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Research and Development for Onboard Navigation (ONAV) Ground Based Expert/Trainer System

Preliminary Ascent Knowledge Requirements

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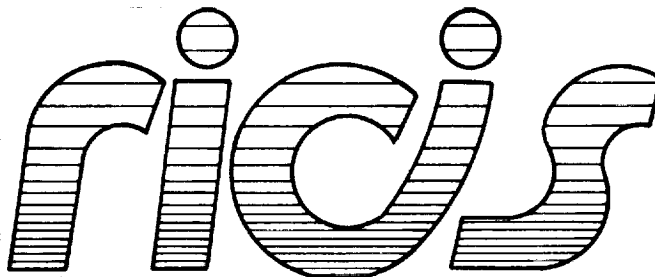
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*Research Institute for Computing and Information Systems
University of Houston - Clear Lake*

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The RICIS Concept

The University of Houston-Clear Lake established the Research Institute for Computing and Information systems in 1986 to encourage NASA Johnson Space Center and local industry to actively support research in the computing and information sciences. As part of this endeavor, UH-Clear Lake proposed a partnership with JSC to jointly define and manage an integrated program of research in advanced data processing technology needed for JSC's main missions, including administrative, engineering and science responsibilities. JSC agreed and entered into a three-year cooperative agreement with UH-Clear Lake beginning in May, 1986, to jointly plan and execute such research through RICIS. Additionally, under Cooperative Agreement NCC 9-16, computing and educational facilities are shared by the two institutions to conduct the research.

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***Research and Development for
Onboard Navigation (ONAV)
Ground Based Expert/Trainer System***

***Preliminary Ascent Knowledge
Requirements***

Preface

This research was conducted under the auspices of the Research Institute for Computing and Information Systems by LinCom Corporation under the direction of Daniel C. Bocshsler. Terry Feagin, Professor of Computer Science at the University of Houston - Clear Lake, served as the technical representative for RICIS.

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The views and conclusions contained in this report are those of the author and should not be interpreted as representative of the official policies, either express or implied, of NASA or the United States Government.

Research and Development for Onboard Navigation (ONAV)
Ground Based Expert/Trainer System

Preliminary Ascent Knowledge Requirements
(Deliverable D)

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CONSOLE EXPERT/TRAINER SYSTEM

ASCENT PHASE

Preliminary

August 1988

LinCom Corporation
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ACRONYMS

ACC	accumulate
AIF	auto/inhibit/force
BFS	backup flight system
DT	delayed time
GDO	(unidentified; appears on p. 3.3-1)
GND	ground
GPC	general purpose computer
HSTD	high-speed trajectory determinator
IMU	inertial measurement unit
LRU	line replacement unit
MECO	main engine cutoff
MVS	mid-value select
N/A	not applicable
NAV	navigation
n. mi.	nautical mile
OBH	onboard height
ONAV	onboard navigation
PASS	primary avionics software system
PFS	primary flight system
RM	redundancy management
RSS	root sum square
SPEC	specification
TLM	telemetry

SECTION 1
SUMMARY

This document presents the preliminary version of expert knowledge for the onboard navigation ONAV Ascent system. Included is some brief background information along with the information describing the knowledge the system will contain.

for the SP...
shuttle
is provided

...
telemetry data,
...
high speed
...
...
...

ONBOARD NAVIGATION
(ONAV)
GROUND TRAINING

SECTION 2 INTRODUCTION

2.1 BACKGROUND

Developing detailed requirements for an expert system often involves a series of meetings with various combinations of development team and expert personnel. These meetings review available information and discuss operations and functional processes of the proposed system. For the development of these Ascent requirements, such meetings were held. In addition, though, some information applicable to the Ascent phase of Shuttle flight were obtained from the Entry requirements noted in reference 1.

2.2 SCOPE OF THIS DOCUMENT

The target audience for this document is the knowledge domain expert. It will be a reflection of "what the system knows" in a form as close as possible to the expert's language.

It is expected that changes to this document will be required in the future. In particular, efforts to integrate this document into console operator training and operations activities will subject the contents to the utmost scrutiny.

SECTION 3
SYSTEM INFORMATION BASELINE

The following subsections detail the various subsystem rule bases for the ONAV Ascent expert system. Each subsection is divided into five parts.

a. General Information

General information provides for background types of information or assumptions made in other parts. If no information is available or required to clarify general concepts and approaches, only the word -none- need be given. The intent is to provide any information that helps develop and clarify rules, concepts, or heuristics.

b. Inputs

Inputs should give descriptions of those data items or other information used to perform the processing in part c. If possible, the information sources should be specified as well.

c. Rules/heuristics/concepts

Rules/heuristics/concepts gives the specifications for the processing which must occur (or, in the case of rules, for the pieces of expertise which must be gathered). The content may be rules, but may also consist of tables, figures, flowcharts, etc. as appropriate for specifying what is to be done.

d. Outputs

Outputs part should indicate what information is generated and available as a result of the processing performed. Any available destination information should also be included.

e. Support Computations

Support computations makes convenient the specification repetitive computations/manipulations needed as part of the processing activity, but which are not integral elements of the rules, heuristics, and concepts information.

3.1 INITIAL CONDITIONS

a. General Information

The selected atmosphere model must be checked as part of the expert system's initial processing. Information about the atmosphere model comes both from the ONAV operator (as an input) and from the telemetry downlist giving the onboard atmosphere selected by the crew.

The primary avionics software system (PASS) and backup flight system (BFS) should be in Major Mode 304 after blackout. Ignore the major modes of systems which are not operating.

b. Inputs

- 1) Major mode PASS
- 2) Major mode BFS
- 3) BFS engage
- 4) BFS NO GO (ONAV input)

c. Rules/heuristics/concepts

1) Engaged System

IF

- The BFS is engaged

THEN

- The BFS is the engaged system

ELSE

- The PASS is the engaged system

2) System Availability (Part 1)

IF

- The BFS is engaged

THEN

- The BFS is the only system available

3) System Availability (Part 2)

IF

- The BFS is not engaged

- The BFS is NO GO

THEN

- The PASS is the only system available

4) System Availability (Part 3)

IF

- The BFS is not engaged

- The BFS is GO

THEN

- Both systems are available.

d.

