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PRELIMINARY INPUT TO THE
SPACE SHUTTLE
REACTION CONTROL SUBSYSTEM
FAILURE DETECTION AND IDENTIFICATION
SOFTWARE REQUIREMENTS
(UNCONTROLLED)

by
E. Bergmann

January 1976
PRELIMINARY INPUT TO THE SPACE SHUTTLE REACTION CONTROL SUBSYSTEM FAILURE DETECTION AND IDENTIFICATION SOFTWARE REQUIREMENTS (UNCONTROLLED)

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Space Shuttle Orbiter
Orbital Flight Test
Level C
Functional Subsystem
Software Requirements Document

Part D
Redundancy Management

January 1976

Approved: [Signature]

The Charles Stark Draper Laboratory, Inc.
Cambridge, Massachusetts 02139
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Publication of this report does not constitute approval by the National Aeronautics and Space Administration of the findings herein. It is published only for the exchange and stimulation of ideas. Revisions of this report are expected to be published.
ABSTRACT

The current baseline method and software implementation of the Space Shuttle reaction control subsystem failure detection and identification (RCS FDI) system is presented. This algorithm is recommended for inclusion in the redundancy management (RM) module of the Space Shuttle Guidance, Navigation and Control System. Supporting software is presented, and recommended for inclusion in the system management (SM) and display and control (D&C) systems.

RCS_FDI uses data from sensors in the jets, in the manifold isolation valves, and in the RCS fuel and oxidizer storage tanks. A list of jet failures and fuel imbalance warnings is generated for use by the jet selection algorithm of the on-orbit and entry flight control systems, and to inform the crew and ground controllers of RCS failure status. Manifold isolation valve close commands are generated in the event of failed on or leaking jets to prevent loss of large quantities of RCS fuel.
The system description is as complete and detailed as current development allows.

Reference 1 presents rationales for the design, a description of hardware sensor devices, and descriptions of nominal operation of RCS FDI.

Section 1 of this report describes the functional requirements of the method. It contains a statement of the objective of RCS FDI, a list of assumptions governing design of the algorithm, the input-output requirements, and a brief functional description of the software.

Section 2 presents the software formulation of RCS FDI. First, a model executive for FDI is given, followed by the eight functional modules of RCS FDI. An assessment is made of core and timing requirements.

Section 3 contains a glossary of variable names in the software. Supporting data is included in the appendices.
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SECTION 1
SOFTWARE FUNCTIONAL REQUIREMENTS

1.1 Overview

The Flight Control (FC) module controls the attitude and translation of the space shuttle orbiter during the on-orbit mission phase and early in the entry phase by utilizing as effectors the Reaction Control Subsystem (RCS) and/or thrust vector control of the Orbital Maneuvering System (OMS).

In a normal RCS jet firing, the following sequence and delays can be expected:

1. Turn on
   (a) Issuance of on command by Jet Select.
   (b) Transport to driver - TBD milliseconds.
   (c) Opening of solenoids - < 10 milliseconds.
   (d) Thrust buildup to steady state - ~20 milliseconds.
   (e) Steady-state thrust.

2. Turn off
   (a) Issuance of off command by Jet Select.
   (b) Transport to RCS driver - TBD milliseconds.
   (c) Closure of solenoid valves - < 10 milliseconds.
   (d) Thrust tailoff to zero - ~20 milliseconds.

Several possibilities exist for anomalous behavior in either of these sequences leading up to failure. These include:

1. Communication failures.
2. Solenoid failures both opening, closing.
3. Failure to achieve normal chamber pressure.
4. Leakage.

Based on these considerations, failure types are broken up into two groupings, on failures and off failures. Although several subgroupings of these by cause exist, there are but two major types of FDI response; one for all on failures and another for all off failures.
An on failure occurs any time a jet is producing thrust or consuming propellant when not commanded or leaking. Since, in the strictest sense, this would include normal thrust tailoff, an on failure condition must consistently exist for a minimum period of time longer than that of normal thrust tailoff. On failures, then, may include failure of solenoids to close in response to off commands, excessively long tailoffs, or leaks. The current algorithm identifies on failures within 3 seconds.

Off failures are defined as a failure of an RCS thruster to develop thrust in response to an on command from the Jet Select. This could result from communication faults, accidental closure of isolation valves, jamming of either or both of the solenoids in the closed position, or a thruster structural failure. This current method detects off failures and identifies the failed jet in 120 milliseconds.

Nominal chamber-pressure and chamber-temperature histories have been obtained for the RCS jets in vacuum conditions. Changes in these conditions due to atmospheric effects during entry have not yet been determined, so that some parameter modifications in the FDI algorithm may be necessary.

The RCS FDI module will be contained primarily in the RM module, with interacting modules in the SM and D&C modules. Figure 1 shows the relationship of these modules to other GN&C major modules, and to sensors, effectors, controls, and displays.

These modules are scheduled by the Moding, Sequencing, and Control (MSC) software via the Flight Computer Operating System (FCOS).

RCS FDI is accomplished by two procedures in RM, with monitoring of manifold isolation valve positions, fuel/oxidizer ratios in the RCS tanks, and RCS command and feedback data path failures performed by three modules within SM, and crew interaction handled with two modules in D&C.

It is inaccurate, at this time, to refer to the RCS FDI executive as a module, as it is merely a conceptual model of the scheduling of the various RCS FDI modules. In fact, this scheduling will be accomplished by executives for the RM, SM, and D&C modules. However, it is presented here, as design requirements of RCS FDI dictate certain constraints on these executives, which are embodied in the RCS FDI executive.
Figure 1. Relation of RM, SM, GN&C, and DC to other flight software and hardware.
The interaction between RCS FDI, other modules, and the flight hardware are shown in Figure 2, and described in some detail in Reference 1.

