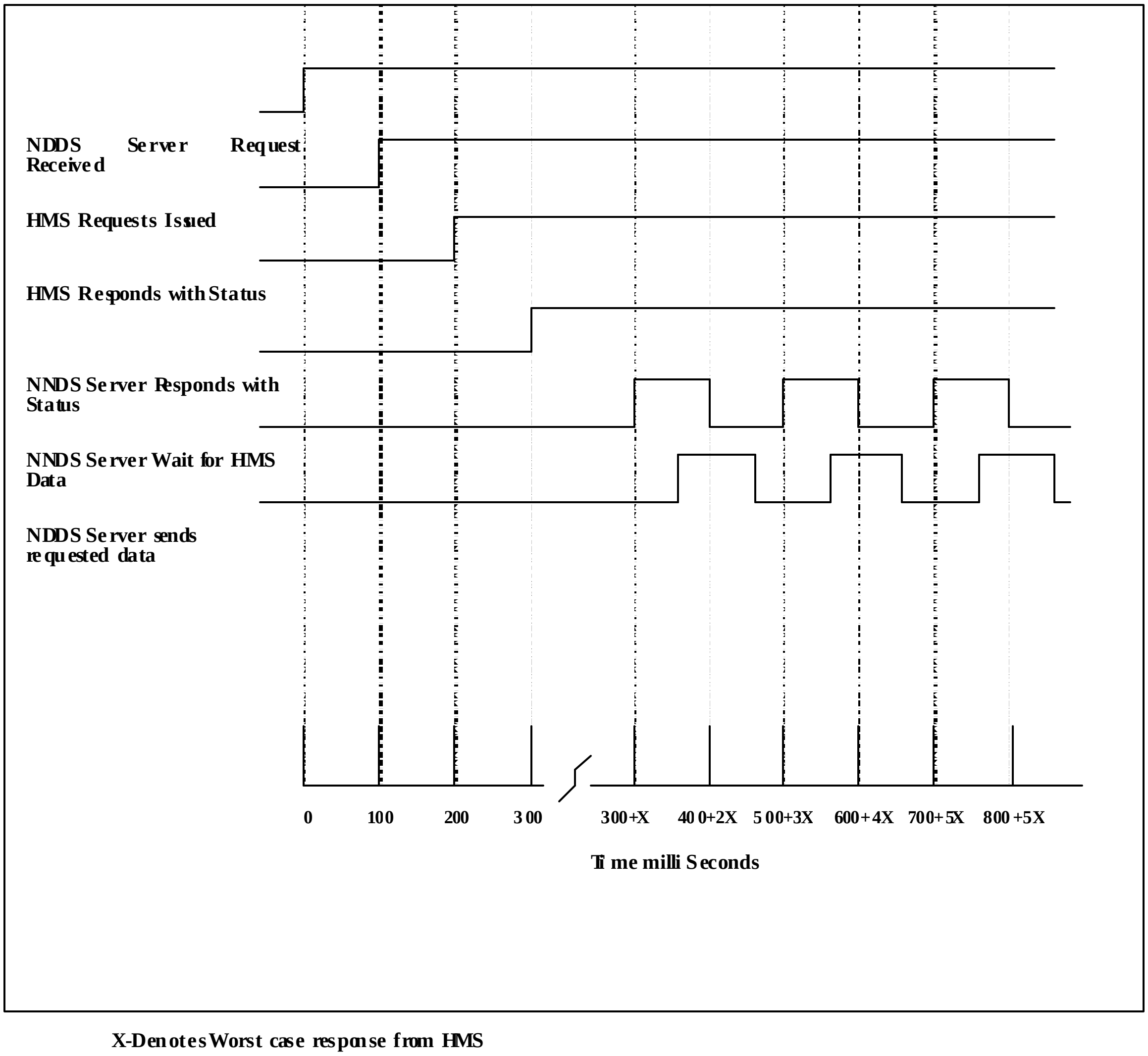



**Figure 52 Interface Timing**

### *4.2.4.2.5 Software Structure*

The HMS software architecture is designed to emulate the functionality of an AP in terms of NDDS connectivity. The interface to HMS NDDS publications will be via the dynamic publish subscribe method developed for the AP to WS interface section 4.5.3.4

An NDDS Server resides on the HMS to perform the function of translating between NDDS and TCP/IP. For the NDDS request type, a class was defined that is a sub-class of the cPSStatic class. The server is responsible for translating HMS information and bundling it into the respective NDDS requested message class. The server also provides the facilities for setting up and maintaining a stream socket connection to the HMS data manager thread via TCP/IP. . The server provides functions for opening, reading and writing the stream socket connection. Error handling of socket data is also included in this server.

To support the remote setting of parameters, a parameters class is included and it inherits the functionality of the HMS socket class and the NDDS derived base class. NDDS is used to perform a client/server request to set a particular named parameter value. The actual value set is in turn sent back as a response to the client server request.

#### 4.2.4.3 ICHM

The ICHM runs an MS-Windows operating system. The ICHM software controls data acquisition and processing, fuses data from multiple ICHM sensors, classifies component health, and generates alert and alarm messages to the SHM. The operation and functionality of the ICHM is controlled via an ASCII text script file. An example of script file is shown in Figure 53. The main ICHM program parses the script file and executes the commands.

##### *4.2.4.3.1 Data Acquisition*

Data acquisition (AcquireData command in script file) is controlled by specifying the range of channels (start channel, stop channel), sample frequency, number of samples, and the name of the file in which to save the resulting data. Data are stored in files on a solid-state static RAM disk. Raw data can also be compressed using zip utilities for storage on the ICHM and for transmission of raw data files to the SHM.

