSTEM | | 24,900 |
| PICE-51 EMULATION VEHICLE FOR SERIES IV | | * 6,000 |
| ASM-51 ASSEMBLER FOR 8051 FAMILY | | 1,995 |
| IUPP200A-213C EPROM PROGRAMMER | | 1,975 |
| PRINTER | | 300 |
| | TOTAL | 35,170 |

COMMENTS:

THIS DEVELOPMENT SYSTEM IS THE TOP-OF-THE-LINE SYSTEM FROM INTEL. THE SERIES IV SYSTEM CAN BE USED WITH EVERY INTEL MICROPROCESSOR OR MICROCOMPUTER. THE IN CIRCUIT EMULATION PACKAGE (PICE-51) IS NOT NEEDED FOR LOW LEVEL DEVELOPMENT. THIS SYSTEM IS VERY EXPENSIVE AND NOT PORTABLE.

| HP | | |
|---|---|---|
| Hp 64110A | DEVELOPMENT SYSTEM | 11,150 |
| Hp 64264S | 8051 IN-CIRCUIT EMULATOR | * 5,800 |
| Hp 64156S | EMULATION MEMORY | * 3,140 |
| Hp | DISK OPERATING SYSTEM (DOS) | 700 |
| Hp 64855A | ASM-51 ASSEMBLER FOR 8051 FAMILY | 600 |
| Hp 64500S opt 27C64 | EPROM PROGRAMMER | 1400 |
| | PRINTER | 795 |
| | | 23,585 |

COMMENTS:

THE 64110A DEVELOPMENT SYSTEM IS A UNIVERSAL SYSTEM IT CAN BE USED TO DEVELOP CODE FOR MOST MICROPROCESSORS AND MICROCOMPUTERS. HEWLETT PACKARD GIVES EXCELLENT SUPPORT AND WILL CONTINUE TO UPDATE THE SYSTEM. THIS SYSTEM IS PORTABLE BUT EXPENSIVE.

E1-30564

| INTEL | PRICE |
|---|---|
| PDS-100 DEVELOPMENT SYSTEM | 4,495 |
| EMV-51 & ASM-51 | * 2,995 |
| PDS-140 EMV/PROM PROGRAMMING ADAPTER | 495 |
| IUPFAST 27 KIT MODULE | 940 |
| PRINTER | 300 |
| | 9,225 |

COMMENTS:

INTEL IS OFFERING A LOW END DEVELOPMENT SYSTEM. THE PDS-100 CAN BE USED TO DEVELOP CODE FOR ONLY 4 MICROPROCESSORS. THE EMULATION VECHICLE IS NOT NEEDED, BUT IT COMES WITH THE ASSEMBLER (ASM-51). THE ASSEMBLER ALONE COST 2,950 SO ITS BETTER TO BUY THE EMV-51. THIS SYSTEM IS PORTABLE AND FAIRLY LOW COST.

IBM PC BASED DEVELOPMENT SYSTEM.

| METALINK | |
|---|---|
| METAICE-31 IN-CIRCUIT-EMULATOR | 1,495 |
| MEMORY EXPANSION TO 16K | 200 |
| POWER SUPPLY | 100 |
| XASM-51 | 200 |
| CABLE | 35 |
| IBM PC (2 DISK DRIVES, 256K RAM, RS232, DOS, MONO) (PRINTER, OKI 192) | 2500 |
| EPROM PROGRAMMER (LOGICAL DEVICES PPU) | 444 |
| | 4,974 |

COMMENTS:

THIS IS A LOW COST IN-CIRCUIT-EMULATOR FOR ONLY THE 80C31. THIS SYSTEM USES AN IBM PC AS A HOST COMPUTER. THIS SYSTEM HAS FULL DEVELOPMENT CAPABILITIES.

81-30564

| ASHLING | PRICE |
|---|---|
| MDS 8031 INCLUDES: TEXT EDITOR, XASM-51, ICE, ICE SOFTWARE, PROM PROGRAMMER, PROM PROG. SOFTWARE, CABLES, POWER SUPPLY, CARRING CASE. | 5,750 |
| IBM PC | 2,500 |
| | 8,250 |

COMMENTS:

THIS IS AN INCIRCUIT EMULATOR FOR THE 80C31. THIS SYSTEM USES AN IBM PC AS A HOST COMPUTER. THE MDS 8031 INCLUDES ALL THE SOFTWARE AND HARDWARE FOR COMPLETE DEVELOPMENT. THIS SYSTEM IS VERY PORTABLE.

| HUNTSVILLE | |
|---|---|
| IDP-31 INCLUDES: ICE, POWER SUPPLY, CABLES, XASM-51, DEBUGGER, DOC | 3,495 |
| EPROM PROGRAMMER (LOGICAL DEVICES PP4) | 444 |
| IBM PC | 2500 |
| | 6,439 |

COMMENTS:

THIS IS AN INCIRCUIT EMULATOR FOR THE 8031. THIS SYSTEM USES AN IBM PC AS A HOST COMPUTER.

| CYBERNETIC MICRO SYSTEMS | |
|---|---|
| XASM-51 | 245 |
| 27XX EPROM PROGRAMMING KIT | 295 |
| 8031 SIMULATOR/DEBUG | 595 |
| POWER SUPPLY | 150 |
| IBM PC | 2500 |
| | 3785 |

COMMENTS:

THIS SYSTEM IS SOFTWARE & EPROM PROGRAMMER ONLY. THE CODE CAN BE WRITTEN AND THEN PROGRAMMED INTO EPROM.

81-30564

3.

| MICROCOMPUTER TOOLS CO. | PRICE |
| --- | --- |
| XASM-51 | 150 |
| EPROM PROGRAMMER | 444 |
| IBM PC | 2,500 |
| COMMENT | 3,094 |

THIS IS A LOW END DEVELOPMENT SYSTEM. THIS SYSTEM USES ONLY AN ASSEMBLER TO DEVELOP THE CODE AND AN EPROM PROGRAMMER TO GENERATE A PROM. THIS IS VERY LOW COST AND PORTABLE.

| AVOCET | |
| --- | --- |
| XASM-51 | 250 |
| SIMULATOR | 299 |
| EPROM PROGRAMMER | 444 |
| IBM PC | 2500 |
| COMMENTS: | 3493 |

THIS IS A LOW COST DEVELOPMENT SYSTEM WITH A SOFTWARE SIMULATOR.

| ORION INSTRUMENTS | |
| --- | --- |
| UDL32 UNIVERSAL DEVELOPMENT LAB | 2,995 |
| CA-E | 85 |
| C8-28 | 75 |
| IBM PC | 2500 |
| XASM-51 | 250 |
| COMMENTS: | 5,905 |

THIS IS A VERY POWERFUL SYSTEM BESIDES IN-CIRCUIT-EMULATION IT CAN MONITOR THE DATA BUS. THIS SYSTEM IS VERY PORTABLE.

| DEVELOPMENT SYS | XASM-51 | EPROM | IBM PC | ICE | PRICE | COMMENTS | HIGH LEVEL LANG. |
|---|---|---|---|---|---|---|---|
| PMDX 431A | x | x | | x | 35,170 | NOT PORTABLE | x |
| HP 64110A | x | x | | x | 23,585 | PORTABLE UNIVERSAL | |
| PDS-100 | x | x | | x | 9,225 | PORTABLE | x |
| MDS-8031 | x | x | x | x | 8,250 | PORTABLE TOOL BOX | x |
| IDP-31 | x | x | x | x | 6,439 | PORTABLE | x |
| META ICE -31 | x | x | x | x | 4,974 | PORTABLE | x |
| CYBERNETIC | x | x | x | | 3,785 | NO ICE | x |
| MICROCOMPUTER TOOLS | x | x | x | | 3,094 | NO ICE | x |
| AVOCET | x | x | x | | 3,493 | NO ICE | x |
| ORION INST. | x | x | x | x | 5,905 | VERY PORTABLE | x |
| OKI | | | | | | | |

MINIMUM SYSTEM

XASM-51
TEXT EDITOR
EPROM PROGRAMMER

NEXT STEP UP

XASM-51
SIMULATOR (RUNS PROGRAM WITHOUT ACTUAL HARDWARE)
TEXT EDITOR
EPROM PROGRAMMER

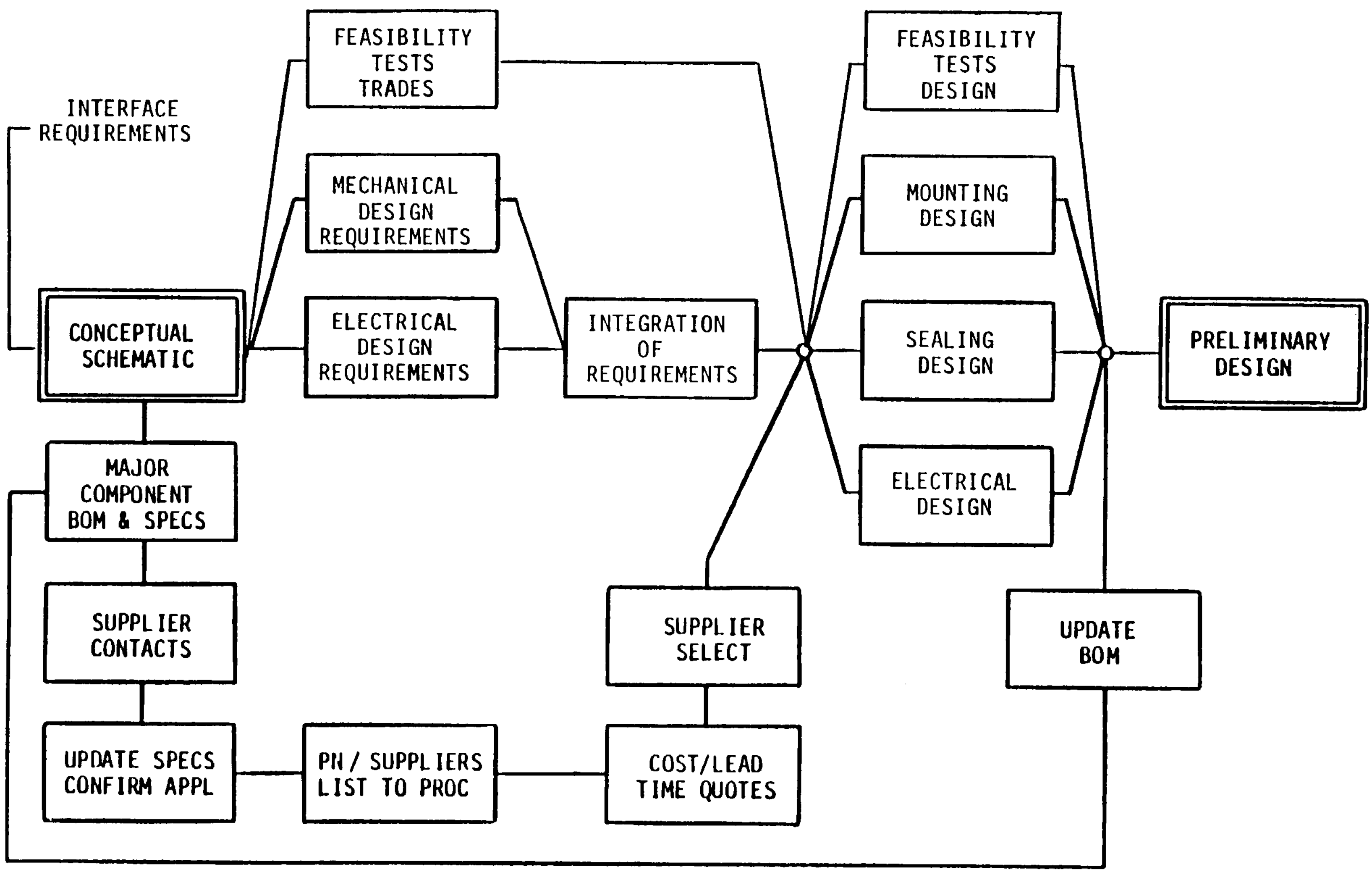
NEXT STEP UP

IN-CIRCUIT EMULATOR (RUNS PROGRAM WITH HARDWARE)
XASM-51
TEXT EDITOR
EPROM PROGRAMMER

Beechcraft
Boulder Division

# CURRENT GAGING SYSTEM DESIGN ACTIVITIES

(ANTENNA)



| | | | |
|---|---|---|---|
| PART NAME | FEED THRU ASSY | TEST C. O. 27237 | REV ---- |

| WRITTEN BY | PROJ. ENGINEER | NO. REQUIRED | DISPOSITION OF PARTS | USE | REW'RK | SCRAP | NOTED | TOOLING AFFECTED |
|---|---|---|---|---|---|---|---|---|
| K.Van Leuven<br>PHONE NO. | K.Van Leuven 3/12/86 | AS NOTED | PREFORMED STOCK | | | | | |
| CHECKER | APPROVAL 3/12/86 Roger Scarlett | MODEL: N/A<br>APPLICATION: zero-gravity gaging | IN PROCESS | | | | | |
| | | | FINISHED | | | | | TOOLING STOPPED YES NO |

| PURPOSE OF TEST: | REQUIRED COMPLETION DATE | WORK ORDER NO. |
|---|---|---|
| ANTENNA DEVELOPMENT- RF MODAL | APRIL 10, 1986 | 22885 |

REFERENCE

REV DATE

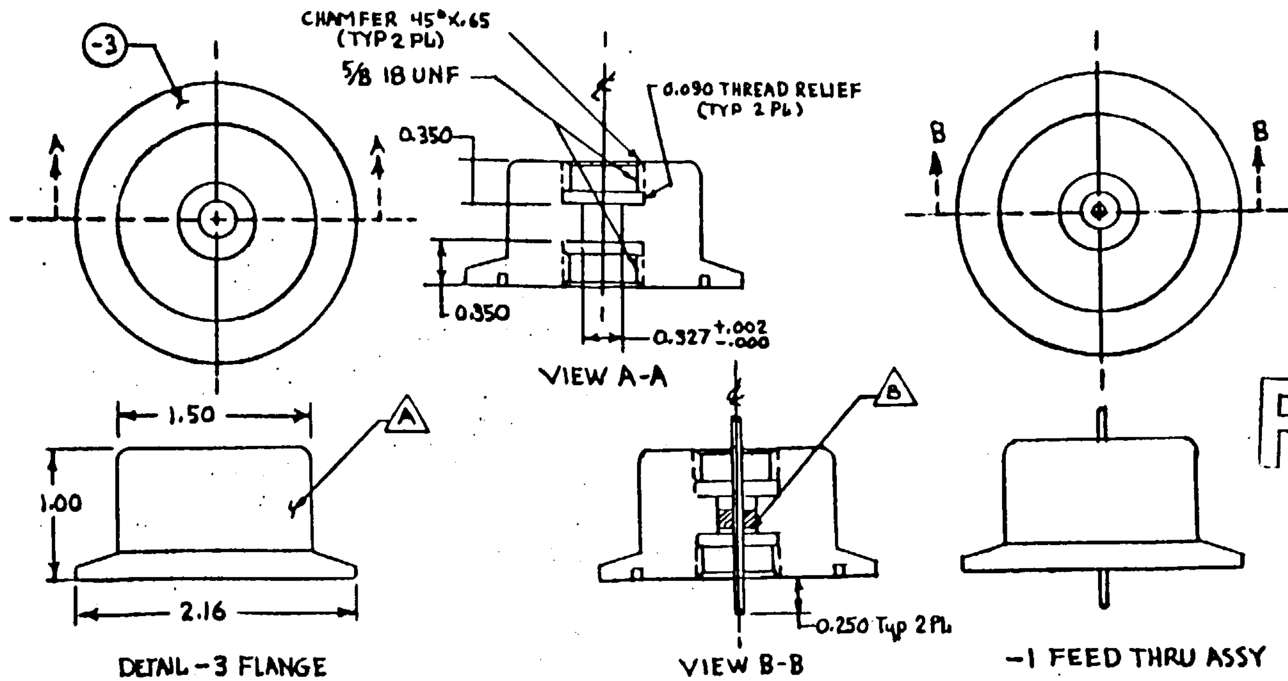
MFG (Dept 601) Fabricate: 5 ea. -3 FLANGE (DO NOT USE SULPHENATED CUTTING OIL)

OP (see B) USING TWO OF THE FIVE -3 FLANGES, DEVELOP THE CERAMIC SEAL BRAZE CYCLE. THEN FABRICATE 3 ea. -1 FEED THRU ASSY.

A MAKE FROM HPS CORPORATION 31-1305 UNBORED FLANGE.

B HERMETIC CERAMIC SEAL AND INTEGRAL KOVAR PIN (0.058dia.)TO BE SUPPLIED AND BRAZED INTO -3 FLANGE BY THREE-E LABORATORIES INC.; 840 W.MAIN STREET, LANSDALE, PENNSYLVANIA 19446;(215) 822-3669 M. POLLACK. SEAL IS TO WITHSTAND 80 PSIA,-425°F AND MAINTAIN HERMITICITY OF 1x $10^{-8}$ SCC He/sec.

F-22




5

BEECH R MAR 12 1986 R BOULDER

EDPR J44273 Lucy

90-34145A

BEECH AIRCRAFT CORPORATION - WICHITA, KS 67201

SHEET 1 OF 1 SHEETS

| | | | |
|---|---|---|---|
| PART NAME | ZERO-G ANTENNA HEAD ASSEMBLY | TEST C. O. 27239 | REV --- |

| | | | | |
|---|---|---|---|---|
| WRITTEN BY: K. VanLEUVEN<br>PHONE NO. | PROJ. ENGINEER: K. VanLEUVEN | NO. REQUIRED: AS NOTED | | |
| CHECKER: --- | APPROVAL: R. Scarlott. 3/24/86 | MODEL: N/A | APPLICATION: ZERO-G GAGING | |

| DISPOSITION OF PARTS | USE | REW'RK | SCRAP | NOTED |
|---|---|---|---|---|
| PREFORMED STOCK | | | | |
| IN PROCESS | | | | |
| FINISHED | | | | |

TOOLING AFFECTED

TOOLING STOPPED: YES XXXX

PURPOSE OF TEST: DESIGN FEASIBILITY TESTING - ZERO GRAVITY QUANTITY GAGING USING RF MODAL TECHNIQUES

REQUIRED COMPLETION DATE: APRIL 15, 1986

WORK ORDER NO.: 22885

REV DATE

5

MFG: (Dept 601)
(1) Fabricate 3 ea 561468-1 Antenna Head Assembly*
(2) Clean Assembly (pre-weld clean level)*
(3) Deliver assemblies to Government Stock Room 677-691*

Layout Drawing 561468 and TCO 27237 form a part of this TCO.
Conformity Inspection not required.

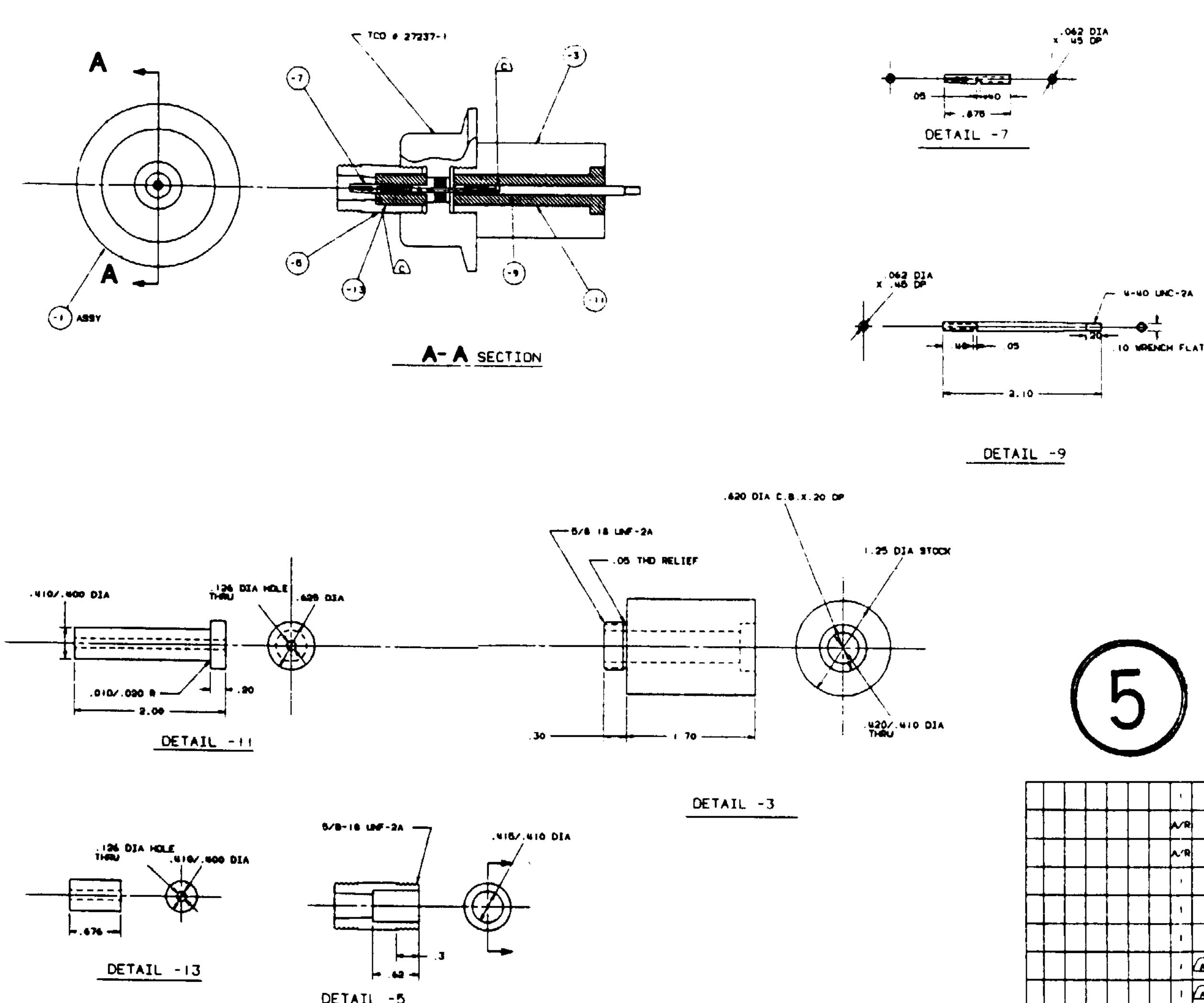
*NOTE: The 27237-1 Feed Thru Assembly which forms a part of the Antenna Head Assembly contains a hermetic seal which could be damaged by pushing, tapping or twisting the Kovar pin sticking out either side of the -1 Feed Thru Assembly. Care should be taken in handling and assembly operations with this part.

TCØ 3-27-86

F-23

REFERENCE

BEECH
R D MAR 24 1986 R D
BOULDER




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | | FEED THRU ASSY | TCO # 27237-1 | | | | |
| A/R | | FLUX | | | FED-O-F -499C | | 3D |
| A/R | | SILVER SOLDER | | | QQ-O-604 | GRADE II | |
| 1 | | PIN INSULATOR | | -13 | | .50 DIA TFE ROD | |
| 1 | | ROD INSULATOR | | -11 | | .75 DIA TFE ROD | 2D |
| 1 | | ANTENNA ROD | | -9 | | .125 DIA ROD 303 CRES | 2D |
| 1 | (A) | PIN | UG-29A (B) | -7 | | | 3C |
| 1 | (A) | CONNECTOR | UG-29A (B) | -5 | | | 4A |
| 1 | | STANDOFF PLUG | | -3 | | 1.250 DIA BAR 304 CRES | 3A |
| X | | ZERO-G ANTENNA HEAD ASSY | | -1 | | | 1C |

NOTES:

(C) SILVER BRAZE PER BEECH SPEC BS16106 USING SILVER SOLDER PER QQ-O-604 GRADE II & FLUX PER FED-O-F-499C. CHILL BAR HERMETIC SEAL SIDE OF JOINT.