Figure 2. Interaction of FDI with other modules and hardware.
1.2 RCS FDI Executive

The RCS FDI executive, as herein described, is a model for segments of the RM, SM, and D&C executives which will schedule RCS FDI. It is not intended that this be a specific software module, and it must be emphasized that it is presented for engineering purposes only. Actual implementation of software to schedule the various RCS FDI modules will be accomplished as part of the design of the RM, SM, and D&C executives.

In each minor cycle (and major cycle, as major cycles will coincide with each 25th minor cycle), the executive calls MONITOR_BTU_MAsk, OFFAIL, and MANIFOLD_CHECK. OFFAIL is scheduled on a minor cycle basis because it is quite fast, and such scheduling enables the most rapid possible detection of off failed RCS jets. MANIFOLD_CHECK is scheduled each minor cycle to meet the requirement that no RCS jet on a given manifold be fired 80 milliseconds after the closure of that manifold's isolation valves. Because of an uncertain lag in valve closure, and because the GPC has no other way of sensing manual manifold closure checks, MANIFOLD_CHECK cannot predict the closure times, and must therefore be executed each minor cycle. Running MONITOR_BTU_MAsk each minor cycle prevents the other procedures run each minor cycle from acting on erroneous data by disabling them within a minor cycle of detecting a communication failure.

STORE_FDI_INIT_DATA, OVERRIDE_UPDATE, ONFAIL, and FUEL_IMBALANCE are each run no more frequently than every major cycle to minimize computer burden.

The tradeoff is that STORE_FDI_INIT_DATA provides initialization data which may be as stale as one major cycle, manual interactions with RCS FDI will take one major cycle to be implemented, and on failures of RCS jets will exist for two major cycles before detection. It is held that the first two penalties are readily ignored, and that the cost of running ONFAIL each major cycle (rather than each minor cycle) will be an acceptably small loss of RCS propellant.

Since the rate of depletion of the RCS propellant tanks is so small during normal RCS activity or leaks, FUEL_IMBALANCE can safely be run each major cycle, and it may be safe to execute it at a lower frequency if timing considerations so dictate.
In the presence of a communication fault, the FDI executive inhibits STORE_FDI_INIT_DATA to maintain the initialization data stored on the last major cycle before the communication failure. The executive also inhibits OVERRIDE_UPDATE except on those major cycles when the D&C SOP indicates a new override, inhibit, or enable command has been keyed in. The procedure RECHECK_ONFAILS is only scheduled when ONFAIL indicates a jet is newly on failed and requires checking.

1.3 RCS FDI
1.3.1 Objective
The RCS FDI detects and identifies RCS failures and off-nominal performance, and takes appropriate action. This action consists of sending a list of failed jets to the RCS jet selection algorithm, closing manifold isolation valves where a leak is detected, and informing the crew and ground controllers of RCS performance.

1.3.2 Assumptions
The following assumptions are made about inputs to RCS FDI:

(1) Driver talkbacks, jet commands, chamber-pressure talkbacks, and manifold isolation valve commands and talkbacks will be packed discretes channelized as in Appendix A and available to FDI in the concatenated form shown in Appendix A.

(2) RCS leak detector talkbacks will be available in 16-bit fixed-point format as in Appendix B, and can be treated as bit strings, i.e., operated upon by logical AND.

(3) Inputs from D&C will be packed as described in Appendix A, and preceded by appropriate flags (Section 2.3.3).

The following assumptions are made about RCS FDI output:

(1) Jet fail lists will be produced in packed form, bit assignments jet by jet being as those for jet commands.

(2) Manifold isolation valve commands are packed as in Appendix A.

(3) Interfacing software will be developed to reformat RCS FDI data for crew display and telemetry.

It is further assumed that the sensors and actuators used by RCS FDI are completely reliable, pending further study.

This software may be included in a later revision of this document.
1.3.3 Input/Output Requirements

Table 1 lists the interface requirements for RCS FDI.

1.3.3.1 Inputs

Inputs to RCS FDI are:

1. Copies of packed RCS jet commands concatenated as in Reference 2.
2. Packed chamber pressure discretes.
3. Packed driver talkback discretes.
4. Packed isolation manifold discretes.
5. Packed manual overrides, inhibits, enables.
6. RCS fuel and oxidizer tank quantities.

1.3.3.2 Outputs

Outputs of RCS FDI are:

1. Jet fail lists packed the same way as the input jet commands.
2. Manifold isolation valve automatic close commands.
3. Fuel imbalance warning flags.

1.3.4 Functional Description

The RCS FDI algorithm compares packed discretes representing jet commands, jet chamber pressures and jet driver talkbacks, and integers representing jet fuel injector and jet oxidizer injector temperature, to arrive at a list of failed jets. In the event of leaks, it can automatically close manifold isolation valves to prevent the loss of fuel and oxidizer.

1.3.4.1 MONITOR_BTU_MASK

MONITOR_BTU_MASK checks eight discretes which indicate failure status of critical cards in the MDM used to control the RCS jets. When one of these discretes goes on, MONITOR_BTU_MASK inhibits the Jet Select from using the jets commanded via that data path, and issues a close command to the manifold controlled via that card. The state of RCS FDI at the last major cycle before the failure is kept for use in reinitializing FDI after the data path failure. When the flags are all down, reinitialization of RCS FDI using that data is commanded by MONITOR_BTU_MASK.
Table 1. RCS FDI interface requirements.

