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OARE OBJECTIVES

To design, develop and implement, on the Shuttle Orbiter, a sensitive triaxial accelerometer system which will:

- **Provide accurate measurement data of aerodynamic acceleration along the Orbiter's principal axes in the free molecular flow flight regime at orbital altitudes and in the transition regime during reentry.**
- **Accurately measure low-frequency (1 to 10^{-6} Hz), nanogravity on-orbit acceleration perturbations due to structural vibration noise produced by on-board crew activities, thruster jet firings, cabin atmospheric leaks, and water/waste dumps.**
- **Measure momentum transfer effects such as gravity gradient, in-plane and out of plane motion, APU exhaust and other venting forces giving rise to a residual acceleration component.**

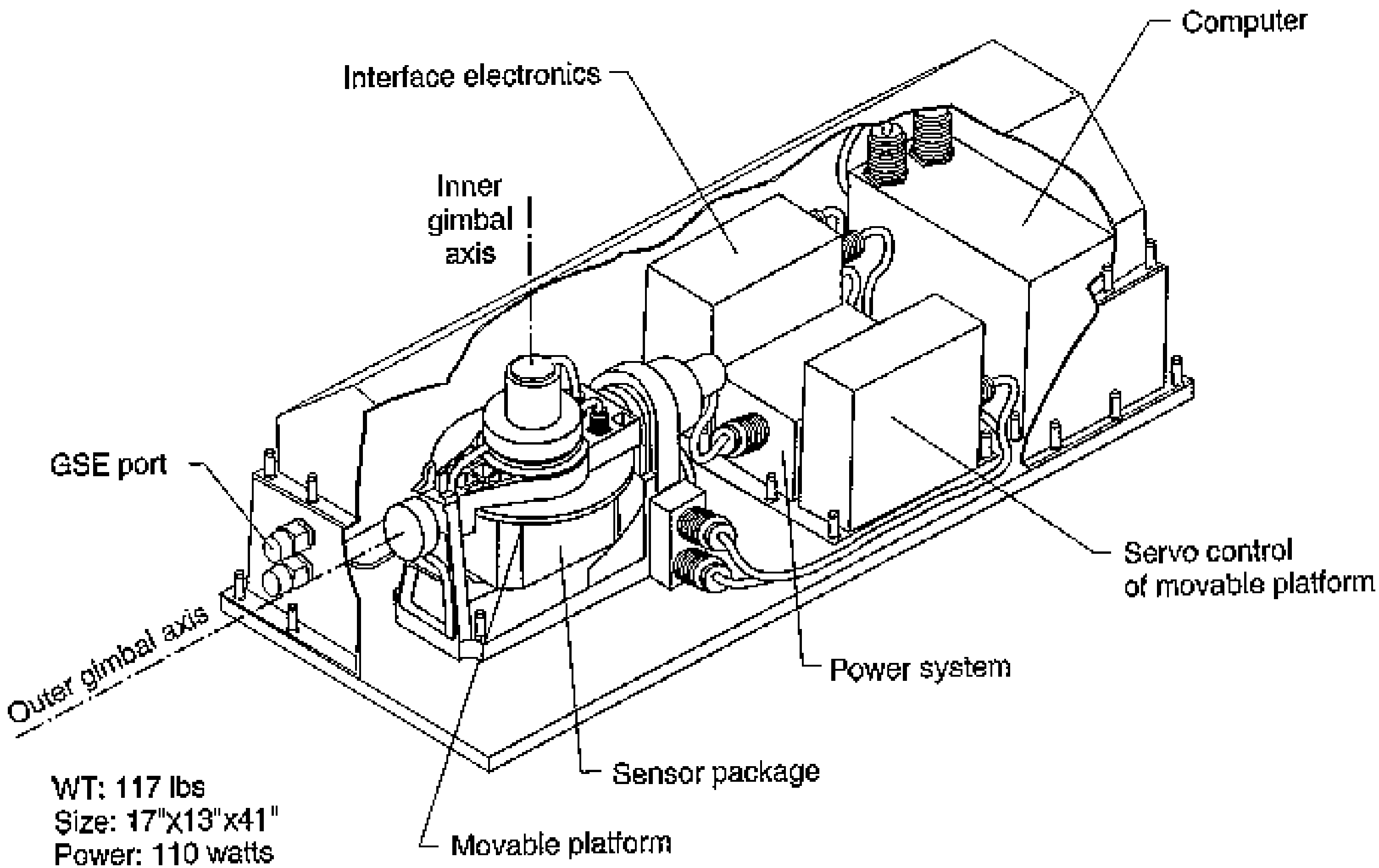
Orbital Acceleration Research Experiment Requirements

- Provide Space Shuttle on-orbit linear acceleration measurement in the low frequency spectrum
- Developed to measure on-orbit atmospheric drag (100's of nano-g's) and reentry drag
- Measures nano-g level low frequency signals (below 1 Hz) in noisy vibration environment
- Requires high accuracy and good sensor drift and linearity characteristics to separate components in the measured residual acceleration vector
- Currently utilized to characterize Microgravity Science Applications requirements for
  - Directional solidification crystal growth
  - Semi conductor crystal growth
  - Protein crystal growth
  - Fluids transfer, surface and mixing properties
  - Microgravity combustion physics