(B) M/F UG-29A(OR EQUAL) TYPE N COAXIAL CONNECTOR, JACK TO JACK, PER MIL-C-39012.

(A) P/N OF: AMPHENOL
2122 YORK RD
OAK BROOK, ILL 60521

BEECH AIRCRAFT CORPORATION
BOULDER DIVISION, BOULDER, COLORADO

ZERO-G ANTENNA HEAD ASSEMBLY

E 07399 561468

561468

FOLDOUT FRAME

PART NAME — ERO NTE... ELE...S

TEST C. O. 27[illegible]1 REV ---

| WRITTEN BY | PROJ. ENGINEER | NO. REQUIRED | |
|---|---|---|---|
| K. VanLEUVEN | K. VanLEUVEN | AS NOTED | |
| PHONE NO. | | | |
| CHECKER | APPROVAL | MODEL | APPLICATION |
| --- | R. Scarlett 3/25/86 | N/A | ZERO-G GAGING |

PURPOSE OF TEST: DESIGN FEASIBILITY TESTING - ZERO GRAVITY QUANTITY GAGING USING RF MODAL TECHNIQUES

| DISPOSITION OF PARTS | USE | REW'RK | SCRAP | NOTED |
|---|---|---|---|---|
| PREFORMED STOCK | | | | |
| IN PROCESS | | | | |
| FINISHED | | | | |

TOOLING AFFECTED

TOOLING STOPPED YES NO

REQUIRED COMPLETION DATE: APRIL 16, 1986

WORK ORDER NO. 22885

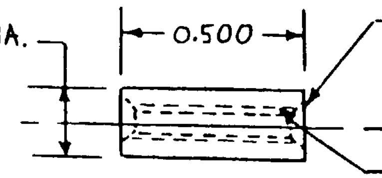
REV DATE

MFG: (Dept 601)

Fabricate: 4 ea -1
2 ea -3

Stock: Deliver to Gov't Stock Room 677-691 for Zero-G Quantity Gaging Program

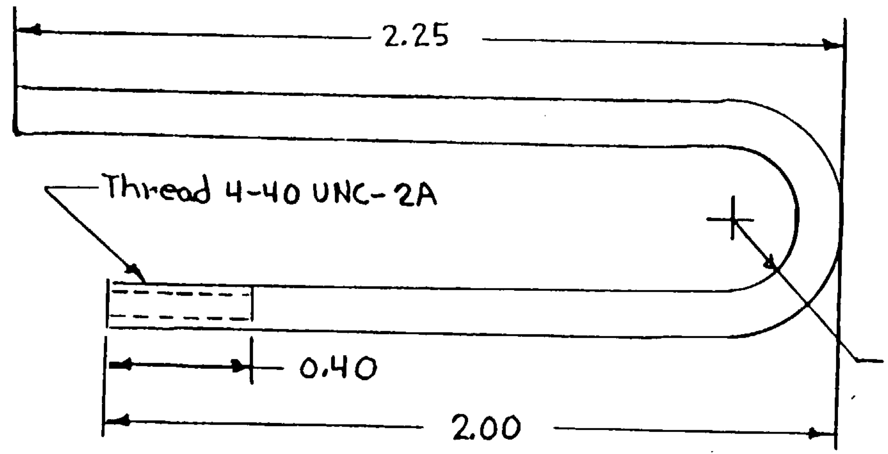
Conformity Inspection Not Required




-1 Detail make from 3/16 Dia. Cress Rod
Scale 2:1

TCØ 3-27-86

5




-3 Detail make from 1/8 Dia. Cress Rod
Scale 2:1

BEECH
R MAR 25 1986 R
BOULDER

REFERENCE

F-25

90-34145A

PART NAME: ZERO-G ANTENNA ASSEMBLIES

TEST C. O. 27552 REV ---

| WRITTEN BY | PROJ. ENGINEER | NO. REQUIRED | |
|---|---|---|---|
| K. VanLEUVEN | K. VanLEUVEN | AS NOTED | |
| PHONE NO. | | | |
| CHECKER | APPROVAL | MODEL | APPLICATION |
| --- | [signature] 3/25/86 | N/A | ZERO-G GAGING |

| DISPOSITION OF PARTS | USE | REW'RK | SCRAP | NOTED |
|---|---|---|---|---|
| PREFORMED STOCK | | | | |
| IN PROCESS | | | | |
| FINISHED | | | | |

TOOLING AFFECTED

TOOLING STOPPED YES XXXX

PURPOSE OF TEST: DESIGN FEASIBILITY TESTING - ZERO-GRAVITY QUANTITY GAGING USING RF MODAL TECHNIQUES

REQUIRED COMPLETION DATE: APRIL 16, 1986

WORK ORDER NO. 22885

REV DATE

GOV STOCK ROOM 677-691:

ISSUE:
3 ea 31032-KETR Metal Gaskets (Indium Seal Rings) } P/N's of VAT Inc.
3 ea 31032-KESR Stainless Steel Clamps
3 ea 561468-1 Antenna Head Assembly } Beech Fabricated Parts
4 ea TCO 27551-1 Antenna Element
2 ea TCO 27551-3 Antenna Element

To Dept 693 (Attn: Dick Lohry). Parts are to be used in Zero-Gravity Quantity Gaging Design Feasibility Testing.

TEST:
(Dept 693) Assemble test Antenna Components per Engineering Instructions to conduct Design Feasibility Tests.

MFG:
(Dept 601) Provide tack weld of TCO 27551-3 loop to end of 561468-3 plug (2 ea) to support Test Antenna Assembly by Test Department 693.

Layout Drawing 561468 and TCO 27551 form a part of this TCO.
Conformity Inspection not required.

TCO 3-27-86

5

BEECH R MAR 25 1986 R BOULDER

REFERENCE

F-26

PAR. NAME: ANTENNA TEST FIXTURE ASSEMBLY

TEST C. O. 27553 | REV ---

| WRITTEN BY | PROJ. ENGINEER | NO. REQUIRED | |
|---|---|---|---|
| K. VanLEUVEN | K. VanLEUVEN | AS NOTED | |
| PHONE NO. | | | |
| **CHECKER** | **APPROVAL** | **MODEL** | **APPLICATION** |
| --- | [signature] 3/3/86 | N/A | ZERO-G GAGING |

| DISPOSITION OF PARTS | USE | REW'RK | SCRAP | NOTED |
|---|---|---|---|---|
| PREFORMED STOCK | | | | |
| IN PROCESS | | | | |
| FINISHED | | | | |

TOOLING AFFECTED

TOOLING STOPPED | YES | NO

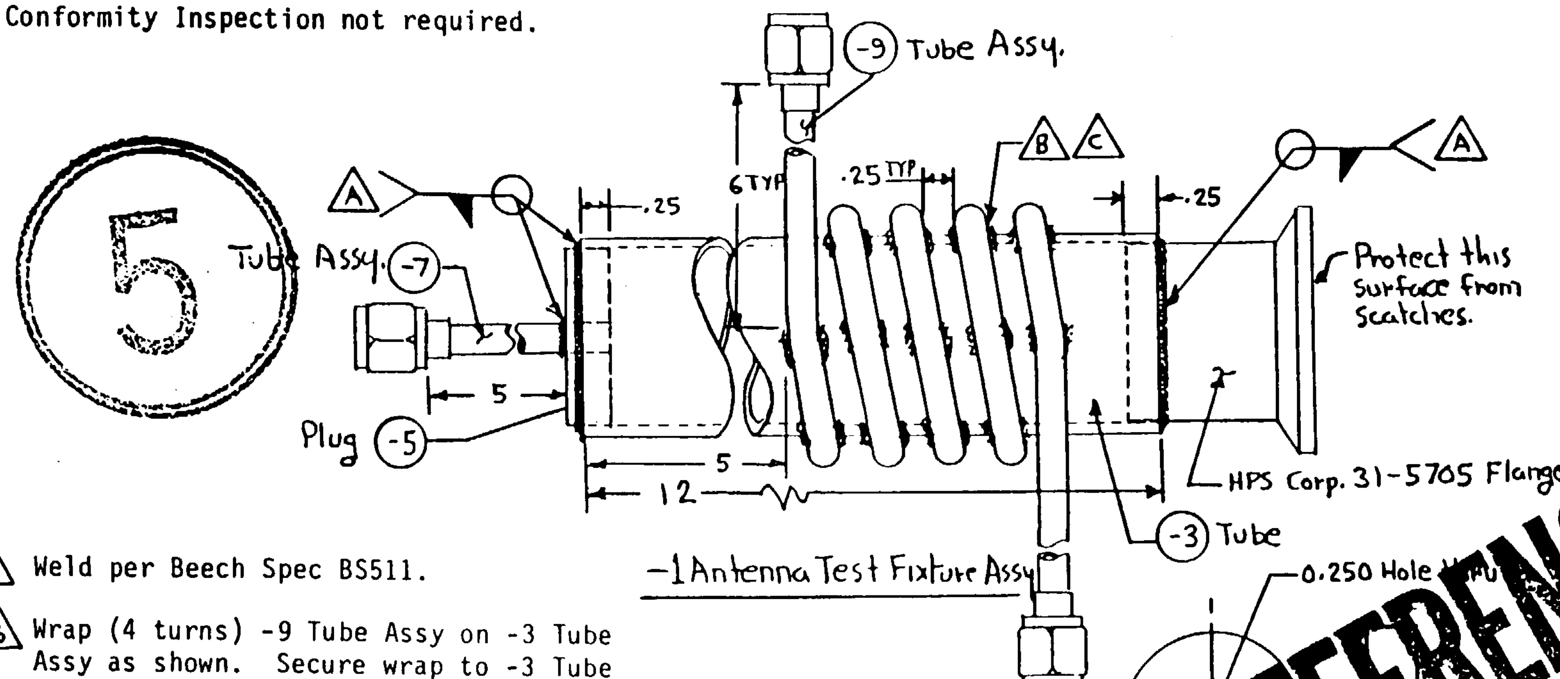
**PURPOSE OF TEST:** DESIGN FEASIBILITY TESTING - ZERO GRAVITY QUANTITY GAGING ANTENNA MECHANICAL DESIGN

**REQUIRED COMPLETION DATE:** APRIL 17, 1986

**WORK ORDER NO.:** 22885

REV DATE

1. Fabricate 1 ea -1 Antenna Test Fixture as shown below. Deliver to Dick Lohry, Department 693.
2. The -3 Tube, -7 Tube Assembly, -9 Tube Assembly and 3/8" thick Cress Material for the -5 Plug will be furnished from existing stock by Juan Hernandez. The HPS Corp. 31-5705 Flange is in Government Stock Room 677-691 (Zero-Gravity Quantity Gaging W/O 22885).
3. Conformity Inspection not required.




-1 Antenna Test Fixture Assy

(A) Weld per Beech Spec BS511.

(B) Wrap (4 turns) -9 Tube Assy on -3 Tube Assy as shown. Secure wrap to -3 Tube with intermittant silver braze about 3/8" long every two inches.

(C) Silver braze per Beech Spec BS16106.


Detail -5 Plug

BEECH R APR 2 1986 R BOULDER

REFERENCE

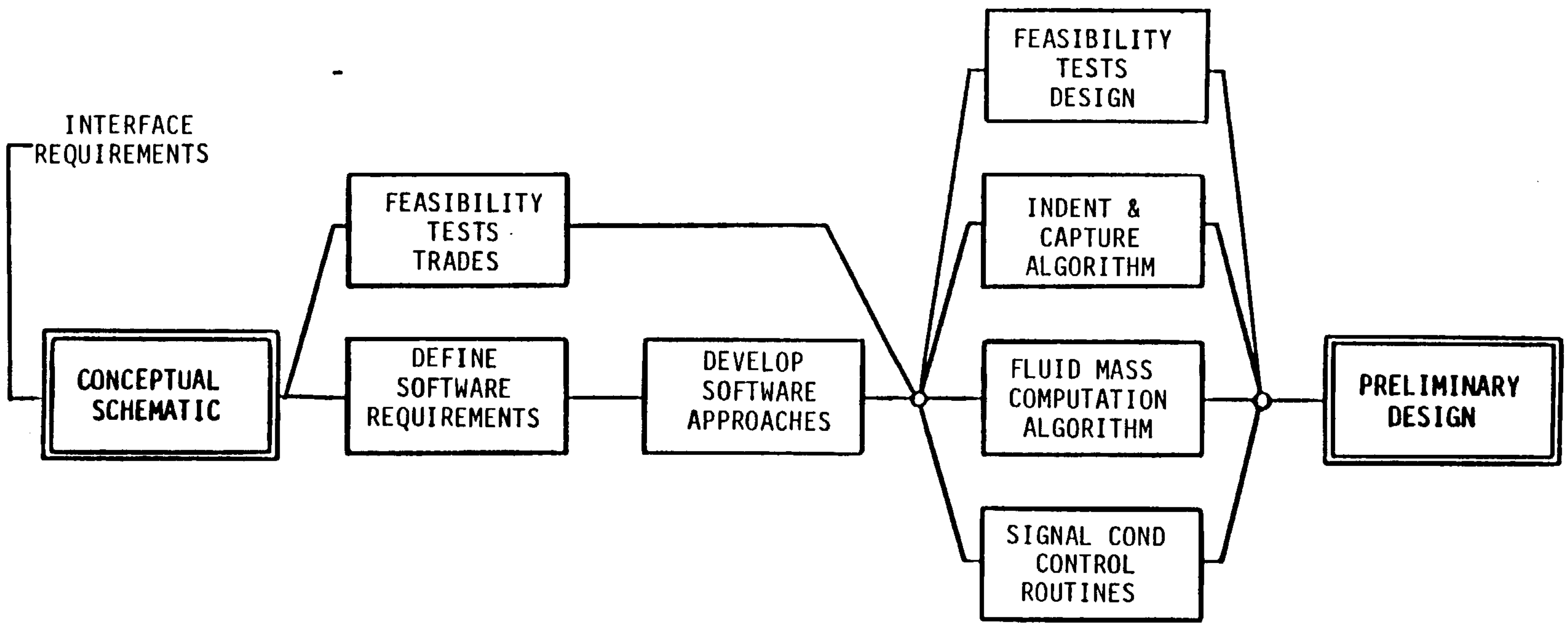
TCØ SØR 4-3-86

F-27

Beechcraft
Boulder Division

# CURRENT GAGING SYSTEM DESIGN ACTIVITIES

(SOFTWARE)



# Appendix G

**STATEMENT OF WORK**

**FOR**

**ZERO-GRAVITY QUANTITY GAGING SYSTEM**

**BENCH-TOP TESTS**

## TABLE OF CONTENTS



## LIST OF FIGURES

## 1.0 PURPOSE

1.1 Objective. The primary objective of this effort is to evaluate the performance of the RF Modal Quantity Gaging approach with Bench-Top Testing using simulated propellant gas/liquid interfaces more nearly representative of interface configurations which might actually be encountered in near zero-gravity space flight. The results of this effort will provide the basis for a decision for whether to continue the development of the RF Modal Quantity Gaging approach.

1.2 End Products. The end product of this effort will be the final report documenting the results of the RF modal gaging approach performance evaluation.

1.3 Background. To date the performance evaluation testing of the RF model gaging approach under the current contracted effort has been conducted using cryogenic fluids in a rotatable dewar. This has provided a means of obtaining a wide variety of liquid attitudes in the test dewar but did not provide a means of simulating single bubble, wetted wall, or floating globule liquid interface configurations which might be encountered in near zero-gravity space flight. These unique interface conditions were to be experienced later in the program during "zero-gravity" test flights conducted using the Johnson Space Center KC-135 zero-gravity aircraft. This exposure to the more realistic zero-gravity liquid interface conditions so late in the program became of sufficient concern to the NASA that they have decided to implement a series of Bench-top tests during the early feasibility testing phase of the contract which simulate the more realistic liquid interface conditions. These tests are to be completed before proceeding any further with currently scheduled feasibility testing in support of design or gaging system design tasks.

Bench-top testing became a viable approach when it was discovered that paraffin could be used to model the more realistic liquid interface configurations and that the RF modal frequencies were scalable to a manageable size of the test tank. The internal volume of the Bench-top Test Tank is to be empty of any constructs save gaging antenna, for the initial tests, to eliminate issues ancillary to the evaluation of the more realistic "liquid" interface configurations on the performance of the RF modal gaging approach. The basic configuration of the Bench-top Test Tank is to be a scale version of the empty Universal Test Tank used for all gaging system performance tests to date. This is to provide a link between the Bench-top tests and the Universal Tank cryogenic baseline testing. Since the Universal Test Tank is also dimensionally similar to the CFMFE receiver tank, the link to CFMFE is established.

## 2.0 SCOPE

2.1 General. Ball Aerospace Systems Division (BASD) will provide the planning, design, and fabrication leading to the setup and verification of a bench-top test resource. BASD will then use this resource to conduct tests to evaluate the performance of the RF modal quantity gaging approach when exposed to realistic near zero-gravity liquid interface configurations modeled with paraffin. The test data will be collected, reduced, and analyzed by BASD for the development of a microprocessor-compatible algorithm for converting tank cavity modal response into fluid mass contained in the tank cavity. The accurancy of this algorithm must be five percent or less of full tank cavity fluid mass for the gaging concept to be considered viable. A final report will be prepared which will document the tests, the data, the algorithm, and the results of the performance evaluation.

2.2 Work Breakdown Structure. The work breakdown structure (WBS) shown in Figure 2-1 outlines the work to be performed in this effort. This effort interfaces with the original contract by simply adding a subtask (2.3 Bench-Top Tests) to the 2.0 Feasibility Testing task. The numbering scheme of the subtasks follows a "standardized" BASD WBS format.

2.3 Program Schedule. The schedule for this additional work is presented in Figure 2-2. The schedule assumes receipt of the NASA authorization to proceed (ATP) in the first week of February 1987. This start date will easily allow completion of the Bench-top Tests before the end of the current fiscal year.

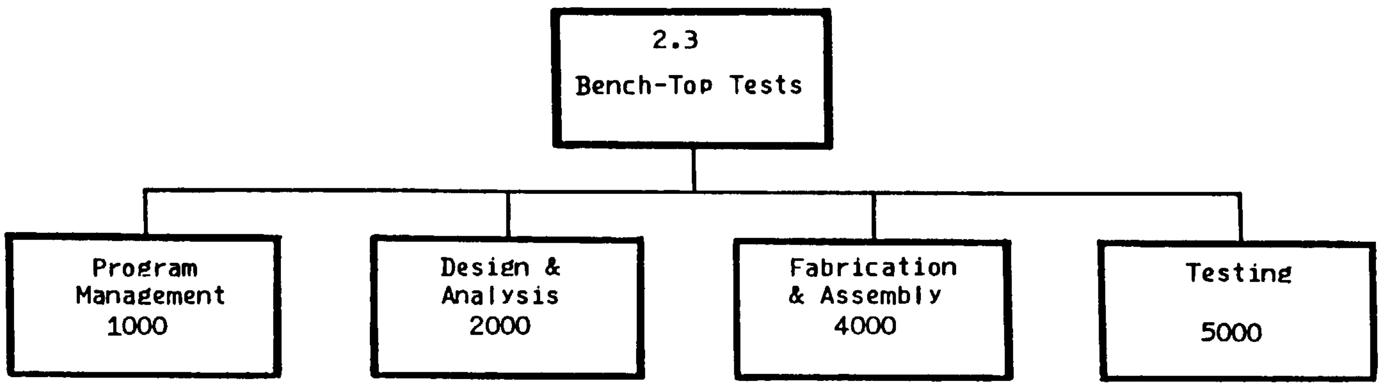



Figure 2-1 Work Breakdown Structure Bench-Top Testing Effort

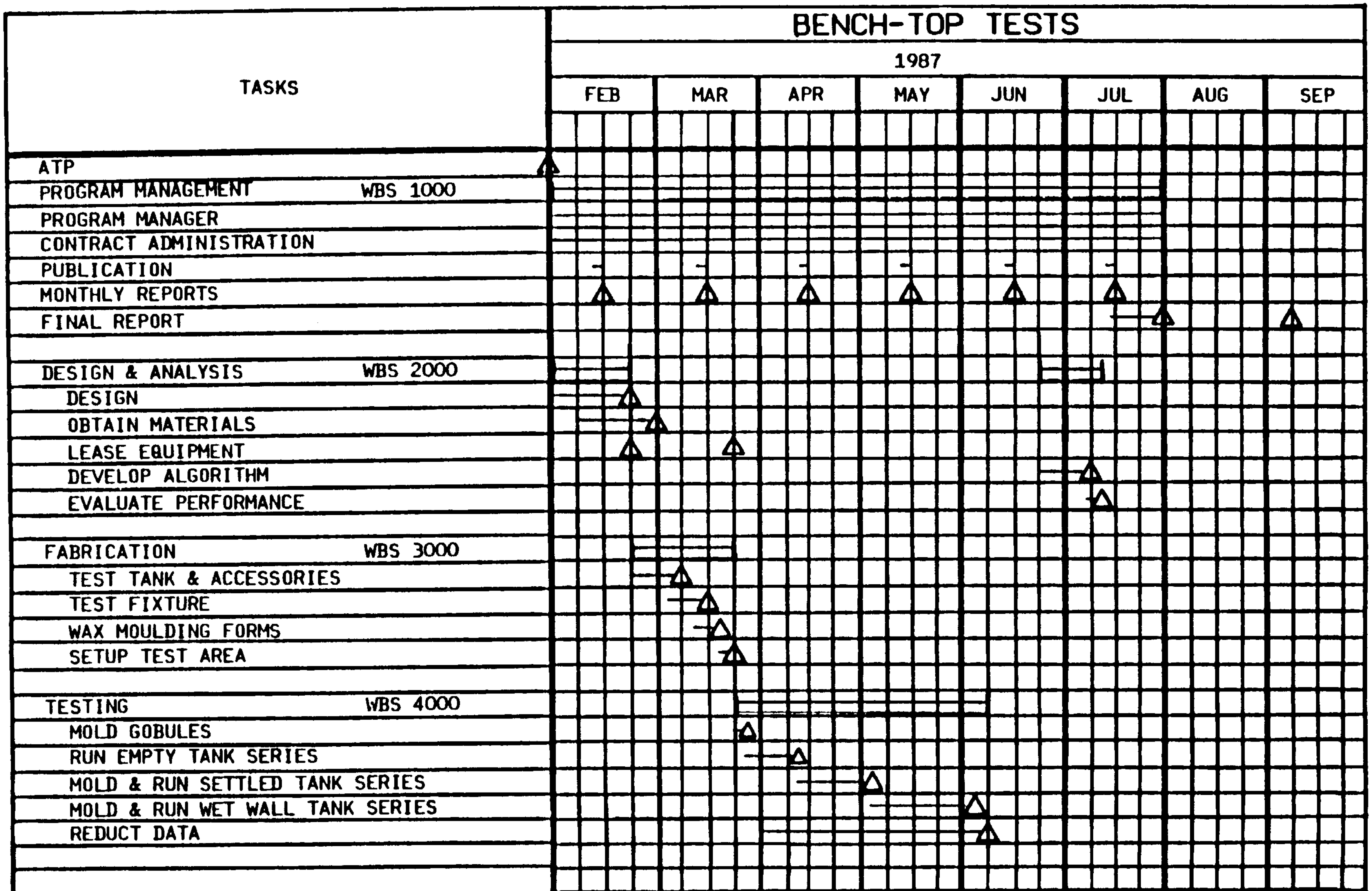



**Figure 2-2 BENCH-TOP TESTS SCHEDULE**

## 3.0 TECHNICAL REQUIREMENTS

### 3.1 Bench-Top Test Requirements

3.1.1 General Requirements. The bench-top testing effort will comply with the following general requirements:

a) The Bench-top Test Tank shall be a half-scale model of the empty Universal Test Tank (18-inch hemispherical heads and 4-inch cylinder section).

b) The Bench-top Test Tank will not be required to hold pressure but must be substantial enough to contain the paraffin liquid simulant without deflection or distortion.

c) The RF modal gaging system will be assembled using a laboratory implementation consisting of a HP 8568B spectrum analyzer, a HP 8444A-059 tracking generator, and a HP 778D directional coupler.

d) The RF modal gaging system will be manually operated for these tests.

e) Antenna mounts will be based on standard TNC bulkhead fittings.

f) Multiple antenna mounting positions (no more than eight) will be provided on the test tank.

g) ASTM 132 aliphatic paraffin wax will be used to model the test liquid interface configurations.