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<th>COMPUTER NAME</th>
<th>SOURCE OR DESTINATION</th>
<th>DESCRIPTION</th>
<th>UNITS</th>
<th>VALUE OR RANGE</th>
<th>SAMPLE RATE (Hz)</th>
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<td>Percent</td>
<td>0-109</td>
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*Pending design of IOPs.
1.3.4.2 STORE_FDI_INIT_DATA

STORE_FDI_INIT_DATA snapshots the failure list, the overrides from crew input, and the automatic manifold isolation valve close commands each major cycle, for use in reinitializing RCS FDI after an MDM card failure. Since it is inhibited in the presence of the failure, the data it provides for reinitialization will not reflect any errors in RCS FDI due to data errors caused by the failure.

1.3.4.3 OVERRIDE_UPDATE

OVERRIDE_UPDATE receives crew requests to inhibit, reenable, and manually override RCS fail status. It ensures that mutually exclusive requests are not implemented, and builds a list of which jets are to be added to the fail list, and which are to be deleted due to crew requests.

1.3.4.4 OFFAIL

OFFAIL detects failures of jets to fire in response to on commands from the jet selection software. It compares these on commands with chamber pressure discreet generated by pressure sensors and level detection equipment in the hardware. When a jet is commanded on but shows no chamber pressure for three consecutive minor cycles, OFFAIL adds it to the fail list, unless it is manually overridden by the crew.

1.3.4.5 ONFAIL

ONFAIL detects leaks in RCS jets, and jet firings occurring in the absence of jet on commands (i.e., failures to shut off). ONFAIL first compares the temperature of the fuel and oxidizer injectors with a 30°F threshold. If either temperature is below this valve, or if the driver talkback is on and the jet command is off, for two consecutive major cycles, ONFAIL adds the jet to the fail list, and flags it for recheck.

1.3.4.6 RECHECK_ONFAILS

One major cycle after ONFAIL flags jets, they are checked for driver on talkbacks or leaks by RECHECK_ONFAILS. If those jets continue to show leaks or drivers on, RECHECK_ONFAILS issues a command to close the isolation valve on the manifold feeding fuel and oxidizer to those jets.
1.3.4.7 **MANIFOLD CHECK**

**MANIFOLD CHECK** examines the manifold isolation valve open talkbacks each minor cycle. If one such talkback was on (open) but goes off indicating partial or total closure of the valve, **MANIFOLD CHECK** copies the failure status of the jets on that manifold, then adds all the jets on that manifold to the fail list. If one such talkback goes from off (closed) to on, **MANIFOLD CHECK** deletes from the fail list those jets on the manifold that were not failed prior to manifold closure.

1.3.4.8 **FUEL IMBALANCE**

**FUEL IMBALANCE** checks the percentage of fuel and oxidizer remaining in the tanks of each of three RCS modules. If the difference between the fuel percentage remaining and the oxidizer percentage remaining exceeds 1.6, **FUEL IMBALANCE** sets a warning flag for that RCS module which is displayed to the crew. The procedure then picks the lesser of fuel or oxidizer in each module and provides it as the critical quantity to the crew display.
SECTION 2

SOFTWARE FORMULATION

2.1 RCS FDI EXECUTIVE (see automatic flowchart)

The software herein described is only a working model for software in the RM, SM, and D&C executives and is only presented as a conceptual model.

The FDI EXECUTIVE will either be executed each minor cycle, or will check a flag which will trigger it each minor cycle. The latter is implemented for generality. On a minor cycle, the FDI EXECUTIVE calls MONITOR_BTU_MASK, OFFAIL, and MANIFOLD_CHECK. A flag indicating a major cycle is next checked. On a major cycle, STORE_FDI_INIT_DATA and OVERRIDE_UPDATE are called, subject to conditions described in Section 1.2. FUEL_IMBALANCE is called every major cycle.
MODEL FOR SCHEDULING IN RM, SM, DSC

IF MINOR_CYCLE = ON

THEN CALL OVEAL;

CALL MANIFOLDCHECK;

IF MAJOR_CYCLE = ON

THEN

IF (CALL INIT OR INIT OVERRIDE UPDATE = ON) OR (CALL INIT OR INIT OVERRIDE UPDATE = OFF)

THEN CALL STORE?DI_ INIT DATA: OR EMIT OFFAIL OR INIT ONFAIL = OFF

IF MAJOR_CYCLE = ON

THEN CALL MONITOR 1T2 MASK;

CALL STORE?DI_ INIT DATA:
* IF (INIT_OVERRIDE_UPDATE OR CHANGE_OVERRIDE_STATUS) = ON
* THEN 10

* IF (RECHECKA OR RECHECKB OR RECHECKC )
* THEN CALL RECHECK_ONFAILS:
* OR (RECHECK) NOT = 'CO'

* CALL UNFAIL:

* CALL FUEL_IMBALANCE:
CALL CVEI_RIDE_UPDATE;
2.2 RCS FDI

2.2.1 MONITOR_BTU_MASK (see automatic flowchart)

MONITOR_BTU_MASK checks eight flags called BTU_MASKs, which indicate failures in the hardware communication paths between the GPC and the RCS hardware. Each flag corresponds to an MDM, and if it is on, is assumed to indicate failure of all data paths on that MDM.