Outputs

- a) PASS sequencing problem
- b) BFS sequencing problem
- d) System availability
- e) Engaged system

e.

Support Computations

None.

3.2 TELEMETRY STATUS

a. General Information

The telemetry status tells the operator how much data is being downlisted. This is important because some variables are not available in low data rate.

b. Inputs

- 1) data-available
- 2) high data rate
- 3) low data rate

c. Rules/Heuristics/Concepts

- 1) Telemetry Status Change

IF

- the current status is not the same as the previous status

THEN

- notify the operator of a telemetry status change

d. Outputs

- a) TLM status (high, low, or none)
- b) Status-change message

e. Support Computations

None

3.3 LANDING SITE

a. General Information

It is important for the ground and onboard runways to match because delta state updates are computed in runway coordinates.

b. Inputs

- 1) I-load runway names and slots
- 2) desired runway (name or slot number) (ONAV input)
- 3) PASS runway (slot number)
- 4) BFS runway (slot number)
- 5) GND runway (name)
- 6) system availability

c. Rules/Heuristics/Concepts

1) Check GND Runway

IF

- the GND runway (name) is not the same as the desired runway (name)

THEN

- notify operator that the selected GND runway is in error
- recommend call to GDO to have trajectory change the GND runway

2) Check Onboard Runway

IF

- for the available systems
- the system runway (slot) is not the same as the desired runway (slot)

THEN

- notify operator that the system has selected the wrong runway
- recommend call to crew to select proper runway

d. Outputs

- 1) runway selection error
- 2) item entry for area selection
- 3) item entry for primary/secondary runway

e. Support Computations

Calculate desired item entries to correctly select the runways.

For actual and desired runways in the same area

desired = primary - spec 50 item 3
desired = secondary - spec 50 item 4

For actual and desired in different areas

desired = primary - spec 50 item 41 + area
desired = secondary - spec 50 item 41 + area item 4

where area = (desired slot + 1) / 2 truncated to an
integer

3.4 INERTIAL MEASUREMENT UNITS (IMU)

This section is divided up into 3 major parts Availability, Error Growth and Recommended Actions.

3.4.1 Availability

The purpose of this section is to determine which IMUs are available for use by Nav, or why an IMU is not available, and to note any changes in availability. Note that the check for good IMUs is to determine 1) how many IMU's can be used in the error detection and isolation sections, 2) if the IMU is independent of redundancy management (RM), and 3) if it is not a check of which IMUs are available.

3.4.1.1 PASS Availability

a. General Information

None

b. Inputs

- 1) IMU selection filter command
- 2) commfault flags
- 3) string commfault flags
- 4) RM failure flags
- 5) select/deselect flags
- 6) BFS engage

c. Rules/Heuristics/Concepts

- 1) IMU Commfault PASS
IF
- The BFS is not engaged.
- An IMU was not previously commfaulted in the PASS.
- The commfault flag for that IMU is on in the PASS.
THEN
- Notify operator that an IMU is commfaulted (unless the whole string is commfaulted).
- 2) IMU commfault clear PASS (part 1)
IF
- The BFS is not engaged
- An IMU has been unavailable to the PASS due to commfault.
- The commfault flag for that IMU is off in the PASS.

- The fail flag or deselect flag for that IMU is on in the PASS.
 - THEN
 - Notify operator that the commfault has cleared (unless it was a string commfault)
 - Conclude the IMU is unavailable to the PASS due to failure or deselect, whichever flag is on.
- 3) IMU commfault clear PASS (part 2)
- IF
 - The BFS is not engaged.
 - An IMU has been unavailable to the PASS due to commfault.
 - The commfault flag for that IMU is off in the PASS.
 - The fail flag for that IMU is off in the PASS.
 - The deselect flag for that IMU is off in the PASS.
 - THEN
 - Notify operator that the commfault has cleared (unless it was a string commfault)
 - Conclude the IMU is now available to the PASS.
- 4) IMU failed PASS
- IF
 - The BFS is not engaged.
 - An IMU has been available to the PASS.
 - The fail flag for that IMU is on in the PASS.
 - THEN
 - Notify operator of IMU failure.
 - Conclude the IMU is unavailable to the PASS due to failure.
- 5) IMU deselected PASS
- IF
 - The BFS is not engaged.
 - An IMU has been available to the PASS.
 - The deselect flag for that IMU is on in the PASS.
 - THEN
 - Notify operator of crew deselection.
 - Conclude the IMU is unavailable to the PASS due to deselect.
- 6) IMU reselected PASS
- IF
 - The BFS is not engaged.
 - An IMU has been unavailable to the PASS due to failure or deselect.
 - The fail flag for that IMU is off in the PASS.
 - The deselect flag for that IMU is off in the

- PASS.
THEN
- Notify operator of crew reselection.
- Conclude the IMU is now available to the PASS.
- 7) Three good IMUs
IF
- The BFS is not engaged.
- All three IMUs are not commfaulted in the PASS.
- All three IMUs are good.
THEN
- Conclude that there are three good IMUs in the PASS.
- 8) Two good IMUs
IF
- The BFS is not engaged.
- IMU A is not commfaulted in the PASS.
- IMU A is good.
- IMU B is not commfaulted in the PASS.
- IMU B is good.
- IMU C is commfaulted in the PASS or suspect.
THEN
- Conclude we have two good IMUs in the PASS.
- 9) One good IMU
IF
- The BFS is not engaged.
- IMU A is not commfaulted in the PASS.
- IMU A is good.
- IMU B is commfaulted in the PASS or suspect.
- IMU C is commfaulted in the PASS or suspect.
THEN
- Conclude we have one good IMU in the PASS.
- 10) No good IMUs
IF
- The BFS is not engaged.
- All three IMUs are commfaulted in the PASS or suspect.
THEN
- Notify operator of IMU shortage in the PASS.
- Conclude we have no good IMUs in the PASS.

d. Outputs

- 1) IMU good status
- 2) IMU downmodes
- 3) IMU upmodes

e. Support Computations

None

3.4.1.2 BFS Availability

a. General Information

When the BFS is engaged, the expert system cannot keep track of IMU deselections and reselections except in certain situations.