OARE Principal Requirements

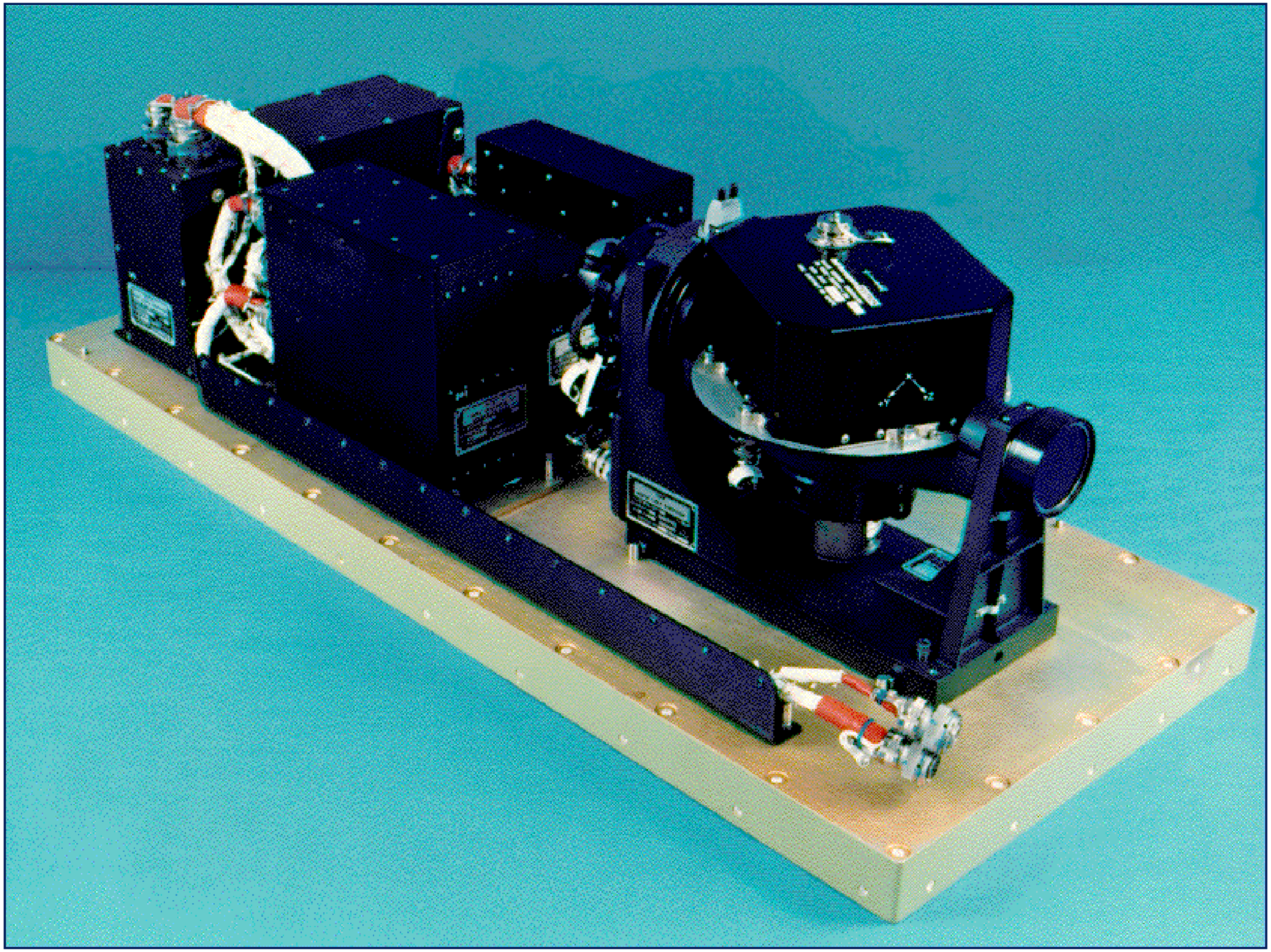
- **Dynamic Range:**
  - **X axis: 3.1 nano-g to 10,000 micro-g**
  - **Y & Z axes: 4.6 nano-g to 25,000 micro-g**
- **Bandwidth: DC to 1 Hz where "DC" is at least as low as 10^{-5} Hz**
- **Accuracy: 20 nano-g on C range**
- **Linearity: 0.1%**
- **On-Orbit calibration for temperature/drift compensation**
- **High disturbance rejection, primarily just above the bandpass**
- **Data sampling at 10 sps**
- **Data storage: 4 Mbyte on instrument; unlimited at 32Kbps on external tape recorder**

Sketch of the OARE System



WT: 117 lbs
Size: 17"X13"x41"
Power: 110 watts

OARE Flight Assembly



Miniature ElectroStatic Accelerometer (MESA)

Software Processing and Filtering

Normal Data Collection:

- 10 sps collection and transmittal to Spacelab HRM and PTR
- Internal trimmed mean filtering and storage every 25 sec.
- Temperature of OSS and OIS to high resolution
- Sensor automatic range control

Bias Calibration: table and sensor control

- Critical sequence timing
- Trimmed mean filter data storage

Scale Factor Calibration: table and sensor control

- Critical sequence timing
- Raw data storage

Mode and Logic Control:

- launch
- recapture
- normal
- quiet (cmd)
- reentry (cmd)
- shutdown

Sensor Calibration Approach

- System Bias calibrations provide measurement of actual sensor drift due to temperature, electronics, etc.
- During data measurement the sensor output consists of signal plus bias drift
- Actual bias data utilized to construct bias model as a function of time, temperature level, temperature gradients and environmental noise
- Over mission time, statistical models provide good estimates of bias history
- Scale factor calibrations performed by utilizing different slew rates (ω) to produce a calibrated acceleration signal ($\omega^2 r$)
- Velocity servo controls the commanded slew rate of 0.1% accuracy
- OARE System provides high flexibility of interactive calibration control via use of adaptation parameters (frequency, duration, type, delays, rate level, etc.)

GENERAL BIAS CONSIDERATIONS

- Measured quasi-steady acceleration (A) at each sampling period is derived by the instrument model where

  SF_C = calibrated scale factor multiplier
  SF_N = nominal scale factor
  CTS = measured number of digital counts and
  BIAS = Computed number of sensor bias counts