When a BTU_MASK goes on, the procedure adds the jets commanded through that MDM to the fail list, and issues a close command to the manifold isolation valve controlled through that MDM. The temporary flag CALL_INIT is set on. MONITOR_BTU_MASK then checks CALL_INIT. If it is on, the procedure checks the eight BTU_MASKs. When all eight are again off, the procedure sets initialization flags for OVERRIDE_UPDATE, ONFAIL, and OFFAIL, and sets CALL_INIT off.
CICSES A MANIFOLD AND J176 ON MDM INDICATING COMM FAULT
CHANNELIZATION ASSUMED WILL HAVE TO CHECK

*******
* IF BTU_FF01.13 = ON *
** **
*******

*******
** IF BTU_FF01.05 = ON *
** **
*******
* IF ETU_FA01_02 = ON THEN *

* MANCOMC = MANCOMC OR MAP_MANCOMC OR *

3: *

* MAP_MANCOMC ;

4: *

* JFAILC = JFAILC OR BIN(16)'0' || BIN( *

16)'1';

* CALL_INIT = ON;

*****************************************************************************

* IF ETU_FA0J_10 = ON THEN *

* MANCOMD = MANCOMD OR MAP_MANCOMD OR *

1: *

* MAP_MANCOMD ;

2: *

* JFAILD = JFAILD OR BIN(16)'0' || BIN( *

16)'1';

* CALL_INIT = ON;

*****************************************************************************
********
* 25 *
********

* INIT_OVERRIDE_UPDATE = ON; *
* INIT_ONFAIL = ON; *
* INIT_OFFAIL = ON; *
* CALL_INIT = OFF; *

**********
2.2.2 **STORE_FDI_INIT_DATA (see automatic flowchart)**

STORE_FDI_INIT_DATA maintains a record of the jet failure list, the overrides, and the automatic manifold isolation valve close commands. Each time it is called, the procedure copies these items into separate storage locations, used only for initialization of the RCS FDI software.
TO BE CALLED ONCE PER MAJOR CYCLE

******************************************************************
* GOCL_JFAILA = JFAILA;
* GOCL_JFAILB = JFAILB;
* GOCL_JFAILC = JFAILC;
******************************************************************

******************************************************************
* GOCL_JFAILD = JFAILD;
******************************************************************

******************************************************************
* GOCL_CFF_OVERRIDE_A = CFF_OVERRIDE_A;
* GOCL_CFF_OVERRIDE_B = CFF_OVERRIDE_B;
* GOCL_CFF_OVERRIDE_C = CFF_OVERRIDE_C;
* GOCL_CFF_OVERRIDE_D = CFF_OVERRIDE_D;
******************************************************************

******************************************************************
* GOCL_CN OVERRIDE_A = CN_OVERRIDE_A;
* GOCL_CN OVERRIDE_B = CN OVERRIDE_B;
* GOCL_CN OVERRIDE_C = CN OVERRIDE C;
* GOCL_CN OVERRIDE D = CN OVERRIDE D;
******************************************************************
2.2.3 OVERRIDE_UPDATE (see automatic flowchart)

This procedure implements crew inputs to inhibit, override, and reenable RCS jets.

Initialization of this procedure consists of replacing the current override lists with copies of the lists provided by STORE_FDI_INIT_DATA.

Each time it is called, the procedure generates the lists ON_OVERRIDE and OFF_OVERRIDE for use by other RCS FDI software, and modifies the fail list to include temporary enables. ON_OVERRIDE _A, _B, _C, and _D are updated by ORing ON_OVERRIDE with the requests to reenable jets (NEW_ON_OVERRIDE) regardless of FDI, then ANDing the result with the complement of the inhibit requests (NEW_OFF_OVERRIDE), thus including the new requests to reenable jets, and preventing a conflict with the new requests to inhibit jets.

Similarly, OFF_OVERRIDE _A, _B, _C, and _D are updated by ORing OFF_OVERRIDE with the requests to inhibit jets, then ANDing the result with the complement of requests to reenable jets, thus including new inhibits, and preventing conflicts with new reenables.

JFAIL is then modified to incorporate requests to reenable jets, while still performing FDI on them. This is done by ORing JFAIL with these requests (TEMP_ON_OVERRIDE).
CN_OVERRIDE = OFF OVERRIDE C OR OVERRIDE D AND (NOT OVERRIDE C);
CFF OVERRIDE A = OFF OVERRIDE A OR INHIBIT A AND (NOT OVERRIDE A);
CFF OVERRIDE B = OFF OVERRIDE B OR INHIBIT B AND (NOT OVERRIDE B);
CFF OVERRIDE C = OFF OVERRIDE C OR INHIBIT C AND (NOT OVERRIDE C);
CFF OVERRIDE D = OFF OVERRIDE D OR INHIBIT D AND (NOT OVERRIDE D);

JFAILA = JFAILA AND (NOT OVERRIDE A);
JFAILB = JFAILB AND (NOT OVERRIDE B);
JFAILC = JFAILC AND (NOT OVERRIDE C);
JFAILD = JFAILD AND (NOT OVERRIDE D);

CHANGE OVERRIDE STATUS = OFF;
2.2.4 **OFFAIL (see automatic flowchart)**

OFFAIL detects failures of jets to fire in response to "ON" commands from the GPC.

Upon initialization, OFFAIL replaces the jet fail list with the fail list stored by STORE_FDI_INIT_DATA, and zeroes the first slot in its pushdown list.