b. Inputs

- 1) commfault flags
- 2) string commfault flags
- 3) hardware failure flags
- 4) BFS IMU
- 5) BFS NO GO
- 6) BFS engaged
- 7) IMU deselect flag

c. Rules/Heuristics/Concepts

- 1) IMU Commfault BFS
IF
- The BFS is available.
- An IMU was not previously commfaulted in the BFS.
- The commfault flag for that IMU is on in the BFS
THEN
- Conclude the IMU is not available to the BFS due to commfault.
- Notify operator of IMU commfault (unless the whole string is commfaulted).
- 2) IMU Commfault Clear BFS (Not Engaged)
IF
- The BFS is available.
- The BFS is not engaged.
- An IMU was unavailable to the BFS due to commfault.
- The commfault flag for that IMU is off in the BFS.
THEN
- Conclude the IMU is available to the BFS (if the fail flag is off) or unavailable due to failure (if the fail flag is on).
- Notify operator that commfault has been cleared (unless the whole string is commfaulted).

- 3) IMU Commfault Clear BFS (Engaged) (Part 1)
IF
- The BFS is engaged
- An IMU has been unavailable to the BFS due to commfault.
- The commfault flag for that IMU is off in the BFS
- The fail flag or deselect flag for that IMU is on in the BFS.
THEN
- Notify operator that the commfault has cleared (unless it was a string commfault)
- Conclude the IMU is unavailable to the BFS due to failure or deselect, whichever flag is on.
- 4) IMU Commfault Clear BFS (Engaged, Part 2)
IF
- The BFS is engaged
- An IMU has been unavailable to the BFS due to commfault.
- The commfault flag for that IMU is off in the BFS.
- The fail flag for that IMU is off in the BFS.
- The deselect flag for that IMU is off in the BFS.
THEN
- Notify operator that the commfault has cleared (unless it was a string commfault)
- Conclude the IMU is now available to the BFS.
- 5) IMU Failed BFS
IF
- The BFS is available.
- An IMU was available to the BFS
- The fail flag for that IMU is on in the BFS.
THEN
- Conclude the IMU is unavailable to the BFS due to failure.
- Notify operator of IMU failure in the BFS.
- 6) IMU Deselected BFS (part 1) (Not engaged)
IF
- The BFS is available.
- The BFS was mid-value-selecting IMUs
- All IMU commfault flags are off in the BFS.
- All the IMU fail flags are off in the BFS
- The BFS is prime selecting an IMU.
THEN
- Notify the operator that BFS has changed IMU status due to a crew action.

- 7) IMU Deselected BFS (part 2) not engaged
 - IF
 - The BFS is Go.
 - The BFS is not engaged.
 - The BFS was prime selecting an IMU
 - The commfault flag for that IMU is off in the BFS.
 - The fail flag for that IMU is off in the BFS.
 - The BFS is now prime selecting a different IMU.
 - THEN
 - Notify operator the formerly selected IMU has been deselected.

- 8) IMU Deselected BFS (Engaged)
 - IF
 - The BFS is Go.
 - The BFS is engaged.
 - An IMU has been available to the BFS
 - The deselect flag for that IMU is on the BFS.
 - THEN
 - Notify operator of crew deselection in the BFS.
 - Conclude the IMU is unavailable to the BFS due to deselection.

- 9) IMU reselection BFS (Engaged)
 - IF
 - The BFS is engaged.
 - An IMU has been unavailable to the BFS due to failure or deselect.
 - The fail flag for that IMU is off in the BFS.
 - The deselect flag for that IMU is off in the BFS.
 - THEN
 - Notify operator of crew reselection.
 - Conclude the IMU is now available to the BFS.

- 10) IMU Change BFS
 - IF
 - The BFS is Go.
 - The fail flag or commfault flag for an IMU is on in the BFS.
 - That IMU was the prime selected IMU or the BFS was mid-value selecting.
 - THEN
 - Notify operator of a change in BFS IMU status due to commfault or failure.

d. Outputs

- 1) BFS downmodes
- 2) BFS upmodes
- 3) Changes in selected IMU in the BFS

e. Support Computations

None

3.4.2 Error Growth

This section's purpose is to detect that an IMU is going bad, isolate which IMU is going bad, predict whether that IMU will fail in the next minute, and determine the magnitude of the IMU error.

3.4.2.1 Error Detection

The comparisons in this section can be done with an IMU that is not available for NAV. This is only done so that if there is a problem at the two IMU level, the IMU not available to NAV can be used to help isolate the bad IMU in some circumstances. The term "valid" in the following sections means that an IMU can be used in comparisons with other IMUs; it does not refer to the overall health of an IMU or its suitability for use in the onboard system.

All comparisons are either good, over half the RM threshold, or over the RM threshold.

3.4.2.1.1 Velocity Comparisons

a. General Information

None

b. Inputs

- 1) Velocity differences
- 2) IMU status (PASS)
- 3) BFS engage

c. Rules/Heuristics/Concepts

- 1) Valid Velocity
IF
 - The BFS is not engaged.
 - An IMU is not commfaulted or failed.
 - That IMU is good or is suspect due to drift.THEN
 - Conclude that velocity comparisons with that IMU are valid.
- 2) Invalid Velocity
IF

- The BFS is not engaged.
- An IMU is commfaulted, failed or is suspect due to anything but drift.
- THEN
- Conclude that velocity comparisons with that IMU are invalid.

3) Velocity Comparison (part 1)

- IF
- The BFS is not engaged.
 - IMU A is not commfaulted or failed
 - IMU B velocity is valid
 - Velocity comparison A-B is different from IMU A's earlier velocity comparison status.
 - IMU C velocity is invalid.
 - THEN
 - Change IMU A's velocity comparison status to current A-B comparison status.

