## Guidance and Control Sensors GNC Systems

**SENSORS 2102** 



# Mission Operations Directorate Space Flight Training Division

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# Guidance and Control Sensors GNC Systems SENSORS 2102

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## Foreword

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A Training Materials Evaluation is included at the end of this document. Inputs on this sheet will be used to evaluate the lesson material. You do not need to sign the sheet.

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# **Section 1: Introduction**

## **Performance Objectives**

As a result of studying this section, you should be prepared to

- Describe the purpose of the four accelerometer assemblies (AAs) during ascent and entry
- Describe the purpose of the four orbiter rate gyro assemblies (RGAs) during both ascent and entry
- Describe the purpose of the two RGAs on each solid rocket booster (SRB) during first-stage ascent

## Sensors

Sensors mounted on the body of the orbiter are critical to flight control during ascent and entry. See figure 1-1.

Acceleration readings and rotation rates are critical to Flight Control as feedback to augment orbiter stability.



Figure 1-1.– Forward AAs.

Four AAs located in the two forward avionics bays measure lateral (along the Y-axis) and normal (along the Z-axis) accelerations of the orbiter. The lateral acceleration readings enable flight control software to null side forces during both ascent and entry. The normal acceleration readings are used to relieve the load on the wings during first-stage ascent. During entry, the normal acceleration measurements cue guidance software when it is time to incorporate ranging. During the latter stages of entry, the normal acceleration measurements provide feedback for guidance to control the pitch commands.

Four RGAs located on the aft bulkhead below the floor of the payload bay (figure 1-2) sense rates of roll (about the X-axis), pitch (about the Y-axis), and yaw (about the Z-axis). These rates are used by Flight Control to augment stability during both ascent and entry. They provide feedback on the vehicle's response to commands, particularly in entry turn coordination. During entry, rates from these RGAs are converted to stability axis rates and displayed on the attitude direction indicator (ADI).



Figure 1-2.- Aft bulkhead RGAs.

There are also two RGAs mounted on each SRB which sense rates of *pitch and yaw* (*but not roll*) during the first stage of ascent (figure 1-3). Because the SRBs are more rigid than the orbiter body, these rates are less vulnerable to errors created by structural bending and, thus, they are particularly useful in thrust vector control.

Because the data from the RGAs are processed 25 times faster than the data from the gyros in the inertial measurement units (IMUs), these rates are integrated by the attitude processor to help propagate the shuttle's attitude during ascent and entry. The data from the SRB RGAs are preferred during first-stage powered flight.



Figure 1-3.– SRB RGAs.

The functions of the AAs and RGAs are different from the functions of the accelerometers and gyros that make up the IMUs. The orbiter AAs and RGAs sense accelerations and rates about the vehicle reference axes and are used primarily by the flight control system (FCS) in ascent and entry. In contrast, the accelerometers within the IMUs measure accelerations used in Navigation to calculate state vector changes. The gyros within the IMUs measure attitude changes for the flight control system. The four AAs, four orbiter RGAs, and two RGAs on each SRB afford failoperational redundancy.

Because they are so critical to flight control, redundant sensor assemblies are provided. The two RGAs on each SRB work in conjunction with the opposing set to afford fail-operational redundancy during first-stage powered ascent. The four orbiter-mounted RGAs and the four AAs afford fail-operational redundancy during both ascent and entry. In each of these cases, the data used are chosen by an interchangeable midvalue selection (IMVS) scheme, described in section 5 of this training manual.

The crew conducts an on-orbit checkout of the orbiter-mounted RGAs and AAs during FCS checkout to ensure their effectiveness during entry. These self-test procedures are described at the end of sections 2 and 3. Although the crew exercises no control over the SRB-mounted RGAs, these RGAs are checked out on the ground to ensure their effectiveness during ascent.

## Questions

- 1. How are normal acceleration measurements used during ascent?
- 2. During entry, rates from orbiter RGAs are converted to \_\_\_\_\_\_

\_\_\_\_\_ for display on the attitude indicator.

3. Pitch rates and yaw rates from SRB RGAs are particularly useful in thrust vector

control because \_\_\_\_\_\_.

ŧ

### Answers

- 1. They are used to calculate the need for load relief in first stage.
- 2. During entry, rates from orbiter RGAs are converted to stability axis rates.
- 3. These rates are less vulnerable to errors created by structural bending.

# **Section 2: Accelerometer Assemblies**

### **Performance Objectives**

As a result of studying this section, you should be prepared to

- Describe the location and the operating principles of the AAs
- Identify the power source(s) of each AA
- Identify data flow paths to and from each AA
- Describe data processing performed on AA measurements
- Perform the AA portion of the FCS checkout

### **AA** Location

The four AAs are located in the forward avionics bays (figures 2-1 and 2-2) because the environment there is favorable in terms of both vibration (there is less vibration forward than aft) and temperature (coldplates are not needed because environmental control system fans cool these bays).



Figure 2-1.- Top view of AAs in forward avionics bays.

Each AA contains two identical single-axis accelerometers positioned so that one senses lateral acceleration (along the orbiter Y-axis) and the other senses normal acceleration (along the orbiter Z-axis). Since the system consists of four assemblies, each containing these two accelerometers, it provides quadruple redundancy in each of these axes.



Figure 2-2.- Side view of AAs in forward avionics bays.

### **How an Accelerometer Works**

Each of the eight single-axis accelerometers in the system works the same way. Figure 2-3 shows a conceptual diagram. A pendulum is suspended in a permanent field between two magnets. A lamp directs a beam through an opening in the upper magnet. When the pendulum is in its null position, it splits the light evenly between the two photodiode pickoffs located on the lower magnet. When the force of an acceleration deflects the pendulum, the two photodiode pickoffs detect a difference in the intensity of the incident light, setting up a differential voltage output to the amplifier.

The polarity of the differential voltage depends on the direction in which the pendulum has moved (which is opposite to the direction of acceleration). The amplifier sends an analog output signal which is proportional to the sensed linear acceleration. It also sends a feedback signal to rebalance the pendulum at an offset position representing the measured acceleration. The maximum output for a lateral accelerometer is  $\pm$  one g, and that for a normal accelerometer is  $\pm$  4g.



Figure 2-3. – Accelerometer conceptual diagram.

#### Power

AAs are turned off on orbit to prolong the life of the assembly. The AAs require relatively little power (about 2 watts each). Power sources for AAs are shown in figure 2-4. This figure, and those similar figures later in the manual, show only the major bus supplying power to each line replaceable unit (LRU). Most LRUs draw power from a sub-bus. See drawing 9.8 in the Space Shuttle Systems Handbook for the applicable sub-busses for each LRU. Power to the AAs is controlled by:

| AA1 | Circuit breaker | Panel O14 |
|-----|-----------------|-----------|
| AA2 | Circuit breaker | Panel O15 |
| AA3 | Switch          | Panel O16 |
| AA4 | Switch          | Panel O15 |

Although circuit breakers provide only single-bus power to AAs 1 and 2, twocontact switches control redundant power to AAs 3 and 4 and thus prevent the loss of more than one AA with the loss of a main power bus.



Figure 2-4.– Power sources for AAs.

## **Data Processing**

The four AAs send their acceleration readings to the flight-critical forward (FF) multiplexer/demultiplexers (MDMs) and receive self-test commands from the same MDMs (figure 2-5).

From the MDMs, the acceleration outputs flow to the general purpose computers (GPCs) through flight-critical data buses. Data request commands flow from the GPCs to the MDMs through the same flight-critical data buses.



Figure 2-5.– Data exchange flow between AAs and GPCs.

In the GPC, the acceleration outputs are first operated on by the AA subsystem operating program (SOP). The SOP converts the measured signal (input in volts) to units of g and adds a bias term to produce a compensated acceleration signal. The equation is

Compensated signal = measured signal  $\cdot$  scale factor + bias

$$[g] = [V] \cdot \begin{bmatrix} g \\ V \end{bmatrix} + [g]$$

The scale factor and bias values are I-loaded. The four compensated lateral acceleration signals and the four compensated normal acceleration signals are output to redundancy management (RM) where an operative signal (called the selected value) for each axis is chosen by the processes of fault detection, identification, and reconfiguration (FDIR) and selection filtering. Refer to figure 2-6 below while reading page 2-7.

| 3011/ /018   | GNC SYS SUMM 1   | 1 005/09:50:02<br>000/01:09:58                    |
|--|--|---|
| MANFFAILVLV<br>F1 OP<br>2 OP<br>3 OP<br>4 OP<br>5 OP | SURF   POS   MOM     L   OB   U11.1   57     IB   U11.1   48     R   IB   U10.1   45     OB   U10.1   55     AIL   L   1.0 | DPS 12345<br>GPC<br>MDM FF<br>FA                  |
| L1 OP<br>2 OP<br>3 OP<br>4 OP<br>5 OP<br>R1 OP       | RUD L 4.0<br>SPD BRK 65.0<br>BDY FLP 30.0  | <u>FCS_CH_1_2_3_4</u><br><u>NAV1_2_3_4</u><br>IMU |
| 3 OP<br>4 OP<br>5 OP                                 | RHC L<br>R<br>A<br>THC L<br>SBTC L   | RGA<br>TAC<br>MLS<br>ADTA                         |
| RM FAIL ACC  | R  |   |

4285. CRT, 3

Figure 2-6.- GNC System Summary 1.