### 3.2 Detail Technical Requirements

3.2.1 General. This additional effort is divided into four seperate tasks. The first task provides for the program management administration of the efforts and the provision of publication resources. The remaining three tasks are technical and provide for the design and fabrication of the test articles, conduction of tests and the analysis and evaluation of results. More definitive descriptions of each of these tasks is provided in the following paragraphs.

3.2.2 Program Management - WBS 1000. The program management function consists of project administration, cost and schedule monitoring, secretarial and reporting tasks. Reporting will be accomplished by BASD at three levels. First, the Bench-top test status will be reported in the Zero-Gravity Quantity Gaging Program monthly status report. Secondly, a final report documenting all aspects of the Bench-top test series will be prepared and 15 copies will be provided to NASA. Thirdly, a specific viewgraph briefing for the Bench-top test series will be prepared and presented at the next regularly scheduled program review following completion of the tests.

3.2.3 Design & Analysis - WBS 2000.

Design. BASD will prepare fabrication drawings of sufficient detail to permit the ordering of parts and materials and subsequent fabrication of the following Bench-top test hardware.

a) Bench-top test tank
b) Test fixture
c) Wax forms

Purchase requisitions will be prepared for parts and materials to fabricate the test hardware as well as for the liquid simulant wax and the leased laboratory equipment for the RF modal gaging system.

Analysis. The reduced modal response data from the testing task will be used in the development of a microprocessor-compatible algorithm which will convert tank modal response information into a value for the fluid mass inside the tank cavity. The performance of the gaging system using the algorithm will be evaluated. The performance goal for this conversion using simulated zero-gravity fluid interfaces is a fluid mass determination accuracy of five percent or less of the full tank mass. The performance of the RF modal gaging approach must achieve this accuracy to be considered viable for further development. The developed algorithm will be implemented on a Hewlett Packard 9835 computer in basic and its compatibility verfied using measured tank modal response data. The algorithm will be documented in the final report including the HP 9835 program listing.

3.2.4 Fabrication - WBS 4000. BASD will fabricate the Bench-top test hardware as detailed in the drawings prepared in the design task. Liaison with manufacturing and acceptance of the completed hardware will be the responsibility of the Project Engineer.

Assembly of all elements of the Bench-top test series in the designated test area will be arranged for by the Project Engineer. Specifically, the laboratory implementation of the RF modal gaging system will be assembled and operationally checked out. The empty Bench-top Test Tank will be mounted in the test fixture and all antenna positions verified operational. The wax melting, molding, and shaping hardware will be set up and verified functional.

3.2.5 Testing - WBS 5000. Engineering will perform all tasks required to conduct the Bench-top tests. These will include the molding and installation of paraffin fluid simulations in the test tank, the acquisition of modal response data for each antenna position, the documentation of each test sequence, and the reduction of data. All test data will be collected and organized into a formal archive. Reduced data will be put into forms suitable for publication in the final report.

The Bench-top testing effort is organized into three basic test series. These are the empty tank series, the settled tank series, and the wet-wall series.

(1) Empty Tank Series - An empty test tank is perturbed with two paraffin globules in various positions or a metallic spray bar simulation.

(2) Settled Tank Series - The test tank with its longitudinal axis vertical will be filled with paraffin to levels corresponding to quarter full, half full, three-quarters full, and full.

(3) Wet-Wall Series - Paraffin masses corresponding to tank fill levels of quarter full and half full, will be placed on the inside surface of the test tank as a uniform thickness layer. In addition to the basic wet-wall responses, the tank will be perturbed with two paraffin globules in various positions or a metallic spray bar simulation.

Figure 3.1 details the entire Bench-top test matrix, and Figure 3.2 summarizes the number of modal response data sets which will be obtained during the test effort.

| Test Series | Tank Fill Level (1) | | | | |
|---|---|---|---|---|---|
| | Empty | 1/4 Full | 1/2 Full | 3/4 Full | Full |
| Empty Tank Series: | | | | | |
| Empty | x(2) | | | | |
| Empty with two globule | x(1/8 ea)(3) | | | | |
| Empty with spray bar(4) | x | | | | |
| Settled Tank Series: | | | | | |
| Settled at 0° | | x | x | x | x |
| Wet-Wall Series: | | | | | |
| Basic wet-wall | | x | x | | |
| Wet-wall with two globule | | x(1/8 ea) | x(1/8 ea) | | |
| Wet-wall with spray bar(4) | | x | x | | |

(1) Basic tank fill level not counting additional mass in globules if present.

(2) x signifies standard set of modal measurements consisting of at least the four lowest mode responses at each of eight antenna positions.

(3) (1/8 ea) notations define the globular mass as being equivalent to one-eighth of the full tank mass. The "ea" notation is used to indicate both globules will be of equal mass but different shape. Measurements at different positions of the globules will be made as indicated in the following table:

| Number of Globules | Tank Fill Level | | | |
|---|---|---|---|---|
| | Empty | 1/4 Full | 1/2 Full | 3/4 Full |
| Two globule | 2 Position | 2 Position | 2 Position | - |

(4) Spray bar tests will be undertaken only to the extent that funding will permit.

Figure 3.1 BENCH-TOP TEST MATRIX

| Test Series | Tank Fill Level | | | | | |
|---|---|---|---|---|---|---|
| | Empty | 1/4 Full | 1/2 Full | 3/4 Full | Full | Totals |
| <u>Empty Tank Series:</u> | | | | | | |
| Empty | 32 | | | | | 32 |
| Empty with two globule | 64 | | | | | 64 |
| Empty with spray bar | 32 | | | | | 32 |
| <u>Settled Tank Series:</u> | | | | | | |
| Settled at $0^o$ | | 32 | 32 | 32 | 32 | 128 |
| <u>Wet-Wall Series:</u> | | | | | | |
| Basic wet-wall | | 32 | 32 | | | 64 |
| Wet-wall with two globule | | 64 | 64 | | | 128 |
| Wet-wall with spray bar | | 32 | 32 | | | 64 |
| Total | 128 | 160 | 160 | 32 | 32 | 512 |

Figure 3.2 SUMMARY OF MEASUREMENTS

## 4.0 QUALITY ASSURANCE

In the conduct of this effort, no exceptional quality assurance effort beyond the requirements for the Zero-Gravity Quantity Gaging System in NASA contract NAS9-17378 are needed.

# Appendix H

Aerospace
Systems
Group

# Zero Gravity Quantity Gaging System Mode Tracking and Identification Algorithm Development Review

April 19, 1989

Contract NAS9-17378 Effective Date 28 May 1985

# THE NEED FOR A MODE TRACKING AND IDENTIFICATION ALGORITHM

- GAGING IN ZERO GRAVITY REQUIRES USING THE THREE LOWEST TM MODE RESPONSES

- MANY MODE RESPONSES BESIDES THE THREE LOWEST TM MODES ARE OBTAINED IN THE FREQUENCY SWEEP

- THE TWO HIGHER FREQUENCY MODES ARE CAPABLE OF "CROSSING OVER"

ZEROGRAV112AA2-3

# THE NEED FOR A MODE TRACKING AND IDENTIFICATION ALGORITHM (Concluded)

IN-RANGE RESPONSE COUNTS FOR BENCH-TOP TEST SERIES

| ITEM | NO. OF RESPONSES | ITEM | NO. OF RESPONSES | ITEM | NO. OF RESPONSES | ITEM | NOS. OF RESPONSES |
|---|---|---|---|---|---|---|---|
| 1 | 42 | 10 | 25 | 19 | 16 | 28 | 14 |
| 2 | 28 | 11 | 16 | 20 | 20 | 29 | 15 |
| 3 | 26 | 12 | 18 | 21 | 17 | 30 | 14 |
| 4 | 27 | 13 | 25 | 22 | 17 | 31 | 7 |
| 5 | 28 | 14 | 20 | 23 | 17 | R1 | 20 |
| 6 | 20 | 15 | 18 | 24 | 20 | R2 | 24 |
| 7 | 21 | 16 | 19 | 25 | 17 | R3 | 21 |
| 8 | 25 | 17 | 17 | 26 | 19 | R4 | 22 |
| 9 | 29 | 18 | 15 | 27 | 16 | R5 | 24 |

ZEROGRAV112AA4-1

# PLANNED APPROACH TO MODE TRACKING AND IDENTIFICATION ALGORITHM DEVELOPMENT

- USE OF BENCH-TOP TEST DATA BASE
- DEVELOPMENT OBJECTIVES
- DEVELOPMENT FLOW CHART

ZEROGRAV112AA2-4

# USE OF BENCH-TOP TEST DATA BASE

- DATA BASE CONSISTED OF TABULAR DATA FROM APPENDIX A OF ZERO GRAVITY QUANTITY GAGING SYSTEM BENCH-TOP TEST REPORT, NO. ZG-011, DATED MAY 1988 (155 PAGES)

- FREQUENCIES WERE AVERAGED ACROSS THE EIGHT ANTENNA POSITIONS TO OBTAIN A SINGLE LIST OF FREQUENCIES FOR EACH TEST NUMBER OVER THE FREQUENCY RANGE OF 300 TO 879 MHz

ZEROGRAV112AA2-5

# DEVELOPMENT OBJECTIVES

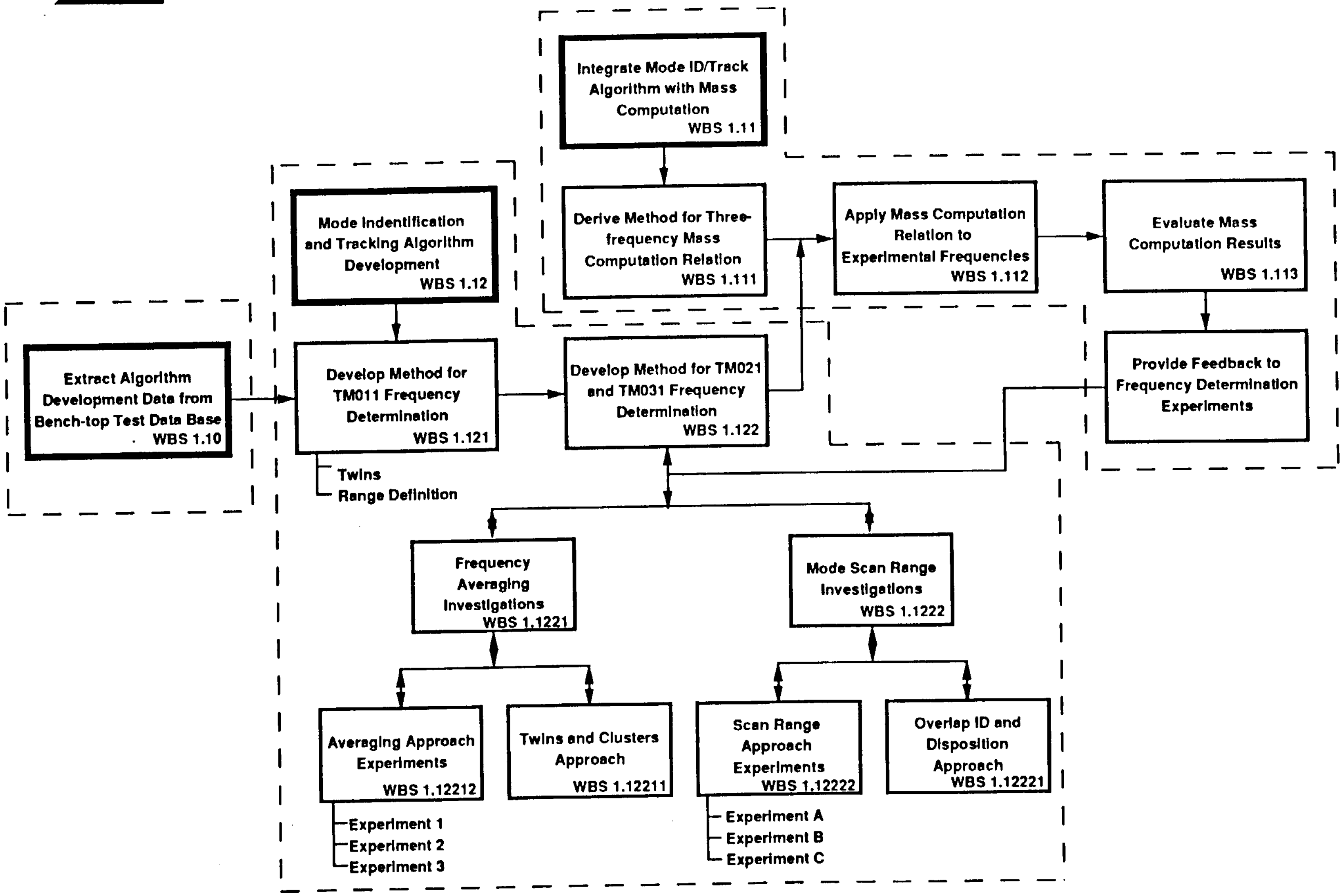
- USE BENCH-TOP TEST DATA BASE FOR ALGORITHM DEVELOPMENT

- INTEGRATE THE MODE TRACKING AND IDENTIFICATION ALGORITHM WITH THE MASS COMPUTATION ALGORITHM

- OBTAIN AT LEAST ±5 PERCENT OF FULL-SCALE ACCURACY WITH THE INTEGRATED ALGORITHM

ZEROGRAV112AA2-6

# DEVELOPMENT FLOW CHART




A/N 9989/MD209.10

ZEROGRAV112AA3-2

# WHAT WAS DONE

- PREPARATION OF DATA
- INVESTIGATION OF FREQUENCY SELECTION APPROACHES
- INTEGRATION WITH MASS COMPUTATION ALGORITHM

ZEROGRAV112AA2-7

# PREPARATION OF DATA

- SELECTION OF DATA
- IDENTIFICATION OF DATA
- CONVERSION TO SINGLE LIST



ZEROGRAV112AA2-8

# SELECTION OF DATA

THE TWO BENCH-TOP TEST DATA SETS THAT WERE NOT USED WERE:

- EMPTY TANK WITH SPRAY BAR (TEST NO. 2)
  - MODAL BASIS OF TANK IS CHANGED FROM SPHERICAL CAVITY TO COAXIAL BY SPRAY BAR
- WET WALL, 1/2 FULL, 1 GLOB, TOP (TEST NO. 32)
  - DATA FROM THIS TEST WAS IDENTICAL TO WET WALL, 1/2 FULL, 1 GLOB, BTM (TEST NO. 30)

# IDENTIFICATION OF DATA

| DATA ITEM NO. | MASS (LB) | BENCH TEST NO. | DATA ITEM NO. | MASS (LB) | BENCH TEST NO. | DATA ITEM NO. | MASS (LB) | BENCH TEST NO. |
|---|---|---|---|---|---|---|---|---|
| 1 | 138.25 | 22 | 13 | 54.80 | 18 | 26 | 21.86 | 13 |
| 2 | 105.05 | 33 | 14 | 43.87 | 17 | 27 | 10.86 | 6 |
| 3 | 103.65 | 21 | 15 | 42.00 | 23 | 28 | 10.86 | 7 |
| 4 | 91.60 | 30 | 16 | 36.50 | 3 | 29 | 10.86 | 8 |
| 5 | 91.60 | 31 | 17 | 36.50 | 4 | 30 | 10.86 | 9 |
| | 91.60 | 32 | 18 | 36.50 | 5 | 31 | 0.00 | 1 |
| 6 | 78.50 | 24 | 19 | 36.05 | 19 | | 0.00 | 2 |
| 7 | 78.50 | 25 | 20 | 32.93 | 14 | R1 | 49.33 | RAN1 |
| 8 | 78.50 | 26 | 21 | 32.93 | 15 | R2 | 49.33 | RAN2 |
| 9 | 73.35 | 29 | 22 | 32.93 | 16 | R3 | 49.33 | RAN3 |
| 10 | 67.55 | 20 | 23 | 21.86 | 10 | R4 | 49.33 | RAN4 |
| 11 | 60.25 | 27 | 24 | 21.86 | 11 | R5 | 49.33 | RAN5 |
| 12 | 60.25 | 28 | 25 | 21.86 | 12 | | | |

ZEROGRAV112AA4-2

# CONVERSION TO SINGLE LIST

ITEM: 20

| ANTENNA POSITION | | | | | | | | AVERAGE RESPONSE FREQUENCY (MHz) |
|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | |
| 414.90 | 414.90 | | 414.58 | 414.79 | 414.79 | 414.79 | 414.37 | 414.72 |
| 419.41 | 419.20 | 419.41 | 419.52 | 419.41 | 419.20 | 419.33 | 419.52 | 419.38 |
| | 422.67 | 422.56 | 422.35 | | 422.56 | 422.46 | | 422.52 |
| | 572.50 | 572.71 | 572.71 | 572.50 | 572.50 | 572.50 | 572.40 | 572.55 |
| | 582.79 | | 582.79 | | | 582.69 | 582.69 | 582.74 |
| 587.62 | 587.94 | 587.52 | 587.10 | 587.94 | 587.94 | 587.94 | | 587.71 |
| 652.72 | 652.72 | 652.72 | 652.72 | 651.99 | 651.65 | 651.67 | 652.20 | 652.30 |
| 661.65 | 660.60 | 661.65 | 662.07 | 661.54 | 661.65 | 661.65 | 660.81 | 661.45 |
| | | | 667.50 | | | | 667.29 | 667.40 |
| | 677.61 | | | 677.50 | | 677.29 | | 677.47 |
| 697.24 | 697.14 | 697.03 | 696.82 | 697.14 | 697.03 | 696.93 | | 697.05 |

ZEROGRAV112AA4-3

# INVESTIGATION OF FREQUENCY SELECTION APPROACHES

- FREQUENCY SCAN RANGES

- SPECIFIC FREQUENCY SELECTION

- FREQUENCY LIST REDUCTION TECHNIQUES

ZEROGRAV112AA2-10

# FREQUENCY SCAN RANGES

- TM011 MODAL RESPONSE
- BASIC RELATIONSHIP BETWEEN THREE LOWEST MODAL RESPONSES
- FORM OF SCAN RANGE BOUNDARIES
- REDUCTION TO COMPUTATION APPROACH

ZEROGRAV112AA2-11

# TM011 MODAL RESPONSE

- LOWEST MODAL RESPONSE FREQUENCY

- IS PRONE TO BE A TWIN RESPONSE WITH $\Delta F$ LESS THAN 1 MHz (22 OF 36 CASES)

- DETERMINE F011 BY FINDING THREE LOWEST FREQUENCY MODAL RESPONSES; TAKE ARITHMETIC AVERAGE OF LOWEST AND ANY OTHERS WITHIN 1 MHz OF LOWEST

ZEROGRAV112AA2-12

# BASIC RELATIONSHIPS BETWEEN THREE LOWEST TM RESPONSES

- IN THE EIGEN FUNCTION RELATION DEFINING THE TANK CAVITY MODAL RESPONSE FREQUENCIES:

$$fnp = Unp/2\pi R \ (\mu\epsilon)^{1/2}$$

THE THREE LOWEST TM MODE EIGEN VALUES ARE:

$$U_{11} = 2.744$$
$$U_{21} = 3.870$$
$$U_{31} = 4.973$$

- IF THE TANK LOAD WAS UNIFORMLY DISPERSED THROUGHOUT THE TANK, WE COULD DETERMINE FO21 AND FO31 USING FO11 AND A SIMPLE RATIO OF THE EIGEN VALUES

$$FO21 = FO11 \times (U_{21}/U_{11}) = FO11 \times 1.410$$
$$FO31 = FO11 \times (U_{31}/U_{11}) = FO11 \times 1.812$$

- THIS WORKS WELL AT TANK EMPTY AND TANK FULL CONDITIONS

ZEROGRAV112AA1-18

# BASIC RELATIONSHIPS BETWEEN THREE LOWEST TM RESPONSES (Concluded)

- WHEN THE TANK LOAD IS NOT UNIFORMLY DISPERSED THROUGHOUT THE TANK
  - THE MODAL RESPONSES CAN OCCUR OVER A RANGE OF FREQUENCIES FOR A GIVEN LOAD
  - THE FREQUENCY RANGES OF THE MODES CAN OVERLAP
- THE FREQUENCY INTERVAL BETWEEN MODES DECREASES AS THE FREQUENCY INCREASES
- THE NUMBER OF MODAL RESPONSES/INTERVALS INCREASES AS THE FREQUENCY AND/OR LOADED MASS INCREASES

ZEROGRAV112AA1-19

# FORM OF SCAN RANGE BOUNDARIES

- TM011 MODES DO NOT REQUIRE A SCAN RANGE

- TM021 AND TM031 MODES WILL REQUIRE SCAN RANGES DEFINED TO
  - SORT THE MEASURED RESPONSES INTO F021 AND F031 RELATED GROUPS
  - IDENTIFY OVERLAP CONDITIONS

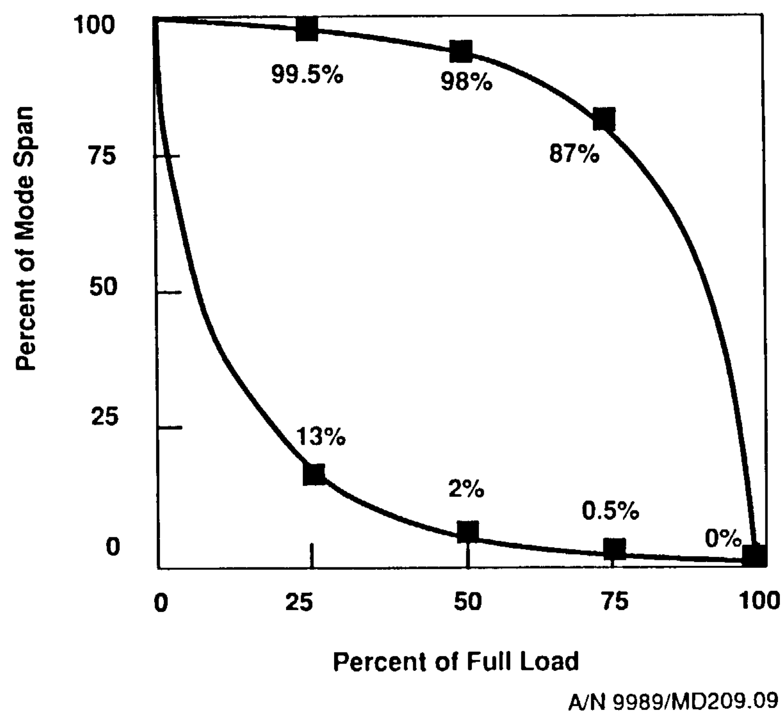
- THE WIDTH OF THE SCAN RANGE WILL BE ZERO AT EMPTY AND FULL TANK LOAD CONDITIONS