4) Velocity Comparison (part 2)

- IF
- The BFS is not engaged.
 - IMU A is not commfaulted or failed
 - IMU B velocity is valid
 - Velocity comparison A-B is some status (call it status-1)
 - IMU C velocity is valid
 - Velocity comparison A-C is some status (call it status-2)
 - The smaller of status-1 and status-2 is different from IMU A's earlier velocity comparison status
 - THEN
 - Change IMU A's velocity comparison status to the smaller of status-1 and status-2.

d. Outputs

- 1) Velocity miscompare indicators

e. Support Computations

None

3.4.2.1.2 Attitude Comparisons

a. General Information

None

b. Inputs

- 1) Gyro differences (RSS of gyro errors on 1417)
- 2) IMU status (PASS)
- 3) BFS engage

c. Rules/Heuristics/Concepts

- 1) Valid Attitude
IF
 - The BFS is not engaged
 - An IMU is not commfaulted or failed
 - That IMU is good or is suspect due to accelerometer bias.THEN
 - Conclude that attitude comparisons with that IMU are valid.
- 2) Invalid Attitude
IF
 - The BFS is not engaged
 - An IMU is commfaulted, failed or is suspect due to anything but bias.THEN
 - Conclude that attitude comparisons with that IMU are invalid.
- 3) Attitude Comparison (part 1)
IF
 - The BFS is not engaged
 - IMU A is not commfaulted or failed
 - IMU B attitude is valid
 - Attitude comparison A-B is different from IMU A's earlier attitude comparison status
 - IMU C attitude is invalidTHEN
 - Change IMU A's attitude comparison status to current A-B comparison status.
- 4) Attitude Comparison (part 2)
IF
 - IMU A is not commfaulted or failed
 - IMU B attitude is valid
 - Attitude comparison A-B is some status (call it status-1)
 - IMU C attitude is valid
 - Attitude comparison A-C is some status (call it status-2)
 - The smaller of status-1 and status-2 is different from IMU A's earlier attitude comparison status.THEN
 - Change IMU A's attitude comparison status to the

smaller of status-1 and status-2.

d. Outputs

- 1) Attitude miscompare indicators

e. Support Computations

If you use RSS of gyro errors from 1417 and calculate threshold in the preprocessor, then you can use these values exactly as the ATT differences in the Entry system.

Note: you must store the OPS 9/1 transition times for PASS and BFS.

3.4.2.1.3 ACC Comparisons

a. General Information

None

b. Inputs

- 1) ACC differences
- 2) IMU availability (PASS)
- 3) reference IMU
- 4) ACC delta-t

c. Rules/Heuristics/Concepts

- 1) Valid to use ACC comparison
IF
- The BFS is not engaged
- The ACC delta-t > 30 seconds
THEN
- Valid to use ACC comparison
- 2) Valid ACC
IF
- An IMU is not commfaulted or failed
- That IMU is good or is suspect due to resolver.
THEN
- Conclude that ACC comparisons with that IMU are valid.
- 3) Invalid ACC
IF
- An IMU is commfaulted, failed or is suspect due to anything but resolver.
THEN
- Conclude that ACC comparisons with that IMU are

invalid.

- 4) ACC Comparison (part 1)
IF
 - IMU A is not commfaulted or failed
 - IMU B ACC is valid
 - Worst axis ACC comparison A-B is different from IMU A's earlier ACC comparison status.
 - IMU C ACC is invalidTHEN
 - Change IMU A's ACC comparison status to current A-B comparison status.

- 5) ACC Comparison (part 2)
IF
 - IMU A is not commfaulted or failed
 - IMU B ACC is valid
 - Worst axis ACC comparison A-B is some status (call it status-1).
 - IMU C ACC is valid
 - Worst axis ACC comparison A-C is some status (call it status-2).
 - The smaller of status-1 and status-2 is different from IMU A's earlier ACC comparison status.THEN
 - Change IMU A's ACC comparison status to the smaller of status-1 and status-2.

- 6) Worst Comparison
IF
 - Exactly 2 good IMUs are available
 - Those 2 IMUs disagree in any way.THEN
 - Conclude that 2-level isolation must be used to determine which of the 2 IMUs has a problem.

d. Outputs

- 1) ACC miscompare indicators

e. Support Computations

None

3.4.2.2 Error Isolation

3.4.2.2.1 Three-level Isolation

a. General Information

At the 3-level with no suspect IMU's, use the following fault matrix, with a miscompare indicated for an IMU if it disagrees with both other IMUs.

A table drawn up to categorize the type of error that probably exists when problems have been isolated to a component are as follows:

vel	0	0	y	y	y	0	y)--- isolated or not /
att	0	y	0	y	0	y	y	
acc	y	0	0	0	y	y	y	

att and vel problems
 drift
 bias
 resolver
 probably velocity
 probably attitude
 probably attitude

note: acc means either acc-x, acc-y, or acc-z
 0 means O.K., y means yes there is a problem
 (i.e., an IMU miscompared with both other IMU's).

b. Inputs

- 1) velocity miscompare indicators
- 2) attitude miscompare indicators
- 3) ACC miscompare indicators
- 4) IMU availability (PASS)

c. Rules/Heuristics/Concepts

- 1) Three Level Component Isolation
 - IF
 - The BFS is not engaged
 - There are 3 good IMUs
 - An IMU disagrees with the other 2 IMUs.
 - THEN
 - Use the fault matrix to determine the problem with the IMU.
 - Notify operator of an IMU problem.

d. Outputs

- 1) IMU quality rating

e. Support Computations

None

3.4.2.2.2 Two-level Isolation

a. General Information

When a miscompare exists between the two remaining good IMU's there are four methods that can be used to determine which IMU has the problem. The results of these methods is combined via a voting scheme.

Method 1) Check A/GND and B/GND (where A and B are the two remaining IMUs) to see if exactly one is over the threshold. If so, vote 1 for that IMU; otherwise vote zero for both.

Method 2) Check PASS and BFS state vectors. If BFS better than PASS, then BFS IMU better and vote 2 for other IMU. Else, if BFS worse than PASS, then PASS IMU better and vote 2 for BFS IMU. Else vote 0 for both.

Method 3) Let A be the reference IMU for the ACC comparison. If ACC miscompares are in the X-Y plane or the Z axis (but not both) then vote 1 for A.

Method 4) : you can ditto method 3 for the gyro compare.

If either IMU outvotes the other by 2 or more, then that IMU is declared suspect.