#### PASS

In the primary avionics software system (PASS), AA failure during ascent or entry is announced to the crew by

- A down arrow on the GNC System Summary 1 display
- The illumination of the SM ALERT light on panel F7
- The fault message "RM FAIL ACC" on any active cathode-ray tube (CRT)

Although the RM scheme has been carefully set up to handle the most likely problems in the best possible way, crew interaction may be necessary in cases where the problem is disguised. The FCS checkout, which is performed on the day before deorbit, includes a self-test of the AAs. The crew will deselect any AA which fails the self-test. In OPS 1, 3, and 6, the crew can also deselect an AA if its output is compromised by data processing system (DPS) or electrical power system (EPS) failures. Toggling items 10, 11, 12, and 13 on SPEC 53 will deselect/reselect AAs 1 through 4 in OPS 1, 3, and 6, as needed. Figure 2-7 shows SPEC 53, CONTROLS display.

| XXXX/   | 053/  | CONTR   | OLS   | XX X                                    | 000/ HH: H   | 11 SS<br>11 SS |
|---|---|---|---|---|--|----------------|
| SEC AC<br>CHI<br>2<br>3<br>4<br>START<br>STOP | T CK<br>1X<br>2X<br>3X<br>4X<br>5X<br>6X      | POR<br>L OR 1 5<br>IB 2 5<br>R IB 3 5<br>OB 4 5<br>RUD 5 5<br>SPD BRK 6 5 | T STAT<br>2 3 4<br>5 5 5 5<br>5 5 5 5 | MDM<br>STRING<br>1<br>2<br>3<br>4<br>PL | PORT<br>G ASSIGN<br>PR1 SEC<br>22X 23X<br>24X 25X<br>26X 27X<br>26X 29X<br>30X 31X |                |
| NEG S<br>Ena                                  | T I H<br>7X                                   | 8 BYPASS<br>9 Reset   | ACT/CH<br>XX<br>XX  |   |  |                |
| LRU<br>1<br>2<br>3<br>4                       | AA<br>DES<br>10X S<br>11X S<br>12X S<br>13X S | RGA S<br>DES<br>14X S<br>15X S<br>16X S<br>17X S                          | SURF FD8K<br>DES<br>18X S<br>19X S<br>20X S<br>21X S                              |   | XXX FCS  | 32             |
|   |   |   |   |   |  | ( xx           |

Figure 2-7. – SPEC 53.

BFS

Data processing in the backup flight system (BFS) differs slightly from that done in the primary flight system. Acceleration inputs to the hardware interface program (HIP) are first subjected to selection filtering as shown in table 2-1. (The HIP is analogous to the SOP in the primary software.)

|                               | PASS  | BFS   |
|-------------------------------|---|---|
| Data source                   | AAs 1, 2, 3, and 4  | Same as PASS  |
| Redundancy<br>management      | Interchangeable midvalue selection of compensated signals                 | Interchangeable midvalue selection of measured signals                                    |
|                               | FDIR, terminates after<br>annunciating the first<br>failure/commfault     | No FDIR   |
|                               | Commfault indications from FCOS*  | Selection filter downmoded<br>only by crew item entries on<br>SPEC 51, "OVERRIDE" display |
| Compensation                  | Before selection  | After selection   |
| Changes by<br>Mission Control | Can alter compensation<br>equation to counteract bias of<br>individual AA | N/A   |

| Table 2-1.– | Data | processing | in | the | BFS. |
|-------------|------|------------|----|-----|------|
|-------------|------|------------|----|-----|------|

\* Flight computer operating system.

#### Accelerometer Assemblies

#### Self-Test Procedures

The procedures the crew uses to check out the accelerometer assemblies during OPS 8 are outlined in the accompanying flow chart. They are part of the FCS checkout in section 7 of the Orbit Operations Checklist (ORB OPS C/L).

To call up the sensor test display, type in "SPEC 40 PRO" on the keyboard. The acceleration signals in ft/sec<sup>2</sup> should appear under the Y (lateral) and Z (normal) and continue cycling until the sensor test is initiated. If any AA has been deselected by FDIR during ascent, an asterisk will appear by the respective item number.



To null vehicle rates, select Digital Autopilot mode A (DAP A), inertial attitude hold, vernier RCS jets, and discrete rate rotation mode on panel C3.





Figure 2-8.- OPS 8 checkout procedures.



Figure 2-8.– Continued.

To initiate the sensor selftest, type in "ITEM 13 EXEC." An asterisk will appear to the right of item 13. Note that this entry will initiate tests of all of the systems listed on the display; however, we will consider only the AA test. Initiation of the test will cause a torgue command to be sent from the GPC to the AAs. When the test is completed (about 10 sec later), the asterisk will disappear, and the test results (in ft/s<sup>2</sup>) will appear and remain static until the test terminates. An "M" will appear if a datum is missing. An up or a down arrow will appear to the right of a result if that result is above or below specified limit.

If a datum is missing or if a reading is above or below the limits of 16.1  $\pm$  1.7 ft/s for lateral accelerations and 64.4 ± 6.7 ft/s for normal accelerations, you should deselect that AA by item number execution. If an AA has been deselected by FDIR during ascent and the self-test results for that AA look good, you have the option of reselecting the AA by the same action (the item number execution has a toggle capability of deselection or reselection).

To terminate the sensor selftest, type "ITEM 14 EXEC." An asterisk will appear to the right of item 14. Sensed data will resume cycling.



Figure 2-8.– Concluded.

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## Questions

- 1. If main bus A failed, which AAs could still work? (Refer to power diagram.)
- 2. If the FF3 MDM and main bus B failed, which AAs would still provide good data? (Refer to power and data processing diagrams.)
- 3. If, after you have nulled the vehicle rates, confirmed them on the ADI, and moded to free drift, the cycling AA data on the sensor test display appear as shown here, what, if anything, should you do?

|      | DES | Y      | Z      |
|------|-----|--------|--------|
| AA 1 | 9   | + 00.1 | + 00.0 |
| 2    | 10  | -01.5  | -04.5  |
| 3    | 11  | -00.1  | + 00.0 |
| 4    | 12  | + 00.0 | + 00.3 |

- 4. According to this SENSOR TEST display, shown after self-test completion but before test termination,
  - a. Which AA has already been deselected?
  - b. What is wrong with the readings from AA2?
  - c. Should you deselect any other AA?

| 8001/040 | Y           |                             | SENSOR                                  | TEST                                   | 1 005/07:25:31                          |
|----------|-------------|-----------------------------|---|--|---|
| MLS      | 1<br>2<br>3 | DES<br>1<br>2<br>3          | STAT RNG<br>15.0<br>15.2<br>15.4        | AZ<br>-2.96<br>-3.01<br>-3.13          | EL 000/03+34+29<br>5.92<br>6.05<br>5.17 |
| TAC      | 123         | DES<br>4<br>5<br>6          | STAT RNG<br>0.2<br>0.5<br>0.4           | AZ<br>177.57<br>178.38<br>182.54       |   |
| RA       | 1<br>2      | DES<br>7<br>8               | STAT ALT<br>1100<br>900                 |  |   |
| **       | 1234        | DES<br>9<br>10•<br>11<br>12 | Y<br>+15.0<br>+11.8†<br>+12.2†<br>+15.6 | Z<br>+65.1<br>+39.6(<br>+60.0<br>+64.2 |   |
|          |             |                             | START 13                                | STOP 14                                |   |

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### Answers

- 1. AAs 2,3, and 4 could still work. AA1 is powered by main bus A and would be failed. AA3 is redundantly powered by main buses A and C, so it would still function.
- 2. The failure of FF3 would cause a loss of data from AA3, and the failure of main B would cause the loss of AA2. AAs 1 and 4 would still function.
- 3. You should deselect AA2. Both its lateral (Y) accelerometer and its normal (Z) accelerometer are biased beyond the 4  $\sigma$  tolerances (±0.5 ft/s<sup>2</sup> in Y and ±1.3 ft/s<sup>2</sup> in Z).
- 4. a. AA2. In the display below, the asterisk beside item 10 indicates that AA2 has been deselected.
  - b. They are below the specified limits. As the down arrows indicate, the lateral (Y) acceleration reading is <14.4 ft/s<sup>2</sup> and the normal (Z) acceleration reading is <57.7 ft/s<sup>2</sup>.
  - c. Yes. You should deselect AA3. As the down arrow indicates, its lateral acceleration reading is below the specified limit (14.4 ft/s<sup>2</sup>). Even though the normal acceleration reading from the same AA is acceptable, you should deselect this AA before terminating the sensor test.

| 8001/ | 040 | V           |                             | :    | SENSOR                                | TEST                                   | 1 005/07:25:31                |
|-------|-----|-------------|-----------------------------|------|---------------------------------------|--|-------------------------------|
| 7     | ٩.5 | 1<br>2<br>3 | DES<br>1<br>2<br>3          | STAT | RNG<br>15.0<br>15.2<br>15.4           | AZ<br>-2.96<br>-3.01<br>-3.13          | EL<br>5. 92<br>6. 05<br>5. 17 |
| ٦     | TAC | 1<br>2<br>3 | DES<br>4<br>5<br>6          | STAT | RNG<br>D. 2<br>C. 6<br>C. 4           | AZ<br>177.57<br>178.38<br>182.54       |                               |
| F     | RA  | 1<br>2      | DES<br>7<br>8               | STAT | ALT<br>1100<br>900                    |  |                               |
| J     | **  | 1234        | DES<br>9<br>10=<br>11<br>12 |      | Y<br>+15.0<br>+11.8<br>+12.2<br>+15.6 | 2<br>+65.1<br>+39.61<br>+60.0<br>+64.2 | )                             |
|       |     |             |                             | STAR | T 13                                  | STOP 14                                |                               |
|       |     |             |                             |      |                                       |  |                               |

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# Section 3: Orbiter Rate Gyro Assemblies

### **Performance Objectives**

As a result of studying this section, you should be able to

- Describe the location and the operating principles of the RGAs
- Identify the power source(s) of each RGA
- Identify data flow paths to and from each RGA
- Describe data processing performed on RGA measurements
- Perform the RGA portion of the FCS checkout

The four orbiter RGAs are located on the aft bulkhead below the floor of the payload bay to be near the center of gravity; the placement of the RGAs at this location makes them less subject to bending effects. Vibration in this location is extreme but acceptable. To counteract extremely high temperatures, the RGAs are mounted on Freon-loop coldplates (figure 3-1).



Figure 3-1.- Location of rate gyro on orbiter.

#### Each RGA contains three identical rate gyros, each with a single degree of free-

*dom.* They are oriented so that one senses roll rate (about the orbiter X-axis), another senses pitch rate (about the orbiter Y-axis), and the third senses yaw rate (about the orbiter Z-axis). Since the system consists of four RGAs, each containing three gyros, it provides quadruple redundancy in each axis.