- WILL HAVE CONTINUOUS UPPER AND LOWER BOUNDARIES

ZEROGRAV112AA1-20

# FORM OF SCAN RANGE BOUNDARIES (Continued)

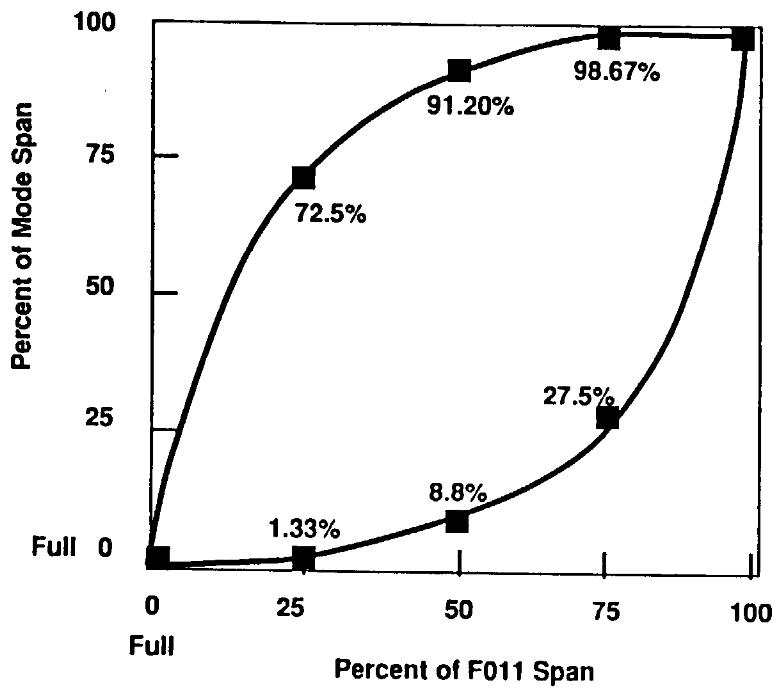
PLOTS OF TEST DATA PLUS GENEROUS MARGINS WERE USED TO DEVELOP A BASIC RANGE PROFILE




ZEROGRAV112AA1-21

# FORM OF SCAN RANGE BOUNDARIES (Concluded)

CROSS PLOTS WITH EQUIVALENT F011 RANGE CURVE GIVE SCAN RANGE AS A FUNCTION OF F011




A/N 9989/MD209.08

MODE SPAN

F021 = 210.07 MHz
F031 = 271.33 MHz
F011 = 153.27 MHz

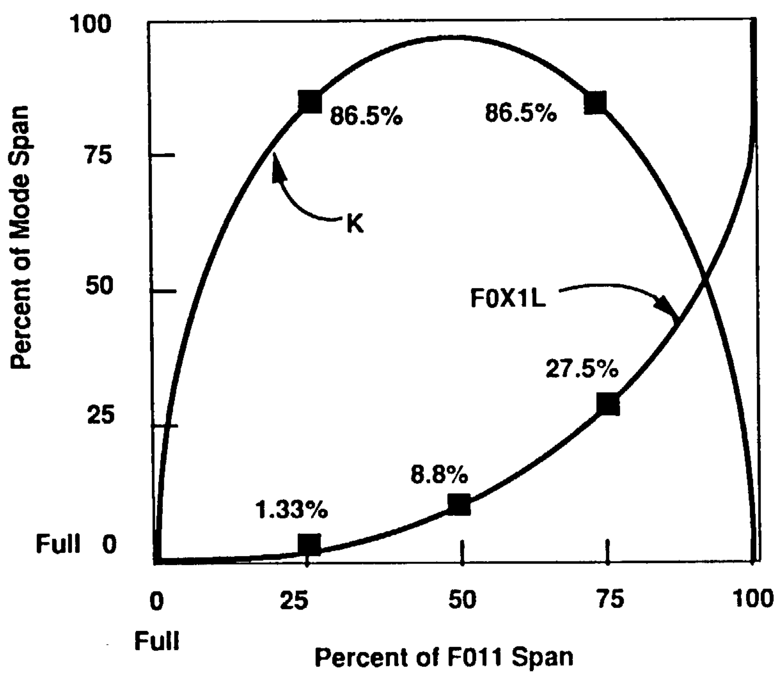
FULL FREQUENCY

F021 = 470.07 MHz
F031 = 607.36 MHz
F011 = 332.10 MHz

ZEROGRAV112AA1-22

# REDUCTION TO COMPUTATION APPROACH

THE LENS-SHAPED RANGE CURVES PROVED TO BE RESISTANT TO ACCURATE CURVE FITTING. AN ALTERNATIVE PLOT FORM WAS CREATED WHICH COULD BE COMPUTED USING A SIEVE AND INTERPOLATION APPROACH.




F0X1Δ = 0.824 x K x F0X1 Span

A/N 9989/MD209.07

ZEROGRAV112AA1-23

# REDUCTION TO COMPUTATION APPROACH (Concluded)

- SIEVE AND INTERPOLATION

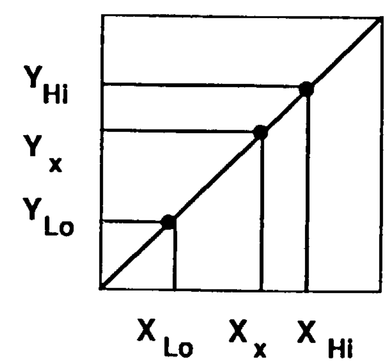
  - THE SIEVE PARTITIONS THE F011 RANGE INTO 21 INTERVALS; EACH INTERVAL ALLOWS ACCURATE REPRESENTATION OF THE SCAN RANGE CURVES BY STRAIGHT LINE SEGMENTS
  - EACH OF THE PARTITIONS HAS A SET OF LINEAR INTERPOLATION COEFFICIENTS FOR EACH RANGE CURVE
  - A VALUE OF F011 IS SORTED BY THE SIEVE TO A SET OF INTERPOLATION COEFFICIENTS THAT ARE USED IN EQUATIONS OF THE FORM $Yx = (Xx * C + B)/A$

  WHERE $A = XHi - XLo$

  $B = YLo\ XHi - YHi\ XLo$

  $C = YHi - YLo$

  TO CALCULATE THE SCAN RANGE PARAMETERS




A/N 9989/MD209.06

# SPECIFIC FREQUENCY SELECTION

- ORIGINAL APPROACH
- EVOLUTION OF THINKING
- THE NEW APPROACH

ZEROGRAV112AA1-25

# ORIGINAL APPROACH

SPECIFIC TM011, TM021, AND TM031 MODAL FREQUENCIES WERE DETERMINED BASED ON THE FACT THAT:

- F011 WOULD BE THE LOWEST FREQUENCY RESPONSE
- TRUE MODAL RESPONSES TENDED TO HAVE AT LEAST MEDIUM AMPLITUDE AND HIGH Q RESPONSES
- THE RESPONSE FELL WITHIN A FAIRLY LIMITED FREQUENCY RANGE
- THE RESPONSE FREQUENCIES WOULD LAY ON A SOLUTION SURFACE



ZEROGRAV112AA1-26

# EVOLUTION OF THINKING

THE FOCUS OF THE MODE TRACKING AND IDENTIFICATION ALGORITHM DEVELOPMENT SHIFTED FROM DETERMINATION OF A SPECIFIC MODAL FREQUENCY TO DETERMINATION OF A REPRESENTATIVE MODAL FREQUENCY AS A RESULT OF:

- THE DERIVATION OF A THREE-FREQUENCY LEAST SQUARES CURVE FIT TO THE SPECIFIC MODAL FREQUENCY/TANK MASS DATA WITH AN AVERAGE ERROR OF ±6 PERCENT
- THE RAPID ESCALATION OF ALGORITHM COMPUTATIONAL REQUIREMENTS WHEN SOLUTION SURFACE METHODS WERE ATTEMPTED
- THE SUCCESS OF FREQUENCY LIST COMPRESSION TECHNIQUES TO REDUCE THE F021 AND F031 FREQUENCY ARRAYS TO ONLY 3 TO 5 MEMBERS, ON AVERAGE
- THE NEED TO CONSIDER THAT RESPONSE AMPLITUDE AND Q WOULD BE ELIMINATED

ZEROGRAV112AA1-27

# THE NEW APPROACH

THE REVISED APPROACH WOULD:

- DETERMINE F011 BY THE KNOWN METHOD
- USE FREQUENCY SCAN RANGES TO SORT OUT FREQUENCIES POTENTIALLY NEEDED TO DETERMINE F021 AND F031
- COMPRESS THE RESULTING ARRAYS
- TEST VARIOUS FINAL AVERAGING SCHEMES TO OBTAIN SINGULAR F021 AND F031 VALUES BY COMPARING THEIR THREE-FREQUENCY LEAST SQUARES CURVE FIT ACCURACIES

# FREQUENCY LIST REDUCTION TECHNIQUES

- SCAN RANGE
- CLUSTER COMPRESSION
- FINAL AVERAGES

ZEROGRAV112AA1-29

# SCAN RANGE

SCAN RANGE CURVES PROVIDE FREQUENCY LIST REDUCTION BY:

- ELIMINATING ALL FREQUENCIES OUTSIDE USEFUL RANGE
- DISPOSITIONING OVERLAPS TO EITHER THE F021 OR F031 ARRAY, NOT BOTH
- ELIMINATING FREQUENCIES BETWEEN THE F021 AND F031 SCAN RANGES

ZEROGRAV112AA1-30

# CLUSTER COMPRESSION

EXAMINATION OF THE MODAL RESPONSE DATA SHOWED THAT:

- THERE WERE CLUSTERS OF MODAL RESPONSE FREQUENCIES
- THESE CLUSTERS ARE ABOUT 5 MHz WIDE IN THE F021 RANGE AND 11 MHz WIDE IN THE F031 RANGE
- THE CLUSTERS APPEARED TO REFLECT NEAR DEGENERACY CONDITIONS
- REDUCTION OF THESE FREQUENCY CLUSTERS TO THEIR AVERAGE VALUES COMPRESSED THE FREQUENCY ARRAYS

ZEROGRAV112AA1-31

# CLUSTER COMPRESSION (Concluded)

## BENCH-TOP TEST ITEM 5 DATA

### EXAMPLE OF CLUSTER COMPRESSION

| ORIGINAL F031 ARRAY | | COMPRESSED F031 ARRAY |
|---|---|---|
| 663.88 | ADD 11.00 | |
| 664.48 | | 664.18 |
| 710.20 | ADD 11.00 | |
| 711.13 | | |
| 715.58 | | 712.30 |
| 725.24 | ADD 11.00 | |
| 729.19 | | |
| 730.55 | | 728.33 |
| 825.62 | ADD 11.00 | |
| 825.85 | | 825.74 |

ZEROGRAV112AA1-32

# FREQUENCY LIST REDUCTION RESULTS

| REDUCTION TECHNIQUE | RESULTS (36 CASE AVERAGES) F021 | F031 |
|---|---|---|
| (ALL DATA IN RANGE) | (20.5) | |
| AFTER SCAN RANGE | 4.5 | 10.1 |
| AFTER COMPRESSION | 2.7 | 4.7 |
| AFTER FINAL AVERAGE | 1.0 | 1.0 |



ZEROGRAV112AA1-33

# FINAL AVERAGES

- FINAL SINGULAR VALUES FOR F021 AND F031 ARE OBTAINED FROM THE COMPRESSED ARRAYS BY TAKING THE ARITHMETIC AVERAGE OF THE ARRAY FREQUENCIES FROM THE LOWEST THROUGH NO MORE THAN THREE SUCCEEDING ARRAY VALUES

- THE TANK EMPTY AND FULL ARRAYS CONTAIN ONLY A SINGLE FREQUENCY

# INTEGRATION WITH MASS COMPUTATION

- INTEGRATION WITH EXISTING MASS COMPUTATION ALGORITHM

- THREE-FREQUENCY CURVE FIT

- A NEW CORRECTION APPROACH

ZEROGRAV112AA1-35

# INTEGRATION WITH EXISTING MASS COMPUTATION ALGORITHM

- USING A LEAST SQUARES CURVE FIT RELATION OF THE THREE LOWEST TM MODES TO COMPUTE THE BASIC UNCORRECTED VALUE FOR TANK LOADED MASS IS A SIGNIFICANT DEPARTURE FROM THE AVERAGE MASS APPROACH OF THE EXISTING ALGORITHM

- USING THE LEAST SQUARES CURVE FIT RELATION MASS IN CONJUNCTION WITH THE EQUIVALENT UNIFORM LOAD MASS AVERAGE FOR THE LOWEST THREE MODES HAS PROVIDED AN IMPROVED CORRECTION CORRELATION COEFFICIENT (K = M-Z)

  WHERE: K = THE CORRECTION COEFFICIENT
  M = MASS COMPUTED FROM THE THREE-FREQUENCY CURVE FIT
  Z = AVERAGE UNIFORM LOAD MASS



ZEROGRAV112AA1-36

# THREE-FREQUENCY CURVE FIT

- METHOD OF COMPUTATION
- FORM OF EQUATION
- PERFORMANCE OF EQUATION

ZEROGRAV112AA1-37

# METHOD OF COMPUTATION

FORMULATING THE PROBLEM

- THE OBJECTIVE IS TO FIND A FUNCTION OF THE FIRST THREE TM MODAL RESPONSES THAT WILL CALCULATE THE LOADED TANK MASS (P lb); F (F011, F021, F031) = P

- A POSSIBLE FUNCTION MIGHT BE A POLYNOMIAL OF THE FORM

$$F(F011, F021, F031) = C_0 + C_1\,F011 + C_2\,F021 + C_3\,F031 + C_4\,F011^2 + C_5\,F021^2 + C_6\,F031^2 + C_7\,F011\,F021 + C_8\,F011\,F031 + C_9\,F021\,F031$$

- THEN THE PROBLEM BECOMES: GIVEN THE MEASURED DATA, FIND THE VALUES OF THE COEFFICIENTS, $C_N$, SO THE RESULTING FUNCTION IS BEST FIT TO THE MEASURED DATA.

ZEROGRAV112AA1-38

# METHOD OF COMPUTATION (Continued)

THE USUAL APPROACH TO OBTAINING THE BEST FIT IS TO MINIMIZE THE SUM OF THE SQUARES OF THE ERROR VECTOR ELEMENTS IN THE MATRIX FUNCTION $(J \cdot C) = (Y + \Delta)$

WHERE:

$$J = \begin{bmatrix} 1, F011_1, F021_1, F031_1, F011_1^2, F021_1^2, F031_1^2, F011_1\ F021_1, F011_1\ F031_1, F021_1\ F031_1 \\ 1, F011_2, F021_2, F031_2, F011_2^2, F021_2^2, F031_2^2, F011_2\ F021_2, F011_2\ F031_2, F021_2\ F031_2 \\ 1, F011_N, F021_N, F031_N, F011_N^2, F021_N^2, F031_N^2, F011_N\ F021_N, F011_N\ F031_N, F021_N\ F031_N \end{bmatrix} \text{ MATRIX}$$

$$C = \begin{bmatrix} C_0 \\ C_1 \\ C_2 \\ \cdot \\ \cdot \\ \cdot \\ C_9 \end{bmatrix} \text{ COEFFICIENT VECTOR} \qquad Y = \begin{bmatrix} P_1 \\ P_2 \\ P_3 \\ \cdot \\ \cdot \\ \cdot \\ P_N \end{bmatrix} \text{ MASS VECTOR} \qquad \Delta = \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \cdot \\ \cdot \\ \cdot \\ \delta_N \end{bmatrix} \text{ ERROR VECTOR}$$

ZEROGRAV112AA1-39

ZEROGRAV112AA4-5

# METHOD OF COMPUTATION (Concluded)

- IF WE DEFINE $\epsilon$ AS THE SUM OF THE SQUARES OF EACH $\epsilon_i$, THEN:

$$\epsilon = \sum_{i=1}^{N} \delta_i^2 = \Delta^T \bullet \Delta$$

- TAKING THE GRADIENT OF $\epsilon$ AND SETTING IT EQUAL TO ZERO WILL MINIMIZE IT:

$$\nabla\epsilon = 2J^T JC - 2J^T P = 0$$

- SOLVING THE LINEAR SYSTEM $J^T JC = J^T P$ FOR C WILL CALCULATE THE BEST COEFFICIENTS

ZEROGRAV112AA1-40

# FORM OF EQUATION

- SECOND AND THIRD ORDER POLYNOMIALS WERE TRIED USING THE LEAST SQUARES CURVE FIT APPROACH
- THE SECOND ORDER POLYNOMIALS PROVIDED THE BEST OVERALL FIT AND SMOOTHNESS, ALTHOUGH THE THIRD ORDER POLYNOMIAL GAVE A SLIGHTLY BETTER LEAST SQUARES MINIMUM
- THE SECOND ORDER POLYNOMIAL WAS SELECTED FOR THE THREE-FREQUENCY LEAST SQUARES CURVE FIT FUNCTION

# PERFORMANCE OF EQUATION

- A SECOND ORDER, THREE-FREQUENCY CURVE FIT EQUATION WAS ABLE TO MATCH THE MEASURED DATA WITH AN AVERAGE ERROR OF 6 lb (4.3 PERCENT) WHEN THE SPECIFIC MODAL FREQUENCIES WERE USED; THE WORST ERROR WAS 14.8 PERCENT (ONLY THE 31 ALGORITHM DEVELOPMENT TEST CASES WERE USED TO ESTABLISH THE CURVE FIT EQUATION)

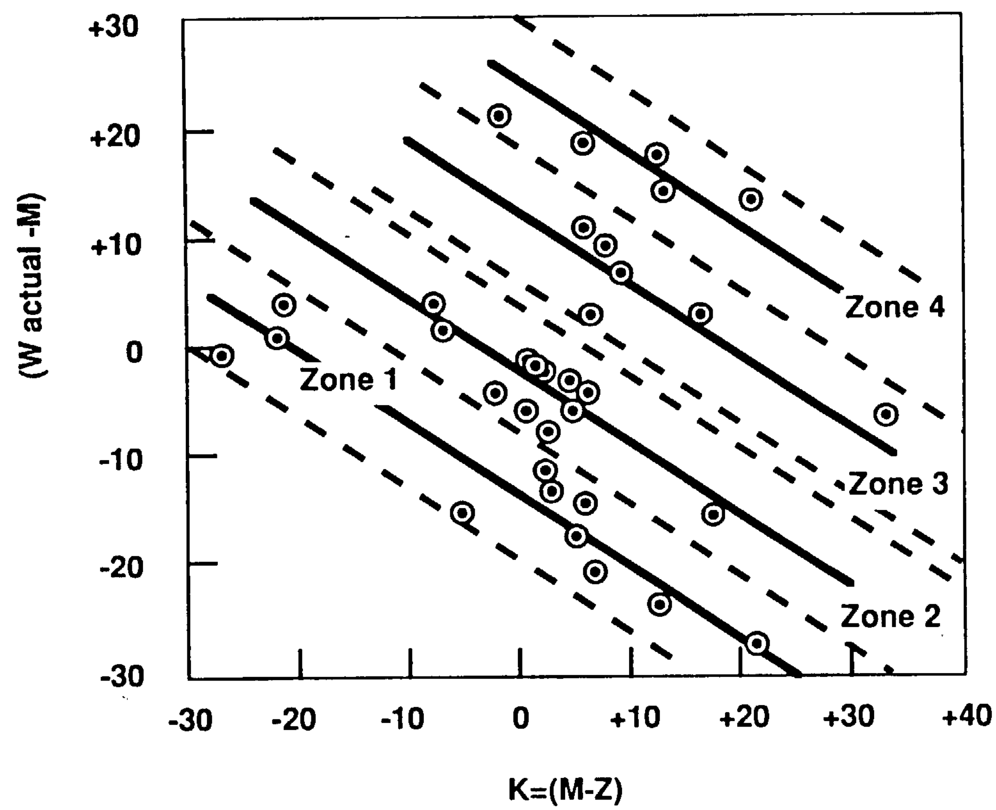
- A SIMILAR CURVE FIT TO THE REPRESENTATIVE MODAL FREQUENCIES WAS ABLE TO MATCH THE MEASURED DATA WITH AN AVERAGE ERROR OF 9.2 lb (6.7 PERCENT); THE WORST ERROR WAS 19.9 PERCENT

- FURTHER CORRECTION WOULD BE REQUIRED TO OBTAIN AT LEAST 5-PERCENT ACCURACY

ZEROGRAV112AA1-42

# A NEW CORRECTION APPROACH

## THE CORRECTION CORRELATION COEFFICIENT






ZEROGRAV112AA1-43

A/N 9989/MD209.05

# A NEW CORRECTION APPROACH (Continued)

- THE CORRECTION ZONE FOR A MEASUREMENT IS DETERMINED FROM THE MEASUREMENT CLASS AND K

  WHERE: MEASUREMENT CLASS IS A THREE-DIGIT NUMBER RANKING THE RELATIVE MAGNITUDES OF THE EQUIVALENT UNIFORM LOAD MASS CALCULATIONS IN ASCENDING ORDER FROM THE LEFT USING THE MODE NUMBERS (i.e., IF THE MODE MASSES WERE $W_{011}$ = 40.86, $W_{021}$ = 38.74, AND $W_{031}$ = 44.20, THE CLASS WOULD BE 213)

- THE MEASUREMENT CLASS IS USED TO SELECT A GROUP OF LOGICAL STATEMENTS IN K WHICH DETERMINES THE APPROPRIATE CORRECTION ZONE; FOR EXAMPLE, FOR CLASS 123:

  IF K<O AND ABSK<24, THEN ZONE = 2 ELSE ZONE = 1
  IF K<2, ZONE = 2, ETC.