Each time it is called, OFFAIL first advances its three-level pushdown lists OFA, OFB, OFC, and OFD. That is, the jets in the second slot are moved into the third slot, and those in the first slot are moved into the second. OFFAIL then moves into the first slot those jets which are commanded on but whose pressure transducer talkbacks are off. OFFAIL adds to the jet fail list those jets which appear in all three slots by ORing those three slots with the fail list. Finally, OFFAIL implements the reenable command by ANDing the jet fail list with the complement of ON_OVERRIDE.
MAY WANT TO CALL OTHER MINCH CYCLE STUFF FROM HERE TO
SAVE CONFLICT CHECKING

*********              THEN ***********
* IF INIT_OFFAIL = ON   * JFAILA = GOOD_JFAILA; *
*                     * JFAIIB = GOOD_JFAIIB; *
*                     * JFAIIC = GOOD_JFAIIC; *
*                     * JFAIIL = GOOD_JFAIIL; *
*                     * JERICA = BIN(32)'0'; *
*                     * QF81 = BIN(32)'0'; *
*                     * QF82 = BIN(32)'0'; *
*                     * INIT_OFFAIL = OFF; *
*                      ***********
**GFC3 = CFC2;
**
**OFD3 = CFD2;
**
**CFA2 = CFA1;
**
**GFH2 = CFB1;
**
**CFA2 = CFA1;
**
**CFC2 = CFC1;
**
**CFA1 = JETCCMA AND (NCT PRESSA);
**
**OFB1 = JETCCMB AND (NCT PRESSB);
**
**GFC2 = JETCCMC AND (NCT PRESSC);
**
**GFD1 = JETCCMD AND (NCT PRESSD);**
C. S. DRAPER LABORATORY AUTOMATIC FLOWCHART OF PROCEDURE OFFAIL

**LNOT FAIL JETS CYLWILLEN AS GCOD**

```
* JFAILA = (JFAILA CR CFA AND CFA2 AND
* CFA1) AND (NOT ON_OVERRIDE_A);  
* JFAILB = (JFAILB CR CFE3 AND CFE2 AND
* CFB1) AND (NOT ON_OVERRIDE_B);  
* JFAILC = (JFAILC CR CFC3 AND CFC2 AND
* CFC1) AND (NOT ON_OVERRIDE_C);  
* JFAILD = (JFAILD CR CFD3 AND CFD2 AND
* CFD1) AND (NOT ON_OVERRIDE_D);  
```
2.2.5 ONFAIL (see automatic flowchart)

ONFAIL detects failures of jets to shut off in response to off commands, spurious RCS firings, and RCS fuel and oxidizer leaks within the jets.

Upon initialization, ONFAIL sets the automatic manifold isolation valve close commands equal to the good copies from STORE_FDI_INIT_DATA.

Each pass, ONFAIL checks leak detector outputs, combines them with driver talkbacks, checks for failed on jets, and flags such jets for rechecking.

To check leak detector output, ONFAIL treats each output as a string of 16 bits. It ANDs each output with a mask representing the logical complement of a 31°F output (BIN '1111111111000000'). Since the transition from 30°F to 31°F occurs in the bit strings as BIN '0000000000111111' to BIN '0000000000100000', the result will be BIN '0000000000000000' if the indicated temperature is below 31°F, the condition for a leak. If this occurs for either the fuel or oxidizer injector temperature sensor, ONFAIL sets the software copy of the driver talkback to on (or leaves it on if it is already so).

Having completed this, ONFAIL loads into the first slot of its pushdown list (NEWFAIL) those jets not commanded on, but whose driver talkbacks are on and which have not been previously failed by ONFAIL, by ANDing the driver talkbacks with the logical complement of the jet commands ORed with the previous fail data. ONFAIL then adds to the fail list, and flags for recheck, those jets which are in both slots of the pushdown list. Finally, ONFAIL advances its pushdown list for the next pass, by loading entries from the first slot into the second slot.
C. S. DEARER LABORATORY AUTOMATIC FLOWCHART OF PROCEDURE ONFAIL


* * *

**PROCEDURE:**

**THEN**

* IF INIT_ONFAIL = ON

* MANCOMA = GOOD_MANCOMA;

* MANCOMB = GOOD_MANCOMB;

* MANCOMC = GOOD_MANCOMC;

* MANCOMD = GOOD_MANCOMD;

* INIT_ONFAIL = OFF;

* * *
DO FOR I = 1 TO 8 BY 1;

IF ((FLEAK AND MASK_THRESHOLD) = HEX'0') THEN

DO FOR I = 9 TO 16 BY 1;

IF ((FLEAK AND MASK_THRESHOLD) = HEX'0') THEN

DO FOR I = 17 TO 30 BY 1;

IF ((FLEAK AND MASK_THRESHOLD) = HEX'0') THEN
WORL E

* DO FOR I = 31 TO 44 BY 1; *

* IF ((FLA EAK AND MASK_THRESHOLD) = HEX '0') *
  * I:

* OR ((FLA EAK AND MASK_THRESHOLD) = HEX '0') *
  * I:

* ***************************************************
C. S. DRAPER LABORATORY AUTOMATIC FLOWCHART OF PROCEDURE ONFAIL


NEWFAILA = DRIVER AND NOT (JETCCMA OR PREV_FAILA);

NEWFAILB = DRIVER AND NOT (JETCCMB OR PREV_FAILB);

NEWFAILC = DRIVER AND NOT (JETCCMC OR PREV_FAILC);

NEWFAILD = DRIVER AND NOT (JETCCMD OR PREV_FAILD);

RECHECKA = NEWFAILA AND OLDFAILA;

RECHECKB = NEWFAILB AND OLDFAILB;

RECHECKC = NEWFAILC AND OLDFAILC;

RECHECKD = NEWFAILD AND OLDFAILD;

JFAILA = JFAILA OR RECHECKA;

JFAILB = JFAILB OR RECHECKB;

JFAILC = JFAILC OR RECHECKC;

JFAILD = JFAILD OR RECHECKD;