Once the IMU has been isolated, use comparisons with the other IMU and the fault matrix in section 3.4.2.2.1.1 to determine the problem with the bad IMU.

b. Inputs

- 1) 1,2,3/GND IMU differences
- 2) PASS and BFS state errors
- 3) velocity miscompare indicators
- 4) ACC miscompare indicators
- 5) IMU availability (PASS)
- 6) reference IMU
- 7) IMU quality rating
- 8) HSTD status
- 9) BFS selected IMU

c. Rules/Heuristics/Concepts

- 1) Two Level GND Comparison (velocity)
IF

- HSTD is good
 - An error between IMUs A and B has been detected at the two level.
 - Worst axis GND-IMUA comparison is some status (call it status-a).
 - Worst axis GND-IMUB comparison is some status (call it status-b).
 - GND-IMU comparison has not yet voted.
- THEN
- When status-a = status-b, vote 0 for both IMUs.
 - Otherwise, vote 1 for the IMU with the larger difference, and 0 for the other IMU.
- 2) Two Level GND Can't Vote
- IF
- An error between IMUs A and B has been detected at the two level.
 - The HSTD is not good.
 - GND-IMU comparison has not voted yet.
- THEN
- Vote 0 for IMUs A and B.
- 3) Two Level State Comparison
- IF
- HSTD is good
 - An error between IMUs A and B has been detected at the two level.
 - GND-PASS comparison is some status (call it status-a).
 - GND-BFS comparison is some status (call it status-b).
 - State comparison has not voted yet.
- THEN
- When status-a = status-b, vote 0 for both IMUs.
 - Otherwise, vote 2 for the IMU with the larger difference, and 0 for the other IMU.
- 4) Two Level ACC Comparison
- IF
- An error between IMUs A and B has been detected at the two level.
 - IMU A is the reference for ACC comparisons.
 - X-axis ACC comparisons A-B is some status (call it status-x).
 - Y-axis ACC comparisons A-B is some status (call it status-y).
 - Z-axis ACC comparisons A-B is some status (call it status-z).
 - ACC comparison has not voted yet.
- THEN
- If status-x, status-y, and status-z indicate the error lies in the x-y plane or z-axis of IMU A,

- vote 1 for IMU A; otherwise, vote 0 for IMU A.
 - Vote 0 for IMU B.

- 5) Two Level ACC Can't Vote
 - IF
 - An error between IMUs A and B has been detected at the 2 level.
 - Neither A nor B is the ACC reference IMU.
 - ACC comparison has not voted yet.
 - THEN
 - Vote 0 for both IMUs A and B.

- 6) Two Level Vote Count
 - IF
 - GND-IMU comparison rules have cast v1 votes for an IMU.
 - State comparison rules have cast v2 votes for that IMU.
 - ACC comparison rules have cast v3 votes for that IMU.
 - Partial IMU comparison rules have cast v4 votes for that IMU.
 - THEN
 - Compute vote total for the IMU as v1+v2+v3+v4.

- 7) Two level IMU Isolation
 - IF
 - Votes for IMU A exceeded votes for IMU B by 2 or more.
 - THEN
 - Conclude IMU A has an error.

- 8) Two Level Component Isolation
 - IF
 - An error between IMUs A and B has been detected at the 2 level.
 - IMU A is the one with the problem.
 - THEN
 - Use the fault matrix to determine the problem with IMU A.
 - Notify operator of the problem.
 - Clear the miscompare indications for IMU B.

- 9) Two level Can't Isolate
 - IF
 - Votes for IMU A did not exceed votes for IMU B by 2 or more.
 - Votes for IMU B did not exceed votes for IMU A by 2 or more.
 - THEN
 - Notify operator that the IMU error cannot be isolated.

10) Change IMU Quality

IF

- An IMU was previously diagnosed as having a problem.
- That IMU's comparisons now indicate a different diagnosis
- The new indicated diagnosis is a bias, resolver or drift, or no problem at all.

THEN

- Update the IMU's quality rating to reflect the new diagnosis.
- Notify the operator of the new diagnosis.

d. Outputs

- 1) IMU quality rating

e. Support Computations

None

3.4.2.3 Error Magnitude

a. General Information

It is desirable for notification messages to contain the following information: who, why and magnitude. For example, "IMU# <who> has a <why> of <magnitude>; It <should/should not> fail". Magnitude information is used to make the "should/should not" determination.

Algorithms exist to do this, including using the largest compare (largest valid compare).

b. Inputs

- 1) IMU quality rating
- 2) velocity differences
- 3) attitude differences

c. Rules/Heuristics/Concepts

- 1) Bias Magnitude

IF

- IMU A has an accelerometer bias.
- IMU B velocity is valid.
- IMU C velocity is invalid or IMU C has a lower number than B.

THEN

- Compute the magnitude of the bias using the

A - B pairwise velocity comparison.
- Notify operator of the magnitude of the bias.

2) Resolver Magnitude

IF

- IMU A has a resolver error.
- IMU B attitude is valid.
- IMU C attitude is invalid or IMU C has a lower number than B.

THEN

- Compute the magnitude of the resolver error using the A - B pairwise attitude comparison.
- Notify operator of the magnitude of the resolver error.

3) Drift Magnitude

IF

- IMU A has a drift.
- IMU B attitude is valid.
- IMU C attitude is invalid or IMU C has a lower number than B.

THEN

- Compute magnitude of the drift using the A - B pairwise attitude comparison.
- Notify operator of the magnitude of the drift.

d. Outputs

- 1) accelerometer bias
- 2) drift rate
- 3) resolver error

e. Support Computations

For velocity (bias),
magnitude = $2023 * \sqrt{\text{largest-valid-velocity-difference}}$
(units of micro-g's)

For attitude (resolver),
magnitude = $\text{deg/rad} * \sqrt{\text{largest-valid-attitude-difference}}$
(units in degrees)

For attitude (drift),
magnitude = $\frac{\text{sec/hour} * (\text{resolver-t} - \text{resolver-o})}{(t - t-o)}$
(units in deg/hr)

o is at some initial time, (e.g., deorbit prep).
resolver-t and resolver-o are computed by the
resolver magnitude equation above.