##### *4.2.4.3.2 Data Processing*

Data processing on the ICHM is performed using executable programs called by the main script processing program. The RunMatlab command in the script file specifies the executable program used to process the data, the data file and the parameter file (with extension ini). The RunMatlab command name comes from the fact that the data processing executable programs are executable versions of Matlab m-files generated using the Matlab compilers and math libraries. All processed data results, processing parameters, and ICHM configuration information, and current alert and alarm messages are all stored in an initialization file stored on the ICHM (ichm1params.ini in the example script). The initialization file provides the "memory" for the ICHM from one processing cycle to another.

A call to execute the *ProcessICHMRawData.exe* executable program extracts the ICHM-specific parameters from the raw data file and updates processed data parameters in the initialization file. The *ProcessICHMAlertData.exe* executable program determines the health of the components monitored by the ICHM based on the processed data or features, thresholds, and other settings stored in the specified ICHM initialization file. Appropriate alert and alarm messages are generated or updated and stored in the initialization file. The *ProcessICHMParamFile.exe* and *ProcessICHMAlertFile.exe* executable files generate parameter and alert message files for transmission to the SHM based on the information contained in the ICHM initialization file.

#### *4.2.4.3.3 ICHM Control*

ICHM operation is controlled by the script file as described earlier. In addition to controlling the acquisition of data, the script file also controls communication from the ICHM to the SHM. Other commands define the ICHM ID, set the current working directory, put the ICHM in "sleep" mode for a specified duration (the delay( ) command in the example script file). The ICHM can be accessed from the SHM as a mapped disk drive. The SHM can halt execution of an ICHM at which time the ICHMs script file can be replaced. When execution resumes on the ICHM, the ICHM will begin executing the commands in the new script file.

#### *4.2.4.3.4 ICHM to SHM Communications*

The original concept of operations for the machinery health monitoring system called for the ICHM to send alert and alarm messages to the SHM asynchronously whenever the status of the health of the component monitored by the ICHM changed. Similarly, the ICHM would send parametric or raw data to the SHM upon request. This operational mode is preferred when the ICHM is operated on battery power to preserve battery life. A disadvantage of this approach is that the SHM also needs a way to know that the ICHM is actually functioning and has nothing to report instead of being inoperable. This is typically solved by having the ICHM send a periodic heartbeat message to the SHM. Since the ICHMs in the RSVP installation were not operated on batteries and power to the ICHMs was not an issue, it was decided to have the ICHMs send the full parameter and alert/alarm information to the SHM on each processing cycle. This is accomplished by the SendSHMMessage command in the script file.

### 4.2.4.4 SHM

The SHM is responsible for controlling operation of the ICHMs, receiving raw data, processed data and alert/alarm messages from the ICHM, archiving processed and raw machinery data, and serving requested parameters, alert/alarm messages and parameter trend data to the watchstation.

#### *4.2.4.4.1 Communications Control*

Machinery health monitoring system information and data from the SHM to the watchstation are routed through the RSVP access points. Conversely, the access point will route Watchstation requests to the HMS subsystem. The protocol chosen to support the information exchange is the Network Data Delivery Service (NDDS). The functionality of this protocol is based upon the NDDS publish/subscribe paradigm. Using this protocol, subscription requests will be sent to the HMS and an interface between the HMS data and NDDS will be responsible for obtaining the necessary HMS data, bundling it into NDDS messages and publishing of those messages. Communication within the HMS subsystem (between the SHM and ICHMs) was implemented using TCP/IP socket connections. An HMS data manager thread running on the SHM hosts a socket connection to the NDDS interface server. Communication between the SHM and the

ICHMs is handled over socket connections. Control of the ICHMs is achieved by remotely logging into the SHM and accessing the ICHMs as mapped logical devices.

#### *4.2.4.4.2 Scheduling*

The ICHMs communicate asynchronously with the SHM. Because the ICHMs operate on ship's power instead of batteries, there is no penalty on the amount of communication between the ICHM and SHM – any possible penalty for bandwidth use is further minimized by processing the data on the ICHM and only sending a relatively small amount of data to the SHM in each message.

#### *4.2.4.4.3 Data Fusion*

The original concept of operations called for data fusion at the SHM to determine the health of individual components within the HMS system and to reduce false alarms related to machinery health by correlating machinery-related health information with both existing SSGTG signals and environmental and structural information. Several factors resulted in the elimination of this data fusion role for the SHM. First, the design of the ICHMs permitted each ICHM to acquire enough sensor data to sufficiently determine the health of major subsystems on the SSGTG. Much of the data fusion functionality that was originally to be implemented at the SHM was actually implemented on the ICHMs due to the availability of the data at that level. Second, access to existing signals for the SSGTG was not possible within the scope of the project. Although fusion of the existing SSGTG signals, health data and features from mechanically coupled components on the SSGTG could be used to improve the reliability of the information and could potentially reduce false alarms or alerts, it was not necessary and was not implemented. At the system level, environmental and structural data from the access points was not provided to the SHM (the access points only published data "up" to the watchstation and not "down" to the SHM); therefore, the SHM was not able to fuse machinery health information with environmental and structural information.