ZEROGRAV112AA1-44

# A NEW CORRECTION APPROACH (Concluded)

- KNOWING THE CORRECTION ZONE ESTABLISHES THE VALUE OF A IN THE CORRECTION EQUATION:

$$C = -0.4066 * K + A$$

WHERE: C = THE CORRECTION IN lb
K = (M-Z) THE CORRECTION CORRELATION COEFFICIENT
A = -14.66 FOR ZONE 1
-3.77 FOR ZONE 2
+9.45 FOR ZONE 3
+21.20 FOR ZONE 4

- THE MEASURED TANK MASS IS COMPUTED BY ADDING THE CORRECTION VALUE TO THE CURVE FIT MASS:

$$P = M + C \text{ lb}$$

ZEROGRAV112AA1-45

# RESULTS - PUTTING IT ALL TOGETHER

- THE INTEGRATED ALGORITHM

- THE DEMONSTRATION PROGRAM



ZEROGRAV112AA1-46

# THE INTEGRATED ALGORITHM

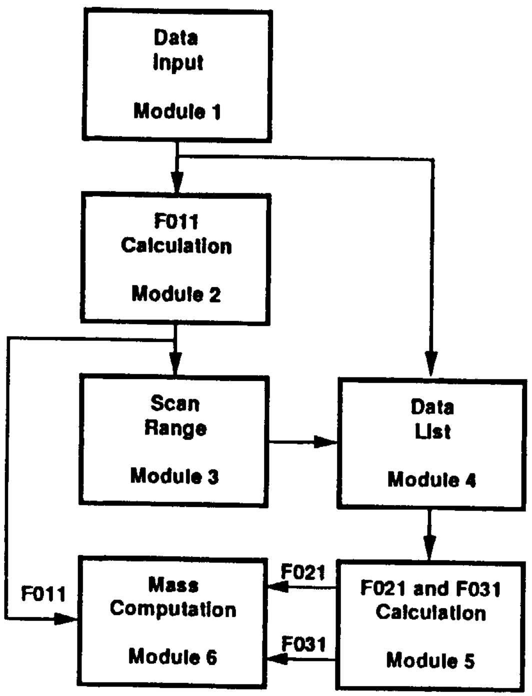
- THE SIX MODULES AND THEIR FUNCTIONS

- THE MATH MODEL

- MODEL PERFORMANCE AND PREDICTIONS

ZEROGRAV112AA1-47

# THE SIX MODULES AND THEIR FUNCTIONS




A/N 9989/MD209.04

| MODULE | FUNCTION |
|---|---|
| 1 | LIST ALL MODAL FREQUENCIES IN 330 TO 879 MHz RANGE |
| 2 | USE FIRST 3 MODAL FREQUENCIES TO CALCULATE F011 |
| 3 | USE F011 TO DETERMINE FREQUENCY RANGE FOR F021 AND F031 ARRAYS |
| 4 | SORT LIST OF ALL MODAL FREQUENCIES INTO F021 AND F031 ARRAYS |
| 5 | USE ARRAY COMPRESSION AND FINAL AVERAGING RULES TO DETERMINE F021 AND F031 |
| 6 | COMPUTE MASS USING F011, F021, AND F031 IN LEAST SQUARES CURVE FIT EQUATION AND ADDING A CORRECTION |

ZEROGRAV112AA4-9

# THE INTEGRATED ALGORITHM

## THE MATH MODEL

- APPLIED THE FREQUENCY DETERMINATION RULES TO ALL 36 TESTS IN THE BENCH-TOP DATA (INCLUDING THE FIVE RANDOM CONFIGURATION TESTS)

- USED THE RESULTING VALUES FOR F011, F021, AND F031 OBTAINED FROM THE 31 ALGORITHM DEVELOPMENT TESTS (EXCLUDES THE FIVE RANDOM CONFIGURATION TESTS) TO COMPUTE A THREE-FREQUENCY LEAST SQUARES CURVE FIT EQUATION RELATING MODAL FREQUENCIES AND LOADED TANK MASS (M)

- USED THE VALUES FOR F011, F021, AND F031 OBTAINED FROM ALL 36 TESTS TO COMPUTE THE EQUIVALENT UNIFORM LOAD MASSES FOR EACH MODE, THE AVERAGE UNIFORM LOAD MASS (Z), THE MEASUREMENT CLASS, AND THE DELTA MASS (K) BETWEEN THE CURVE FIT EQUATION AND AVERAGE UNIFORM LOAD ($K = M - Z$)

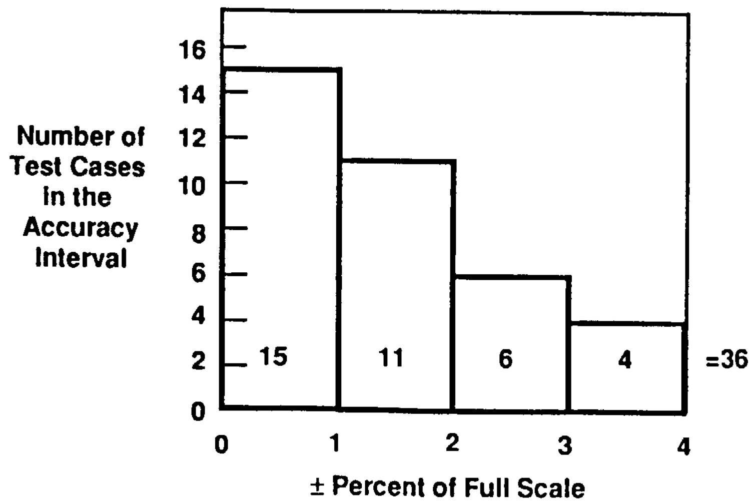
- THE MEASUREMENT CLASS AND DELTA MASS (K) VALUES WERE USED TO COMPUTE A CORRECTION (C) TO BE ADDED TO THE CURVE FIT EQUATION MASS (M), GIVING THE COMPUTED TANK LOAD (P) ($P = M + C$)

ZEROGRAV112AA1-48

# THE INTEGRATED ALGORITHM (Concluded)

THE MATH MODEL PERFORMANCE AND PREDICTIONS

- APPLYING THE MATH MODEL APPROACHES TO ALL 36 TEST CASES RESULTED IN THE FOLLOWING ACCURACY PERFORMANCE HISTOGRAM



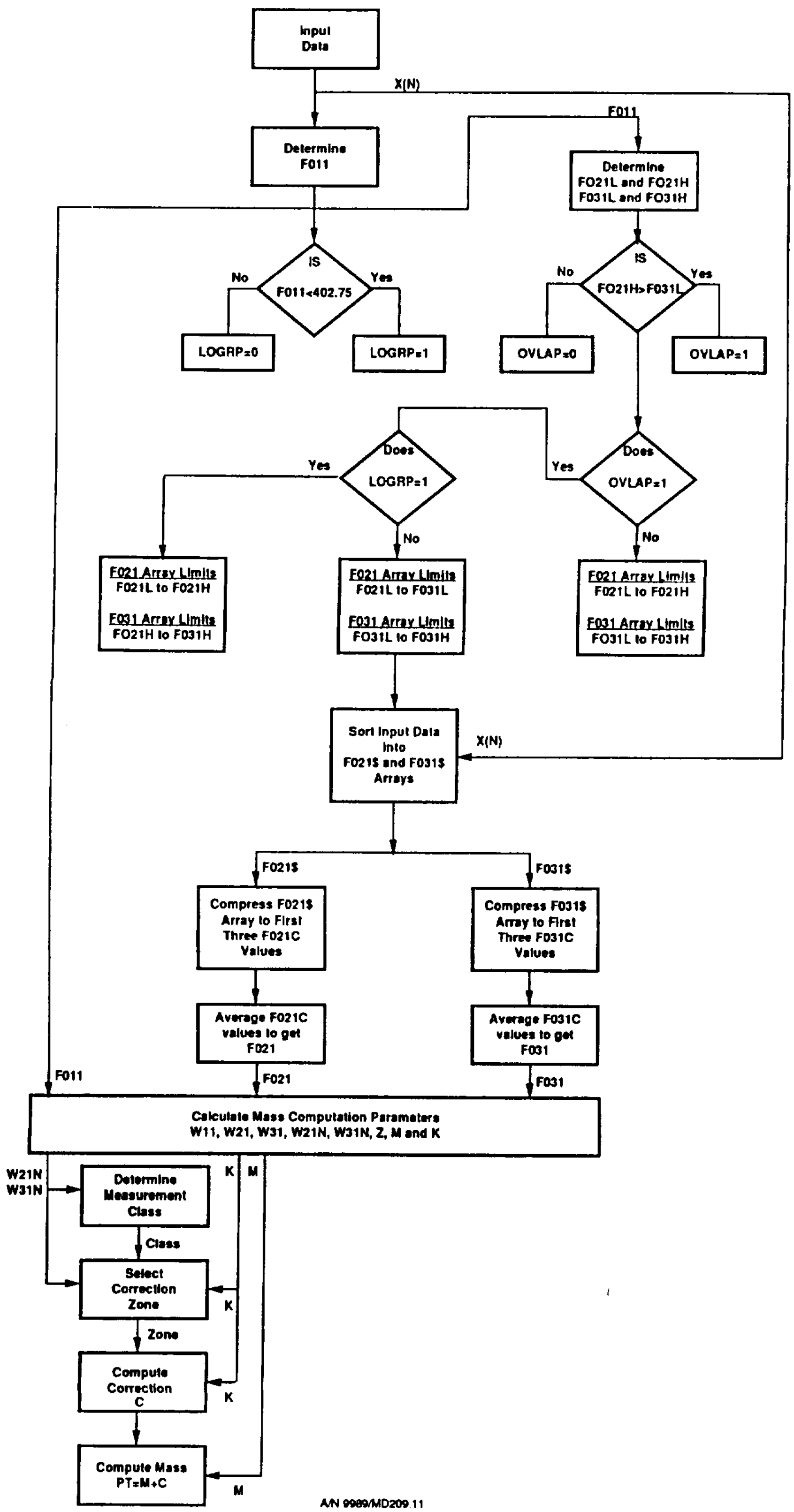

A/N 9989/MD209.03

- AN ACCURATE IMPLEMENTATION OF THE MATH MODEL APPROACHES IN A DEMONSTRATION COMPUTER PROGRAM COULD BE EXPECTED TO PROVIDE EQUAL ACCURACY PERFORMANCE

# THE DEMONSTRATION PROGRAM

- PROGRAM FLOW CHART
- PERFORMANCE RESULTS
- CODING STATISTICS

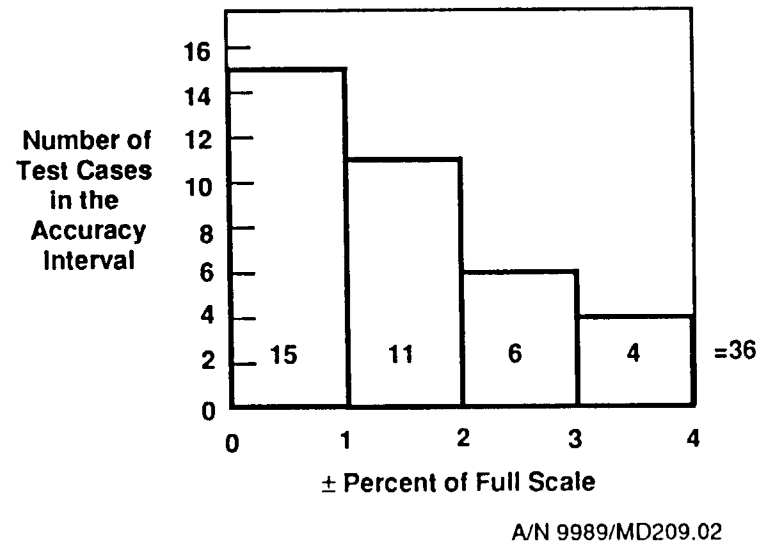
# DEMONSTRATION PROGRAM FLOW CHART




A/N 9989/MD209.11

# THE DEMONSTRATION PROGRAM

- AS PREDICTED BY THE MATH MODEL, THE HISTOGRAM OF ACCURACY PERFORMANCE WAS THE SAME AS THAT OBTAINED FOR THE MODEL




- AVERAGE ACCURACY FOR THE 31 DEVELOPMENT TEST CASES WAS ±1.42 PERCENT; FOR THE 5 RANDOM TEST CASES IT WAS ±1.51 PERCENT

- THE STANDARD DEVIATION FOR THE 31 DEVELOPMENT TEST CASES WAS 1.00 PERCENT

# THE DEMONSTRATION PROGRAM (Concluded)

## CODING STATISTICS

| MODULE NO. | FUNCTIONAL ELEMENT | LINES OF CODE: DEMONSTRATION PROGRAM | LINES OF CODE: INSTRUMENT PROGRAM |
|---|---|---|---|
| 1 | DATA INPUT EDITOR | 265 | 10 |
| 2 | F011 CALCULATION | 13 | 5 |
| 3 | SCAN RANGE | 101 | 91 |
| 4 | DATA LIST | 27 | 24 |
| 5 | F021/F031 CALC. | 44 | 41 |
| 6 | MASS COMPUTATION | 132 | 65 |
| | TOTALS | 582* | 236 |

*NOTE: THE DEMONSTRATION PROGRAM'S 582 LINES OF CODE USE 20,730 BYTES OF MEMORY

ZEROGRAV112AA1-52

# CONCLUSIONS

# CONCLUSIONS

- A WORKABLE MODE IDENTIFICATION AND TRACKING ALGORITHM HAS BEEN REALIZED
- IT HAS BEEN INTEGRATED WITH A MASS COMPUTATION ALGORITHM
- THE OVERALL ALGORITHM SET PERFORMANCE IS BETTER THAN THE ±5 PERCENT FS CRITERIA
- THE RF MODAL APPROACH TO QUANTITY GAGING REMAINS VIABLE

ZEROGRAV112AA1-53

USERS MANUAL

for the

RF MODAL QUANTITY GAGING
DEMONSTRATION PROGRAM

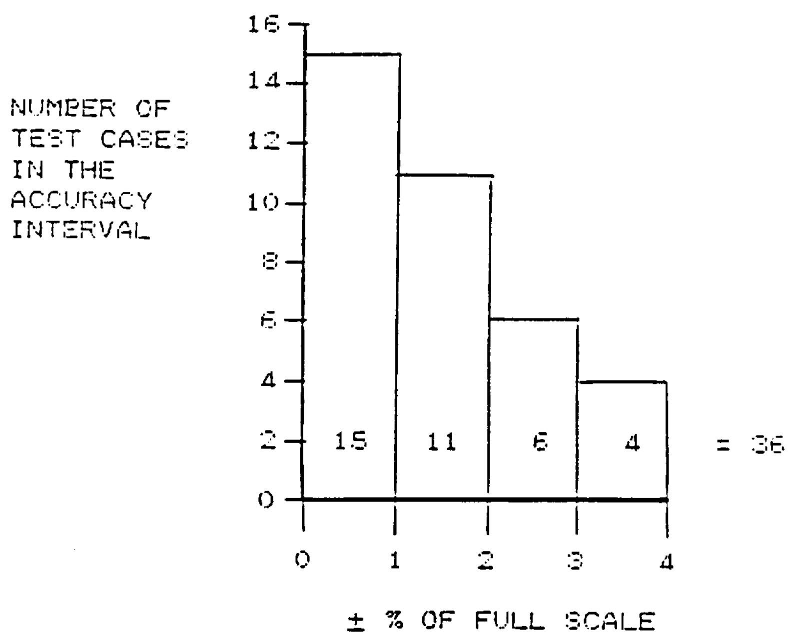
March 20, 1989

Prepared for NASA-JSC under contract NAS9-17378.

## 1.0 INTRODUCTION

Development of this demonstration computer program completes the RF Modal Identification and Tracking Algorithm, task 2.4 under Feasibility Testing in the Zero Gravity Quantity Gaging Program work breakdown structure. all work was performed at the Ball Aerospace Systems Group facilities located in Boulder Colorado. This effort was authorized by the NASA Lyndon B. Johnson Space Center under contract NAS9-17378.

The program incorporates the Mode Tracking and Identification Algorithms developed during this task using the origional Bench-Top test data, and integrates them with a mass computation algorithm based on prior developments. The result is a program capable of taking measured modal response frequency data in the range of 330.00 to 879.00 MHz and converting it into loaded tank mass with an accuracy better than 5% of full scale for all 36 simulated orientations and distributions of tank mass tested during the Bench-Top test series. The actual histogram of the program performance is shown below.




## 2.0 COMPUTER EQUIPMENT REQUIRED

The following computer equipment will be required to use the demonstration program.

- An IBM PC or compatible with at least 128K of memory. (The demonstration program only requires 26k bytes)
- A monochrome monitor, the program does not display in color.
- Two floppy disk drives, 360 DSDD or a floppy drive and a hard disk.

- A copy of the PC DOS operating system with BASIC, version 2.0 or later.
- A printer

## 3.0 USING THE DEMONSTRATION PROGRAM

The following section presents a step by step procedure for using the demonstration program with the data from Bench-Top test 12 (Item 12 wet wall,1/4 full,1 globule mid) as an example. The left margin extensions are the action identifiers. The text provides notes, explanations and instructions. Since the program is menu driven and has quite a bit of error trapping only minimal instruction should be required.

***************

Power up the computer system and boot to the DOS prompt.
    To insure that DRIVE A is designated primary or default drive.
type (A:) - Hit RETURN key.
Load BASIC - Either directly from ROM in IBM machines or from the DOS disk in some IBM compatibles. The versions of this language which will support the RF Modal Demonstration program are standard IBM or GW-BASIC 2.01 or later.
    When BASIC has been loaded and the OK prompt has been obtained.
Place the Demonstration Program disk in DRIVE A and the Demo Data disk in DRIVE B.
type (LOAD "RFDEM1.BAS")- Hit RETURN key -When OK prompt returns and DRIVE A active light goes out.
type (RUN) - Hit RETURN key.
Main program menu of the RF MODAL QUANTITY GAGING DEMO PROGRAM appears.
    Before anything useful can be done with the program,it must be provided with some data. So,the first thing to do is to input some RF modal frequency data in MHz. To do this select menu item "(3) EDIT DATA".
enter 3
    This brings the "EDIT RF DATA" menu screen up, and we find that we have two ways to input data to the program. Either directly from the keyboard using option "(1) ADD DATA", or from a data disk using option "(6) LOAD NEW DATA FROM DISK". (Note-options (2) through (4) are avaliable to correct or modify data input from the keyboard; also you can return to the "EDIT RF DATA" menu from options (1) through (4) by typing the double quote "" at the input prompt).The modal frequency data must be in the range of 330.00 to 879.00 MHz. and in ascending order or the program will give a warning BEEP, reject your input and return

to the data input prompt.
The most efficient way to provide input data for the program is to load it from a data disk. This is true even for data entered from the keyboard (It all has to get entered from the keyboard initially). In this case , after entry, the data is saved to the data disk using option "<5> SAVE DATA TO DISK".
When saving data to or loading data from a disk you will need a file name.The program will prompt for this by the screen prompts "SAVE AS" or "LOAD"; and it will accept the first eight characters which are typed after the prompt as the disk drive designator and a file name. A data file extension is automatically appended by the program and should not be typed. The program is most conveniently used with the program disk in DRIVE A (with A the designated primary drive) and a formatted data disk in DRIVE B.
With the system configured this way, typical eight character file designators would be B:TESTxx or B:ITEMxx. Where the x's represent numeric or alphabetic file identifiers like 04, R3, or AA. The leading two characters "B:" simply designate DRIVE B as the data disk drive.
Also, If we are loading data from a disk we will need to remember to erase any data from prior runs from memory. The "EDIT RF DATA" menu screen will help you to remember to do this by displaying in the heading the number of data points that are currently in memory. If you are about to select option <6> to load new data from a disk, the menu screen should indicate zero data points in memory. If it does not, select option "<8> CLEAR ALL DATA FROM MEMORY" first. This selection is followed by a warning BEEP and the screen query "CLEAR ALL DATA (Y/N)". Selecting "Y" clears the memory and returns you to the "EDIT RF DATA" menu where you can now select option <6> to load new data. Selecting "N" will also return you to the "EDIT RF DATA" menu without erasing any data (maybe you rememberd you had not saved the current data to disk yet).
Once data has been loaded it can be saved as hard copy by using option "<7> PRINT DATA". Make sure the printer is connected and turned on prior to selecting this option.
Only the RF modal frequency data and the data point numbers are printed, any test identification infor- -mation etc. will have to be manually annotated. A formfeed is issued at the end of the data printing.

Make sure that the number of data points currently in memory are zero by examining the "EDIT RF DATA" menu heading and using option <8> if required. Select option <6>.

enter 6 - Which results in the screen prompt "LOAD"
TYPE (B:ITEM12) - Hit RETURN key.
The DRIVE B active light will come on briefly and then the screen returns to the "EDIT RF DATA "menu. Note that

the menu heading indicates 18 data points in memory. When the DRIVE B light is out, select option <7> to make a hard copy of the ITEM12 data.

enter 7 - The screen will show the message "PRINTING DATA" as the 18 frequency data points are printed out. At the conclusion of printing, the "EDIT RF DATA" menu screen returns. Select option <R> so as to return to the main menu.

enter R - The main menu screen returns, and since we now have data input to the program, select option "<1> COMPUTE MASS FROM RF FREQUENCIES".

enter 1 - Screen shows query "HAS RF DATA BEEN INPUT ?(Y/N)" this is done to make sure the program has input data prior to continuing. A "Y" response allows the mass computation to continue while a "N" response returns the program to the main menu.

enter Y - A few seconds after the "Y" response the screen query changes to "ENTER ACTUAL MASS IN LBS.(XXX.XX)="

enter 60.25 - Hit RETURN key.- The screen will display a list of data as shown below, and a continuation mess-age.

```
COMPUTED MASS = 59.92
ACTUAL MASS = 60.25
MASS ERROR = -0.33
PERCENT ERROR = -0.24
F011 = 408.10
F021 = 617.80
F031 = 758.47
```

TYPE <Y> WHEN FINISHED RECORDING RESULTS

enter Y - Program returns to the main menu - select option "<2> PRINT RESULTS"

enter 2 - Screen query "HAS MASS BEEN COMPUTED? (Y/N)" makes sure there are results to print prior to contin-uing. A "Y" response results in the results being printed as shown below. A "N" response returns the program to the main menu.

enter Y - Printer prints mass computation results as follows

| COMP.MASS LB | ACTUAL MASS LB. | DELTA MASS LB. | %ERROR |
|---|---|---|---|
| 59.92 | 60.25 | -.33 | -.24 |

At the conclusion of printing a form feed is issued and the program returns to the main menu.

At this point option <3> can be selected to allow inputing a new set of data for mass computation or option "<1> QUIT" can be selected to terminate further work.

enter Q - Results in screen query "QUIT (Y/N)"- If "Y" is selected the program is exited, data cleared from memory and the system returns to the BASIC command

line and the OK prompt. (The program can be restarted at this point by typing "RUN" and hitting the RETURN key, the data is not restored to memory however).
A "N" response returns the program to main menu.

If it is desired to power the computer system down, the "Y" response should be given.

enter Y - Hit RETURN key -When the OK prompt is obtained

type (SYSTEM) - This returns the system to the DOS command line and the A> prompt.

remove the program and data disks from DRIVES A&B.

turn the computer system off.

4.0 CONCLUDING REMARKS

The data disk provided with the RF Modal Quantity Gaging Demonstration program contains the averaged modal frequency responses from all eight antenna positions of the Bench-Top test series. Data for all 31 algorithm development test cases as well as the 5 random mass cofigurations used to test the algorithm are included on the disk, each as a seperate file. The file names for each test case are linked to the test numbers used in the Bench-Top test report by using the same numerical identifiers. The file names are listed below

| | | |
|---|---|---|
| B:ITEM01 | B:ITEM13 | B:ITEM25 |
| B:ITEM02 | B:ITEM14 | B:ITEM26 |
| B:ITEM03 | B:ITEM15 | B:ITEM27 |
| B:ITEM04 | B:ITEM16 | B:ITEM28 |
| B:ITEM05 | B:ITEM17 | B:ITEM29 |
| B:ITEM06 | B:ITEM18 | B:ITEM30 |
| B:ITEM07 | B:ITEM19 | B:ITEM31 |
| B:ITEM08 | B:ITEM20 | B:ITEMR1 |
| B:ITEM09 | B:ITEM21 | B:ITEMR2 |
| B:ITEM10 | B:ITEM22 | B:ITEMR3 |
| B:ITEM11 | B:ITEM23 | B:ITEMR4 |
| B:ITEM12 | B:ITEM24 | B:ITEMR5 |

A listing of the Demonstration Program is provided in Appendix A of this manual.