It should be noted that at the two level, for example, if IMU 1 is failed, then 2-3 is the compare to use.

3.4.2.4 Failure Prediction

a. General Information

Failure prediction is based on mismatches which exceed an RM threshold. Recall that error detection and isolation is based on mismatches exceeding half of an RM threshold.

b. Inputs

- 1) IMU selection filter command
- 2) velocity differences
- 3) attitude differences (RSS of gyro compares, with threshold calculated in preprocessor)

c. Rules/Heuristics/Concepts

- 1) Three Level Failure Prediction
IF
- Onboard IMU RM is at the 3 level.
- Exactly two pairwise differences exceed the fail threshold in either velocity or attitude.
- A failure has not yet been predicted.
THEN
- Predict RM will fail the IMU common to the two pairs that exceed the threshold.
- 2) Three Level No Failure Prediction
IF
- Onboard IMU RM is at the 3 level.
- All 3 pairwise differences in velocity or attitude exceed the fail threshold.
- A failure has not yet been predicted.
THEN
- Predict IMU RM will not take any action.
- 3) Two Level Failure Prediction
IF
- Onboard IMU RM is at the 2 level
- IMU A is available but not good.
- IMU B is available and good.
- IMUs A and B differ in velocity or attitude by more than some threshold.
- A failure has not yet been predicted.
THEN
- Predict an RM action, and indicate IMU A is the one that needs to be failed.

4) Check bite

When at 2 level and IMU A has bite and IMU B is bad, then predict that RM will fail the wrong IMU. This must consider the possibility of needing a test on previous rules in order to know that IMU RM will do anything at all.

d. Outputs

- 1) predicted IMU failure

e. Support Computations

None

3.4.3 Recommended Actions

3.4.3.1 PASS IMU Actions

a. General Information

None

b. Inputs

- 1) IMU availability (PASS)
- 2) IMU quality rating
- 3) attitude IMU

c. Rules/Heuristics/Concepts

- 1) Reselect IMU
IF
- An IMU is unavailable to the PASS due to deselection.
- That IMU is good.
THEN
- Recommend that IMU be reselected (after zero delta state if 3-state nav is still active).
- 2) Help IMU Dilemma
IF
- IMU RM is in dilemma.
- IMU A is available to the PASS and good.
- IMU B is available to the PASS and not good.
THEN
- Recommend deselecting IMU B.
- 3) Can't Help IMU Dilemma
IF

- IMU RM is in dilemma
 - IMU A is available to the PASS.
 - IMU B is available to the PASS.
 - Either A and B are both good or A and B are both not good.
- THEN
- Notify operator that dilemma cannot be resolved.

- 4) Incorrect IMU failure
- IF
- IMU A is unavailable to the PASS due to failure
 - IMU A is good.
 - IMU B is available to the PASS.
 - IMU B is not good.
- THEN
- Notify operator of incorrect RM isolation and recommend switching to IMU A.
- 5) Deselect Commfaulted IMU
- IF
- An IMU is unavailable to the PASS due to commfault for some amount of time.
 - That IMU has not been deselected.
- THEN
- Recommend deselecting the IMU.

d. Outputs

- 1) PASS deselect/reselect messages

e. Support Computations

None

3.4.3.2 BFS IMU Actions

a. General Information

A general rule for BFS IMUs is that an IMU should not be available in BFS if not available in PASS, except if its the only one left in BFS.

b. Inputs

- 1) IMU availability (BFS)
- 2) BFS IMU
- 3) IMU quality rating

c. Rules/Heuristics/Concepts

- 1) Deselect IMU in BFS
 - IF
 - IMU A is not available to the PASS.
 - IMU A is available to the BFS.
 - IMU B is available to the BFS.
 - THEN
 - Recommend deselecting IMU A in the BFS.

- 2) No BFS IMUs
 - IF
 - The BFS is on IMU A.
 - IMU A is unavailable to the PASS.
 - Neither IMUs B or C are available to the BFS.
 - THEN
 - Notify operator of IMU shortage in the BFS.

- 3) Change BFS IMU (part 1)
 - IF
 - The BFS is on IMU A.
 - IMU A is not good.
 - IMU A is available to the PASS.
 - IMU B is available to the BFS.
 - IMU B is good.
 - Either IMU C is unavailable to the BFS or has a higher number than IMU B.
 - THEN
 - Recommend deselect/reselect IMU A to put the BFS on IMU B.

- 4) Change BFS IMU (part 2)
 - IF
 - The BFS is on IMU A.
 - IMU A is not good.
 - IMU B is available to the BFS and is good.
 - IMU C is available to the BFS but is not good
 - IMU C has a lower number than IMU B.
 - THEN
 - Recommend deselect/reselect IMU's A and C to put the BFS on IMU B.

d. Output

- 1) BFS deselect/reselect messages

e. Support Computations

None

3.5 STATE VECTORS

3.5.1 State Error Status

a. General Information

Don't do any NAV checking until NAV init.

IF GROUND COMPARES AVAILABLE
Use this table [see Note #3]

<u>GND-PRI</u>	<u>GND-BFS</u>	<u>PFS-BFS</u>	<u>CALL TO GUIDANCE</u>
> UPDATE LIMIT	> XFER LIMIT	N/A	PASS has (error) [see Note #1] BFS has (error) Need ST. VECTOR UPDATE; No XFER required
"	> GAL	N/A	PASS has (error) BFS has (error) Need ST. VECTOR UPDATE; No XFER required
"	IN LIMITS	N/A	PASS has (error) BFS is GO Need ST. VECTOR UPDATE; NO XFER needed
> GUID ADV. LIMIT (GAL)	> XFER LIMIT "	>GAL <GAL	PASS has (error) [see Note #1] BFS has (error) Need ST.VECTOR XFER PASS has (error) [see Note #2] BFS has (error) No XFER is needed
"	> GAL	N/A	PASS has (error) BFS has (error)
"	IN LIMITs	N/A	PASS has (error) BFS is GO
IN LIMIT	> XFER LIMITS	N/A	PASS is GO BFS has (error) Need ST. VECTOR XFER
"	> GAL	N/A	PASS is GO BFS has (error)
"	IN LIMITS	N/A	PASS and BFS ARE GO