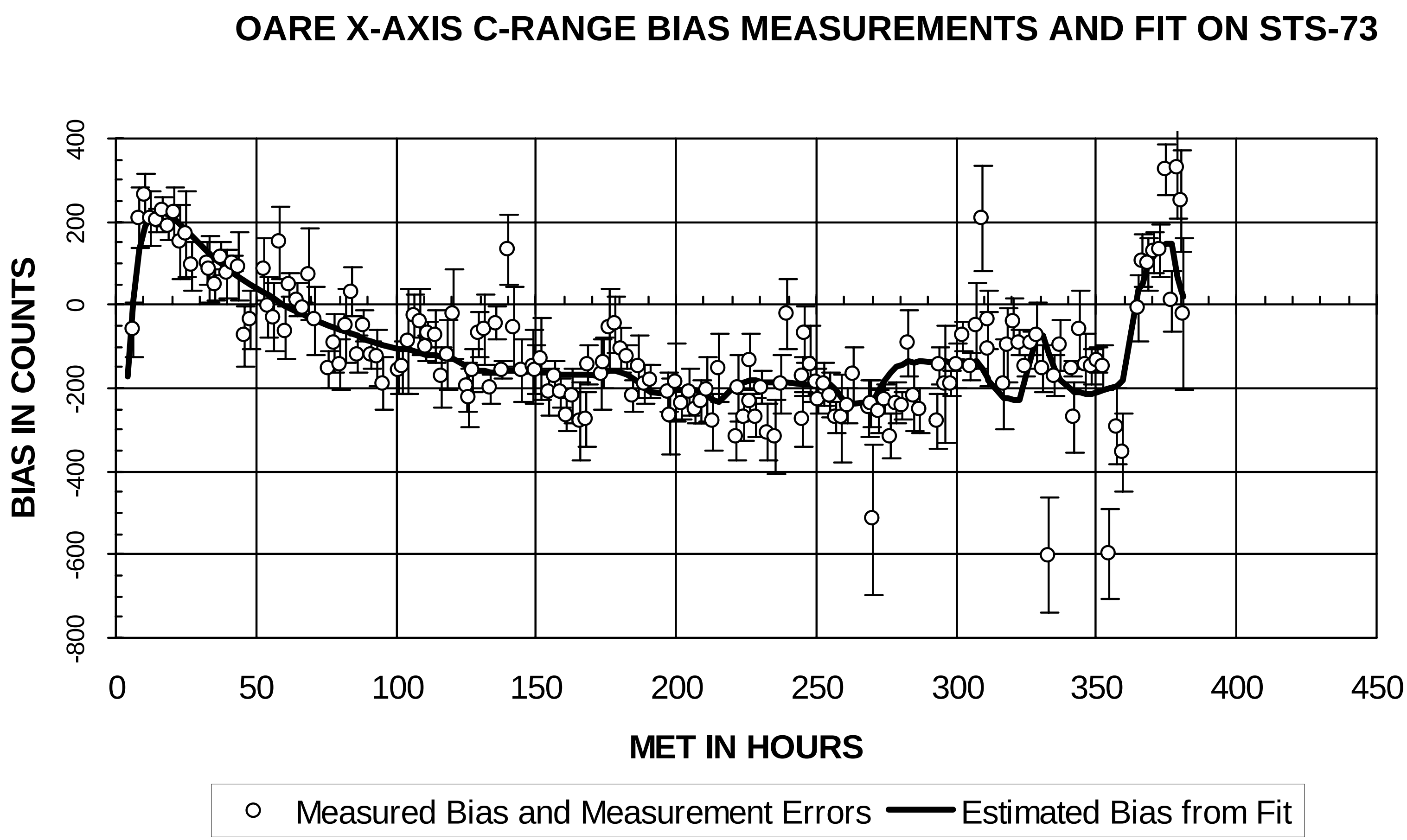
$$A = -SF_C * SF_N (CTS - 32768 - BIAS)$$

- At low acceleration levels, the bias is the major source of error in acceleration measurements.
- OARE measures or estimates the instrument bias by taking trimmean measurements with the accelerometer at normal orientation (1) and at inverted orientation (2) at a time separation of about 85 seconds apart.
- If the input acceleration remains constant, then the bias measurement is the true instrument bias; If the acceleration changes, then these changes in acceleration generate a bias measurement error.

$$BIAS_M = (CTS_1 + CTS_2)/2 - 32768 + (A_1 + A_2)/(SF_C * SF_N), \text{ Where}$$

$$A_2 = -A_1 \text{ if Input Acceleration Remains Constant.}$$

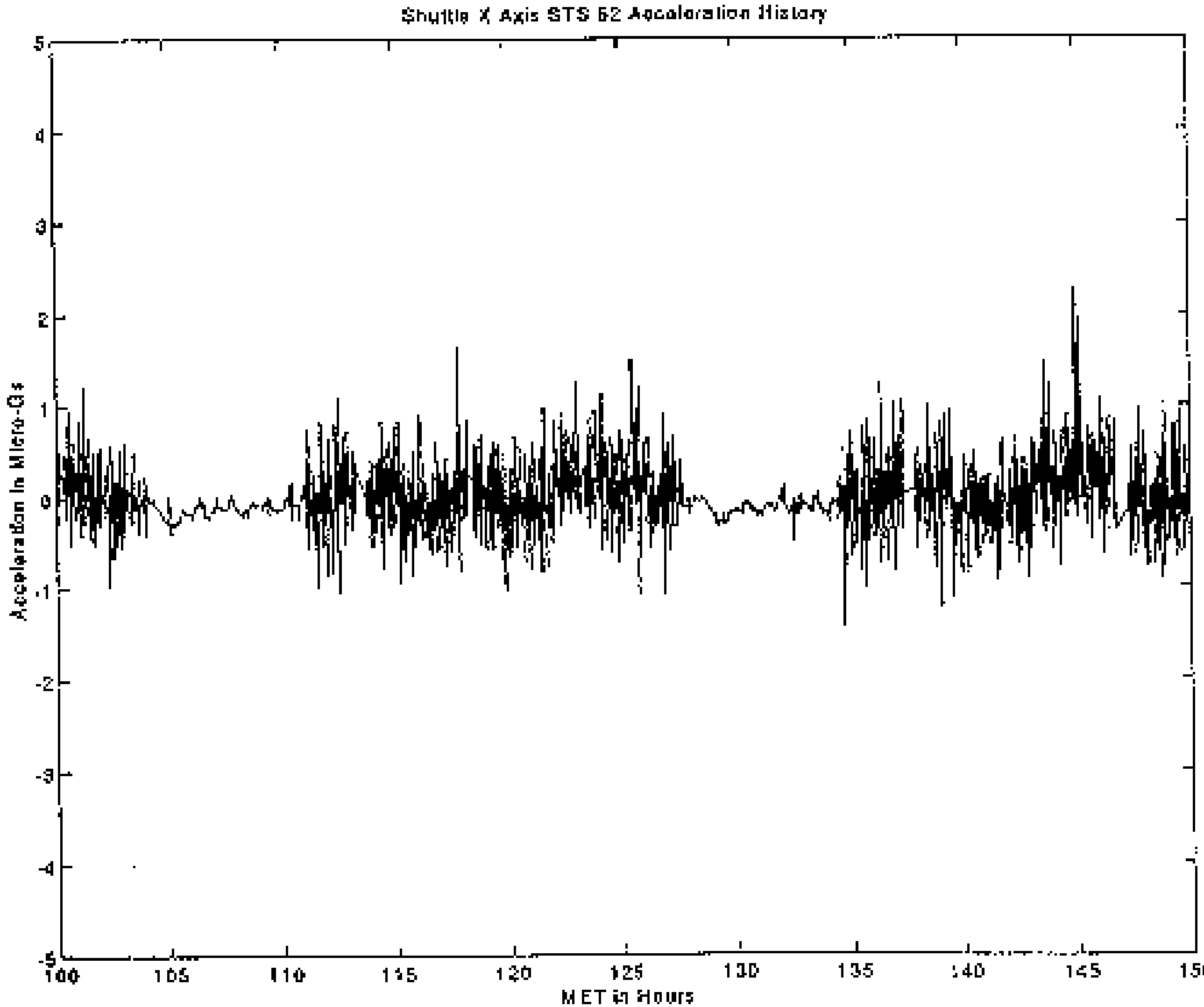
OARE X-AXIS BIAS FITS ON STS-73, NDOF =157 Chi-Sq =242, StDev of fit = 74.6 Counts