***********************
2.2.6 **RECHECK_ONFAILS** *(see automatic flowchart)*

RECHECK_ONFAILS examines those jets which have been added by ONFAIL to the jet fail list on the previous major cycle, and closes the manifold isolation valves for those jets which still indicate leaks, or whose driver talkbacks remain on. The procedure then flags as previously rechecked, those jets currently flagged for rechecking, by ORing PREV_FAIL and RECHECK.
C. S. DRAPER LABORATORY AUTOMATIC FLOWCHART OF PROCEDURE RECHECK_ONFAILS


```plaintext
* *************************************************************
* IF (NEWFAILC AND RECHECKC AND MAP = L+8) THEN ***************
* * NOT = HXI'O
* *************************************************************

* *************************************************************
* IF (NEWFAILD AND RECHECKD AND MAP = L+12) THEN ***************
* * NOT = HXI'O
* *************************************************************

* **************************************************************************
* PREV_FAILA = PREV_FAILA OR RECHECKA;
* **
* PREV_FAILB = PREV_FAILB OR RECHECKB;
* **
* PREV_FAILC = PREV_FAILC OR RECHECKC;
* **
* PREV_FAILD = PREV_FAILD OR RECHECKD;
* **************************************************************************
```
2.2.7 MANIFOLD_CHECK (see automatic flowchart)

MANIFOLD_CHECK compares the manifold isolation valve OPEN talkbacks with their values on the last pass through MANIFOLD_CHECK. If a manifold isolation valve OPEN talkback changes from OFF to ON, the jets on that manifold not failed prior to valve closure are deleted from the jet fail list, by ANDing JFAIL and the complement of REINSTATE for this manifold.

If a manifold isolation valve OPEN talkback changes from ON to OFF, MANIFOLD_CHECK does the following. First, a record of the jets on the manifold which are not failed at the time of manifold closure is made by ANDing the complement of the jet fail list with a map of the jets on this manifold. Next, the map of the jets on this manifold is ORed with the jet fail list to add those jets to the fail list. Finally, the complement of the map of jets on this manifold is ANDed with ON OVERRIDE A to prevent RCS FDI deleting those jets from the fail list while the manifold isolation valve is closed.

MANIFOLD_CHECK then ORs the OFF OVERRIDEs with the fail list to implement the crew inhibit function. Finally, a copy of the current manifold isolation valve OPEN talkbacks is stored for use on the next pass.
I

C. S. DRAPER LABORATORY AUTOMATIC FLOWCHART OF PROCEDURE MANIFOLD_CHECK

JANUARY 21, 1976.

22:40:31.56.

************

* ELSE DO:

* IF XOR (IVCB, OLD_IVCB) NOT = R16(16) '0'

* THEN DO:

************

* DO FOR I = 1 TO 4:

************

* IF IVCB = ON

* MAP_IVCB

* THEN ************

* JFAILB = JFAILB AND NOT REINSTATE:

* I:

************

ELSE ************

************

* [REINSTATE] = MAPB AND NOT JFAIL:

* I:

************

* JFAILB = JFAILB OR MAPB:

* I:

************

* ON OVERRIDE_B = ON OVERRIDE_B AND NOT

* I:

* MAPB:

* I:

************

END;

ELSE DO;

* IF XOR (IVGC, OLD_IVGC) NOT = R16(16) '0'

* THEN DO;

************
**DO FOR I = 1 TO 4:**

**IF IVOC = ON THEN**

* MAP_IVOC = I

**ELSE**

* MAP_IVOC = I

**END:**

**DO FOR I = 1 TO 4:**

**IF IVOD = ON THEN**

* MAP_IVOD = I

**ELSE**

* MAP_IVOD = I

**END:**
ELSE

* REINSTATED = MAPD AND NOT JFAILD; *
* I:*
* I:*
* *
* JFAILD = JFAILD OR MAPD ; *
* I:*
* I:*
* *
* ON_OVERRIDE_D = ON_OVERRIDE_E AND NOT *
* *
* *
* MAPD : *
* I:*

******************************************************************************

* END;
* *
* END;
* *
* END;
* *
* END;
* *
* JFAILA = JFAILA OR OFF_OVERRIDE_A;
* *
* JFAILB = JFAILB OR OFF_OVERRIDE_B;
* *
* JFAILC = JFAILC OR OFF_OVERRIDE_C;
* *
* JFAILD = JFAILD OR OFF_OVERRIDE_D;
* *
* CLL_IVGA = IVGA;
* *
* CLL_IVGB = IVOB;
* *
* CLL_IVGC = IVOC;
* *
* CLL_IVGD = IVOD;

******************************************************************************
2.2.8 FUEL_IMBALANCE (see automatic flowchart)

FUEL_IMBALANCE receives fuel quantities and oxidizer quantities in the RCS tanks in each of the three RCS modules. These quantities are expressed as percent of tank capacity. The procedure compares the quantities, and also compares their difference to a preset threshold. If the magnitude of the difference between the percentages is greater than 1.6, an imbalance flag is set. FUEL_IMBALANCE then decides whether the remaining oxidizer in each module is less than the fuel quantity remaining in that module. If so, it flags the oxidizer as the lesser quantity, and provides it for display. Otherwise, it flags the fuel quantity and makes it similarly available.
CHECKS RATIO OF FUEL QUANTITY TO OXY QUANTITY IN EACH OF THREE PAIRS OF TANKS AND FLAGS IMBALANCE TO WARN CREW.

***************
* {FUEL_IMBALANCE_FLAG} = OFF; *
***************
DO FOR I = 1 TO 3; 

* IF ABS(OXY_QUANTITY - FUEL_QUANTITY) > * 
**imbalance_threshold** 
* then ********* 
* fuel_imbalance_flag = on; 
* 

**else** *********** 

**if OXY_QUANTITY > FUEL_QUANTITY** 
* then ****************** 
* MIN_QUANTITY = FUEL_QUANTITY; 
* 

**else** *********** 

**if OXY_QUANTITY > FUEL_QUANTITY** 
* then ****************** 
* MIN_QUANTITY = OXY_QUANTITY; 
* 

**else** ***********
2.2.9 Core Requirements and CPU Time

The timing and core requirements (Table 2) for RCS FDI are estimates based on results of compilation by the HAL/S and HAL/F compilers (HAL/S release 14.0 of 16 Dec. 75, HAL/F release 10.0 of 16 Dec. 75). They are not to be taken as final values, as studies of code and timing optimization are still in progress, and requirements levied on RCS FDI are in a state of flux.