- Note #1: Unless the GND-PRI is about to violate the update criteria the transfer will take out a significant amount of error in the BFS. Otherwise it might be better to wait for the GND-PRI error to violate the update criteria and treat it appropriately.
- Note #2: The error taken out by a transfer is not significant in this case.
- Note #3: Prior to Mecoc
 DELTA STATE
 Post Mecoc
 WHOLE STATE

IF GROUND COMPARES NOT AVAILABLE
 Use this table

<u>PFS-BFS</u>	<u>IMU-SITUATION</u>	<u>CALL TO GUIDANCE</u>
> XFER LIMITS	2 IMU Level One BAD IMU BFS on Good One	(error) between PASS and BFS BFS better than PASS so NO XFER needed [see Note #4]
"	ALL OTHER CASES	(error) between PASS and BFS need state vector transfer
> GAL	N/A	(error) between PASS and BFS
IN LIMITS	N/A	PASS and BFS are TRACKING

Note 4: A transfer would make the BFS as bad as the PASS

VERIFY STATE VECTOR UPDATE

when | GND-PRI->~0
 | call "Guidance the update is onboard"

VERIFY STATE VECTOR TRANSFER

when | GND-BFS ~ GND-PRI or PFS-BFS ~ 0
 | CALL "Guidance we see the transfer"

b. Inputs

- 1) HSTD health
- 2) GND-PASS
- 3) GND-BFS
- 4) PASS-BFS
- 5) System availability
- 6) DT (PASS - BFS state vector time tag difference)
- 7) NAV init

c. Rules/Heuristics/Concepts

- 1) NAV Init
If
- NAV init = off
- PASS-BFS = bad previously
- PASS-BFS now good
THEN
- NAV init = on
- Notify operator of nav init
- 2) State error change
IF
- For available systems
- The system worst axis error is different from what it was on the previous cycle.
THEN
- Record the new worst axis status.
- 3) Report state error
IF
- More than 60 seconds has elapsed since the last report.
THEN
- Report the error on every axis whose status is the same as the worst axis.
- 4) PASS and BFS timing problem
IF
- the HSTD is not good
- both systems are available
- the DT is $> |0.0003|$
THEN
- there is a timing problem between the PASS and BFS
- 5) PASS BFS error change
IF
- Both systems are available
- No timing problem between the PASS and the BFS
- The HSTD is not good
- The PASS-BFS worst axis error is different from

what it was on the previous cycle.
 THEN
 - Record the new worst axis status.

- 6) Report PASS BFS error
 IF
 - both systems are available
 - No timing problem between the PASS and the BFS
 - The HSTD is not good.
 - More than 60 seconds has elapsed since the last report of PASS-BFS errors.
 THEN
 - Report the error on every axis whose status is the same as the worst axis.

d. Outputs

- 1) state error messages
 2) timing problem between PASS and BFS

e. Support Computations

The following table is valid for GND-PASS, GND-BFS, and PASS-BFS.

PASS	PRE LIFTOFF		L/O - MECO (GNDFIL-PAS)		POST MECO (GNDEPH-PAS)	
	GAL	UPDATE	GAL	UPDATE	GAL	UPDATE
u	N/A	N/A	3K	6K	6K	12K
v			3K	6K	24K	48K
w			3K	6K	24K	48K
uD			20	50 *	20	50 *
vD			20	40 *	20	40 *
wD			20	50	20	50

BFS	PRE LIFTOFF		L/O - MECO (GNDFIL-BFS)		POST MECO (GNDEPH-BFS)	
	GAL	XFER	GAL	XFER	GAL	XFER
u	N/A	N/A	3K	6K	6K	12K
v			3K	6K	24K	48K
w			3K	6K	24K	48K
uD			15	50 *	15	50 *
vD			15	40 *	15	40 *
wD			15	50	15	50

If NO ground compares

PFS-BFS	PRE LIFTOFF		L/O - MECO		POST MECO	
	GAL	XFER	GAL	XFER	GAL	XFER
x	N/A	N/A	3K	6K	24K	48K
y			3K	6K	24K	48K
z			3K	6K	6K	12K
xD			20	50	20	50
yD			20	40	20	40
zD			20	50	20	50

If any value > GAL limit
|GOTO STATE ERROR (Section 7.0)

- R: o GAL-Guidance Advisory Limit -> means that the error is significant enough to inform the Guidance officer.
- * o update limits are per flight rules.
- o Guido relies on ONAV for all information on the BFS; therefore, when possible give as much information as possible when making calls as the situation allows.

i.e., it is growing steadily or we expect it to degrade quickly.

- o NOTE The GNDEPH-PAS AND THE GNDEPH-BFS algorithms are not valid during burns due to the way ground nav models the burns.

Results from this table will be such that:

GRND-PASS is = good/suspect/over
GRND-BFS is = good/suspect/over
PASS-BFS is = good/suspect/over
All units are in feet and feet/sec.

3.5.2 Delta State Update

a. General Information

Note that delta state is done before MECO and a whole state is done after MECO.

b. Inputs

- 1) HSTD status
- 2) GND-PASS
- 3) GND-BFS
- 4) engaged system
- 5) Doing a Delta state (ONAV input)

c. Rules/Heuristics/Concepts

- 1) Need delta state
IF
- For the engaged system
- GND-System shows the System is above the update limits.
THEN
- a delta state is needed.
- 2) OK for Delta state (Part 1)
IF
- a delta state is needed
- GND and engaged system runways are the same
THEN
- recommend a delta state update
- 3) Not OK for Delta State
IF
- a delta state is needed
- the GND and engaged system runways are not the

same
THEN
- notify operator that a delta state is needed but
there is runway mismatch

- 4) DELTA STATE is in BFS
IF
- BFS engaged
- delta-state in progress
- GND-system errors previously not close to zero
- GND-system errors are now close to zero
THEN
- Report that state update is in

d. Outputs

- 1) delta-state recommendation
- 2) delta state no go due to runway mismatch
- 3) Delta state in

e. Support Computations

"Previously not close to zero" and "are now close to zero" refer to a comparison between the current measurement and previous measurement.