Summary of Scale Factor Calibrations

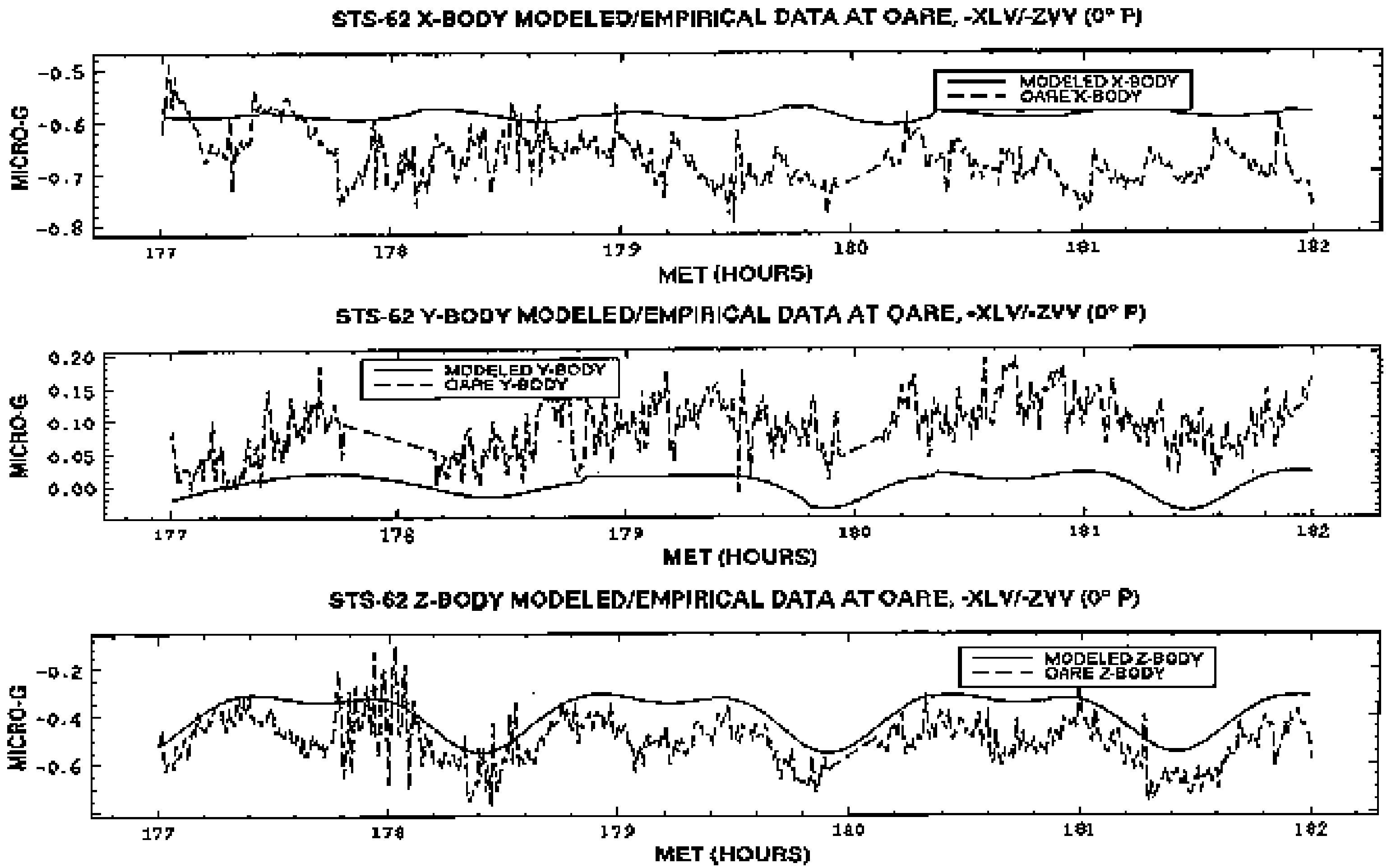
- **Earlier approximate 12% differences between ground and on-orbit calibrations are explained by extra ground test capacitance.**
- **Ground calibrations have been repeatable to 1% over 3 years.**
- **Ground and on-orbit calibrations now agree to within about 2% at ambient**
- **At 1 µG, this yields an error of about 20 nG.**
- **An on-orbit scale factor calibration may not be required if accuracy requirements are about 50 nG or 2% of reading, whichever is greater.**

Shuttle X Axis STS 62 Acceleration History



STS-62 Body Modeled/Empirical Data at OARE

Acceleration Model Reference: Microgravity Environment for AADSF, B. Matisak, MGMG#13, Sept. 1994



Estimated Statistical Bias Errors on STS 62 and STS 65

OARE Axis and Range	STS 65 Error (nano-g)	STS 62 Error (nano-g)
X-C	48	14
Y-C	24	15
Z-C	14	15