#### *4.2.4.4.4 Data Archival*

Although it is not shown in the example ICHM command script, the ICHM can compress data files (using standard zip utilities) and send the compressed data to the SHM. The ICHMs also send to the SHM the initialization files and files containing parameter data and alert/alarm messages. All of this information is archived at the SHM. Compressed data files (containing the data from all channels along with the updated initialization file) are stored in directories corresponding to each ICHM. The SHM also maintains a Microsoft Access database with the processed data parameter or features for each ICHM. The database is used to respond to specific data and trend requests from the watchstation.

```
'
'                         Test script file for ICHM 1
'
'
'            DataID's Currently Defined
'            1 - Raw Voltage and Current (8 channels)
'            2 - ICHM Internal Temp
'            3 - Raw ACCEL Data
'            4 - ACCEL Temp
'            5 - Sensor Bias
'            6 - External Temp
'
'                         Start by reading in Calibration data
'                         And seting up gain
DirectoryPrefix(C:\)
'ICHMID (Location,Machine,Component)
ICHMID(0,1,2)
ReadCalInfo(CalibrationFile1.txt)
Delay(4000)
'
'                         Go Get 8 Voltage and Current channels
'
'            AcquireData(LowChannel,HighChannel,SampleRate,NumSamples,DataID,FileName)
AcquireData(0,7,22000,44000,1,LowSpeed2.dat)
'
'                         Get ICHM Internal Temp
'
AcquireData(14,14,1000,1000,2,IchmTmp.dat)
RunMatlab(ProcessICHMRawData.exe lowspeed2.dat ichm1params.ini)
RunMatlab(ProcessICHMRawData.exe ichmtmp.dat ichm1params.ini)
RunMatlab(ProcessINIAlertData.exe  ichm1params.ini)
RunMatlab(ProcessICHMParamFile ichm1params.ini ichm1params.shm)
RunMatlab(ProcessICHMAlertFIle ichm1params.ini ichm1alerts.shm)
sendshmmessage(Info, Now we process parameter file)
sendshmmessage(Process,ichm1params.shm)
delay(1000)
sendshmmessage(Info, Now we process alert file)
SendSHMMessage(Process, ichm1alerts.shm)
delay(10000)
```

**Figure 53 Example ICHM Script File**

## 4.2.5 Operational Characteristics

### 4.2.5.1 Machinery Virtual Presence

This section describes the operational characteristics of the machinery health monitoring system in support of machinery virtual presence. Defining machinery virtual presence as follows;

- Sum total of all information and knowledge needed to operate and manage all aspects of a piece of machinery or machinery system in multiple contexts.
- Accomplished by fusing data from multiple sources to determine the static and dynamic operational state and condition.
- Information/knowledge conveyed in a coherent, navigable efficient user interface supporting the management of complex systems with fewer people.

The machinery health monitoring system provided information in five categories.

1. Operation monitoring
2. Performance monitoring
3. Alerts and alarms
4. Component health diagnostics and prognostics
5. Maintenance recommendations

<u>Note:</u> *A subset of the information described below was implemented for the actual demonstrations based on sensor/signal access limitations of the installed system. Even so, the final installed system demonstrated the capability to provide virtual presence information in the five identified categories.*

**Operation and Performance Information**

The operation information includes the machine settings, and readout information the operator would have at the machine or in the engineering operation center. Performance monitoring information provides the user at the watch station with an assessment of how well the machine is operating and includes information such as efficiency, and pressure and temperature ratios. Parameter trending supports both operational and performance information categories. Examples of Operation and Performance Information is shown in Figure 54and Figure 55.


**Figure 54 Engine and Accessory Gearbox Operational Information**


**Figure 55 SSGTG Electrical Power Generation Performance Information**

## Alerts and Alarms

There are two basic types of alert and alarm messages/information: operational and component health. Operational alerts and alarms are generated when a sensor reading is out of the normal operating range (alarm) or when the sensor reading is close to being out of range and is continuing to change in a manner that will result in the reading being out of range within some set time window (alert). Component health alert and alarm messages warn the operator that the condition of a particular component has degraded to the point that it should be replaced (alarm) or that the component is degrading and will need replacement within the some set time window (alert). An alert is considered a precursor to an alarm and provides a warning that an alarm condition is developing. A third type of alert is associated with the monitoring system itself, providing an indication of an adverse condition that could impact the performance of the monitoring system.

Alert and alarm information, along with component health diagnostics and prognostics, comprise the 'health-monitoring' portion of the HMS. From a health monitoring perspective, operational range violations may serve as indicators of required maintenance actions or developing component faults, but merely indicate that an adverse condition already exists. On the other hand, a successful diagnostics/prognostic capability would provide an indication of a developing adverse condition and the time it will take to reach an unacceptable condition. Valid diagnostics/prognostics will reduce the number of operational range violations that occur, by detecting and alerting the operator in a proactive manner.

Alert and alarm messages were mapped to functional areas of the SSGTG. At the highest level, the health monitoring system alerts and alarms are associated with four subsystems on the SSGTG:

- Generator - Electrical
- Generator - Mechanical
- Reduction gear box
- Accessory gear box

Alert, Alarm and System Health messages are shown in the lower portion of the User Interface Data Screen in Figure 56.