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#### How a Rate Gyro Works

Each of the 12 rate gyros in the system works the same way. Refer to figure 3-2. The basic element of the gyro is the wheel, which is actually the rotor of an electric motor. The stator about which this wheel revolves synchronizes its spin rate to 24,000 rpm. The gyro wheel is mounted in a gimbal assembly which is allowed to rotate about the output axis (perpendicular to the spin axis). Because of the angular momentum of the spinning wheel, a rotation of the vehicle about the input axis (orthogonal to the other two) creates a torgue which results in a rotation about the output axis (gimbal precession). When the gimbal assembly moves, the signal generator sets up a voltage which is proportional to the rotation about the output axis and thus to the sensed vehicle rotation about the input axis. The generated voltage provides a rate signal and is also applied to a torgue generator, which counteracts gimbal precession and thus prevents excessive gimbal displacement. The torque generator will also torgue the gimbal assembly about the output axis in response to an external signal such as the self-test command. A spin motor run detector (SMRD) detects underspeed or overspeed of the motor and signals an error of  $\pm 2$  percent, thus serving as built-in test equipment (BITE). The maximum output for the roll rate gyros is  $\pm 40$  deg/sec, and that for the pitch and yaw rate gyros is  $\pm 20$  deg/sec.



(Example is positioned to sense yaw rates)

#### Figure 3-2.– Position and diagram of rate gyro.

### Power

In the interest of power conservation, *the RGAs* (which draw about 25 watts each when running, about 36 watts when spinning up) are turned off on orbit except during FCS checkout (OPS 8). Before proceeding to OPS 3 (entry), the crew must be sure that the RGAs are back on. Without them, the vehicle will spin out of control. The crew can turn the RGAs off and on by using switches on these panels:

- RGA 1 Panel O14 RGA 2 Panel O15
- RGA 3 Panel O16
- RGA 4 Panel O15

The dual switch contacts for RGAs 1 and 4 supply them with redundant power sources and thus prevent the loss of more than one RGA with the loss of a main power bus. See figure 3-3.



Figure 3-3.- Rate gyro power system.

### **Data Processing**

Each RGA is hardwired to a flight-critical aft MDM. From the MDMs, the rate outputs flow to the GPCs through flight-critical data buses. Data request commands flow from the GPCs to the MDMs through the same flight-critical data buses (figure 3-4).

In the GPC, the rate outputs are first operated on by the RGA SOP. The SOP converts the measured signal (input in volts) to units of degrees per second and adds a bias term to produce a compensated rate signal. The equation is as follows:

Compensated signal = measured signal  $\cdot$  scale factor + bias

[rate] = [V] ·  $\left[\frac{rate}{V}\right]$  + [rate]

The scale factor and bias values are I-loaded. The four compensated rate signals in each axis (roll, pitch, and yaw) are output to RM where the three operative signals (one in each axis) are chosen by the processes of FDIR and selection filtering. RM is described in section 5.

SMRD signals follow the same path as the rate signals through the MDMs to the GPCs (GPC 5 does not receive SMRD signals). The RGA SOP downlists the SMRD signals to Mission Control. SMRD indications also appear on the RGA/air data transducer assembly (ADTA)/RCS self-test display (OPS 8) if a gyro wheel is spinning at an off-nominal speed.

As of OI-22, SMRD signals are also used by the orbiter RGA RM scheme (see section 5 for details).


### **Rate Gyro Assembly Failure**

An RGA failure during ascent or entry is announced to the crew by a down arrow on the GNC Systems Summary 1 display (reference page 2-6), the illumination of the SM ALERT light on panel F7, and the fault message "RM FAIL RGA" on any active CRT. Although the RM scheme has been carefully set up to handle the most likely problems in the best possible way, the crew may need to interact with the ground to solve unusual problems. A self-test of the RGAs is done during the OPS 8 FCS checkout, and the crew can deselect an individual RGA during OPS 1, 3, and 6. Toggling items 14, 15, 16, and 17 on the Entry Controls display will deselect/ reselect RGAs 1 through 4 in OPS 1, 3, and 6, as needed. (Refer to SPEC 53, CONTROLS display, figure 3-5.)

| XXXX/053/   | CONTROLS   | XX X DOD/HH: MTH SS<br>DDD/HH: MTH SS  |
|---|--|--|
| SEC ACT CK<br>CHI 1X<br>2 2X<br>3 3X<br>4 4X<br>START 5X<br>STOP 6X<br>NEG STIM | PORT STAT<br>1 2 3 4<br>L OR 1 5 5 5 5<br>1B 2 5 5 5 5<br>R 1B 3 5 5 5 5<br>OB 4 5 5 5 5<br>RUD 5 5 5 5 5<br>SPD BRK 6 5 5 5 5<br>ACT/CH | MOM PORT<br>STRING ASSIGN<br>PRI SEC<br>1 22X 23X<br>2 24X 25X<br>3 26X 27X<br>4 28X 29X<br>PL 30X 31X |
| ENA 7X<br>LRU AA<br>DES<br>1 IOX S<br>2 IIX S<br>3 12X S                        | B BYPASS XX<br>9 RESET XX<br>RGA SURF FDBK<br>DES DES<br>14X S 18X S<br>15X S 19X S<br>15X S 19X S                                       | XXX FCS 32   |
| 4 13X S   | 10A 5 20A 5<br>17X 5 21X 5   | (  |

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Figure 3-5. – CONTROLS display (SPEC 53).

Processing of RGA data in the *BFS*, like that of AA data in the BFS, differs from the processing done in the primary flight system, as shown in table 3-1. The HIP first determines the selected value for each axis; it then applies the rate compensation equation to each of the three selected rates and outputs one compensated rotation rate for each axis, roll, pitch, and yaw. Because the compensation equation is applied to the selected rate in the BFS rather than to each of the measured rates as in the primary flight system, the equation cannot be used to correct a bias discovered during a flight in a particular RGA.

If two of the values considered by the BFS selection filter are bad, the BFS may be temporarily "no-go" (not usable). This call is made by Mission Control because the crew has no way to directly detect a second failure. However, they are aware of power, GPC, and MDM failures that might affect the RGA. Mission Control will direct the crew to deselect the problem RGA, downmoding the selection filter to again provide good selected rates to Flight Control.

|                               | PASS   | BFS   |
|-------------------------------|--|---|
| Data source                   | RGAs 1, 2, 3, and 4  | Same as PASS  |
| Redundancy<br>management      | Interchangeable midvalue<br>selection of compensated<br>signals            | Interchangeable midvalue selection of measured signals                                    |
|                               | FDIR, terminates after<br>annunciating the first failure/<br>commfault     | No FDIR   |
|                               | Commfault indications from<br>FCOS   | Selection filter downmoded<br>only by crew item entries on<br>SPEC 51, "OVERRIDE" display |
| Compensation                  | Before selection   | After selection   |
| Changes by<br>Mission Control | Can alter compensation<br>equation to counteract bias of<br>individual RGA | N/A   |

#### Table 3-1.– RGA data processing.

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## Self-Test Procedures

The procedures the crew uses to check out the rate gyro assemblies during OPS 8 are outlined in the accompanying flow chart.

To call up the RGA/ADTA/RCS display, type in "SPEC 41 PRO" on the keyboard. The rate signals should appear and continue cycling until the self-test is initiated. If an RGA has been deselected by FDIR during ascent, an asterisk will appear by the corresponding item number. If the wheel of any rate gyro is not spinning synchronously, an "SMRD" indication will appear in the STAT column next to the item number of the assembly containing the gyro in question.



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• To null vehicle rates, select orbital DAP A, inertial attitude hold, vernier RCS jets, and discrete rate rotation mode on panel C3.





Figure 3-6. – Self-test procedures.

- To verify that roll, pitch, and yaw rates are less than 0.1 deg/sec, look at the rate pointers on the attitude direction indicator.
- To place the vehicle in free drift, depress the FREE mode pushbutton on panel C3.

Scan the cycling data on the RGA/ ADTA/RCS display. You are looking for a bias beyond the 4 o tolerance depicted in the flow chart. If you find such a large bias, you should deselect that RGA now so that subsequent failures will not lead to the use of its biased readings. To deselect a biased assembly. enter the item number beside the RGA number (for example, to deselect RGA 3, type in "ITEM 3 EXEC"). Deselection of an RGA before self-test will not keep that particular RGA from being tested.

To initiate the high test, type in "ITEM 9 EXEC." An asterisk will appear to the right of item 9. Note that the RGA self-test consists of two parts - the high test and the low test. The test must be done in two parts simply because the rotation rates may be either positive (roll and yaw right, pitch up) or negative (roll and yaw left, pitch down). You may do either the high or the low test first, but the first test must be properly terminated before the second is initiated. Note also that the high test of the ADTA will also be initiated by keying in item 9. However, we will ignore the ADTA selftest in this discussion.



Figure 3-6. – Continued.

Initiation of the RGA high test will cause a positive torque command to be sent from the GPC to the RGAs. When the test is completed (about 10 seconds later), the asterisk will disappear and the test results will appear and remain static until you terminate the high test. An M will appear if a datum is missing. An up or a down arrow will appear to the right of a result if that result is above or below specified limits.

If a datum is missing or if a reading is above or below the limits of +20 $\pm 1.2$  deg/sec for roll rates and  $+10 \pm 0.6$  deg/sec for pitch and yaw rates, you should deselect that RGA by item number execution. If an RGA has been deselected by FDIR during ascent and the selftest results for that RGA look good, you have the option of reselecting the RGA by the same item entry (that is, the item number execution has a toggle capability of deselection or reselection).

| Orbiter RGA Self-Test Limits |              |             |  |  |  |  |  |
|------------------------------|--------------|-------------|--|--|--|--|--|
| "High"                       | ' test limit | ts, deg/sec |  |  |  |  |  |
| Roll                         | + 18.8       | + 21.2      |  |  |  |  |  |
| Pitch                        | + 9.4        | + 10.6      |  |  |  |  |  |
| Yaw                          | + 9.4        | + 10.6      |  |  |  |  |  |

To terminate the high test, type in "ITEM 11 EXEC." An asterisk will appear to the right of item 11. Sensed data will resume cycling.