## CROSS INDEX TO BENCH-TOP TESTS

| ITEM NO. | BENCH-TOP TEST NO. | ACTUAL MASS | TEST NAME |
|---|---|---|---|
| 1 | 22 | 138.25 | FULL |
| 2 | 33 | 105.05 | WET-WALL 3/4 |
| 3 | 21 | 103.65 | SETTLED 3/4 |
| 4 | 30 | 91.60 | WET-WALL 1/2,1G,BTM |
| 5 | 31 | 91.60 | WET-WALL 1/2,1G,MID |
|  | 32 | 91.60 | WET-WALL 1/2,1G,TOP |
| 6 | 24 | 78.50 | WET-WALL 1/4,2G,BTM |
| 7 | 25 | 78.50 | WET-WALL 1/4,2G,MID |
| 8 | 26 | 78.50 | WET-WALL 1/4,2G,T/B |
| 9 | 29 | 73.35 | WET-WALL 1/2 |
| 10 | 20 | 67.55 | SETTLED 1/2 |
| 11 | 27 | 60.25 | WET-WALL 1/4,1G,BTM |
| 12 | 28 | 60.25 | WET-WALL 1/4,1G,MID |
| 13 | 18 | 54.80 | 55 LB CENTER |
| 14 | 17 | 43.87 | 44 LB CENTER |
| 15 | 23 | 42.00 | WET-WALL 1/4 |
| 16 | 3 | 36.50 | EMPTY,2G,BTM |
| 17 | 4 | 36.50 | EMPTY,2G,MID |
| 18 | 5 | 36.50 | EMPTY,2G,T/B |
| 19 | 19 | 36.05 | SETTLED 1/4 |
| 20 | 14 | 32.93 | 33 LB CENTER |
| 21 | 15 | 32.93 | 33 LB BTM |
| 22 | 16 | 32.93 | 33 LB KEY |
| 23 | 10 | 21.86 | 22 LB CENTER |
| 24 | 11 | 21.86 | 22 LB SPREAD WALL |
| 25 | 12 | 21.86 | 22 LB ASYRH |
| 26 | 13 | 21.86 | 22 LB ASYBK |
| 27 | 6 | 10.86 | 11 LB CENTER |
| 28 | 7 | 10.86 | 11 LB SPREAD WALL |
| 29 | 8 | 10.86 | 11 LB ASYRH |
| 30 | 9 | 10.86 | 11 LB ASYBK |
| 31 | 1 | 0.00 | EMPTY |
|  | 2 | 0.00 | EMPYT SPRAY BAR |
| R1 | RAN1 | 49.33 | RANDOM NO.1 |
| R2 | RAN2 | 49.33 | RANDOM NO.2 |
| R3 | RAN3 | 49.33 | RANDOM NO.3 |
| R4 | RAN4 | 49.33 | RANDOM NO.4 |
| R5 | RAN5 | 49.33 | RANDOM NO.5 |

APPENDIX A

PROGRAM LISTING

```
10 REM ***************************************************************
20 REM **                                                           **
30 REM **  PROGRAM TITLE: RF MODAL DEMONSTRATION PROGRAM            **
40 REM **                                                           **
50 REM **  WRITTEN BY: K.VAN LEUVEN, FEBRUARY,1989, REV:ORIG        **
60 REM **                                                           **
70 REM **  PROGRAM INTENT: THE PURPOSE OF THIS PROGRAM IS TO        **
80 REM **     PROVIDE A DEMONSTRATION OF AN INTEGRATED RF MODAL     **
90 REM **     QUANTITY GAGING ALGORITHM. THE INTEGRATION            **
100 REM **     INCLUDES MODE ID AND TRACK FUNCTIONS AS WELL AS      **
110 REM **     MASS COMPUTATION ROUTINES.ALGORITHMS ARE BASED ON    **
120 REM **     BENCH-TOP TEST DATA. WORK DONE UNDER NASA-JSC        **
130 REM **     CONTRACT NAS9-17378.                                 **
140 REM ***************************************************************
150 REM
160 REM**INITIALIZATION
170 REM
180 ON ERROR GOTO 2460
190 DIM X(60)
200 DIM F021S(25)
210 DIM F031S(25)
220 DIM F021C(4)
230 DIM F031C(4)
240 REM
250 REM
260 REM*****MAIN PROGRAM
270     CLS
280     PRINT "RF MODAL QUANTITY GAGING DEMO PROGRAM"
290     PRINT "===================================="
300     PRINT: PRINT
310     PRINT "MAIN MENU"
320     PRINT
330     PRINT "     <1> COMPUTE MASS FROM RF FREQUENCIES"
340     PRINT "     <2> PRINT RESULTS"
350     PRINT "     <3> EDIT DATA"
360     PRINT "     <Q> QUIT"
370     PRINT: PRINT
380     PRINT "SELECT (1-3 OR Q)";
390     S$=INPUT$(1)
400  IF S$="Q" THEN GOSUB 480: GOTO 270
410     ON VAL(S$) GOSUB 2660,580,800
420     GOTO 270
430 REM
440 REM
450 REM
460 REM**VERIFY QUIT CHOICE
470 REM
480     CLS
490     LOCATE 5,1
500     INPUT "QUIT (Y/N)";A$
510  IF A$<>"Y" THEN RETURN
520     END
530 REM
540 REM
550 REM
560 REM**PRINT RESULTS ROUTINE
570 REM
580     CLS
590     PRINT "HAS MASS BEEN COMPUTED ?(Y/N)";
600     A$=INPUT$(1)
610  IF A$<>"Y" THEN RETURN
620     LPRINT "RESULTS OF MASS COMPUTATION"
630     LPRINT: LPRINT
```

```
640      REM
650         LPRINT TAB(5);"COMP.MASS LB.";
660         LPRINT TAB(21);"ACTUAL MASS LB.";
670         LPRINT TAB(39);"DELTA MASS LB.";
680         LPRINT TAB(60);"%ERROR"
690         LPRINT STRING$ (79,"-")
700         LPRINT TAB(6);PT;
710         LPRINT TAB(24);WT;
720         LPRINT TAB(40);ERRLBS;
730         LPRINT TAB(59);ERRPER
740         LPRINT CHR$(12)
750        PT=0: WT=0: ERRLBS=0: ERRPER=0
760         RETURN
770      REM
780     REM**EDIT RF DATA ROUTINE
790     REM
800        CLS
810        PRINT "EDIT RF DATA (";N;"POINT";
820      IF N<>1 THEN PRINT "S";
830        PRINT "  IN MEMORY):"
840        PRINT
850        PRINT "    <1> ADD DATA"
860        PRINT "    <2> INSERT DATA"
870        PRINT "    <3> CHANGE DATA"
880        PRINT "    <4> DELETE DATA"
890        PRINT "    <5> SAVE DATA TO DISK"
900        PRINT "    <6> LOAD NEW DATA FROM DISK"
910        PRINT "    <7> PRINT DATA"
920        PRINT "    <8> CLEAR ALL DATA IN MEMORY"
930        PRINT "    <R> RETURN TO MAIN MENU"
940        PRINT
950        PRINT
960        PRINT " ENTER SELECTION =";
970        S$=INPUT$(1)
980      IF S$="R" OR S$=CHR$(13) THEN RETURN
990        ON VAL(S$) GOSUB 1030,1170,1400,1580,1800,1940,2070,2210
1000         GOTO 800
1010     REM**ADD DATA FUNCTION
1020     REM
1030      IF N=60 THEN RETURN
1040        L1=N-14: L2=N: GOSUB 2290: REM LIST LAST 15 POINTS
1050        LOCATE 20,1
1060        PRINT "ADD POINT #"; N+1
1070        INPUT "  X=";X$: IF X$="" THEN RETURN
1080      IF N=0 GOTO 1100
1090      IF (VAL(X$)-X(N))<0 THEN GOTO 1140
1100      IF VAL(X$)<330 OR VAL(X$)>879 THEN GOTO 1140
1110        N=N+1: REM UPDATE NUMBER OF POINTS
1120        X(N)=VAL(X$)
1130        GOTO 1030: REM ADD ANOTHER POINT
1140        BEEP: GOTO 1070
1150     REM**INSERT DATA FUNCTION
1160     REM
1170      IF N=0 THEN RETURN
1180      IF N=60 THEN RETURN
1190        CLS
1200        PRINT "INSERT AT POINT # (1..";N;")=";: INPUT "";P$
1210      IF P$="" THEN RETURN
1220        P=VAL(P$)
1230      IF P<1 OR P>N GOTO 1190: REM CHECK FOR PROPER RANGE
1240        L1=P-5: L2=P-1: GOSUB 2290
1250        PRINT
1260        PRINT "<--------INSERT POINT HERE--------->"
```

```
1270        PRINT
1280        L1=P: L2=P+4: GOSUB 2350
1290        LOCATE 20,1
1300        PRINT "INSERT POINT #";P
1310        INPUT "X=";X$: IF X$="" THEN RETURN
1320        N=N+1: REM UPDATE NUMBER OF POINTS
1330        FOR I=N TO P STEP-1: REM SHIFT ARRAY ELEMENTS P--N RIGHT
1340        X(I+1)=X(I)
1350        NEXT I
1360        X(P)=VAL(X$): REM INSERT POINT INTO ARRAYS
1370        RETURN
1380    REM**CHANGE DATA FUNCTION
1390    REM
1400      IF N=0 THEN RETURN
1410       CLS
1420       PRINT "CHANGE POINT #(1..";N;")=";: INPUT P$
1430      IF P$="" THEN RETURN
1440       P=VAL(P$)
1450      IF P<1 OR P>N GOTO 1410: REM CHECK FOR PROPER RANGE
1460       L1=P-5: L2=P-1: GOSUB 2290
1470       PRINT
1480       L1=P: L2=P: GOSUB 2350
1490       PRINT
1500       L1=P+1: L2=P+5: GOSUB 2350
1510       LOCATE 20,1
1520       PRINT "CHANGE POINT #";P
1530       INPUT " NEW X=";X$: IF X$="" THEN RETURN
1540       X(P)=VAL(X$)
1550       RETURN
1560    REM**DELETE DATA FUNCTION
1570    REM
1580      IF N=0 THEN RETURN
1590       CLS
1600       PRINT "DELETE POINT # (1..";N;")=";: INPUT "";P$
1610      IF P$="" THEN RETURN
1620       P=VAL(P$)
1630      IF P<1 OR P>N GOTO 1590: REM CHECK FOR PROPER RANGE
1640       L1=P-5: L2=P-1: GOSUB 2290
1650       PRINT
1660       L1=P: L2=P: GOSUB 2350
1670       PRINT
1680       L1=P+1: L2=P+5: GOSUB 2350
1690       LOCATE 20,1
1700       PRINT "DELETE POINT #";P;"(Y/N)";: INPUT A$
1710      IF A$<>"Y" THEN RETURN
1720      IF P=N GOTO 1760: REM DELETE LAST POINT
1730       FOR I=P TO N: REM SHIFT ARRAY ELEMENTS P..N LEFT
1740       X(I)=X(I+1)
1750       NEXT I
1760       N=N-1: REM UPDATE NUMBER OF POINTS
1770       RETURN
1780    REM**SAVE ENTERED DATA TO DISK FUNCTION
1790    REM
1800      IF N=0 THEN RETURN
1810       CLS
1820       INPUT "SAVE AS";A$
1830      IF LEN(A$)>8 THEN A$=MID$(A$,1,8)
1840       A$=A$+".DAT"
1850       OPEN "O",#1,A$
1860       PRINT #1,N: REM SAVE NUMBER OF POINTS
1870       FOR I=1 TO N: REM SAVE POINTS
1880       PRINT #1,X(I)
1890       NEXT I
```

```
1900       CLOSE #1
1910       RETURN
1920    REM**LOAD NEW DATA FROM DISK FUNCTION
1930    REM
1940       CLS
1950       INPUT "LOAD";A$
1960      IF LEN (A$)>8 THEN A$=MID$(A$,1,8)
1970       A$=A$+".DAT"
1980       OPEN "I",#1,A$
1990       INPUT #1,N
2000       FOR I=1 TO N
2010       INPUT #1,X(I)
2020       NEXT I
2030       CLOSE #1
2040       RETURN
2050    REM**PRINT DATA ROUTINE
2060    REM
2070      IF N=0 THEN RETURN
2080       CLS
2090       PRINT "PRINTING DATA..."
2100       LPRINT: LPRINT
2110       LPRINT TAB(10);"X"
2120       LPRINT STRING$ (79,"_")
2130       FOR I=1 TO N
2140       LPRINT USING "##";I;
2150       LPRINT TAB(5);X(I)
2160       NEXT I
2170       LPRINT CHR$(12)
2180       RETURN
2190    REM**CLEAR ALL DATA IN MEMORY ROUTINE
2200    REM
2210       CLS
2220       BEEP
2230       INPUT "CLEAR ALL DATA (Y/N)";A$
2240      IF A$<>"Y" THEN RETURN
2250       N=0
2260       RETURN
2270    REM**DATA LISTING ON SCREEN ROUTINE
2280    REM LIST X(L1) THRU X(L2) ON THE SCREEN
2290       CLS
2300       PRINT: PRINT
2310      IF N=0 THEN RETURN
2320       PRINT TAB(15);"X"
2330       PRINT STRING$(40,"_")
2340    REM
2350      IF L1>N OR L2<1 THEN RETURN
2360      IF L1<1 THEN L1=1: REM ADJUST L1 TO VALID RANGE
2370      IF L2>N THEN L2=N: REM ADJUST L2 TO VALID RANGE
2380       FOR I=L1 TO L2
2390       PRINT USING "##";I;
2400       PRINT TAB(12);X(I)
2410       NEXT I
2420       RETURN
2430    REM
2440    REM**ERROR HANDLING ROUTINE, IBM BASIC RELEASE 2.0
2450    REM
2460       BEEP
2470      IF ERR=5 THEN PRINT "ILLEGAL FUNCTION CALL"
2480      IF ERR=6 THEN PRINT "OVERFLOW"
2490      IF ERR=11 THEN PRINT "DIVISION BY ZERO"
2500      IF ERR=18 THEN PRINT "UNDEFINED USER FUNCTION"
2510      IF ERR=27 THEN PRINT "OUT OF PAPER"
2520      IF ERR=53 THEN PRINT "FILE NOT FOUND"
```

```
2530       IF ERR=57 THEN PRINT "DEVICE I/O ERROR"
2540       IF ERR=61 THEN PRINT "DISK FULL"
2550       IF ERR=70 THEN PRINT "DISK WRITE PROTECTED"
2560       IF ERR=71 THEN PRINT "DISK NOT READY"
2570       IF ERR=72 THEN PRINT "DISK MEDIA ERROR"
2580   REM
2590        PRINT "PROGRAM RESTARTED WITHOUT LOSS OF DATA"
2600        PRINT
2610        PRINT " TYPE <SPACE> TO CONTINUE...";
2620        A$=INPUT$(1)
2630        RESUME 800
2640    REM
2650   REM
2660    REM****COMPUTE MEASURED MASS
2670    REM**F011 CALC MODULE
2680    REM
2690      PT=0: WT=0: ERRLBS=0: ERRPER=0
2700       CLS
2710       PRINT "HAS RF DATA BEEN INPUT ?(Y/N)";
2720       A$=INPUT$(1)
2730      IF A$<>"Y" THEN RETURN
2740      IF (X(3)-X(1))<1 THEN F011=(X(3)+X(2)+X(1))/3
2750      IF (X(2)-X(1))<1 THEN F011=(X(2)+X(1))/2 ELSE F011=X(1)
2760      IF F011>402.75 THEN LOGRP=1 ELSE LOGRP=0
2770   REM
2780   REM
2790   REM****SCAN RANGE MODULE
2800   REM
2810   REM**SEIVE TO DETERMINE SCAN CURVE INTERVALS FOR THE
2820   REM  MEASURED VALUE OF F011
2830     IF F011>=331.8 AND F011<332.5 THEN GOTO 5250
2840     IF F011>=332.5 AND F011<333! THEN GOTO 3090
2850     IF F011>=333! AND F011<336! THEN GOTO 3120
2860     IF F011>=336! AND F011<340! THEN GOTO 3150
2870     IF F011>=340! AND F011<350! THEN GOTO 3180
2880     IF F011>=350! AND F011<360! THEN GOTO 3210
2890     IF F011>=360! AND F011<370! THEN GOTO 3240
2900     IF F011>=370! AND F011<380! THEN GOTO 3270
2910     IF F011>=380! AND F011<390! THEN GOTO 3300
2920     IF F011>=390! AND F011<400! THEN GOTO 3330
2930     IF F011>=400! AND F011<410! THEN GOTO 3360
2940     IF F011>=410! AND F011<420! THEN GOTO 3390
2950     IF F011>=420! AND F011<430! THEN GOTO 3420
2960     IF F011>=430! AND F011<440! THEN GOTO 3450
2970     IF F011>=440! AND F011<450! THEN GOTO 3480
2980     IF F011>=450! AND F011<460! THEN GOTO 3510
2990     IF F011>=460! AND F011<470! THEN GOTO 3540
3000     IF F011>=470! AND F011<475! THEN GOTO 3570
3010     IF F011>=475! AND F011<480! THEN GOTO 3600
3020     IF F011>=480! AND F011<483! THEN GOTO 3630
3030     IF F011>=483! AND F011<484.5 THEN GOTO 3660
3040     IF F011>=484.5 AND F011<485.2 THEN GOTO 3690
3050     IF F011>=485.2 AND F011<485.9 THEN GOTO 5270
3060   REM
3070   REM**SCAN CURVE COEFFICIENTS
3080   REM
3090   B2L=463.42: B2D=-16050.4: C2L=.02: C2D=48.33
3100   B3L=597.39: B3D=-17710.9: C3L=.03: C3D=53.33
3110   A=1!: GOTO 3750
3120   B2L=1393.59: B2D=-10026!: C2L=.05: C2D=30.5
3130   B3L=1805.49: B3D=-12843!: C3L=.05: C3D=39!
3140   A=3!: GOTO 3750
3150   B2L=1857!: B2D=-6692.8: C2L=.07: C2D=20.8
```