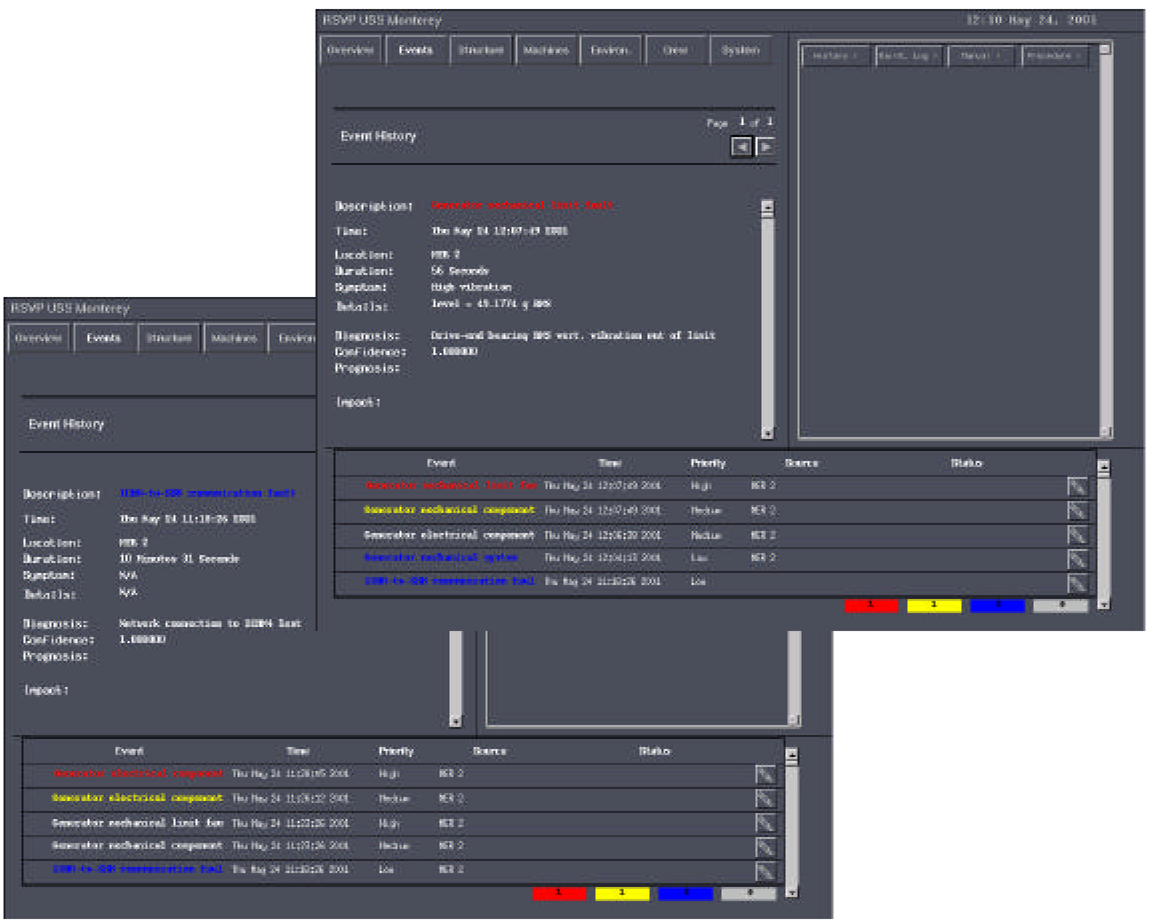



**Figure 56 Examples of Alert, Alarm and System Health Information**

## Component Health Information

Component faults are grouped by functional components within the gas turbine generator.

Electrical generator

- Stator winding deterioration (including turn-to-turn, coil-to-coil, and phase-to-phase)
- Rectifier diode failure
- Field deterioration
- Operating parameters out of limits (voltage, current, power factor, frequency, etc.)

Mechanical generator

- Generator drive-end bearing fault
- Generator other-end bearing fault

Reduction gearbox

- PTO shaft fault
- Front bearing fault
- Rear bearing fault
- RGB gear fault

Accessory gearbox

- AGB drive shaft fault
- AGB gear fault
- AGB bearing fault

An example of Generator Mechanical Component Health Information is also shown in the middle of the right screen in Figure 56 above.

**Maintenance recommendations**

Maintenance information/recommendations associated with abnormal – alert/alarm conditions were reported by the HMS in the form of text messages displayed at the Watchstation. The capability to link this information to maintenance and repair procedures was included as a function of the Watchstation User Interface but not implemented for the demonstrations - Figure 57

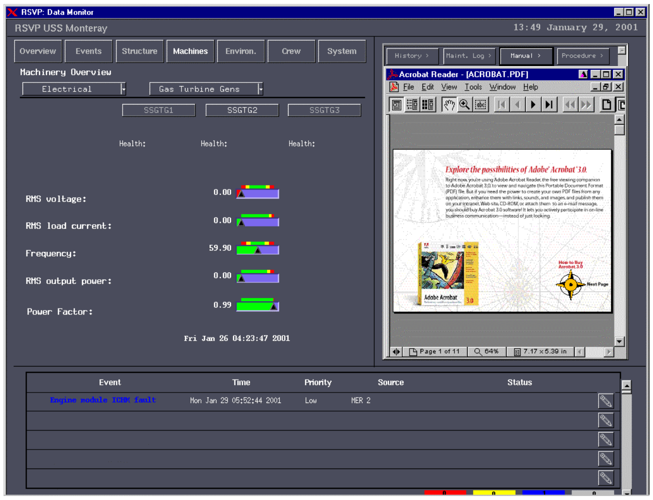



**Figure 57 Maintenance Information Access Capability**

### 4.2.5.2 Information Processing and Flow

This following section describes the information processing and fusion employed in the RSVP machinery health monitoring system. The HMS organization is described from two points of view: from the machinery system, and from the health monitoring system. From the machinery system point of view, the system can be described as a collection of subsystems composed of components that can be further described as a collection of elements. From the health monitoring system viewpoint, the system is composed of a watch station, access points, system health monitors, integrated component health monitors, and sensors - Figure 58.