To initiate the low test, type in "ITEM 10 EXEC." An asterisk will appear to the right of item 10. Initiation of the RGA low test will cause a negative torque command to be sent from the GPC to the RGAs. As in the high test, the results will appear in about 10 seconds for you to consider.



Figure 3-6. – Continued.

As in the high test, you will deselect an RGA with questionable data. In this case the limits are -20 $\pm$  1.2 deg/sec for roll rates and  $-10 \pm$ 0.6 deg/sec for pitch and yaw rates. You may reselect an RGA with good test results.

| Orbiter RGA Self-Test Limits<br>"Low" test limits, deg/sec |        |        |  |  |  |  |
|--|--------|--------|--|--|--|--|
| Roll   | - 18.8 | - 21.2 |  |  |  |  |
| Pitch  | - 9.4  | - 10.6 |  |  |  |  |
| Yaw  | -9.4   | - 10.6 |  |  |  |  |

If an RGA fails to respond to either the high or the low test, the fault may lie with the self-test circuitry rather than with the RGA itself. Similarly, an SMRD indication may be displayed because of a problem in the SMRD circuitry. To double check either of these results. you should rotate the vehicle about the axis in question (any axis for an SMRD) and monitor the **RGA/ADTA/RCS** display to see if the RGA responds appropriately. If it does, then you should reselect it if it was previously deselected.

To terminate the low test,

type in "ITEM 11 EXEC."



Figure 3-6. – Concluded.

## **Attitude Direction Indicator**

The body-mounted RGAs have a data user not shared by the SRB-mounted RGAs or the AAs. This user is the ADI. A complete description of the ADI is presented in the GNC Dedicated Displays Workbook. This training manual covers only the portions of the ADI that display data from the RGAs.

The ADI displays roll, pitch, and yaw rates on pointers located at the top, right side, and bottom of the ADI, as shown in figure 3-7. Near the ADI is a three-position RATE switch which is used to set the full deflection value of the rate pointers. When the switch is set on HIGH (the coarsest setting), a pointer at the end of the scale represents a rotation rate of 10 deg/sec. When it is set on MED, a full-range deflection represents 5 deg/sec. When the switch is set on LOW (the finest setting), a pointer at either end of the scale is read as a rate of 1 deg/sec.

During ascent, the selected attitude rates come directly from the RGAs to the ADI processor for display on the ADI rate pointers. But during entry, only the pitch rate follows this direct route to the ADI display. The selected roll and yaw rates are first processed by Flight Control and output to the ADI as stability roll and stability yaw rates. (This transformation is necessary because in aerodynamic flight, control is achieved about stability axes (figure 3-8), which in the cases of roll and yaw, differ from the body axes.)



Figure 3-7.- Attitude direction indicator.





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## Questions

- 1. If control bus AB1 and main bus B failed, which RGAs would still function? (Refer to power diagram.)
- 2. If the FA1 MDM and GPC 3 failed, which RGAs would be affected? Refer to figure 3-4.
- 3. During ascent and entry, what onboard display provides information about the sensors? Where could you read vehicle rates?
- 4. If the RGA/ADTA/RCS display appears as shown here before self-test initiation, what, if anything, should you do?

| 8              | 011/0                     | 041/             | RGA  | ADTA/RC                                     | S   | 1 005/07                          | 45:23                         |
|----------------|---------------------------|------------------|--|---|---|-----------------------------------|-------------------------------|
| R1<br>G2<br>A3 | DES<br>1 •<br>2<br>3<br>4 | STAT<br>SMRD     | R<br>+0. 12<br>-0. 20<br>+0. 19<br>+0. 03  | P<br>+0.0<br>+0.3<br>+0.1<br>-0.1           | Y<br>-0.1<br>+0.0<br>-0.1<br>+0.0           |                                   |                               |
| 11<br>03<br>72 | DES<br>5<br>7<br>8        | STAT             | PS<br>00.000<br>00.000<br>00.000<br>00.000 | Pac<br>00.000<br>00.000<br>00.000<br>00.000 | Pau<br>00.000<br>00.000<br>00.000<br>00.000 | Pal<br>00,000<br>00,000<br>00,000 | T<br>7.3<br>7.3<br>7.2<br>7.2 |
| TE             | ST                        | 41 9             | LOW  | 10 ST                                       | OP 11                                       |                                   |                               |
|                |                           |                  | (  | RCS DRIV                                    | ERS   |                                   |                               |
|                | RJI<br>RJI                | DF<br>DA-A<br>-8 | 12 Ti<br>13 Ci<br>14 S                     | EST EXEC<br>ONTINUE<br>TOP                  | 15<br>16<br>17                              | TEST<br>JET                       |                               |
|                |                           |                  |  |   |   |                                   |                               |

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Figure 3-9.– RGA/ADTA/RCS display - before self-test initiation.

5. According to this RGA/ADTA/RCS display, shown after high test completion but before test termination

| 12                   | DES<br>1 *<br>2<br>3<br>4 | STAT                   | R<br>+18.9<br>+19.2<br>+19.2<br>+21.1          | P<br>+09.5<br>+10.9<br>+09.8<br>+10.5            | Y<br>+09.5<br>+09.5<br>+09.6<br>+10.5           |  | 031 111 26                    |
|----------------------|---------------------------|------------------------|--|--|---|--|-------------------------------|
| A1<br>D3<br>T2<br>A4 | DES<br>5<br>6<br>7<br>8   | STAT                   | PS<br>00, 000<br>00, 000<br>00, 000<br>00, 000 | Pa C<br>00, 000<br>00, 000<br>00, 000<br>00, 000 | PeU<br>00, 000<br>00, 000<br>00, 000<br>00, 000 | Pa L<br>00. 000<br>00. 000<br>00. 000<br>00. 000 | T<br>7.3<br>7.3<br>7.2<br>7.2 |
| TE                   | ST                        | ні 9                   | LOW  | 10 ST<br>RCS DRI                                 | TOP 11<br>VERS                                  |  |                               |
|                      | RJC<br>RJC                | DF 1<br>DA-A 1<br>-8 1 | 2  | TEST EXE<br>CONTINUE<br>STOP                     | C 15<br>16<br>17                                | TEST<br>JET                                      |                               |
|                      |                           |                        |  |  |   |  |                               |
|                      |                           |                        |  |  |   |  | 4217. 4                       |

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Figure 3-10.– RGA/ADTA/RCS display after high test initiation.

- a. Do the readings for RGA 1 justify its deselection?
- b. Should you deselect any other RGA?
- 6. If during entry, you were out of contact with the ground when RGAs 2 and 3 failed to 0, would it be safe to engage the BFS?

### Answers

- 1. RGAs 3 and 4 would still function. RGA 2 would not work because it is powered by main B. RGA 1 would not work since main B has failed and its redundant power supply is also lost with the failure of control bus AB1.
- 2. The failure of FA1 would cause a loss of data from RGA 1. Data from RGA 3 would be lost with the failure of GPC 3. If the BFS were engaged, RGA 3 would be regained since GPC 5 could communicate with FA 3 and could therefore receive data from RGA 3. RGA 1 would still be lost because FA 1 has failed and engaging the BFS will not have any effect on FA1. It would be safe to engage the BFS because there would be valid data from RGAs 2, 3, and 4.
- 3. The status of the AAs and RGAs appears on GNC Systems Summary 1. Vehicle rates can be seen on the ADI.

4. You might consider deselecting RGA 2. It has a "SMRD" indication, suggesting that at least one gyro wheel in that assembly is not spinning in sync with the 24,000 rpm ± 2 percent requirement. The data displayed at this instant also show an unacceptable bias (>0.2 deg/sec) for the pitch gyro in the same RGA. Thus, it seems likely that the pitch gyro wheel in RGA 2 is out of sync. If you are in contact with the ground, you would consult with the flight controllers at this point. You could deselect this RGA now; it will still be tested. But remember to check for failed SMRD circuitry by doing a 0.5-deg/sec maneuver before you terminate the self-test. If RGA 2 responds appropriately to the maneuver, you can reselect it if it was previously deselected. Again, you would make these decisions in consultation with Mission Control, unless you were out of contact with the ground.

| 80                   | 011/0                    | 041/                   | RGA  | ADTA/RC                                      | S   | 1 005/03                                    | 7: 45: 23                     |
|----------------------|--------------------------|------------------------|--|--|---|---|-------------------------------|
| R1<br>G2<br>A3<br>4  | DES<br>1*<br>2<br>3<br>4 | STAT<br>SMRD           | R<br>+0.12<br>-0.20<br>+0.19<br>+0.03      | P<br>+0.0<br>+0.3<br>+0.1<br>-0.1            | Y<br>-0.1<br>+0.0<br>-0.1<br>+0.0           |   |                               |
| A1<br>D3<br>T2<br>A4 | DES<br>5<br>6<br>7<br>8  | STAT                   | PS<br>00.000<br>00.000<br>00.000<br>00.000 | Pa C<br>00.000<br>00.000<br>00.000<br>00.000 | PaU<br>00.000<br>00.000<br>00.000<br>00.000 | Pal<br>00.000<br>00.000<br>00.000<br>00.000 | T<br>7.3<br>7.3<br>7.2<br>7.2 |
| TES                  | т                        | HI 9                   | LOW 1                                      | CS DRIVI                                     | OP 11<br>ERS                                |   |                               |
|                      | RJD<br>RJD               | )F 1<br>)A-A 1<br>-B 1 | 2 TE<br>3 CC<br>4 ST                       | ST EXEC                                      | 15<br>16<br>17                              | TEST<br>JET                                 |                               |
| <br>                 |                          |                        |  |  |   |   |                               |

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- 5. a. No. They are all within high test limits (18.8  $\leq R \leq 21.2$ ; 9.4  $\leq P$  or Y  $\leq 10.6$ ). Therefore, you might reselect RGA 1. Of course, FDIR may have deselected it because of its negative responses. If so, you can deselect it again during the low test.
  - b. Yes. You should deselect RGA 2. As the up arrow indicates, its pitch reading is above the specified limit (10.6 deg/sec).
- 6. Yes. The crew has no insight into failures internal to the RGA; if the failure is caused by loss of electrical power (main B APC 5 for RGA 2, main C MPC 3 for RGA 3) or loss of the switch (control bus BC1 for RGA 2, CA1 for RGA 3), the Bus Loss Actions sections of the various Pocket Checklists and the Ascent/Entry Systems Procedures should tell the crew to deselect the affected RGA in the BFS. Similar actions would also apply to AAs 1 and 3.