Estimated Systematic Bias Errors on STS 65 are 20 nano-gs.
Estimated Scale Factor and Linearity Errors are 1 - 2 % of reading.
(10 - 20 nano-gs at 1 micro-g)

Overall Estimated Accuracy on OARE Measurements at One Micro-g Acceleration

OARE Axis and Range	STS 65 Error (nano-g)	STS 62 Error (nano-g)
X-C	50-60	30-40
Y-C	35-45	30-40
Z-C	30-40	30-40

"Smart" Sensor Control

Over 70 adaptation parameters can be selected for optimal OARE performance on a per-mission basis:

- Ranging: used to control down-ranging and up-ranging for each sensor axis independently
- Calibration: setting the maximum time intervals between calibrations in the various modes
- Engineering Data: sets the interval for collection of voltage and temperature data
- Trimmed Mean Filter: assigns control parameters to the digital filter and determines the input data sample size to be filtered per mode/activity
- Positioning: positions the inner and outer RTA gimbals for standard data collection and for reentry data collection
- Background: determines sample size and period to collection stored background acceleration data (sampled raw data)
- Reenter: reserves EEPROM memory block for reentry data
- Quiet: sets an Activity-Inhibit time span of quiet mode and modifies calibration sequence

OARE Mission Data Files

Input:

Adaptation Data - controls operation of Flight Data collection per mission objectives.

Output:

Control[t] - Logs key values required to continue after power interruptions

SCIENCE

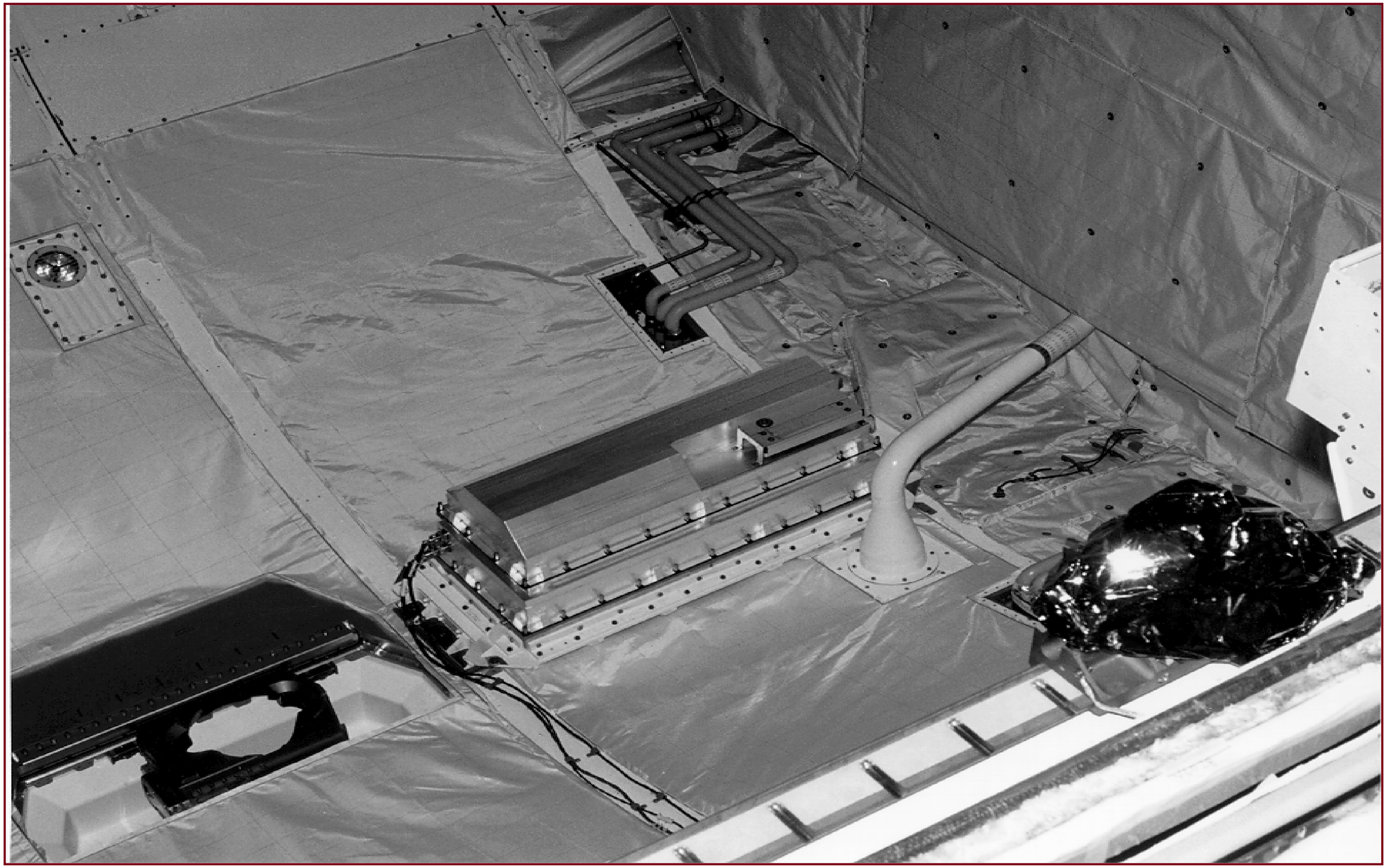
Normal X,Y, & Z	-	Logs results of Trim Mean Filter (TMF) processing. Includes Bias data and low-resolution instrument temperature.
Processed SF	-	Logs results of TMF processing of Scale Factor calibrations. (May not exist if Adaptation directs raw output.)
Raw SF	-	Records raw Scale Factor data. (May not exist if Adaptation file directs Processed SF output.)
Raw	-	Background raw data snapshots. Includes high resolution Instrument temperature. (Same format as telemetry.)
Reenter	-	Raw data throughout Reentry phase in separate file.

ENG

Temperature	-	Instrument and other subassembly temperatures; low resolution.
Status Log	-	Logs key state changes and table movement events.
Error Log[t]	-	Logs detected errors.
Miscellaneous	-	Logs subsystem voltages, currents, and temperatures.

[t] = Text files, all others are binary.