The object of the machinery health monitoring system is to push as much data and information processing as possible down to the integrated component health monitor level. This has the advantage of reducing the bandwidth required to send the health information up to the watch station. Bi-directional event/query driven communications is supported between the lowest and highest levels of the system. The goal is to limit communication from the lowest to the highest levels, to alert messages indicating a problem (event) with a particular machine component. An alert is generated by the system when it detects that a fault indicator will reach a set alarm level within a specified time threshold. This means that the system should never actually reach an alarm state because the machinery health monitoring system should generate an alert message prior to reaching the alarm state. On the other hand, an operator can at any time request data/information (query) from any level within the system all the way down to individual sensor readings.

In general, the processing flow in the machinery health monitoring system follows the following order: calibration, processing, feature extraction, Kalman filtering, decision logic, fusion. The Kalman filter is used to provide smoothed feature tracks from one data snapshot to the next and to predict the future machine state. Sensor and decision level fusion are used to increase or decrease confidence in the fault assessment.

The machinery health monitoring system employs a hybrid data fusion approach. Data were processed and fused only at the ICHM. No access to existing signals and limited ability to add additional sensors prevented planned processing and fusion at the SHM. At the ICHM level – equivalent to the sensor level in classic military data fusion applications – sensor data are first calibrated, then processed using filtering, FFTs, wavelets, or other techniques to enhance the signal to noise ratio. After initial processing, thresholding or other techniques are used to determine whether the sensor output contains signals of interest. Relevant features are extracted from the measured data. The features are processed with Kalman filters to smooth the data and predict the future value.

Initial planned efforts at the SHM are described here to provide the reader with an understanding of how the HMS system would be implemented if signals were available.

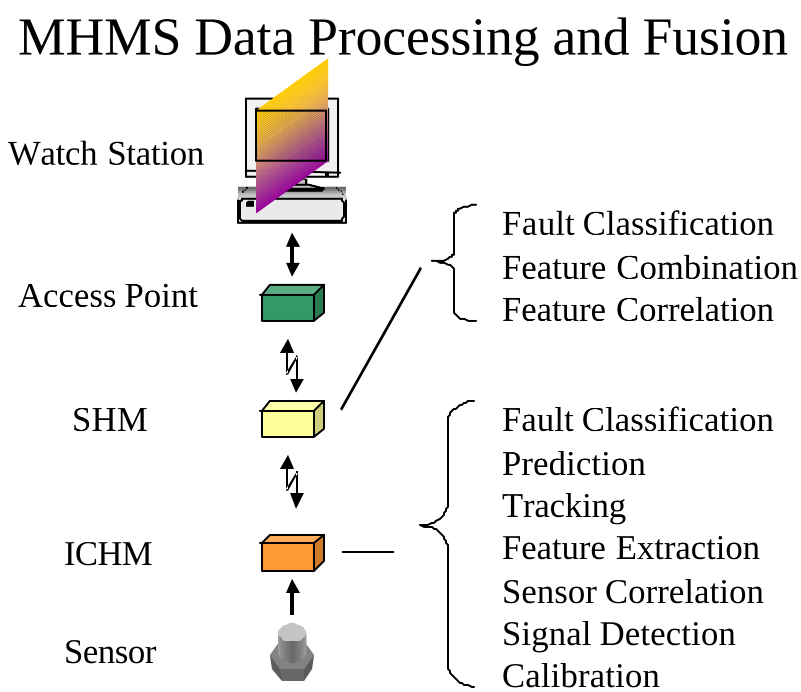



**Figure 58 Information Processing and Flow From Sensor to WS**

### *4.2.5.2.1 Electrical Generator Health Monitoring*

Processing of the generator electrical signals at ICHM #1(generator electrical) is shown in Figure 59. The sensor signals are shown in blue at the left of the figure. The first processing step involves the computation of FFTs of all of the signals. The signal spectra are searched to locate peaks. For the electrical signals, these occur at the main output frequency (nominally 60 Hz) and harmonics. In addition to identifying peaks, the peak statistics are also computed. Peak statistics include the RMS level, frequency, signal-to-noise ratio, and associated variances. The spectral peak and associated statistical information are fed into Kalman filters that provide smoothed track information for the features and predict future feature values.

Operational data that may be displayed at the watch station are shown at the bottom of the figure. These include the individual signal spectra, the output voltage, output current, load power, power factor, and output frequency. The generator electrical component features are passed to decision logic that determines whether a fault condition exists. The use of the Kalman filter permits projection of the measured state into the future enabling the system to assess whether a fault will reach an alarm state within the prescribed time window.