Deselection is not required because the IMVS scheme protects against dual null failures; deselection is, however, highly desirable.

| R1<br>52<br>A3                            | DES :<br>1•<br>2          | STAT         | R<br>+18,9                                 | р<br>•09 б                                   | Y_  | 000/  | 03:11:26                             |
|---|---------------------------|--------------|--|--|---|---|--------------------------------------|
| -   | 4                         |              | +19.2<br>+19.2<br>+21.1                    | +10.9<br>+09.8<br>+10.5                      | +09.5<br>+09.5<br>+09.6<br>+10.5            |   |                                      |
| 6<br>1<br>1<br>1<br>2<br>1<br>2<br>1<br>2 | )ES :<br>5<br>6<br>7<br>8 | STAT         | PS<br>00.000<br>00.000<br>00.000<br>00.000 | Pa C<br>00.000<br>00.000<br>00.000<br>00.000 | PcU<br>00.000<br>00.000<br>00.000<br>00.000 | Pal<br>00.000<br>00.000<br>00.000<br>00.000 | T<br>7.3<br>7.3<br>7.2<br>7.2<br>7.2 |
| rest                                      | T I                       | HI 9         | LOW  | 10 ST<br>RCS DRI                             | OP 11<br>VERS                               |   |                                      |
| 1   | RJDF<br>RJDA              | -A 1<br>-B 1 | 2<br>3<br>4                                | TEST EXE<br>CONTINUE<br>STOP                 | C 15<br>16<br>17                            | TEST<br>JET                                 |                                      |

Figure 3-12. – RGA/ADTA/RCS display.

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# Section 4: SRB-Mounted Rate Gyro Assemblies

## **Performance Objectives**

Upon completion of this section, you should be able to

- Describe the location and the operating principles of the SRB-mounted RGAs
- Identify the power source(s) of each SRB-mounted RGA
- Identify data flow paths to and from each SRB-mounted RGA
- Describe data processing performed on RGA measurements

The four SRB-mounted RGAs, two on each SRB, are located within the forward skirt near the SRB/external tank attach point. This watertight compartment protects its contents against saltwater contamination upon landing. Because the area does not get excessively hot, these RGAs are not mounted on coldplates. See figure 4-1.

The rate gyros making up these assemblies are identical to those that compose the body-mounted RGAs. The main difference is that *these RGAs each contain only two rate gyros, sensing pitch, and yaw rates*; the orbiter RGAs have a third rate gyro sensing roll rate. The SRB-mounted RGAs are tested before launch by torque commands sent from the launch control center. SMRD indications are derived; however, they are not displayed onboard but only telemetered to the ground. The maximum outputs for the SRB-mounted pitch and yaw rate gyros, 10 deg/sec, are half those for the body-mounted pitch and yaw rate gyros.



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Figure 4-1.– SRB-mounted gyros.

### Power

Operation of the SRB-mounted RGAs is initiated before launch through the launch MDMs (located in the SRBs) and maintained throughout boost phase with *no crew control*. Electrical power is supplied to each RGA by an SRB bus. Each SRB bus is redundantly powered by two orbiter main buses. In the cases of SRB buses A and B, a switching circuit brings in power from orbiter main bus C if orbiter main bus A (or B) fails. In the case of SRB bus C, power is supplied from both orbiter main bus B and orbiter main bus C so that if either fails, the other will supply the necessary power. Each SRB RGA draws about 2 watts. See figures 4-2a and 4-2b.





Figure 4-2.- SRB-mounted RGA power system.





Figure 4-2.– Concluded.

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## **Data Processing**

Each of the SRB RGAs (SRGAs) is hardwired to a flight aft (FA) MDM. Self-test commands are received from and SMRD indications are sent to the launch MDMs in the SRBs.

From the FA MDMs, the rate outputs from SRGAs 1, 2, 3, and 4 flow to the GPCs through flight-critical data buses 5, 6, 7, and 8, respectively (figure 4-3). Data request commands flow from the GPCs to the MDMs through the same flight-critical data buses.

In the GPC, the SOP applies the rate compensation equation to each of the left or right pitch and yaw rates input. The compensated rate signals are sent to RM where the operative signals are chosen by the processes of FDIR and selection filtering.

SMRD signals follow similar paths between the launch left (or right) MDM through launch bus 1 and the GPCs. From there they are telemetered to the ground. GPC 5, the BFS computer, does not listen to the SMRD signals.



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Figure 4-3.– SRGA data flow.

Processing of SRB RGA data in the **BFS** differs from the processing done in the primary flight system. As shown in table 4-1, the HIP first selects the middle of the three values input for each rate; it then applies the rate compensation equation to each of the three selected rates and sends users one compensated rotation rate for each axis on each side - left pitch and yaw and right pitch and yaw. SRB RGA selection filter did not change in the BFS for OI-20.

|                          | PASS  | BFS                                       |
|--------------------------|---|---|
| Data sources             | SRGAs 1, 2, 3, 4  | SRGAs 1, 2, 3                             |
| Redundancy<br>management | Interchangeable midvalue selection of compensated signals         | Midvalue selection of<br>measured signals |
|                          | FDIR (terminates after annunciating the first failure/ commfault) | No FDIR                                   |
|                          | Commfault indications from FCOS (downmoding)                      | No commfault indica-<br>tions from FCOS   |
| Compensation             | Before selection  | After selection                           |

#### Table 4-1.- SRB RGA data processing.

## Questions

- 1. In what position are the SRB-mounted RGAs located?
- 2. How do the operating principles of the SRB-mounted RGAs differ from the body-mounted RGAs?
- 3. True or false: Each SRB bus is redundantly powered by two orbiter main buses. If SRB bus A (or B) fails, a switching circuit brings in power from orbiter main bus C.
- 4. Briefly describe the flow of rate outputs from SRGAs 1 through 4 from the flight aft MDMs.

### Answers

- 1. They are located within the forward skirt near the SRB/external tank attach point.
- 2. They are identical except these RGAs contain only two rate gyros sensing pitch and yaw rates. The body-mounted RGAs contain a third rate gyro sensing roll rate.
- 3. True. Each SRB bus is redundantly powered by two orbiter main buses. If SRB A (or B) fails, a switching circuit brings in power from orbiter main bus C.
- 4. From the flight aft MDMs, the rate outputs from SRGAs 1 through 4 flow to the GPCs through flight-critical data buses 5 through 8, respectively.

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## Section 5: PASS Redundancy Management Accelerometer Assemblies, Orbiter Rate Gyro Assemblies, and SRB Rate Gyro Assemblies

## **Performance Objectives**

Upon completion of this section, yourshould be able to

- Trace the flow for selection filtering using the IMVS scheme
- Identify the proper steps to follow and interpret the display results when RM has failed specific RGAs

To avoid the dominance of dual null failures, an IMVS scheme has replaced the old midvalue selection (MVS) scheme.

Originally the RM scheme for the four AAs and the four orbiter RGAs consisted of FDIR, which identified a failed assembly, and selection filtering, which selected the middle of the values from the three assemblies being considered. Assemblies 1, 2, and 3 were considered until an assembly was declared failed, then assembly 4 would replace the failed assembly in the consideration. But then a concern arose that dual null failures could lead to the selection of one of these 0 values over the third (good) datum. Therefore, a new selection filtering scheme involving all four assemblies and called "interchangeable midvalue selection" was instituted, with a corresponding FDIR scheme.

## **Selection Filtering**

The IMVS scheme diagramed in the following flow chart includes the old MVS from assemblies 1, 2, and 3 (R, S, T), with the selected value stored as A, and the other possible comparisons involving assembly 4 (U). From the middle values selected from these three new comparisons, stored as D, E, and F, an MVS is made and stored as B. The absolute value of the difference between A and B is compared with an I-loaded value, C, to determine whether A or B shall be the selected signal. The values of C in the current I-load are 0.03g in lateral acceleration and 0.00g in normal acceleration for the AAs and 0.4 deg/sec in roll and 0.22 deg/sec in pitch or yaw for the orbiter RGAs.

By working out the following cases, readers can assure themselves that the requirement stated in the Redundancy Management Functional Subsystem Software Requirements (RM FSSR, STS 83-0018) is indeed satisfied by this IMVS scheme.

The IMVS filter mode shall provide signal selection (figure 5-1) from four valid input signals and shall provide protection from any single failure and from dual null failures. Dual null failure protection is provided in two ways: (1) it ensures the selection of non-null signal whenever the true input is greater than a null threshold level (I-load) and (2) it minimizes switching between the null and true values when the true input cycles in and out of the null threshold level. IMVS shall be used for the orbiter RGAs, the SRB RGAs, and the AAs.



Figure 5-1.- IMVS signal selection.

### Questions

Note: For these questions, refer to figure 5-1.

1. Normal acceleration readings:

- AA 1 Zero g
- AA 2 Zero g

AA 3 1.25g (40.3 ft/sec<sup>2</sup>)

AA 4 1.30g (41.9 ft/sec<sup>2</sup>)

According to the IMVS scheme diagramed, will A or B be selected? Is it the second or third highest absolute value?

#### 2. Roll rate readings:

RGA10.32 deg/secRGA 20 deg/secRGA 30.36 deg/secRGA 40 deg/sec

Will the IMVS filter select A or B? Is it the second or third highest absolute value?