Table 2. Approximate RCS FDI CPU times and burden (minor cycle = 0.04 s, major cycle = 1.0 s).

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Portion</th>
<th>Case</th>
<th>Time (μs)</th>
<th>%CPU</th>
</tr>
</thead>
<tbody>
<tr>
<td>FDI_EXEC</td>
<td></td>
<td>minor cycle</td>
<td>22.8</td>
<td>0.057</td>
</tr>
<tr>
<td></td>
<td></td>
<td>major cycle, worst</td>
<td>66.1</td>
<td>0.165</td>
</tr>
<tr>
<td>MONITOR_BTU_MASK</td>
<td></td>
<td>no BTU_MASKs on</td>
<td>103.0</td>
<td>0.258</td>
</tr>
<tr>
<td></td>
<td></td>
<td>worst</td>
<td>296.9</td>
<td>0.742</td>
</tr>
<tr>
<td>STORE_FDI_INIT_DATA</td>
<td>all</td>
<td>all</td>
<td>81.4</td>
<td>0.0081</td>
</tr>
<tr>
<td>OVERRIDE_UPDATE</td>
<td>init</td>
<td>each pass</td>
<td>40.6</td>
<td>0.0041</td>
</tr>
<tr>
<td></td>
<td>all but init</td>
<td>each pass</td>
<td>122.6</td>
<td>0.012</td>
</tr>
<tr>
<td>OFFAIL</td>
<td>init</td>
<td>each pass</td>
<td>34.9</td>
<td>0.087</td>
</tr>
<tr>
<td></td>
<td>all but init</td>
<td>each pass</td>
<td>114.3</td>
<td>0.286</td>
</tr>
<tr>
<td>RECHECK_ONFAILS</td>
<td>one fail,</td>
<td>one change,</td>
<td>308.3</td>
<td>0.03083</td>
</tr>
<tr>
<td></td>
<td>close manifold</td>
<td>longest path through code</td>
<td>151.2</td>
<td>0.01512</td>
</tr>
<tr>
<td>ONFAIL</td>
<td>init</td>
<td>one leak</td>
<td>26.2</td>
<td>0.00262</td>
</tr>
<tr>
<td></td>
<td>all but init</td>
<td>one leak</td>
<td>924.8</td>
<td>0.09255</td>
</tr>
<tr>
<td>MANIFOLD_CHECK</td>
<td>one change,</td>
<td>one change,</td>
<td>350.1</td>
<td>0.876</td>
</tr>
<tr>
<td></td>
<td>longest path</td>
<td>longest path through code</td>
<td>151.2</td>
<td>0.01512</td>
</tr>
<tr>
<td>FUEL_IMBALANCE</td>
<td>worst</td>
<td></td>
<td>151.2</td>
<td>0.01512</td>
</tr>
</tbody>
</table>

Core requirements
- Program: 575 whole words
- Data: 285 whole words
Table 3 describes all variables and constants used in RCS FDI. The entries are listed alphabetically by computer name.
Table 3. RCS FDI glossary.

<table>
<thead>
<tr>
<th>Computer Name</th>
<th>Type/Attribute</th>
<th>Description</th>
<th>Units</th>
<th>Value Range</th>
<th>Declared In</th>
<th>Assigned In</th>
<th>Referenced In</th>
</tr>
</thead>
<tbody>
<tr>
<td>ON_OVERRIDE_A</td>
<td>Bit(32)</td>
<td>List of jets to be deleted from fail list by crew</td>
<td></td>
<td>TBD</td>
<td>COMPOOL</td>
<td>HRNRE/IOP</td>
<td>ONFAIL</td>
</tr>
<tr>
<td>ON_OVERRIDE_B</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ON_OVERRIDE_C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ON_OVERRIDE_D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OXY_QUANTITY</td>
<td>Array(3)/</td>
<td>Oxidizer remaining in RCS tanks</td>
<td>percent</td>
<td>0-109</td>
<td>COMPOOL</td>
<td>RCS_PVT</td>
<td>FUEL_IMBALANCE</td>
</tr>
<tr>
<td></td>
<td>Integer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRESSA</td>
<td>Bit(32)</td>
<td>Packed jet chamber pressure sensor talkbacks</td>
<td></td>
<td>ON/OFF</td>
<td>COMPOOL</td>
<td>HRNRE/IOP</td>
<td>OFFAIL</td>
</tr>
<tr>
<td>PRESSB</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRESSC</td>
<td></td>
<td></td>
<td></td>
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Table 3. RCS FDI glossary (Cont.).

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<td>MSGC, MONITOR_BTU_MASK</td>
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Table 3. RCS FDI glossary (Cont).