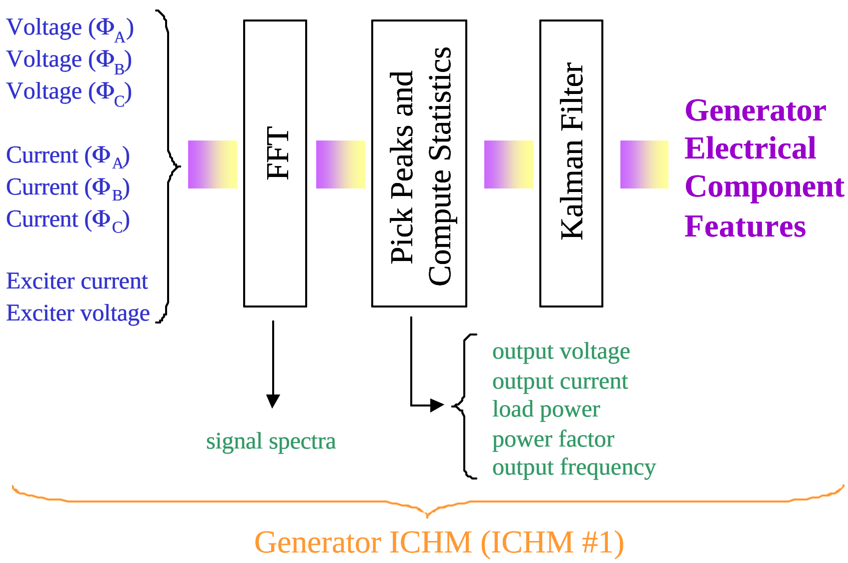
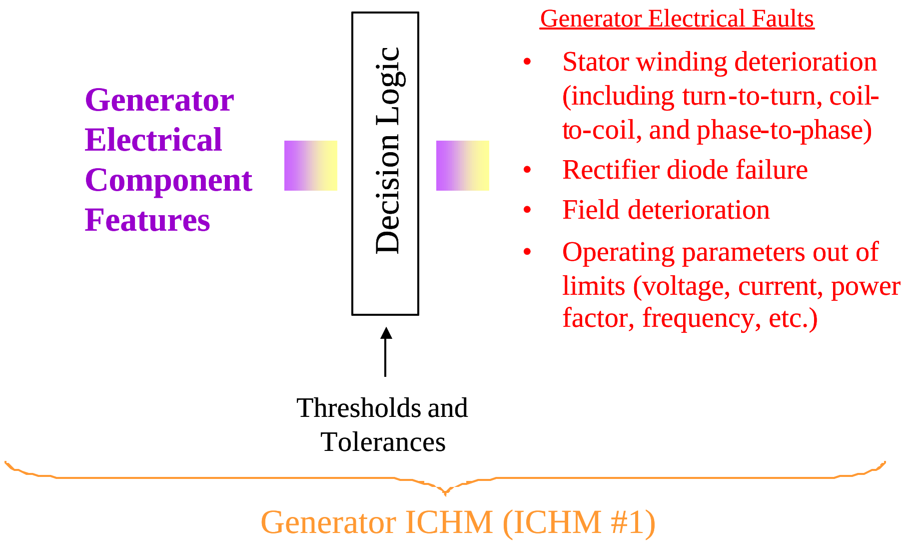



**Figure 59 Generator Electrical Feature Extraction and Operational Data Processing**

After processing the electrical features with the Kalman filters, the feature information is passed to decision logic that identifies fault conditions. This process is shown in the Figure 60. The output of the Kalman filters includes both smoothed tracks of the current machine state as well as a prediction of the future machine state (i.e. the future values of the features associated with the electrical components). The future machine state is predicted at some time t into the future, where t represents the required warning time required before the system enters an alarm state. The decision logic checks the current condition of the system and generates an alarm message if a fault is determined to exist. If the decision logic detects a fault condition using the predicted system state, then an alert message is generated indicating that an alarm will occur at time t in the future is the system continues to operate in its current state.

All of the decision processing shown in this figure takes place at the generator ICHM (ICHM #1). Thresholds and tolerance limits are downloaded to the ICHM from the SHM. The fault information is passed to the SHM as a health vector. The health vector contains the electrical component features, feature statistics, the fault severities and indication of whether and alert or alarm was generated.

**Figure 60 Generator Electrical Fault Processing**



#### *4.2.5.2.2 Bearing Health Monitoring*

The processing of bearing vibration signals used to extract vibration related features is shown in Figure 61. The raw time-domain signals are first calibrated (not shown in the figure), then the signal statistics are calculated and FFTs of the signals are computed. The FFTs are used to update power spectrum estimates and as the basis for subsequent processing. The physical dimensions of the bearings are used to compute defect frequencies. The signal spectrum is searched for narrowband energy at the defect frequencies as an indicator of bearing damage. If energy is present at related defect frequencies, additional processing is performed to extract potential features.

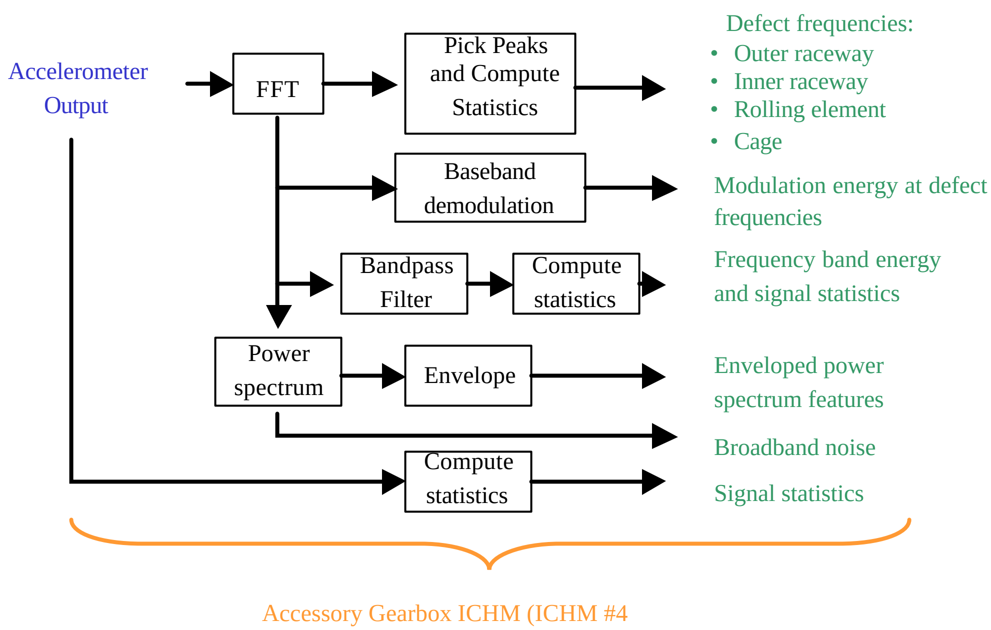



**Figure 61 Bearing Vibration Feature Extraction**

After computing the vibration related features, a Kalman filter is used to smooth the feature tracks and predict the future feature values within the alert time threshold. The processed features are then passed to the fuzzy-logic classifier to determine bearing fault confidences. If temperature data are available for the bearing, the temperature data are processed to update the signal statistics, then filtered with the Kalman filter to produce smoothed signal tracks and predict the future signal values. The predicted temperature data are used to increase or decrease the confidence in the bearing fault predictions. This process is shown in