OARE Installed on Columbia Cargo Bay Deck



OARE FLIGHTS

PREVIOUS OARE FLIGHTS

1.	STS-40	SLS-1	June 91	Aerodynamic Research
2.	STS-50	USML-1	June 92	Aerodynamic Research
3.	STS-58	SLS-2	Oct. 93	Aerodynamic Research
4.	STS-62	USMP-2	March 94	Microgravity Sciences
5.	STS-65	IML-2	July 94	Microgravity Sciences
6.	STS-73	USML-2	Oct. 95	Microgravity Sciences(NRT Data via HRM)
7.	STS-75	USMP-3	Feb. 96	Microgravity Sciences (Lost Tether)
8.	STS-78	LMS-1	June 96	Life/Microgravity Sciences
9.	STS-83	MSL-1	April 97	Life/Microgravity Sciences
10.	STS94	MSL-1R	July 97	Life/Microgravity Sciences
11.	STS87	USMP-4	Nov 97	Life/Microgravity Sciences

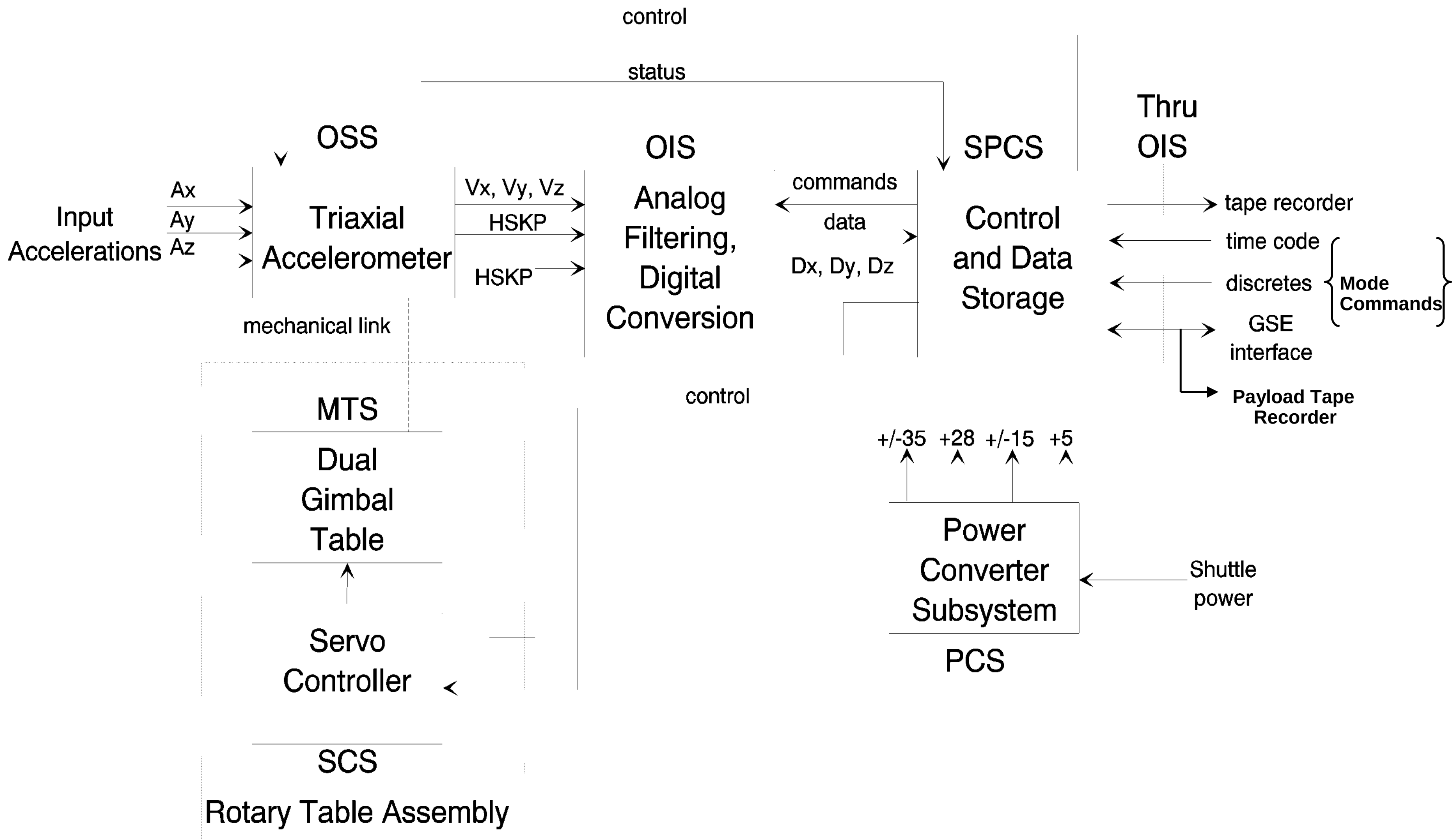
PLANNED OARE FLIGHTS

12.	STS107	Research	July 01	Life/Microgravity Sciences

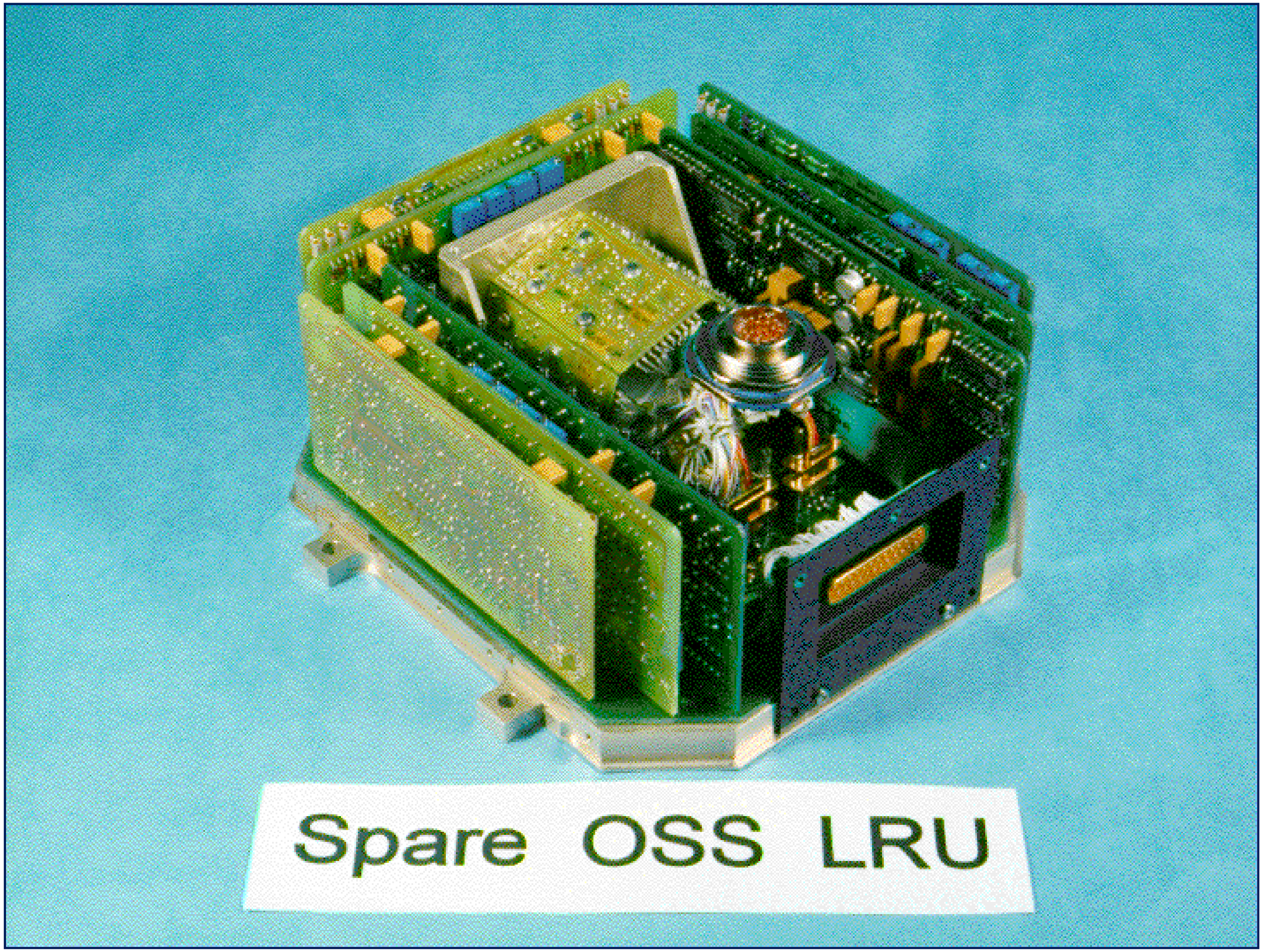
OARE PRESENTATION APPENDIX

1. OARE Functional Block Diagram
2. Spare OARE Sensor Subsystem Line Replaceable Unit
3. OARE Sensor/Table Assembly
4. Rotary Table Assembly Characteristics
5. Comparison of OARE X-Axis Scale Factor Calibrations
6. OARE Software Overview