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**Type/Attribute:**
- Array(4)/Integer
- Array(44)/Bit(32)
- Bit(16)
- Bit(32)
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<tr>
<td>BTU_PAO3_O2</td>
<td>Bit(1)</td>
<td>Flags indicating MDM data path failures</td>
<td></td>
<td>ON/OFF</td>
<td>COMPOOL</td>
<td>FCS</td>
<td>MONITOR_BTU_MASK</td>
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<td>BTU_PAO1_10</td>
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<tr>
<td>CALL_INIT</td>
<td>Bit(1)</td>
<td>Internal flag denoting MDM failure has occurred</td>
<td></td>
<td>ON/OFF</td>
<td>MONITOR_BTU_MASK</td>
<td>MONITOR_BTU_MASK</td>
<td>MONITOR_BTU_MASK</td>
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<td>CHANGE_OVERRIDE_STATUS</td>
<td>Bit(1)</td>
<td>Flag indicating a crew entry to OVERRIDE_UPDATE</td>
<td></td>
<td>ON/OFF</td>
<td>COMPOOL</td>
<td>D&amp;C SOP</td>
<td>OVERRIDE_UPDATE</td>
</tr>
<tr>
<td>DRIVER_A</td>
<td>Bit(32)</td>
<td>Packed jet driver talkbacks</td>
<td></td>
<td>ON/OFF</td>
<td>COMPOOL</td>
<td>HNWE/ICP</td>
<td>ONFAIL</td>
</tr>
<tr>
<td>DRIVER_B</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRIVER_C</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRIVER_D</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FLEAK</td>
<td>Array (44)/Bit(16)</td>
<td>Output of jet fuel injector temperature sensors</td>
<td>°F</td>
<td>TBD</td>
<td>COMPOOL</td>
<td>HNWE/ICP</td>
<td>ONFAIL</td>
</tr>
<tr>
<td>FUEL_IMBALANCE_FLAG</td>
<td>Array(3)/Bit(1)</td>
<td>Flags indicating fuel imbalances in RCS tanks</td>
<td></td>
<td>ON/OFF</td>
<td>COMPOOL</td>
<td>FUEL_IMBALANCE</td>
<td>D&amp;C SOP</td>
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<tr>
<td>FUEL_QUANTITY</td>
<td>Array(3)/Integer</td>
<td>Fuel remaining in RCS tanks</td>
<td>percent</td>
<td>0-109</td>
<td>COMPOOL</td>
<td>RCS_PVT</td>
<td>FUEL_IMBALANCE</td>
</tr>
</tbody>
</table>
APPENDIX A

FORMAT OF FDI INPUT-OUTPUT DISCRETES

Certain of the input discretes and output discretes are packed for FDI processing in groups of four 32-bit strings, designated by the letter A, B, C, or D terminating the name (e.g., JETCOMA, JETCOMB, JETCOMC, JETCOMD). Those discretes which are so arranged include the following:

(1) Manifold isolation valve close commands
(2) Manifold isolation valve open talkbacks
(3) Lists of bit assignments
(4) Lists of manual override requests
(5) Lists of inhibit requests
(6) Jet commands
(7) Jet driver talkbacks
(8) Jet chamber pressure sensor talkbacks
(9) Jet fail list
(10) Jet reenable requests
(11) Previous fail flags
(12) Recheck flags
(13) Lists of jets failed prior to manifold isolation valve closure

The reason for so packing these discretes involves consideration of storage access and CPU time burdens.

One of the desirable properties of any flight code dealing with discretes generated in hardware is that minimal repacking of these discretes be performed. To realize this, the code should operate on strings of bits channelized as they are in the MDM.
It was found that this data would be in eight strings of 16 bits (one AP101 half word). Thus, an operation on all the jet commands, for instance, would be performed as eight half-word instructions. Since many such operations are performed, and since the difference in timing between a half-word instruction and whole-word instruction was small or zero, these eight half words were concatenated into four whole words and then processed. The tradeoff is the time required to perform four concatenations, against performing each operation on twice as many bit strings. Currently, the design favors concatenation, hence the representation of each set of discretes in four whole words.

These four whole words could be stored as an array, or stored in four independent locations as currently done. There is no difference in storage requirements. However, there is a tradeoff between writing code for the strings as DO loops on array members, and replicated code on four independent addresses. Clearly, less code is required for the DO loop, but the current implementation of array addressing makes this time-inefficient for small arrays. Thus, while there is a greater core penalty for the four replications of each instruction, there is a significant saving in execution time. Studies into this tradeoff are currently underway, and should be reflected in subsequent releases of this document.

The MDM channelization of these discretes may be found in either Reference 1 or Reference 2. In general, the assignments by jet for the four words obtained by concatenation are:

<table>
<thead>
<tr>
<th>BIT</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>BIT</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>112</td>
<td>122</td>
<td>211</td>
<td>231</td>
<td>16</td>
<td>132</td>
<td>144</td>
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<td>113</td>
<td>123</td>
<td>213</td>
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<td>135</td>
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<tr>
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<td>116</td>
<td>126</td>
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<td>19</td>
<td>146</td>
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<td>336</td>
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<td></td>
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<td>357</td>
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<td>11</td>
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<td></td>
<td>15</td>
<td></td>
<td></td>
<td>31</td>
<td></td>
</tr>
</tbody>
</table>
Leak detection in the RCS jets is accomplished by measuring the temperature at the fuel and oxidizer injector of each jet and comparing them with a threshold temperature. As leaking RCS fuel and oxidizer would very quickly cool the injectors, a leak is indicated by the sensor output being below the threshold temperature. This data comes through the MDM as 9 bits of fixed-point data, padded to a 16-bit integer in the GPC registers.

While the HAL compiler has means of comparing the size of two numbers, it was believed quicker to mask the output with a threshold, and test the result as zero or nonzero.

This implies the format of these sensor outputs must be such that they can be treated as bit strings, and particularly can be operated upon by the logical AND. There is no conversion from integer format to bit string, so by assuming the data enters the GPL as integer, there is a great saving in code.
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NASA/JSC
Houston, Texas 77058

JM86 (60)
Publications Distribution

BC28 (1)
J. Ford

BM2 (3)
C. Grant

MC2 (1)
J. Prejean

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