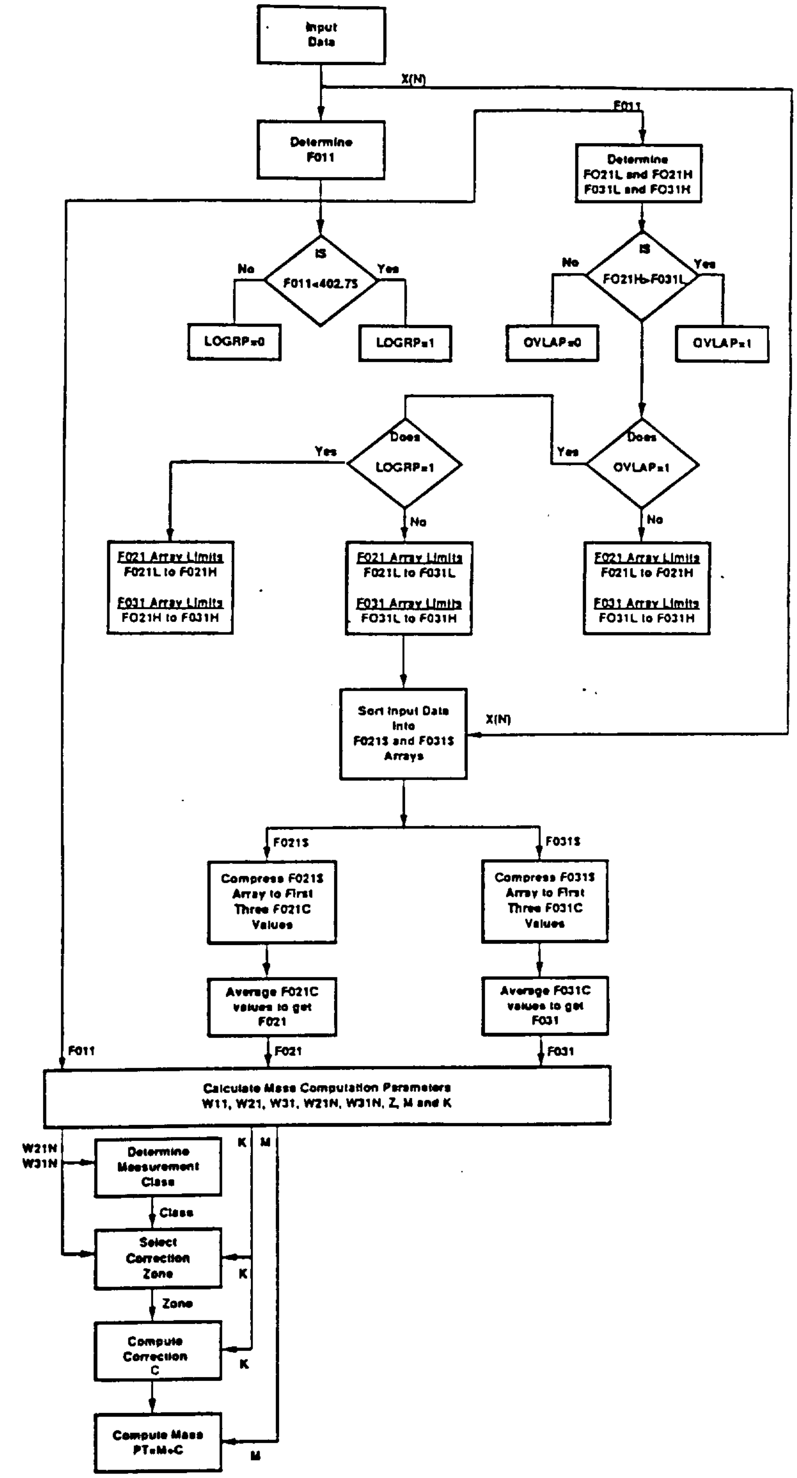
```
3160    B3L=2406.2: B3D=-11076!: C3L=.07: C3D=34!
3170    A=4!: GOTO 3750
3180    B2L=4600!: B2D=-7450!: C2L=.3: C2D=24.7
3190    B3L=6007!: B3D=-9976!: C3L=.2: C3D=32.9
3200    A=10!: GOTO 3750
3210    B2L=4530!: B2D=-5105!: C2L=.5: C2D=18!
3220    B3L=5692!: B3D=-5916!: C3L=1.1: C3D=21.3
3230    A=10!: GOTO 3750
3240    B2L=4170!: B2D=-3665!: C2L=1.5: C2D=14!
3250    B3L=5368!: B3D=-4728!: C3L=2!: C3D=18!
3260    A=10!: GOTO 3750
3270    B2L=3985!: B2D=-3110!: C2L=2!: C2D=12.5
3280    B3L=4739!: B3D=-3174!: C3L=3.7: C3D=13.8
3290    A=10!: GOTO 3750
3300    B2L=3301!: B2D=-1096!: C2L=3.8: C2D=7.2
3310    B3L=4321!: B3D=-1426!: C3L=4.8: C3D=9.2
3320    A=10!: GOTO 3750
3330    B2L=2950!: B2D=425!: C2L=4.7: C2D=3.3
3340    B3L=3970!: B3D=290!: C3L=5.7: C3D=4.8
3350    A=10!: GOTO 3750
3360    B2L=2430!: B2D=1145!: C2L=6!: C2D=1.5
3370    B3L=3050!: B3D=1410!: C3L=8!: C3D=2!
3380    A=10!: GOTO 3750
3390    B2L=2020!: B2D=2375!: C2L=7!: C2D=-1.5
3400    B3L=2640!: B3D=2640!: C3L=9!: C3D=-1!
3410    A=10!: GOTO 3750
3420    B2L=466!: B2D=4517!: C2L=10.7: C2D=-6.6
3430    B3L=624!: B3D=5748!: C3L=13.8: C3D=-8.399999
3440    A=10!: GOTO 3750
3450    B2L=208!: B2D=5377!: C2L=11.3: C2D=-8.600001
3460    B3L=452!: B3D=6479!: C3L=14.2: C3D=-10.1
3470    A=10!: GOTO 3750
3480    B2L=-760!: B2D=6873!: C2L=13.5: C2D=-12!
3490    B3L=-1000!: B3D=8635!: C3L=17.5: C3D=-15!
3500    A=10!: GOTO 3750
3510    B2L=-1930!: B2D=8403!: C2L=16.1: C2D=-15.4
3520    B3L=-1225!: B3D=9085!: C3L=18!: C3D=-16!
3530    A=10!: GOTO 3750
3540    B2L=-3724!: B2D=10381!: C2L=20!: C2D=-19.7
3550    B3L=-4767!: B3D=13409!: C3L=25.7: C3D=-25.4
3560    A=10!: GOTO 3750
3570    B2L=-3225!: B2D=5825!: C2L=12.9: C2D=-11.2
3580    B3L=-6120!: B3D=8772.5: C3L=20.8: C3D=-17.1
3590    A=5!: GOTO 3750
3600    B2L=-6027.5: B2D=10147.5: C2L=18.8: C2D=-20.3
3610    B3L=-14290!: B3D=13237.5: C3L=38!: C3D=-26.5
3620    A=5!: GOTO 3750
3630    B2L=-11018.1: B2D=13778.1: C2L=26.7: C2D=-28.2
3640    B3L=-19950!: B3D=15430.5: C3L=46.5: C3D=-31.5
3650    A=3!: GOTO 3750
3660    B2L=-13068!: B2D=14327.3: C2L=29!: C2D=-29.5
3670    B3L=-11786.3: B3D=11700!: C3L=27!: C3D=-24!
3680    A=1.5: GOTO 3750
3690    B2L=-13347.1: B2D=12833.2: C2L=28.9: C2D=-26.44
3700    B3L=-7595.87: B3D=26777.9: C3L=17.46: C3D=-55.17
3710    A=1!: GOTO 3750
3720    REM
3730    REM**CALCULATE SCAN RANGE FREQUENCIES
3740    REM
3750        F021L=(F011*C2L+B2L)/A: F021D=(F011*C2D+B2D)/A
3760        F021H=F021L+F021D
3770        F031L=(F011*C3L+B3L)/A: F031D=(F011*C3D+B3D)/A
3780        F031H=F031L+F031D
```

```
3790      IF F021H>F031L THEN OVLAP=1 ELSE OVLAP=0
3800    REM ***DATA LIST MODULE    CODED BY P. HEBNER
3810    REM ** INITIALIZATION
3820    Z = 0
3830    I = 0
3840    J = 0
3850    REM **
3860    IF OVLAP = 1 THEN IF LOGRP = 1 GOTO 3870 ELSE GOTO 3930 ELSE GOTO 3990
3870    WHILE X(Z) <= F031H AND I + J <= 25 AND Z < 45 :REM OVLAP=1 AND LOGRP=1
3880       IF X(Z) >= F021L AND X(Z) <= F021H THEN: F021S(I) = X(Z): I = I + 1:G
OTO 3900
3890       IF X(Z) > F031L THEN : F031S(J) = X(Z): J = J + 1
3900    Z = Z + 1
3910    WEND
3920    GOTO 4040
3930    WHILE X(Z) <= F031H AND I + J <= 25 AND Z < 45
3940       IF X(Z) >= F021L AND X(Z) < F031L THEN: F021S(I) = X(Z): I = I + 1:GC
TO 3960
3950       IF X(Z) >= F031L THEN: F031S(J) = X(Z): J = J + 1
3960       Z = Z + 1
3970    WEND
3980    GOTO 4040
3990    WHILE X(Z) <= F031H AND I + J <= 25 AND Z < 45
4000       IF X(Z) >= F021L AND X(Z) <= F021H THEN: F021S(I) = X(Z): I = I + 1:
GOTO 4020
4010       IF X(Z) >= F031L THEN: F031S(J) = X(Z): J = J + 1
4020       Z = Z + 1
4030    WEND
4040    F021S(I) = 0
4050    F031S(J) = 0
4060    Z = 0
4070    REM ***F021/F031 CALC MODULE    CODED BY P. HEBNER
4080    REM **  INITIALIZATION
4090    SUM = 0!
4100    NUM = 0
4110    Y = 0
4120    Q = 0
4130    VALUE = 0
4140    REM **
4150    VALUE = F021S(0) + 5!
4160    FOR Y = 0 TO ( I - 1 )
4170       IF F021S(Y) < VALUE THEN: SUM = SUM + F021S(Y): NUM=NUM+1
4180       IF F021S(Y) > VALUE THEN: F021C(Q)=SUM/NUM: Q=Q+1: VALUE=F021S(Y)+5!:
SUM = F021S(Y): NUM = 1
4190    NEXT Y
4200    IF Q < 3 THEN F021C(Q) = SUM/NUM: Q = Q + 1
4210    SUM = 0
4220      NUM = 0
4230    Q = 0
4240    WHILE F021C(Q) <> 0 AND Q < 3
4250       SUM = SUM + F021C(Q)
4260       NUM = NUM + 1
4270       Q = Q + 1
4280    WEND
4290    F021 = SUM / NUM
4300    Y = 0
4310    Q = 0
4320    SUM = 0
4330    NUM = 0
4340      VALUE = 0
4350    VALUE = F031S(0) + 11!
4360    FOR Y = 0 TO ( J - 1 )
4370       IF F031S(Y) < VALUE THEN: SUM=SUM+F031S(Y): NUM=NUM+1
```

```
4380      IF F031S(Y) > VALUE THEN: F031C(Q)=SUM/NUM: Q=Q+1: VALUE=F031S(Y)+11!
 SUM=F031S(Y): NUM=1
4390     IF Q=3 GOTO 4410
4400    NEXT Y
4410    IF Q < 3 THEN: F031C(Q) = SUM / NUM: Q = Q + 1
4420    Q = 0
4430    SUM = 0
4440    NUM = 0
4450    WHILE F031C(Q) <> 0 AND Q < 3
4460       SUM = SUM + F031C(Q)
4470       NUM = NUM + 1
4480       Q = Q + 1
4490    WEND
4500    F031 = SUM / NUM
4510    REM ***MASS COMP. MODULE    CODED BY P. HEBNER
4520    REM ** INITIALIZATION
4530    W11 = 0!
4540    W21 = 0!
4550    W31 = 0!
4560    W21N = 0!
4570    W31N = 0!
4580    Z = 0!
4590    R = 0!
4600    S = 0!
4610    T = 0!
4620    M = 0!
4630    K = 0!
4640    REM **
4650    W11 = 121.5919077# * (((485.37/F011)^2) -1)
4660    W21 = 126.3711143# * (((680.14/F021)^2) -1)
4670    W31 = 126.3711267# * (((878.69/F031)^2) -1)
4680    W21N = W21/W11
4690    W31N = W31/W11
4700    Z = (W11 + W21 + W31)/3!
4710    R = 1398.173 - (3.350048 * F011) + (2.184247 * F021) - (2.997274 * F031)
4720    S = (2.911028E-02 * (F011^2)) - (6.597137E-04 * (F021^2)) - (2.378183E-02
 * (F031^2))
4730    T = (-7.566952E-02 * F011 * F021) + (3.257759E-02 * F011 * F031) + (4.061
078E-02 * F021 * F031)
4740    M = R + S + T
4750    K = M - Z
4760    REM ** DETERMINE THE MEASUREMENT CLASS
4770    IF W11 < W21 AND W21 < W31 THEN: CLASS = 123
4780    IF W11 < W31 AND W31 < W21 THEN: CLASS = 132
4790    IF W21 < W11 AND W11 < W31 THEN: CLASS = 213
4800    IF W21 < W31 AND W31 < W11 THEN: CLASS = 231
4810    IF W31 < W11 AND W11 < W21 THEN: CLASS = 312
4820    IF W31N < W21N AND W21N < W11 THEN: CLASS = 321
4830    REM ** DEFINE CORRECTION ZONE
4840    IF CLASS = 123 GOTO 4880
4850    IF CLASS = 213 GOTO 4970
4860    IF CLASS = 231 GOTO 5080
4870    GOTO 5130
4880    IF K < 0! THEN IF ABS(K) < 24! GOTO 5180 ELSE GOTO 5160
4890    IF K < 2! GOTO 5180
4900    IF K < 6! THEN IF W31N < 1.6 GOTO 5180 ELSE GOTO 5160
4910    IF K < 11! GOTO 5160
4920    IF K < 22! THEN IF W31N > 2! AND W31N <5.8 GOTO 5220 ELSE GOTO 5180
4930    IF K < 28! GOTO 5180
4940    IF K < 34! GOTO 5200
4950    PRINT "CORRECTION IS OUT OF RANGE."
4960    GOTO 5140
4970    IF K < 0! THEN IF ABS(K) > 18! GOTO 5180 ELSE 5160
```

```
4980  IF K < 1! THEN IF (W21N+W31N) > 2.2 GOTO 5180 ELSE GOTO 5220
4990  IF K < 2! THEN IF (W21N + W31N) < 1.9 GOTO 5180 ELSE GOTO 5220
5000  IF K < 6! THEN IF K > 5.6 GOTO 5180 ELSE GOTO 5160
5010  IF K < 6.8 THEN IF K < 6.2 GOTO 5160 ELSE GOTO 5220
5020  IF K < 7.2 THEN IF (W21N + W31N) > 2.2 GOTO 5220 ELSE GOTO 5200
5030  IF K < 7.5 THEN IF (W21N + W31N) > 3.5 GOTO 5200
5040  IF K < 11! GOTO 5200
5050  IF K < 14! THEN IF K < 13! GOTO 5160 ELSE GOTO 5220
5060  PRINT "CORRECTION OUT OF RANGE."
5070  GOTO 5140
5080  IF K < 0! GOTO 5180
5090  IF K < 18! GOTO 5200
5100  IF K < 22! GOTO 5160
5110  PRINT "CORRECTION OUT OF RANGE."
5120  GOTO 5140
5130  PRINT "CLASS IS NOT IN THIS ALGORITHM."
5140  C = 0!
5150  GOTO 5230
5160  C = -.4066 * K - 14.66364
5170  GOTO 5230
5180  C = -.4066 * K - 3.77273
5190  GOTO 5230
5200  C = -.4066 * K + 9.445461
5210  GOTO 5230
5220  C = -.4066 * K + 21.15
5230  PT = M + C
5240    GOTO 5280
5250    PT=138.25
5260    GOTO 5280
5270    PT=0!
5280    CLS
5290    PRINT "ENTER ACTUAL MASS IN LBS.(XXX.XX)=";: INPUT WT$
5300    WT= VAL(WT$)
5310    ERRLBS= PT-WT
5320    ERRPER= (ERRLBS*100)/138.25
5330    CLS
5340    PRINT "COMPUTED MASS =";
5350    PRINT USING "###.##"; PT
5360    PRINT "ACTUAL MASS =";
5370    PRINT USING "###.##"; WT
5380    PRINT "MASS ERROR =";
5390    PRINT USING "+##.##"; ERRLBS
5400    PRINT "PERCENT ERROR =";
5410    PRINT USING "+##.##"; ERRPER
5420    PRINT "F011=";
5430    PRINT USING "###.##"; F011
5440    PRINT "F021=";
5450    PRINT USING "###.##"; F021
5460    PRINT "F031=";
5470    PRINT USING "###.##"; F031
5480 REM PRINT "W11=";
5490 REM PRINT USING "###.##"; W11
5500 REM PRINT "W21=";
5510 REM PRINT USING "###.##"; W21
5520 REM PRINT "W31=";
5530 REM PRINT USING "###.##"; W31
5540 REM PRINT "M=";
5550 REM PRINT USING "###.##"; M
5560 REM PRINT "K=";
5570 REM PRINT USING "+##.##"; K
5580 REM PRINT "CLASS=";
5590 REM PRINT USING "###"; CLASS
5600 REM PRINT "C=";
```

```
5610 REM PRINT USING "+##.##"; C
5620     PRINT "TYPE <Y> WHEN FINISHED RECORDING RESULTS";
5630     A$=INPUT$(1)
5640    IF A$ <> "Y" THEN GOTO 5620
5650     LOGRP=0: OVLAP=0: F021L=0: F021D=0: F021L=0: F021=0
5660     F031L=0: F031D=0: F031H=0: F031=0: F011=0
5670     FOR U=0 TO 25
5680     F021S(U) = 0
5690     NEXT U
5700     FOR V=0 TO 4
5710     F021C(V) = 0
5720     NEXT V
5730     FOR E=0 TO 25
5740     F031S(E) = 0
5750     NEXT E
5760     FOR H=0 TO 4
5770     F031C(H) = 0
5780     NEXT H
5790     FOR G=0 TO N
5800     X(G)=0
5810     NEXT G
5820     RETURN
```


Input Data
X(N)
Determine F011
F011
Determine F021L and F021H F031L and F031H
IS F011<402.75
No
Yes
LOGRP=0
LOGRP=1
IS F021H>F031L
No
Yes
OVLAP=0
OVLAP=1
Does LOGRP=1
Yes
No
Does OVLAP=1
Yes
No
F021 Array Limits F021L to F021H
F031 Array Limits F021H to F031H
F021 Array Limits F021L to F031L
F031 Array Limits F031L to F031H
F021 Array Limits F021L to F021H
F031 Array Limits F031L to F031H
Sort Input Data Into F021$ and F031$ Arrays
X(N)
F021$
F031$
Compress F021$ Array to First Three F021C Values
Compress F031$ Array to First Three F031C Values
Average F021C values to get F021
Average F031C values to get F031
F011
F021
F031
Calculate Mass Computation Parameters W11, W21, W31, W21N, W31N, Z, M and K
W21N
W31N
K
M
Determine Measurement Class
Class
Select Correction Zone
K
Zone
Compute Correction C
K
Compute Mass PT=M+C
M

Appendix I

# RF MODAL QUANTITY GAGING

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## ABSTRACT

The primary objective of this paper is to provide a concept exposition of a radio frequency (RF) modal resonance technique which is being investigated as a method for gaging the quantities of subcritical cryogenic propellants in metallic tanks. Of special interest are the potential applications of the technique to microgravity propellant gaging situations. The results of concept testing using cryogenic oxygen, hydrogen, and nitrogen, as well as paraffin simulations of microgravity fluid orientations, are reported. These test results were positive and showed that the gaging concept was viable.

## INTRODUCTION

Techniques for the routine, reliable, and safe handling of subcritical cryogenic propellants under conditions of low to zero gravity are essential to resupply operations of future space-based systems such as an orbital vehicle (OTV). One of several technology areas critical to on-orbit management of such propellants is quantity gaging.[1]

A major objective of the work reported in this paper is the development of a high selection merit (i.e., safe, reliable, low weight, etc.) technique for the quantity gaging of subcritical cryogenic propellant oxygen and hydrogen. The ultimate accuracy goal is ±1 percent of full loaded mass. The current development activities have a feasibility cut-off limit of ±5 percent. The gaging technique will be appropriate to a wide range of tank sizes and shapes with minimal gaging system weight or power requirements.

## RF GAGING CONCEPT

Using electromagnetic waves to assess the density of a dielectric medium is not a new idea; it has been investigated and implemented in many forms. Attempts to apply the technique to cryogenic propellants were especially intense during the late 1960's and early 1970's. These efforts resulted in the development of approaches that were straightforward and accurate for normal gravity situations, but were potentially much less accurate in microgravity applications. The uncertainty about microgravity accuracy, and the fact that less complex and inexpensive alternatives were usually available for normal gravity gaging assignments, discouraged further development of the approach for a 10-year period.

Strong advantages of the approach involving spaceborne, two-phase cryogenic propellant tankage applications, plus the impressive technological advancements in the relevant fields of instrumentation and electronics, led to selecting the approach for microgravity applications. Key advantages and disadvantages of the RF modal quantity gaging technique are listed in Table I.

### OPERATING PRINCIPLE

The operating principle of the basic RF quantity gaging technique is based on the following three ideas:[2]

1. Electromagnetic energy introduced into a closed metallic cavity forms repeatable stationary field patterns at certain frequencies known as resonant modes.

2. Frequencies of these resonant modes are dependent upon the physical attributes (size and geometry) of the cavity boundaries, and on the electrical attributes (conductivity, permeability, and dielectric constant) of any medium that might be uniformly dispersed throughout the cavity volume.

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1 Another JANNAF 1989 paper entitled "On-orbit Fluid Quantity Gaging by Adiabatic Compression" by A.J. Nord et al of BASC also addresses this technology.

2 This introductory exposition of operating principle assumes uniform dispersion of dielectric media in the gaged cavity. What occurs when this assumption is not true is developed later in the discussion.

* This work was performed under NAS9-17378 with the NASA-JSC, Houston, Texas. Approved for public release; distribution is unlimited.

Table I. Advantages and Disadvantages of RF Modal Approach.

Advantages:

- Low-weight system, and weight does not significantly vary with tank size.
- Minimal intrusion into tank.
- Small impact on PV structure and MLI of cryogenic tanks.
- No moving parts.
- No special materials, components, or processes are required.
- Electronics located remotely from tank.
- Operating power is low and power input to fluid is negligible.
- Concept particularly applicable to propulsion cryogens.
- Not sensitive to thermodynamic properties of gagable fluids.
- Not affected by species of pressurant gas.

Disadvantages*

- Mass conversion algorithm development is required for each different tank configuration.
- Requires calibration to develop correction algorithm for fluid location effects.
- Is not easily adapted to widespread metallic constructs inside gaged tank.
- Not applicable for use with nondielectric fluids or dielectric fluids with significant loss tangents.
    - All except the last can be overcome.

3. If the medium in the cavity volume is a nonpolar dielectric fluid that is low loss and obeys the Clausius-Mossotti equation relating density and dielectric constant, the resonant mode frequencies are also dependent on the medium density.

Because the cavity volume is known, a determination of medium density leads immediately to mass or quantity of medium in the cavity. The equations illustrating these ideas as applied to a spherical cavity are shown in Fig. 1.

Standing wave electromagnetic field patterns generated by an antenna inside a closed metal cavity occur at resonant mode frequencies which are dependent on the cavity size and shape as well as the dielectric media in the cavity. For a spherical cavity:

(1)
$$f_{ab} = \frac{U_{ab}}{2\pi R(\mu\varepsilon)^{1/2}}$$

Where: $f_{ab}$ = Resonant frequency of mode
$U_{ab}$ = Eigenvalue for mode
$R$ = Tank radius
$\mu$ = Magnetic permeability of fluid
$\varepsilon$ = Dielectric constant of fluid

Since the nonpolar propellants, oxygen and hydrogen, obey the Clausius-Mossotti relation (2), the modal resonant frequencies are related to propellant mass:

(2)
$$z\rho = \frac{\varepsilon - 1}{\varepsilon + 2}$$

Where: $\rho$ = Average propellant density
$\varepsilon$ = Average propellant dielectric constant
$z$ = Constant of proportionality

Noting that $\mu_o$, $\mu_n$ & $\varepsilon_o$ ~ 1 where: Subscript o = empty tank
Subscript n = not empty tank

The ratio of resonant frequencies for a given mode with the tank empty and partially filled can be obtained from (1) as:

(3)
$$\frac{f_o}{f_n} = (\varepsilon n)^{1/2}$$

Since propellant mass (m) is equal to the product of average propellant density and the total tank volume, the equation for (m) is:

(4)
$$m = V_{\rho n} - V\frac{1}{z}\left(\frac{\varepsilon n - 1}{\varepsilon n + 2}\right) - \frac{V}{z}\left(\frac{f_o^2 - f_n^2}{f_o^2 + 2f_n^2}\right)$$

10037/175.01

Figure 1. Spherical Cavity Relations.

This basic form of the RF quantity gaging technique is entirely usable for situations where the medium is uniformly dispersed throughout the cavity (i.e., full and empty are special cases of this). Also, with calibration, this basic technique would likely be adequate for fixed fill and deplete orientations in a gravity field sufficient to form repeatable fluid/vapor interfaces. Zero or microgravity applications with indeterminate fluid orientation require augmenting the technique because the modal frequencies are also dependent on the spatial orientation of dielectric fluid in the cavity. This follows from the fact that the stationary field patterns at the resonant modes do not sample the cavity volume uniformly.

The ability to deal with microgravity conditions and indeterminate fluid orientations is a very desirable attribute of a subcritical cryogenic propellant quantity gaging system. For the RF gaging concept to have this capability, the basic gaging approach requires modification or augmentation. The better known approaches to this are discussed in the next subsection.

VARIOUS APPROACHES

Techniques for adapting the RF gaging concept to microgravity random fluid orientation situations have been based on the following two approaches.

Mode Counting. The Instruments and Life Support Division of the Bendix Corporation developed this technique in the late 1960's. It is based on the theoretically derivable fact that the number of modes that can be established within a cavity over a specified frequency band is linearly dependent upon the amount of dielectric medium in the cavity. If the frequency band limits were chosen to give a full cavity total mode count of one to two thousand, the resulting large number of stationary field patterns would sample the cavity contents so thoroughly as to become independent of dielectric medium orientation.

Normal gravity tests of the approach met the goal of 2 percent accuracy. Near zero-gravity tests in a KC-135 aircraft induced a significant number of hybrid modes and degeneracies, which resulted in readings differing from the normal gravity calibrations by as much as 18 percent of full load.

Modal Analysis. This technique, pioneered by the Cryogenics Division of the National Bureau of Standards in the early 1970's, was based on exciting the cavity over a relatively narrow frequency band and determining the resonant frequencies of only a few modes. The resonant frequencies of these modes were used in a weighted average relation to determine the mass of dielectric in the cavity.

Normal gravity testing results indicated that the technique was capable of accuracies of ±1.2 percent of full load. Subsequent near zero-gravity tests in a KC-135 aircraft also encountered hybrid modes (i.e., those responses not predicted by classical theory) and showed that modal frequencies could vary as much as 15 percent by changes in the geometry of a constant mass of dielectric medium. Enhanced data reduction methods were required to bring the accuracy of the KC-135 test data within ±3 to ±5 percent of full load. These methods involved removing hybrid mode responses and time averaging the working mode responses over a 30-second interval prior to using the weighted average relation to determine the dielectric medium mass.

SELECTED APPROACH

A modal analysis approach was selected to minimize the effects of hybrid modes expected in microgravity applications. The resulting narrow frequency band would limit the number of hybrid modes that could be encountered. Taking this idea even further led to a decision to use the lowest four non-hybrid modal frequencies that could be excited in the cavity. It was believed that only two or three modal responses would be required to uniquely determine the dielectric medium mass, but this was yet to be verified.

Advances in frequency counter and sweep oscillator technology made it reasonable to use an approach that would directly measure and store the frequencies of up to 70 responses that could be obtained covering a four-mode frequency band in a small fraction of a second. The precision of these frequency measurements could be expected to have errors so low (±0.005 percent) as to be negligible in their contribution to the approach accuracy.

The modal analysis that would operate on the measured frequencies would have the following basic structure:

1. Sort the response population into groups of frequencies associated with each mode.
2. Analyze each frequency group to determine the mode frequency.
3. Use the mode frequencies (2 to 4) to classify the response and compute a mass estimate.
4. Compute any required corrections and add to the mass estimate to obtain the measured mass.