Figure 62.

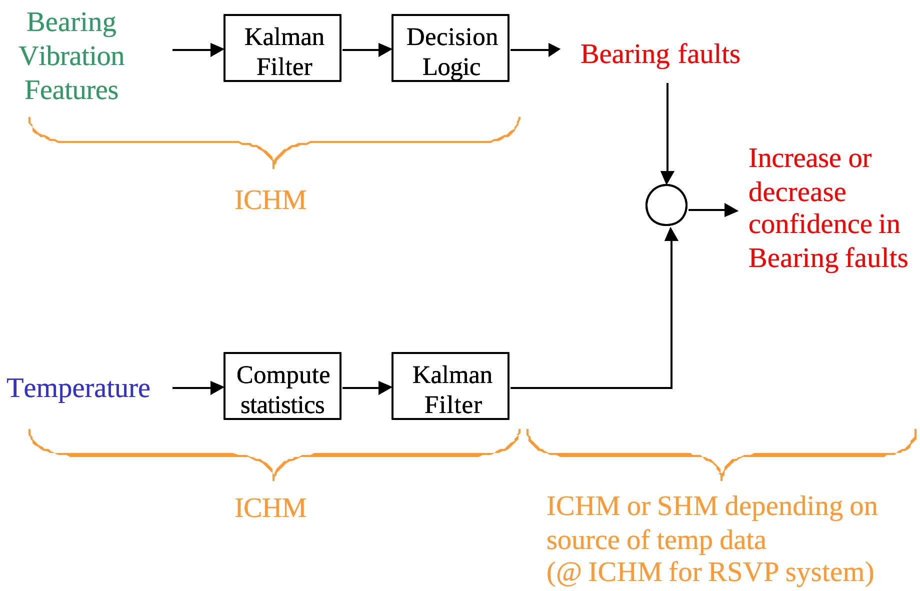



**Figure 62 Bearing Fault Processing**

Features and symptoms for bearing outer and inner race faults and symptoms for bearing rolling element and cage faults are shown in Table 23 and respectively. Outer race faults are indicated by signal energy related to rolling element pass outer raceway (RPOR) defect frequencies while inner race faults are indicated by signal energy related to rolling element pass inner raceway (RPIR) defect frequencies. Rolling element faults are indicated by features related to rolling element spin (RSPIN) defect frequencies while cage faults are indicated by signal features related to the cage defect frequency.

## Table 23 Outer and Inner Race Bearing Faults

| Fault / Enhanced Features | Fault Symptoms |
|---|---|
| **Bearing Outer Race Fault** | |
| Enveloped Power Spectrum RPOR defect frequency energy | Presence |
| EnvPS RPOR harmonics energy | Presence |
| Baseband 1x RPOR defect frequency | Presence |
| Frequency band kurtosis | Above variance, growing –early: Above and decreasing - late |
| Frequency band noise floor | Increasing in later stages |
| Frequency band RMS | Increasing in later stages with high and decreasing kurtosis |
| **Bearing Inner Race Fault** | |
| EnvPS RPIR defect frequency energy | Presence |
| EnvPS RPIR harmonics energy | Presence |
| EnvPS shaft SB energy around RPIR | Presence; total of $1^{st}$ 4 orders approaching, exceeding fundamental |
| EnvPS shaft SB energy around RPIR $1^{st}$ harmonic | Presence; total of $1^{st}$ 4 orders approaching, exceeding fundamental |
| EnvPS shaft frequency energy | Increase above baseline |
| EnvPS shaft harmonics energy | Total of $1^{st}$ 3 harmonics increasing above baseline |
| Baseband 1x RPIR defect frequency | Presence |
| Cepstral rahmonic at shaft period | Increase trend above baseline |
| Frequency band kurtosis | Above variance, growing –early: Above and decreasing - late |
| Frequency band noise floor | Increasing in later stages |
| Frequency band RMS | Increasing in later stages with high and decreasing kurtosis |

## Table 24 Rolling Element and Cage Bearing Faults

| Fault / Enhanced Features | Fault Symptoms |
|---|---|
| **Bearing Rolling Element Fault** | |
| EnvPS 2xRSPIN defect frequency energy | Presence |
| EnvPS 2xRSPIN harmonics energy | Presence |
| EnvPS cage SB energy around 2xRSIN | Presence; total of 1st 4 orders approaching, exceeding fundamental |
| EnvPS cage SB energy around 2xRSPIN 1st harmonic | Presence; total of 1st 4 orders approaching, exceeding fundamental |
| EnvPS cage frequency energy | Presence, increasing with severity |
| EnvPS cage harmonics energy | Presence, increasing with severity |
| Baseband 2xRSPIN defect frequency | Presence |
| Baseband 1x cage rev frequency | Presence |
| Baseband cage harmonics | Presence |
| Cepstral rahmonic at cage period | Presence, increase |
| Frequency band kurtosis | Above variance, growing –early: Above and decreasing - late |
| Frequency band noise floor | Increasing in later stages |
| Frequency band RMS | Increasing in later stages with high and decreasing kurtosis |
| **Bearing Cage Fault** | |
| EnvPS cage frequency energy | Presence, increasing with severity |
| EnvPS cage harmonics energy | Presence, increasing with severity |
| Baseband 1x cage rev frequency | Presence |
| Baseband cage harmonics | Presence |
| Cepstral rahmonic at cage period | Presence |
| Frequency band kurtosis | Increasing in later stages |
| Frequency band noise floor | Increasing in later stages |
| Frequency band RMS | Increasing in later stages |