- 3. Lateral acceleration readings:
  - AA 1 -0.25g (-8.05 ft/sec<sup>2</sup>)
  - AA 2 -0.15g (-4.83 ft/sec<sup>2</sup>)
  - AA 3 Zero g
  - AA 4 0.12g (3.86 ft/sec<sup>2</sup>)

Will A or B be selected? Is it the second or third highest absolute value?

- 4. Pitch rate readings:
  - RGA 1 1.5 deg/sec
  - RGA 2 1.5 deg/sec
  - RGA 3 1.6 deg/sec
  - RGA 4 1.8 deg/sec

Will A or B be selected? Is it the second or third highest absolute value?

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### Answers

1. R = 0 S = 0 T = 1.25 U = 1.30

Therefore,

A = 0 D = 0 E = 1.25 F = 1.25 B = 1.25

 $|0| - |1.25| \ge C$  [0.00 g], so B (the second highest absolute value) is selected. Anytime dual null failures are in A, then B will be selected. B will be the second highest absolute value.

2. R = 0.32S = 0 T = 0.36

U = 0

Therefore,

A = 0.32 D = 0 E = 0.32 F = 0B = 0

 $|0.32| - |0| \ge C$  [0.4 deg/sec], so B (the third highest absolute value) is selected. When U is one of the dual null failures, then A would normally be selected unless, as in this case, it is smaller than C. Here B (a null signal) is chosen, but the good signal is small enough that this choice can be tolerated.

3. R = -0.25 S = -0.15 T = 0U = 0.12

Therefore,

$$A = -0.15$$
  $D = -0.15$   $E = 0$   $F = 0$   
 $B = 0$ 

|-0.15| - |0| > C [0.03 g], so A (the second highest absolute value) is selected. When the two highest absolute values are in A, then A will be selected unless the difference between |A| and |B| is smaller than C. 4. R = 1.5S = 1.5 T = 1.6 U = 1.8

Therefore,

A = 1.5 D = 1.5 E = 1.6 F = 1.6 B = 1.6

 $|1.5| - |1.6| \ge C$  [0.22 deg/sec], so B (the second highest absolute value) is selected. Anytime U is one of the two highest absolute values, then B will be selected. B will be the second highest absolute value.

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## FDIR

The corresponding FDIR logic looks for an excessive difference between a reading from an individual line replaceable unit (LRU) and the selected reading.

The FDIR scheme previously used for the AAs and orbiter RGAs also required altering to avoid the dominance of bad data over good data in a dual null failure situation. The new FDIR logic is diagramed below (figure 5-2).

Rather than subtracting pairs of inputs as was done in the old method, the new FDIR scheme subtracts the selected reading (W) from the reading for each of the four assemblies (R, S, T, U) and compares each absolute difference with a limit. If the absolute difference exceeds the limit for 10 seconds (10 counts for RGAs, 5 counts for AAs), that assembly is identified as failed. The limits for the AAs are OPS-dependent. Currently, the limits for OPS 1 and 6 are 0.08g for lateral acceleration and 0.063g for normal acceleration. For OPS 3, the lateral limit is 0.13g and the normal limit is 0.2g. The limits for the RGAs are dynamic; they are based on the selected rate. The equation for the limit is of this form:



Limit = | selected rate | · scale factor + constant

Figure 5-2.– FDIR logic.

The I-loaded scale factor and constant values are axis-specific and vary slightly with OPS. This chart gives the current values:

| <b>.</b>        | Scale<br><u>factor</u> | Constant,<br><u>deg/sec</u> |
|-----------------|------------------------|-----------------------------|
| Roll<br>OPS 1 6 | 0.08                   | 0.80                        |
| OPS 3           | 0.089                  | 0.70                        |
| Pitch/yaw       |                        |                             |
| OPS 1, 6        | 0.065                  | 0.55/0.63                   |
| OPS 3           | 0.060                  | 0.65                        |

After the FDIR module identifies an assembly as failed and notifies the selection filter of the failure, FDIR will shut down.

The selection filter, upon being notified of a failed assembly, will eliminate the readings for that assembly from consideration and downmode from IMVS to MVS.

No further failures will be detected since the FDIR module shuts down after identifying the first failed assembly.

The RM system receives notice of commfaults from the flight computer operating system (FCOS). The FDIR module treats a commfault as a failure and shuts down after receiving one. However, the selection filter is able to respond to a subsequent commfault by downmoding from MVS to averaging the data from the two remaining good assemblies. If one of the two remaining good assemblies is also commfaulted, the selection filter is able to downmode once again to passing through the remaining good data. If a commfault goes away, both FDIR and selection filtering can upmode.

When power is removed from an orbiter RGA, whether by failure or by turning the power off, its ouput will momentarily spike to half its maximum output and decay to zero over a 10-second period. If a previous RGA failure has caused FDIR to halt, this false rate signature will be input to the selection filter.

Some electrical system failures (control busses and remote power controllers (RPCs)) leave the system vulnerable because another electrical bus failure can result in simultaneous loss of power to two RGAs.

Referring to figure 3-3, notice that a failure of RGA 4 RPC C (on Main C) will result in a loss of redundant power to the RGA. A subsequent loss of control bus CA1 will result in both RGAs 3 and 4 losing power; their output rates will then spike as described above.

If a previous failure to either RGA 1or 2 has caused FDIR to halt, the selection filter will MVS one good value withthe two bad values from LRUs 3 and 4, possibly resulting in a loss of control.

Various other combinations would have similar results. Although the SRB RGAs exhibit the same signature for power failures, because of their power sources, they are not subject to the same problem.

To alleviate the problem with the orbiter RGAs, OI-22 added a module to PASS GNC RM software. This module is called orbiter RGA SMRD RM and is separate and distinct from the RGA FDIR and selection filter software.

The SMRD RM module monitors each SMRD discrete (12, in all).

If an LRU's three discretes are all available, the selected output is the two-out-ofthree majority vote. If one of the 3 discretes disagrees with the other 2 for 10 cycles (2/5 second during dynamic flight), that discrete is deselected and SMRD RM processing downmodes to the two-level scheme. This will protect against an RGA's being erroneously deselected for one of its three gyros running slightly off speed, as long as the rate output satisfies the RGA RM requirements.

At the two-level, the selected output is the logical "OR" of the two available values. Therefore, both remaining axes SMRD's must be "0" to result in "0" being output as the selected value.

The only credible way for the selected output to be "0" is for the RGA to be power failed.

If the selected SMRD output for any RGA is "0" (the failed state), RGA SMRD RM will annunciate the failure and deselect that RGA, even if a previous RGA failure has caused RGA FDIR to terminate. This will protect against the output spike associated with an RGA power failure, because the SMRD RM module will deselect the RGA before the spike has time to pollute the selected rate. Especially important, the system will now protect against simultaneous dual power failures.

If an RGA is lost due to an electrical bus problem, and the bus is later recovered, that RGA can be reselected. This will normally be done only upon request from the ground.

This module continues to operate until only one RGA remains available (if you're down to your last RGA, the module terminates).

Because this module has been installed only in PASS, crew deselection of RGA's in BFS for power problems is covered by existing checklist procedures, backed up by ground call.

Deselection by the crew during FCS checkout (OPS 8) will have the same effect on RM as commfaults.

Although crewmembers do not need a detailed understanding of the RM scheme for the AAs and orbiter RGAs to operate the vehicle, those who are interested may wish to check their understanding by completing the chart on the next page (figures 5-3 and 5-4). Circle any outputs that are based on more bad data than good, and put question marks by any outputs that are based on equal amounts of good and bad data.

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5-11



Figure 5-4.- Exercise solution.





5-13
# **Ground Control**

The flight controllers in the Mission Control Center have some special responsibilities that deserve mention. When the primary flight system is being used, the flight controllers can counteract a bias discovered in an assembly during the flight by altering the compensation equation applied to the affected measurement. Unfortunately this will not work when the BFS is engaged because in the BFS, the compensation equation is applied to the selected signal.

The GNC flight controllers are responsible for monitoring the health of the flight control sensors. PASS will annunciate only the first RM failure in each orbiter system (PASS does not annunciate SRB RGA failures), and will annunciate second and third orbiter RGA failures for power loss (SMRD RM, see page 5-7). BFS does not annunciate any failures in the AAs, orbiter RGAs, or SRB RGAs. Therefore, the crew has no insight into the effects of individual or combined measurement errors on the selected value.

The GNCs monitor the sensor data on one of two displays: during the ascent phase, they use GNC SENSORS - ASCENT (MSK 1417) (figure 5-5) and during entry, GNC SENSORS - ENTRY (MSK 1416) (figure 5-6). The controllers can detect a bias or scale-factor error in any individual measurement, a power failure in any unit, and the effect of each error on the selected measurement. If necessary, they can inform the crew of potential problems and have them deselect a unit (in either PASS or BFS) to prevent bad data from affecting Flight Control adversely.