This makes up the selected approach in which the modal analysis was to be based on frequency data only. Use of other ancillary response information, which could be obtained with increased system complexity, such as relative response strength and sharpness (Q), would be avoided if at all possible.

## CRYOGENIC TESTS

Feasibility testing of the selected RF gaging approach was accomplished using a laboratory equipment implementation of the RF modal gaging system to excite and detect the modal responses of a specially designed test tank. The objectives were to provide experimental assessments of:

1. The probable accuracy, repeatability, and hysteresis of a gaging system for liquid oxygen and hydrogen propellants.
2. The sensitivity of the gaging approach to variations in fluid/vapor interface location and tank internal components.
3. The suitability of tank/fluid Q to the gaging approach.

### METHOD

Test objectives were addressed using the following four test sequences: (1) characterization tests using liquid nitrogen as the test fluid to debug the test setup and perfect details of the operating procedures; (2) baseline tests using liquid nitrogen, oxygen, and hydrogen to obtain bare tank modal responses at all test attitudes; (3) Phase 1 tests using liquid nitrogen to obtain modal responses of the tank in various attitudes containing dummy fluid acquisition channels, a start basket, and a thermodynamic vent; and (4) Phase 2 tests using liquid nitrogen to obtain modal responses of a tank containing all Phase 1 components as well as a dummy spray bar mast and two ring slosh baffles. An exploded view of the internal componetry is shown in Fig. 2.

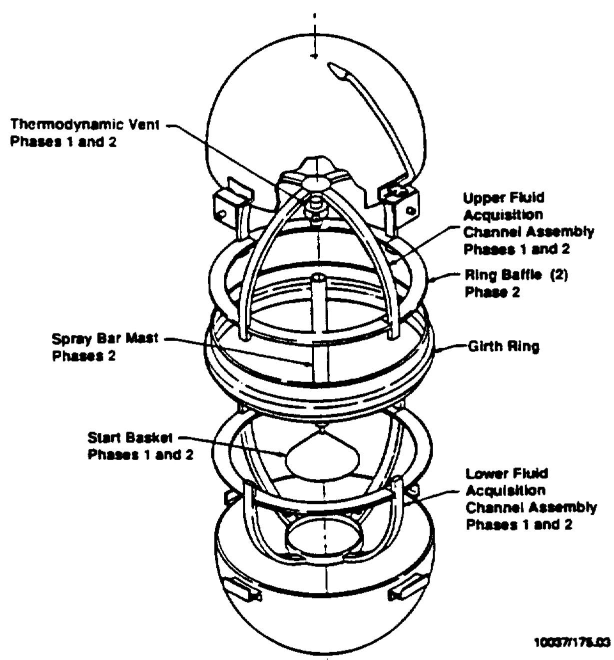


Figure 2. Tank Internal Components.

The tank used for all cryogenic tests was designed for suspension in a vacuum chamber with shrouds operating at liquid nitrogen temperature. More detailed descriptions of the test hardware are provided below.

Modal Gaging System. Laboratory implementation of the RF modal gaging system used in all test sequences is shown in the block diagram of Fig. 3. In this setup, the spectrum analyser/ tracking generator supply a constant power level signal whose frequency is periodically swept from a low to high frequency limit linearly with time. This signal is applied to any of the three tank antennas through a directional coupler. The tank antennas are deliberately mismatched over the test frequency range so that a significant portion of the incident signal is reflected. A connection to the directional coupler reflected power port allows monitoring and display of the reflected power level on the spectrum analyzer scope screen as a function of the instantaneous frequency. As the RF signal is swept over the test frequency range, the various tank resonances (modes) that can be excited by the tank antennas permit the antennas to supply more of the incident power to the tank RF fields. This results in a reduction of the reflected power level being monitored on the spectrum analyzer display. The width and depth of the resonant dips occurring in the analyser display as the test signal is swept through the tank resonances are directly related to the Q and strength of the modal responses.

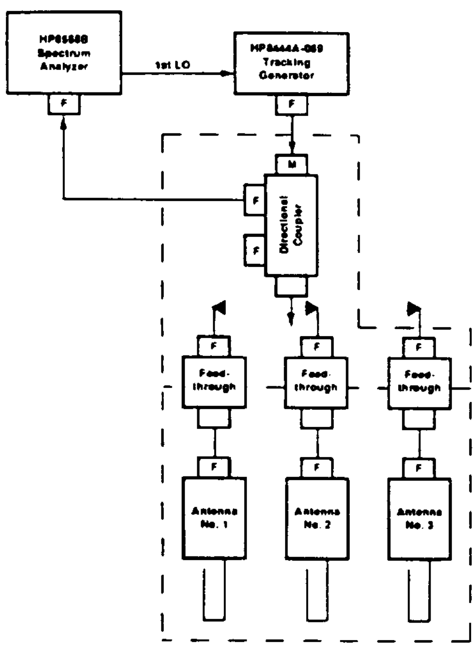


Figure 3. Modal Gaging System Block Diagram.

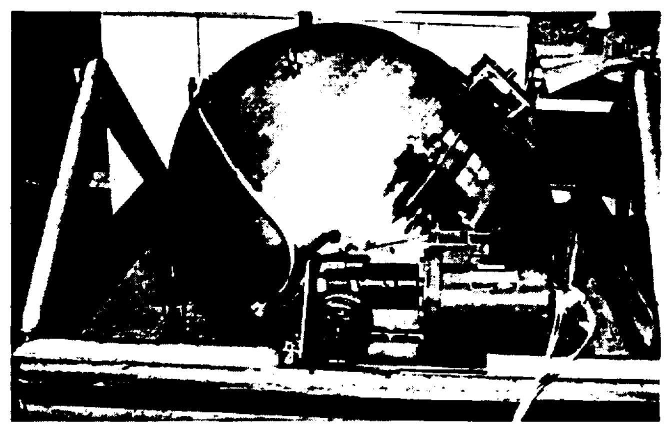

Figure 4. Cryogenic Test Tank Before Insulation.

Test Tank. The tank shell consisted of two 91-cm (36-in.) diameter hemispherical heads with 10-cm (4-inch) straight sections which terminated in reweldable closures. This provided an empty tank volume of 0.536m$^3$ (18.94 ft$^3$) and the closures permitted the test tank to be separated at the girth to accommodate changes in the internal components. Because the tank was to contain cryogens, a removable system of multilayer radiation blankets, consisting of two offset blankets of 15 layers of double aluminised mylar with nylon net spacers, was used. The tank was mounted in a rigid tubular framework which provided two crossed-link load cell suspension points and a tank rotation system. The rotation system consisted of a worm drive to a pinion gear on the tank axle. A photograph of the tank in the test fixture prior to insulation is shown in Fig. 4.

## CRYOGENIC TEST RESULTS

Results of the cryogenic testing effort were positive and indicated that the RF modal gaging approach was viable. The assessment objectives and corresponding test results are provided below. Definitions of parameters used in the results tables are as follows:

Probable accuracy - Most probable percentage difference between actual loaded mass and a mass computed using an algorithm employing modal frequency data. The algorithm incorporates fluid location correction capability only. Values are expressed as percent of full load.

Repeatability - Comparison of two readings of same fill level, attitude, and configuration with data taken in independent measurement cycles. Table value is highest deviation value found expressed as percent.

Hysteresis - Comparison of two readings of same fill level, attitude, and configuration with the data taken in a continuous cycle.

Fluid location sensitivity - Worst-case deviations from reference attitude value regardless of the attitude of occurrence. Expressed as percent of full load.

Sensitivity to internal components - Probable accuracy values for Phase 1 and Phase 2 configurations minus the $LN_2$ Bare Tank probable accuracy. Expressed as percent of full load.

First Objective. Evaluation of probable accuracy and repeatability gave the results summarized in Table II. No measurable hysteresis effects were found.

Table II. Cryogenic Test Results - Accuracy.

| TEST FLUID | TANK CONFIGURATION | PROBABLE ACCURACY* | REPEATABILITY |
|---|---|---|---|
| $LN_2$ | Bare Tank | ±1.05% | 0.024% |
| $LO_2$ | Bare Tank | ±1.61% | 0.059% |
| $LH_2$ | Bare Tank | ±0.92% | 0.036% |
| $LN_2$ | Phase 1 Config. | ±2.61% | 0.078% |
| $LN_2$ | Phase 2 Config. | ±3.65% | 0.131% |

* Corrected for fluid location

Second Objective. Assessment of the gaging approach sensitivity to fluid location and tank internal components is summarized in Table III.

Table III. Cryogenic Test Results - Sensitivity.

| TEST FLUID | TANK CONFIGURATION | FLUID LOCATION SENSITIVITY* | SENSITIVITY TO INTERNAL COMPONENTS |
|---|---|---|---|
| $LN_2$ | Bare Tank | ±6.78% | (Not Applicable) |
| $LO_2$ | Bare Tank | ±8.32% | (Not Applicable) |
| $LH_2$ | Bare Tank | ±10.31% | (Not Applicable) |
| $LN_2$ | Phase 1 Config. | ±6.21% | ±1.56% |
| $LN_2$ | Phase 2 Config. | ±7.69% | ±2.60% |

*Moment analysis methods suggest the upper bound on this sensitivity should be ±15% of full load.

Third Objective. Direct measurements were made of tank/fluid Q to determine if a computed minimum value of 5,400 (the value required to obtain 0.1 percent resolution of modal frequency changes) could be realized. The lowest Q value measured was 7,800 which more than met the resolution criteria.

## BENCH-TOP TESTS

Cryogenic feasibility testing provided performance data for a wide variety of liquid attitudes in the test dewar, but did not provide any data for single bubble, wetted wall, or floating globule liquid interface configurations which could be encountered in near zero-gravity space flight. It was considered vital to challenge the RF modal gaging approach with these types of fluid distributions as early in the feasibility evaluation as possible. The primary objective of this testing effort was to assess the performance of the RF modal gaging approach when challenged with liquid configurations representative of near zero-gravity conditions.

To accomplish this, an algorithm for converting RF modal responses into loaded fluid quantity was to be developed using the zero-gravity simulation data. This algorithm was then to be used to determine the mass of five random fluid configurations. A resulting accuracy of ±5 percent of full load was required for the concept to be considered feasible. The test method used to implement these activities is described below.

### METHOD

Certain refined grades of paraffin are good simulants for cryogenic fluids in tests investigating fluid response to electromagnetic fields. These paraffins are solid at room temperature and can be easily formed -- all characteristics that permit the simulation of zero-gravity fluid orientations in a normal gravity environment. Once the method for simulating the zero-gravity fluid orientations was found, it became desirable to work with a tank physically smaller than the cryogenic test tank, because this would reduce the scope of the paraffin forming tasks to more manageable sizes. This objective was bounded by the upper frequency limit of the laboratory equipment which would implement the RF gaging concept (smaller tank size meant higher frequencies). Also, a change in tank size would permit verification of the cavity size scaling relations, just as the use of paraffin would test the scaling of dielectric constant. This was called the bench-top test series.

Modal Measurement System. The RF modal frequency measurements system used in the bench-top test series was the same as that used in the cryogenic tests, except that the test tank had eight antenna positions instead of three. The additional antenna positions were incorporated for further investigating the effects of antenna placement.

Test Tank. The test tank was scaled as close to a half-size version of the cryogenic test tank as the use of standard stainless steel heads would permit. This resulted in using 48-cm (19-in.) diameter hemispherical heads with 5-cm (2-in.) straight sections. The upper and lower sections of the tank were held in place and made electrically continuous with a simple band around their junction. The tank shell was 4.85-mm (0.191-in.) thick to provide a substantial degree of rigidity, but was not pressure tight. Figure 5 shows the bench-top test tank.

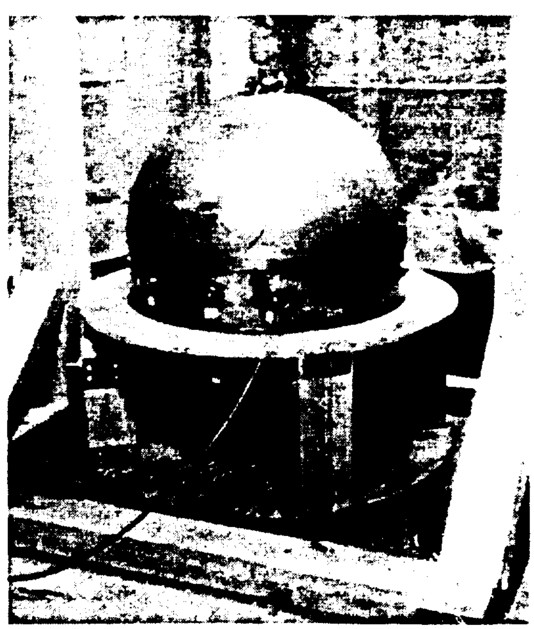

Figure 5. Bench-Top Test Tank.

## BENCH-TOP TEST RESULTS

The RF modal gaging approach was able to successfully meet the challenge of the paraffin simulations of sero-gravity fluid orientations. Results are provided for an algorithm which computes tank loaded mass given a required set of three modal frequencies, and for an integrated algorithm which computes tank-loaded mass given all modal responses in the sweep range. The latter algorithm incorporates the ability to select the required set of three modal frequencies from the raw response data. In both instances, the algorithms were developed using 31 different fluid orientations and then tested using 5 random fluid orientations. Table IV shows accuracy performance for both the 31 algorithm development orientations and the 5 random orientations.

Table IV. Bench-Top Test Accuracy Performance.

| ALGORITHM TYPE | FLUID ORIENTATIONS | ACCURACY PERFORMANCE (AVG) |
|---|---|---|
| Mass Only | 31 Development | ±0.28% |
| Mass Only | 5 Random | ±0.90% |
| Integrated | 31 Development | ±1.42% |
| Integrated | 5 Random | ±1.52% |

## ALGORITHMS

From the beginning of the RF modal feasibility assessment, a method for transforming modal frequencies into a measure of dielectric media mass was necessary. Such a transformation requires 2 basic constituents, an algorithm for extracting the 3 wanted modal frequencies from a group of 21 responses (on average), and an algorithm to compute the mass of dielectric medium using the 3 modal frequencies. Initially, extraction was accomplished manually using numerical and graphical techniques instead of a formally developed algorithm. During this period, algorithm development was concentrated on the mass computation techniques. The basic approach to the mass computation algorithm was to compute a mass using the three lowest TM modal frequencies and then add an empirically derived correction term. A full exposition of the development of the mass computation algorithm and its subsequent integration with a formal modal frequency extraction algorithm cannot be treated in this paper; however, this information will be provided in an upcoming final report for the program.

At the current state of algorithm development, it appears that a mass computation algorithm developed for one basic tank shape, sise, internal components, and dielectric medium would be scalable to other tank sizes and dielectric media. If the tank shapes and internal components had the same characteristic equation forms as solutions to their maxwell equation set. If the characteristic equations are of different form, another algorithm would have to be developed. This task is not particularly onerous, because testing of a scale model similar to the bench-top testing effort could provide the necessary data. Indeed, experiments using the bench-top data base to evaluate artificial neural network technology as a much faster and potentially more accurate method of developing the required algorithm is very promising.

## CONCLUSIONS

In all feasibility challenges, the RF modal gaging approach was able to easily meet the ±5 percent of full-load criteria and come very close to the ultimate ±1 percent of full-load accuracy goal. Reduction of the gaging approach to specific hardware should pose no significant problems to currently available technology.

JANNAF

SPACECRAFT PROPELLANT MANAGEMENT TECHNOLOGIES

SESSION 2J

# RF QUANTITY GAGING

I-10

K. VAN LEUVEN

BALL AEROSPACE SYSTEMS GROUP

JANNAF/102.AA6-1

# IDEAL CASE, DIELECTRIC MEDIUM UNIFORMLY DISPERSED THROUGHOUT CAVITY

RF MODAL GAGING OPERATING PRINCIPLE - KEY IDEAS

1. THE INTRODUCTION OF OSCILLATING ELECTROMAGNETIC ENERGY INTO A CLOSED METALLIC CAVITY WILL FORM REPEATABLE STANDING WAVE PATTERNS AT CERTAIN FREQUENCIES KNOWN AS RESONANT MODES.

2. FREQUENCIES OF THE RESONANT MODES DEPEND ON:

   PHYSICAL ATTRIBUTES OF CAVITY BOUNDARIES

   - SIZE
   - GEOMETRY

   ELECTRICAL ATTRIBUTES OF DIELECTRIC IN CAVITY

   - CONDUCTIVITY
   - PERMEABILITY
   - DIELECTRIC CONSTANT

3. THE DIELECTRIC MEDIUM IN THE CAVITY MUST OBEY THE CLAUSIUS-MOSSOTTI EQUATION RELATING DENSITY AND DIELECTRIC CONSTANT AND SHOULD HAVE A LOW-LOSS TANGENT.

4. IDEAS ONE THROUGH THREE PROVIDE THE BASIS FOR DETERMINING THE DENSITY OF THE DIELECTRIC MEDIUM IN THE CAVITY. SINCE THE CAVITY VOLUME IS KNOWN, DIELECTRIC MEDIUM MASS OR QUANTITY FOLLOWS DIRECTLY AS DENSITY TIMES VOLUME.

# NONIDEAL CASE, DIELECTRIC MEDIUM NOT UNIFORMLY DISTRIBUTED

- WHAT HAPPENS?

  THE RESONANT MODE FREQUENCIES BECOME DEPENDENT ON DIELECTRIC MEDIUM LOCATION.

- WHAT CAUSES THIS?

  THE RESONANT STANDING WAVE PATTERNS DO NOT UNIFORMLY SAMPLE THE CAVITY VOLUME.

- WHAT ARE THE CONSEQUENCES?

  - ONE G, FIXED ATTITUDE: CAN BE CALIBRATED USING ONE RESONANT MODE
  - LOW G, FIXED ATTITUDE: CAN BE CALIBRATED USING ONE RESONANT MODE
  - MICRO G, ANY ATTITUDE: REQUIRES TWO TO FOUR RESONANT MODES AND ALGORITHM
  - FULL AND EMPTY,
    ANY ATTITUDE, ANY G LEVEL: SPECIAL CASE REQUIRES ONE RESONANT MODE

# APPROACHES FOR RESOLVING THE MICROGRAVITY NONUNIFORM DISTRIBUTION CASE

PREVIOUSLY INVESTIGATED APPROACHES

- BENDIX CORPORATION - MODE COUNTING
- NATIONAL BUREAU OF STANDARDS - MODAL ANALYSIS

SELECTED APPROACH

- SWEEP AND STORE ALL RESPONSE FREQUENCIES IN RANGE OF LOWEST FOUR MODES
- SORT RESPONSE POPULATION INTO GROUPS ASSOCIATED WITH EACH MODE
- DETERMINE A MODE FREQUENCY FOR EACH GROUP
- USE MODE FREQUENCIES TO CLASSIFY RESPONSE AND COMPUTE UNCORRECTED MASS
- USE RESPONSE CLASSIFICATION TO COMPUTE CORRECTION
- ADD CORRECTION TO UNCORRECTED MASS TO OBTAIN MEASURED MASS

# CRYOGENIC FEASIBILITY TESTING OF THE RF MODAL GAGING APPROACH

- OBJECTIVES: OBTAIN EXPERIMENTAL ASSESSMENT OF:
  - PROBABLE ACCURACY, REPEATABILITY, AND HYSTERESIS
  - SENSITIVITY TO VARIATIONS IN FLUID LOCATION AND INTERNAL COMPONENTS
- HARDWARE:
  - LABORATORY EQUIPMENT IMPLEMENTATION OF RF MODAL GAGING SYSTEM
  - ROTATABLE CRYOGENIC TANK IN A VACUUM CHAMBER
- METHOD:
  - $LN_2$, $LO_2$, AND $LH_2$ TEST FLUIDS, BARE TANK, 4 FILL LEVELS, 9 TANK ATTITUDES
  - $LN_2$ TEST FLUID, 2 COMPONENT CONFIGURATIONS, 4 FILL LEVELS, 9 TANK ATTITUDES

# CRYOGENIC FEASIBILITY TESTING OF THE RF MODAL GAGING APPROACH (Concluded)

## RESULTS - ACCURACY FEASIBILITY CUTOFF ±5 PERCENT

| TEST FLUID | TANK CONFIGURATION | PROBABLE ACCURACY* (% OF FULL LOAD) | REPEATABILITY (%) | LOCATION SENSITIVITY (%) | COMPONENT SENSITIVITY |
|---|---|---|---|---|---|
| $LN_2$ | BARE | ±1.05 | 0.024 | ±6.78 | N/A |
| $LO_2$ | BARE | ±1.61 | 0.059 | ±8.32 | N/A |
| $LH_2$ | BARE | ±0.92 | 0.036 | ±10.31 | N/A |
| $LN_2$ | PHASE 1 | ±2.61 | 0.078 | ±6.21 | ±1.56% |
| $LN_2$ | PHASE 2 | ±3.65 | 0.131 | ±7.69 | ±2.60% |

*CORRECTED FOR FLUID LOCATION

# BENCH-TOP TESTING OF THE RF MODAL GAGING SYSTEM

- OBJECTIVE:
  - CHALLENGE RF MODAL GAGING APPROACH WITH MICROGRAVITY TYPES OF LIQUID DISTRIBUTIONS
- HARDWARE:
  - LABORATORY EQUIPMENT IMPLEMENTATION OF RF MODAL GAGING SYSTEM
  - BENCH-TOP TEST TANK
- METHOD:
  - USE PARAFFIN TO SIMULATE LIQUID
  - SAME MASS IN UP TO FOUR DIFFERENT LIQUID ORIENTATIONS
  - 31 ALGORITHM DEVELOPMENT TEST LIQUID ORIENTATIONS
  - 5 RANDOM REFEREE TEST LIQUID ORIENTATIONS

# BENCH-TOP TESTING OF THE RF MODAL GAGING SYSTEM (Concluded)

| ALGORITHM TYPE | LIQUID ORIENTATIONS | ACCURACY (AVG) PERFORMANCE (% OF FULL LOAD) |
|---|---|---|
| MASS ONLY | 31 DEVELOPMENT | ±0.28 |
| MASS ONLY | 5 RANDOM | ±0.90 |
| INTEGRATED | 31 DEVELOPMENT | ±1.42 |
| INTEGRATED | 5 RANDOM | ±1.52 |

# CONCLUSIONS

- IN ALL FEASIBILITY CHALLENGES, THE RF MODAL GAGING APPROACH WAS ABLE TO EASILY MEET THE ±5 PERCENT OF FULL LOAD CRITERIA AND CAME VERY CLOSE TO THE ULTIMATE ±1 PERCENT ACCURACY GOAL.

- CURRENT TECHNOLOGY IS SUFFICIENT TO REDUCE THE APPROACH TO SPECIFIC APPLICATION HARDWARE.

- THE APPROACH HAS SOME VERY ATTRACTIVE ADVANTAGES, SUCH AS:

  - LOW-WEIGHT SYSTEM, AND WEIGHT DOES NOT SIGNIFICANTLY VARY WITH TANK SIZE
  - MINIMAL INTRUSION INTO TANK
  - SMALL IMPACT ON PV STRUCTURE AND MLI OF CRYOGENIC TANKS
  - OPERATING POWER IS LOW AND POWER INPUT TO FLUID IS NEGLIGIBLE
  - NOT AFFECTED BY SPECIES OF PRESSURANT GAS
  - NO MOVING PARTS
  - CONCEPT PARTICULARLY APPLICABLE TO PROPULSION CRYOGENS