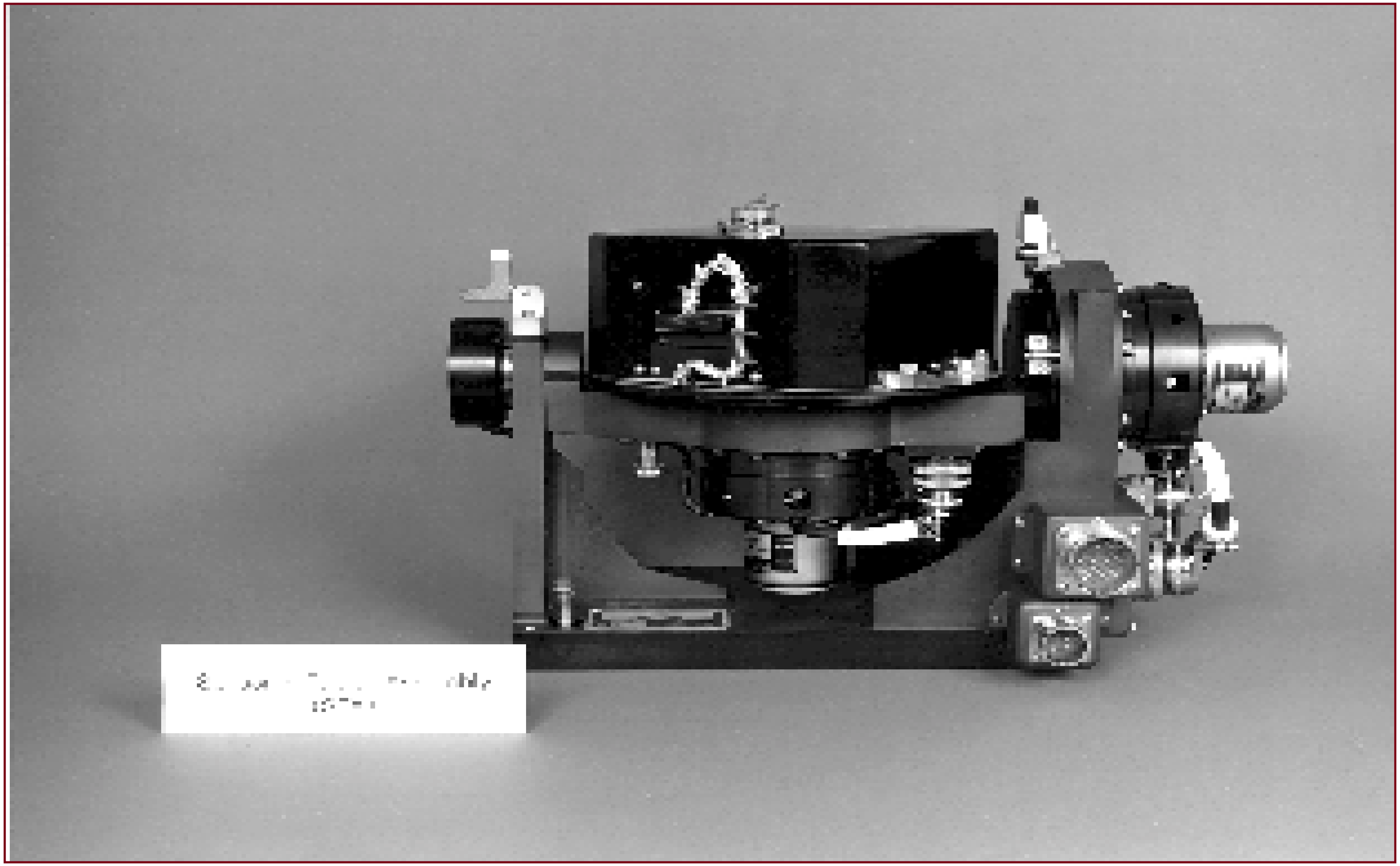
OARE Functional Block Diagram



Spare OSS LRU



OARE Sensor/Table Assembly



Rotary Table Assembly Characteristics

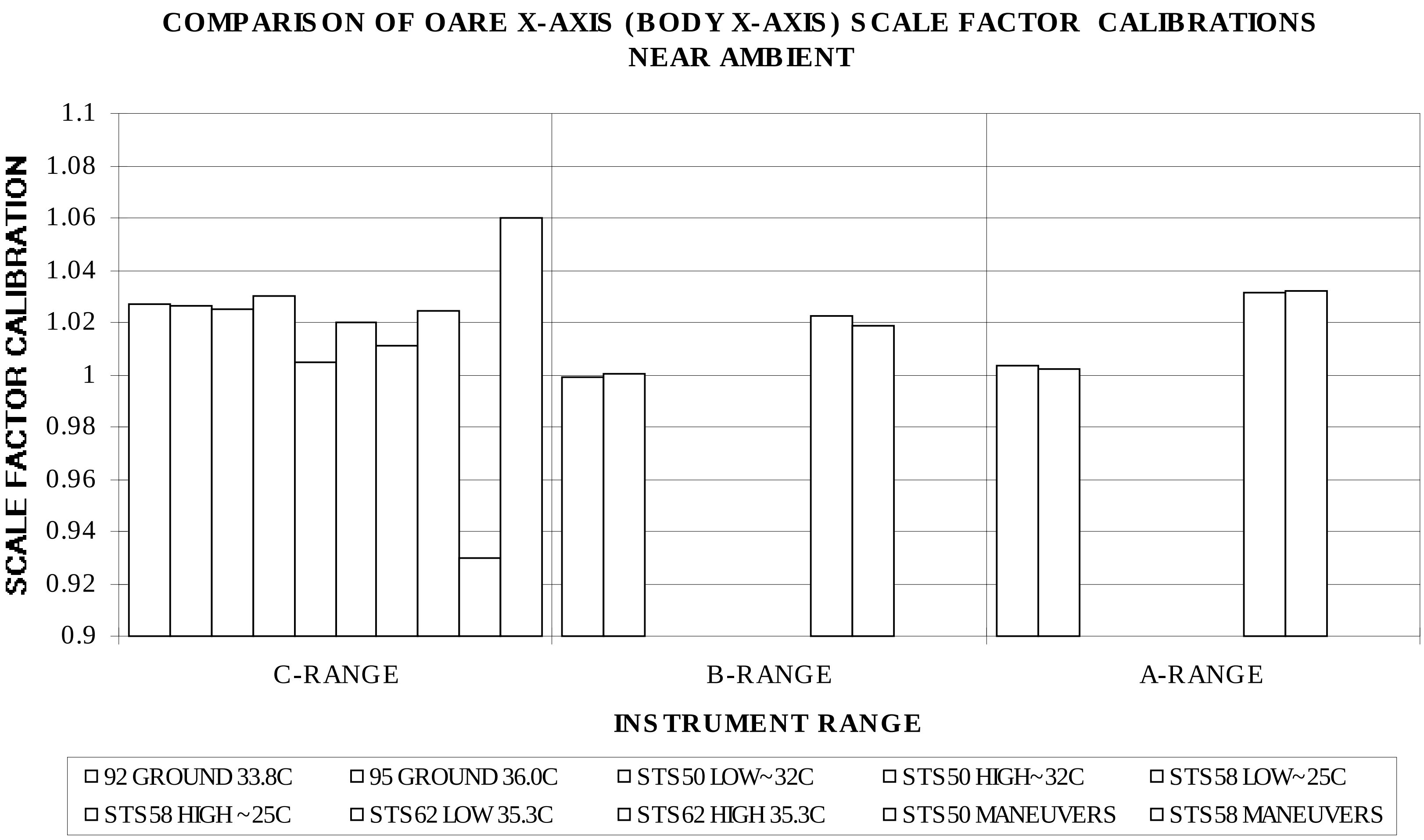
Design

- Brushless d.c. servomotor drives each of two gimbals
- 16 bit position encoder for bias calibrations
- 10 controlled rate slews for scale factor cals
- Computer controlled servo loop and reference ramp generator

Key Performance Requirements:

- Reposition and hold table within 30 arc seconds
- Slew between two positions with rate stability within 0.1%
- +/- 350 degrees of travel, two axes
- Acceleration/deceleration within 150 msec.
- Meet all requirements with 10 rates from 0.0970 to 2.0 rad/sec.

COMPARISON OF OARE X-AXIS SCALE FACTOR CALIBRATIONS NEAR AMBIENT



OARE Software Overview

Flight System	Ground Support	Simulation	Analysis Support
System Software 👍BIOS - Custom I/O 👍ROM Drive - DOS3 + utilities ---------------------------- ☞Flight Data Collection 👍Ground Alignment Test 👍Diagnostics 👍RTA/OSS Performance 👍Level Table - Test Support * RTA Test	👍Ground Support Program - Adaptation file prep. - Flight System Test - Terminal Emulation - Flight S/W Instal - File Transfer - Quick-Look Review/Print * Adaptation File Print	👍RTA/OSS Simulator supports development and accept. testing of Flight S/W. * History File Formatter	Binary to text conversion for: * Normal Data * Bias Data (subset of Normal) * Raw SF Data * Special Raw SF * Raw Data (also Reenter & Ground Alignment) * Temperature * Miscellaneous

Key

☞ Major S/W item - formal specs & revisions control

👍 Critical Support S/W item - some specs, revisions control

* Support S/W - source code revision documentation