| F/V<br>OGMT 278:<br>RGMT 278:<br>IMU<br>MODE<br>BITE<br>STATUS<br>RED RATE | 41/103<br>11:35:10<br>11:35:10<br>0PER<br>./<br>8000<br>-0.04 | OMET 0<br>MM 102<br>2<br>0PER<br>/<br>8000<br>-0.12 | GNC<br>00+ 00+ 10<br>BFS<br>0PER<br>/<br>8000<br>0. 04 | SENSORS                                  | - AS<br>166<br>IMU BIT<br>PLAT T<br>CAPRI T<br>CAPRI T<br>CAPRI T<br>ECHO 1/<br>RED RAT<br>IR NULL | CENT<br>GN 21<br>E/T 1<br>RDY X<br>SAFE X<br>SFE X<br>2 FL /<br>E FL<br>FL | RR141<br>SH 64<br>X<br>X<br>X<br>X | 7 CH<br>3 8<br>X X<br>X X<br>X X | OB5<br>F 12<br>POWER IND<br>IMU<br>1 A/B<br>2 B/C<br>3 A/C<br>OPER CHD<br>IMU |
|--|---|---|--|--|--|--|------------------------------------|----------------------------------|---|
| IMU ATT<br>GYRO 1/2<br>GYRO 1/3<br>GYRO 2/3                                | X<br>-0.01<br>-0.01<br>-0.01                                  | Y<br>-0.01<br>0.01<br>0.01                          | Z<br>0.01<br>0.01<br>-0.00                             | RSS<br>0.01<br>0.02<br>0.02              | VEL LIP<br>RSLVR L<br>ACC SF   | I FL<br>IN FL<br>FL<br>AA  | NORM                               | LAT                              | 1 X<br>2 X<br>3 X   |
| DRIFT 1/2<br>DRIFT 1/3<br>DRIFT 2/3  | -0.022<br>-0.042<br>-0.020                                    | -0.014<br>0.057<br>0.071                            | -0.012<br>0.006<br>0.018                               | IMU DG<br>SEL IMU 2<br>BFS IMU 0         |  | 1<br>2<br>3<br>4   | -3. 1<br>-3. 9<br>-3. 3<br>-3. 1   | 3.3<br>2.6<br>3.3<br>3.3         |   |
| IMU VEL<br>ACC 1/2<br>ACC 1/3<br>ACC 2/3                                   | X<br>-366<br>-337<br>29                                       | Y<br>-35<br>-192<br>-157                            | Z<br>264<br>65<br>-200                                 | G REF 1<br>DRIFT AT<br>DI 08155          | RGA<br>1   | SEL<br>ROLL<br>13.4  | -3.3<br>PITCH<br>2.5               | 3.3<br>YAW<br>2.1                | <u></u>   |
| 1/GND Δ<br>2/GND Δ<br>3/GND Δ  | 3.01<br>3.01<br>3.01  | 7.52<br>7.53<br>7.55                                | 2.69<br>2.69<br>2.68                                   | ACC Δ1<br>0: 00: 06<br>VEH ACC<br>51. 74 | 2<br>3<br>4<br>SEI   | 13.4<br>13.4<br>14.8   | 2.5<br>2.5<br>2.6                  | 2.1<br>2.1<br>2.1                |   |
| NULL ACC1<br>NULL ACC2<br>NULL ACC3  | -480227<br>616947<br>24135T                                   | 39879T<br>302024<br>-322260                         | -509575<br>40537T<br>-895752                           | TGO<br>0.01                              | 522  | SRGA<br>1<br>2   | PITCH<br>3.0<br>3.0                | YAW<br>2.5<br>2.5                |   |
| PRI FAULT<br>BCE S<br>BCE S<br>BCE S                                       | MSG<br>TRG 3 ML<br>TRG 2 ML<br>TRG 1 ML                       | S 2781<br>S 2781<br>S 2781<br>S 2781                | 11: 14: 28<br>11: 14: 28<br>11: 14: 28<br>11: 14: 28   | STRG STAT<br>FF FA BFS                   |  | 3<br>4<br>SEL  | 2.5<br>3.0<br>3.0                  | 2.1<br>2.6<br>2.5                |   |
| BFS FAULT<br>BPC SU  | MSG<br>JM   | 2781  | 11: 12: 57<br>11: 26: 08                               | 3  | CRT<br>1 RES<br>2 SYS<br>3   | UME<br>SUMM  |                                    |                                  | SPEC<br>1021<br>100<br>1011   |

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Figure 5-5.- GNC SENSORS - ASCENT.

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| F/V<br>OGMT 278:<br>RGMT 278:<br>IMU<br>MODE<br>BITE<br>STATUS<br>IMU ATT<br>GYRO 1/2   | 41/103<br>11:36:00<br>11:36:00<br>0PER<br>8000<br>X<br>-0.01                             | OMET 0<br>MM_102<br>2<br>0PER<br>8000<br>Y<br>-0.01   | GNC<br>00: 01: 00<br>BFS<br>0PER<br>8000<br>Z<br>0: 00   | SENSORS<br>SITE HIL_07<br>RSS<br>0.01   | 5 - ENTRY RI<br>166 GN 21 S<br>170 RATE 1<br>TAC BEARING RAN<br>1 0.0 0<br>2 0.0 0<br>3 0.0 0<br>SEL 0.0 0<br>1/GNDA D<br>2/GNDA D  | R1416 CH084     M 64   BF 12     GE   STA     .0   0     .0   0     .0   0     .0   0     .0   0     .0   0     .0   0     .0   182.6     D   NAV ALT |
|---|--|---|--|---|---|---|
| GYRO 1/3<br>GYRO 2/3<br>DRIFT 1/2<br>DRIFT 1/2<br>DRIFT 2/3<br>IMU VEL<br>ACC 1/2<br>ACC 1/3<br>ACC 2/3<br>1/GND 4<br>2/GND 4 | -0.01<br>-0.032<br>-0.032<br>-0.031<br>3 0.001<br>X<br>-195<br>73<br>268<br>4.06<br>4.01 | 0.01<br>0.02<br>-0.024<br>0.066<br>0.090<br>Y<br>-4<br>-46<br>-42<br>0.94<br>0.92<br>0.93       | 0.00<br>-0.060<br>-0.022<br>0.037<br>Z<br>-223<br>-229<br>-206<br>0.61<br>0.63<br>0.57         | 0.02<br>1MU DG<br>SEL IMU 1<br>BFS IMU 0<br>G REF 1<br>DRIFT AT<br>0:09:45<br>ACC AT<br>0:00:09 | ADTA PS PK   ADTA PS PK   1L D   3 D   2R D   4 D   ALT1 DGND ALT   ALT2 D   ALT4 D   ADTA TO G&C AIF I   | EL 0.0<br>U PCC PCL BFS<br>D D D D<br>D D D D<br>LADP1 STON<br>RADP2 STON<br>NAY ADTA H AIF I             |
| RGA ROI<br>1 -0.<br>2 -0.<br>3 -0.<br>4 -0.<br>BEL -0.  | LL PITCH<br>4 -0.2<br>4 -0.1<br>4 -0.1<br>4 -0.1<br>4 -0.2                               | YAW     AA       0.0     1       -0.0     2       -0.0     3       -0.0     4       -0.0     56 | NORM<br>-6.2<br>-6.9<br>-6.2<br>-6.2   | LAT<br>0.6<br>0.0<br>0.6<br>0.6<br>0.6  | MLS     AZ I MUTH     E       1     G     DC     D       2     G     DC     D       3     G     DC     D       1/GNDA     D     D     D       2/GNDA     D     D     D       3/GNDA     D     D     D | ELEVATION RANGE<br>DC D DC F<br>DC D DC F<br>DC D DC F<br>DC D D D<br>D D<br>D D<br>D D<br>D D  |
| PRI FAUL<br>BCE<br>BCE<br>CRT<br>BFS FAUL<br>BPC  | T MSG<br>STRG 3 M<br>STRG 2 M<br>STRG 1 M<br>BITE 2<br>BITE 2<br>BITE 2<br>T MSG<br>SUM  | LS 278<br>LS 278<br>LS 278<br>278<br>278<br>278   | 11: 14: 28<br>11: 14: 28<br>11: 14: 28<br>11: 14: 28<br>11: 14: 28<br>11: 13: 51<br>11: 12: 57 | STRG STAT<br>FF FA BFS<br>2<br>3<br>4   | RA ALT R/H ALT<br>1 D 600000<br>2 D<br>CRT<br>1 RESUME<br>2 SYS SUMM<br>3   | RA DG HLS NAV<br>D NO<br>SPEC<br>1021<br>100<br>1011  |

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# Questions

1. In MM103, redundancy management has failed RGA 3, and the flight controllers' GNC SENSORS - ASCENT display (MSK 1403) shows the following pitch readings:

| RGA 1 | 0.5  |
|-------|------|
| RGA 2 | 1.4  |
| RGA 3 | 12.0 |
| RGA 4 | 0.5  |

- a. What message, if any, will the flight controllers send to the crew?
- b. Can anything be done to make the reading from RGA 2 useful?
- 2. In MM301, RM fails RGA 2, and the flight controllers' GNC SENSORS ENTRY display (MSK 1417) shows the following roll readings:

| RGA 1 | - 0.4 |
|-------|-------|
| RGA 2 | - 2.0 |
| RGA 3 | - 0.4 |
| RGA 4 | - 0.4 |

Now there is an indication that FA MDM 1 has ceased sending data to GPC 5.

- a. What will the call be to the crew?
- b. What can be done to get around the commfault problem?
- c. What can be done to make RGA 2 usable?

3. In MM305, the lateral (Y) acceleration readings are as follows:

| AA 1 | 0.3   |
|------|-------|
| AA 2 | 1.4   |
| AA 3 | - 0.2 |
| AA 4 | 18.3  |

RM has failed AA 2. AA 3 is commfaulted, and the problem has been traced to GPC 3.

- a. What will happen?
- b. What should be done?
- 4. In MM305, RM has failed AA 1 after it commfaulted. Now the flight controllers' GNC SENSORS ENTRY display (MSK 1407) shows the following normal (Z) acceleration readings:

| AA 1 | 0.3   |
|------|-------|
| AA 2 | 39.2  |
| AA 3 | 117.6 |
| AA 4 | 39.2  |

- a. What message might the flight controllers send the crew?
- b. What can the crew do about the situation?
- c. What can the flight controllers do?

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## Answers

- 1. a. RGA 2 has a pitch bias; deselect RGA 2 in the BFS.
  - b. Yes. The flight controllers can alter the compensation equation for RGA 2 to compensate for the + 0.9 deg/sec bias it is displaying.

Note that this action works only for the primary flight system. Since in the BFS the compensation equation is applied to the selected value, it cannot be selectively applied to RGA 2.

- 2. a. Deselect RGA 2 in the BFS. If you have to engage, BFS will average RGAs 3 and 4..
  - b. You might try a portmode to establish BFS communications with FA 1 on the secondary ports.
  - c. The flight controllers can alter the compensation equation for RGA 2 to cut its reading to one-fourth.

Note that this solution works only for the primary flight system. In the BFS, the readings from the different sensors are not individually compensated.

- 3. a. The primary flight system software will respond to the commfault indication by downmoding to averaging the readings from AAs 1 and 4. Since AA 4 is seriously out of whack, the vehicle will go out of control if this average is used.
  - b. There are two possibilities. In both cases, deselect AA 4 in PASS and BFS. Then you could engage BFS or assign string 3 to another GPC.