3.5.3 BFS Transfer

a. General Information

None

b. Inputs

- 1) HSTD status
- 2) GND-BFS
- 3) System availability
- 4) PASS state error status
- 5) PASS - BFS state error status
- 6) PASS - BFS timing problem status
- 7) delta-state in progress

c. Rules/Heuristics/Concepts

- 1) Need transfer (part 1)
IF
- good HSTD
- both systems available

- GND-BFS > update limit
 - PASS state error status is good
 - THEN
 - recommend a transfer to the BFS
- 2) Need transfer (Part 2)
- IF
 - good HSTD
 - both systems available
 - GND-BFS > update limit
 - PASS state error status is suspect
 - no PASS-BFS timing problem
 - PASS-BFS status is suspect or bad
 - THEN
 - recommend a transfer to the BFS
- 3) Need transfer (Part 3)
- IF
 - the HSTD is good
 - both systems are available
 - GND-BFS > update limit
 - delta-state in progress
 - THEN
 - notify operator that a transfer will be needed after the state vector update
- 4) Do not do a transfer (Part 1)
- IF
 - the HSTD is good
 - both systems are available
 - GND-BFS > update limit
 - Pass state error status is suspect
 - Pass-BFS state error status is good
 - THEN
 - notify operator that no transfer is needed because it won't improve the BFS by much.
- 5) Do not do a transfer (Part 2)
- IF
 - The HSTD is good
 - both systems are available
 - GND-BFS > update limit
 - Pass state error status is suspect
 - There is a a PASS-BFS timing problem
 - THEN
 - notify operator that NO transfer is needed because we are not sure how much it will improve the BFS vector.
- 6) Transfer when no HSTD
- IF
 - the HSTD is not available

- both systems are available
- PASS has at least one good IMU
- BFS prime selecting bad or suspect IMU
- PASS-BFS error is bad
- No PASS-BFS timing problem

THEN

- recommend a transfer to the BFS (any other situation could possibly corrupt the BFS with a transfer)

d. Outputs

- 1) transfer recommendation
- 2) confirmation of transfer

e. Support Computations

None

3.6 HIGH SPEED TRAJECTORY DETERMINATOR (HSTD)

a. General Information

These rules have the task of determining the status of the HSTD state vector. These rules depend primarily on operator input. The rules can detect when the filter is stopped, and they can detect some situations where the filter is not converged. In addition, the operator can indicate when the filter is bad. The operator must specify when the filter is good; the rules never do that automatically.

Overall rationale: better to assume ground is bad and not make some recommendations, rather than assume ground is good and encounter bad recommendations. The issue is to keep consistency between ONAV expert system recommendations and ground status (which is available only over the "loop".)

b. Inputs

- 1) operator input,
- 2) ground nav expert system (not yet available)
- 3) internal rules in the ONAV expert system.

c. Rules/Heuristics/Concepts

- 1) start HSTD
IF
- the HSTD has not been running
- the "stopped" indicator is off
THEN
- conclude the HSTD is running but has not converged
- 2) HSTD bad
IF
- the HSTD was good
- the operator entered the HSTD bad indicator
THEN
- conclude the HSTD is bad (not converged)
- 3) HSTD good
IF
- the HSTD was bad
- the operator entered the HSTD good indicator
- at least 10 seconds have elapsed since last restart
THEN
- conclude HSTD is good

4) HSTD stopped
IF
- the HSTD is running
- the stopped indicator is on
THEN
- conclude the HSTD has been stopped

5) HSTD editing
IF
- the HSTD was good
- less than 3 stations are being processed
- a given station is not being excluded
- there is data coming from that station
- at least one good measurement of a given type was available from that station
- all of the measurements of that type from that station were edited by the filter
THEN
- conclude the HSTD is bad

6) HSTD prop
IF
- the HSTD was good
- the prop flag is on
THEN
- conclude the HSTD is bad

7) HSTD covariance
IF
- the HSTD was good
- the RSS position or velocity covariance diagonals are too large
THEN
- conclude the HSTD is bad

8) HSTD restart
IF
- the HSTD restart flag is on
THEN
- conclude the HSTD is bad
- record the current time as the time of the last restart

9) no ground data
IF

- no ground data available

THEN

- Make a statement on NAV as it relates to BFS transfers.

d. Outputs

1) HSTD Health (Good, bad, not running, not available)

e. Support Computations

None

3.7 BFS ALTITUDE CHECK

a. General Information

The first check below gives an indication of how the IMU's are behaving. After OPS 9/1 transition, the IMU is being compensated for the rotation of the earth. However, there is no compensation along the up axis so that IMU's are drifting freely along that axis.

The BFS state vector is initialized at OPS 9/1 transition. The BFS state vector is propagated using IMU data. The position and velocity (PAD 90 vector) of the vehicle on the pad is known. The BFS state vector is compared to the PAD 90 vector. The altitude component of this error is directly related to the performance of the IMU's in up axis. Since the IMU's are not being compensated in that axis, we have an insight into how well the IMU's are performing.

b. Inputs

To be determined.

c. Rules/Heuristics/Concepts

1) Continuous Pre-launch Monitoring of BFS Altitude
IF

- the BFS altitude is greater than 1 sigma

THEN

- conclude that the IMU's are greater than 1 sigma, even though there is nothing that can be done about it by ONAV.

2) PAD 90 Z axis check

IF

- PAD 90 Z (pos and vel of vehicle on the pad) is less than U from the table (see table referenced on p.3-6 of the ONAV/ascent handbook).

THEN

- notify operator that the BFS altitude is less than one sigma

ELSE

- notify operator that the BFS altitude is <td> sigma.

d. Outputs

1) BFS altitude greater than 1 sigma

e. Support Computations

Compute delta-time from OPS 9/1 transition in the BFS.

SECTION 4
REFERENCES

- 1) "Knowledge Requirements for the Onboard Navigation (ONAV) Console Expert/Trainer System," Entry Phase baseline 1.0, NASA/Johnson Space Center, Mission Support Directorate, Mission Planning and Analysis Division, JSC-22657, October, 1987.

END OF DOCUMENT