Engaging the BFS will solve the commfault problem, thus restoring the best two out of three situation. Similarly, a restring (or portmode) will also remove the commfault and allow using AA 3.

4. a. "AA 3 has failed."

Since the FDIR has shut down after declaring AA 1 failed, it cannot declare AA 3 failed. But, since the flight controllers can see on their display that the reading from AA 3 is three times that from the other two valid AAs, they can tell the crew about the problem.

b. They can deselect it on the entry CONTROLS display (SPEC 53).

c. If it is still early enough in the entry phase, they can alter the compensation equation for AA 3 to cut its reading to one-third and thus bring the number of working AAs back up to three.

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# Appendix A: Acronyms and Abbreviations

| AA   | accelerometer assembly                               |
|------|--|
| ACC  | accelerometer  |
| ADI  | attitude direction indicator                         |
| ADTA | air data transducer assembly                         |
| BFS  | backup flight system                                 |
| BITE | built-in test equipment                              |
| C    | center (panel)                                       |
| CNTL | control (bus)  |
| CRT  | cathode-ray tube                                     |
| DAP  | digital autopilot                                    |
| DES  | deselected   |
| DPS  | data processing system                               |
| EPS  | electrical power system                              |
| ET   | external tank  |
| EXEC | execute  |
| F    | forward (panel)                                      |
| FA   | flight aft (MDM)                                     |
| FC   | flight-critical (data bus)                           |
| FCOS | flight computer operating system                     |
| FCS  | flight control system                                |
| FDIR | fault detection, identification, and reconfiguration |
| FF   | flight crititical forward (MDM)                      |
| FSSR | Functional Subsystem Software Requirements           |
| g    | gravitational unit (32 ft/sec <sup>2</sup> )         |
| GNC  | guidance, navigation, and control                    |
| GPC  | general purpose computer                             |
| HIP  | hardware interface program                           |
| IDSD | Integrated Documentation Support Department          |
| IMU  | inertial measurement unit                            |
| IMVS | interchangeable midvalue selection                   |
| JSC  | Lyndon B. Johnson Space Center                       |
| LB   | launch bus   |
| LED  | light emitting diode                                 |
| LL   | launch left (MDM)                                    |
| LR   | launch right (MDM)                                   |
| LRU  | line replaceable unit                                |

| M<br>MAN<br>MDM<br>MEC<br>MM<br>MN<br>MN<br>MOD<br>MSK<br>MVS    | missing (data)<br>manual<br>multiplexer/demultiplexer<br>master events controller<br>major mode<br>main (power bus)<br>Mission Operations Directorate<br>manual select keyboard<br>midvalue selection                          |
|--|--|
| NASA   | National Aeronautics and Space Administration  |
| O<br>OI<br>OPS<br>ORB OPS C/L                                    | overhead (panel)<br>operational increment<br>operational sequence<br>Orbit Operations Checklist  |
| P<br>PASS<br>PRO   | pitch<br>primary avionics software system<br>proceed   |
| R<br>RCS<br>RGA<br>RM<br>RPC                                     | roll<br>reaction control system<br>rate gyro assembly<br>redundancy management<br>remote power controller  |
| SEL<br>SM<br>SMRD<br>SOP<br>SPEC<br>SRB<br>SRGA<br>STAT<br>STSOC | selected<br>systems management<br>spin motor run detector<br>subsystem operating program<br>specialist function<br>solid rocket booster<br>SRB rate gyro assembly<br>status<br>Space Transportation System Operations Contract |
| TDO  | Training Development Office  |
| VERN   | vernier (jets)   |
| Y  | yaw  |

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Appendix B: Sensors Summary

|                  |      | AAs   | Orbiter RGAs   | SRB RGAs  |
|------------------|------|---|--|---|
| Measurement      |      | Lateral and normal accelerations  | Roll, pitch, and yaw rates   | Pitch and yaw rates   |
| Maximum outpu    | lts  | Lateral acceleration ± 1g<br>Normal acceleration ± 4g   | Roll rate ± 40 deg/sec<br>Pitch and yaw rates ± 20 deg/sec   | Pitch and yaw rates ± 10 deg/sec  |
| Location         |      | In forward avionics bays  | On aft bulkhead of payload bay   | Within forward skirt of SRBs  |
| Crew control     |      | Turned off once in orbit and on<br>again before entry (OPS 3).<br>Select/deselect with SPEC 53 (OPS<br>3) | Turned off once in orbit and on again<br>before entry (OPS 3). Select/deselect<br>with SPEC 53 (OPS 3) | No crew control   |
| Data paths       |      | FF 1-4 (data and test)  | FA 1-4 (data, SMRDs, and test)<br>SMRD signals displayed in OPS 8<br>Rates sent to ADIs                | FA 1-4 (data)<br>LL 1 or LR 1 (SRMDs and test)<br>SMRD signals not displayed, only<br>telemetered to ground |
| Checkout         |      | By crew during OPS 8  | By crew during OPS 8   | On ground before launch   |
| Selection filter | PASS | Interchangeable midvalue<br>selection of compensated signals<br>from AAs 1, 2, 3, and 4                   | Interchangeable midvalue selection<br>of compensated signals from RGAs 1,<br>2, 3, and 4               | Interchangeable midvalue<br>selection of compensated signals<br>from RGAs 1, 2, 3, and 4                    |
|                  | BFS  | Interchangeable midvalue<br>selection of measured signals from<br>AAs 1, 2, 3 and 4                       | Interchangeable midvalue selection<br>of measured signals from RGAs 1, 2, 3<br>and 4                   | Midvalue selection of measured signals from SRGAs 1, 2, and 3   |
| FDIR             | PASS | Compares each input with selected acceleration  | Compares each input with selected rate   | Compares pairs of rates   |
|                  | BFS  | No FDIR   | No FDIR  | No FDIR   |
| Commfaults       | PASS | Indicated (downmoding)  | Indicated (downmoding)   | Indicated (downmoding)  |
|                  | BFS  | Not indicated (no downmoding)   | Not indicated (no downmoding)  | Not indicated (no downmoding)   |

# Appendix C: Significant Changes Since 1985 Edition

# Solid Rocket Booster Rate Gyro Assemblies

From STS-1 until STS 51-L, each SRB had three RGAs, designated left/right SRB RGA A, B, or C. Data from A, B, and C units were carried by flight aft (FA) MDMs 1, 2, and 3, respectively. With three measurements from each side, the selected measurement from the opposite side was used as a "fourth" by the software to compute the "selected rate."

During the overall Space Transportation System review following 51-L, the program decided that this configuration did not have sufficient fault tolerance, so the SRB RGA system was redesigned to the configuration shown in section 4.

# **Backup Flight Software Processing**

Until 1991, BFS processing of orbiter RGAs and AAs performed an MVS selection scheme using only the measurements from LRUs 1, 2, and 3 from each system to compute the selected rate or acceleration value. There was no capability to deselect a faulty LRU other than commfaulting the bad unit. If any two units of LRUs 1, 2, and 3 were providing bad data in the same axis, BFS could be "no-go" because the selected (inaccurate) measurement would feed erroneous information to Flight Control.

As a result, a "fourth LRU substitution" procedure was made available to allow the BFS to replace one or more measurement(s) from a failed LRU with the corresponding data from LRU number 4. This procedure protected the BFS from subsequent failures and maintained the usability of the BFS for flight control during entry.

Flight software OI-20, in mid 1991, was the first software "drop" to take advantage of the larger GPCs. Among the improvements incorporated with OI-20, the BFS was upgraded to use a four-value IMVS scheme, with the capability for the crew to deselect the measurements from one or more faulty LRUs, similar to the capability that already existed in the PASS in OPS 3. This capability allowed the Mission Control Center to prevent faulty data from affecting the ability of the BFS to control the vehicle, if necessary. Therefore, "BFS no-go" calls and BFS fourth LRU substitutions are no longer necessary. See section 5 for further details.

## **Training Materials Evaluation**

Please answer the following questions regarding the lesson you just completed. Your feedback will allow us to produce more effective training materials. When complete, mail to: **MOD Training Resource Center, DT49.** 

## TITLE/CODE OF LESSON: \_\_\_\_\_Guidance and Control Sensors

## SIZE OF AUDIENCE/CLASS: \_\_\_\_\_

### 1. How well did this lesson meet its purpose?

For each statement below, mark one box on the scale:

- a. The lesson objectives are clearly stated.
- b. The lesson objectives are clearly defined.
- c. The lesson effectively teaches skills and information.
- d. The lesson meets its purpose and objectives.

#### 2. How satisfying is the content of this lesson?

For each statement below, mark one box on the scale:

- a. The information is structured in a logical flow.
- b. The content is clear.
- c. The content is complete.
- d. The level of detail is correct for this information.
- e. The amount of information is effective.
- f. The graphics contribute to my understanding.

#### 3. How appealing was the presentation of this lesson?

For each statement below, mark one box on the scale:

- a. The overall presentation is appealing.
- b. The visuals chosen are appropriate for the lesson.
- c. The visuals make the information more interesting.
- d. The graphics are legibly reproduced.
- e. The audio/visual or print quality is good.

### 4. How valuable is this information?

For each statement below, mark one box on the scale:

- a. The lesson teaches skills and information I need.
- b. The lesson meets my expectations.
- c. This information is useful for later reference.
- d. I would recommend this lesson to others.

|      | Strongly<br>Disagre |  | Strongly<br>Agree |
|------|---------------------|--|-------------------|
|      | Strongly<br>Disagre |  | Strongly<br>Agree |
| son? | Strongl<br>Disagre  |  | Strongly<br>Agree |
|      | Strongl<br>Disagro  |  | Strongly<br>Agree |

#### PLEASE WRITE YOUR COMMENTS/QUESTIONS ON THE BACK OF THIS FORM. EXPLAIN ANY NEGATIVE ANSWERS IN SPECIFIC TERMS THANK YOU IN ADVANCE FOR YOUR ASSISTANCE!