#### *4.2.5.2.3 Gear and Shaft Health Monitoring*

The processing of gear vibration signals used to extract vibration related features in shown in Figure 63. The raw time-domain signals are first calibrated (not shown in the figure), then the signal statistics are calculated and FFTs of the signals are computed. The physical dimensions and characteristics of the gears and shafts are used to compute defect frequencies. The signal spectrum is searched for narrowband energy at the defect frequencies as indicators of potential gear or shaft faults. If energy is present at related defect frequencies, additional processing is performed to extract potential features.

One form of additional processing is the computation of the cepstrum from the signal spectrum. Cepstral rhamonics (the cepstral equivalent of a frequency response harmonic) at the associated rotational period is one indicator of damage. Time-synchronous averaging is a widely used technique for removing unwanted or uncorrelated vibration energy from the measured signal. After time-synchronous averaging, the averaged signal can be processed in either the time or frequency domain. The figure above only shows time-domain processing of the time-synchronous averaged signal. Statistical measures such as kurtosis applied to bandpass filtered or residual signals are often used as features. The residual signal has the mesh frequency and harmonics removed from the measured signal, thereby revealing low-level signals related to the progressing damage.

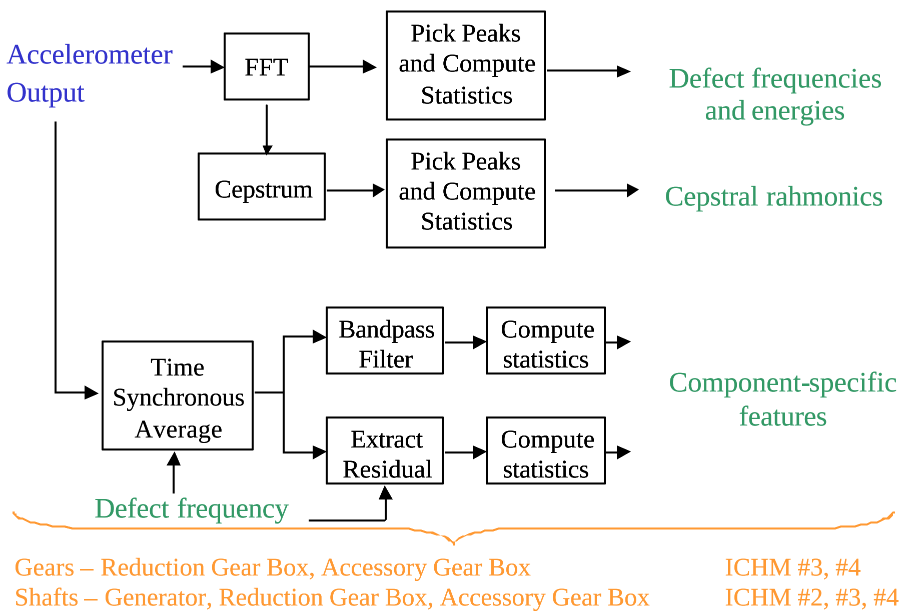



**Figure 63 Extraction of Gear and Shaft Vibration Features**

After computing the vibration related features, a Kalman filter is used to smooth the feature tracks and predict the future feature values within the alert time threshold. The processed features are then passed to the fuzzy-logic classifier to determine gear and shaft fault confidences as shown in Figure 64. In the case of bearings, temperature data can be used to correlate damage to the component. Temperature data typically has less value in gear monitoring due to the relatively small contact area between components compared to bearings. In cases where accelerometers are installed in locations with high operating temperatures, temperature measurements can be used to assess potential sensor problems (e.g. changes in sensor sensitivity due to elevated operating temperature). All processing can be performed at the ICHM level. When the ICHM monitors several vibration sensors, the signals from the different sensors can be correlated to increase or decrease the confidence in the fault assessment or to identify potential sensor problems.

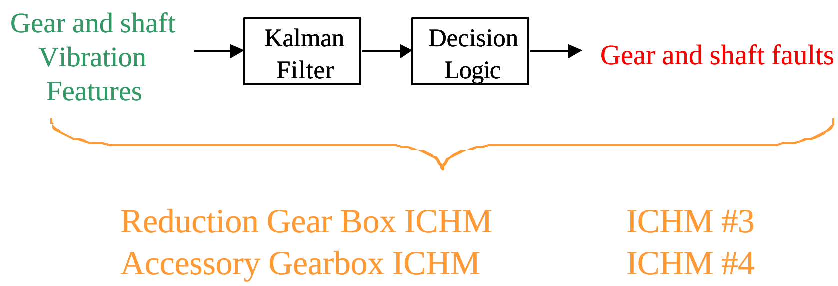



**Figure 64 Gear and Shaft Fault Processing**

Table 25 below, shows features and symptoms for different types of gear-related faults. In general, a fault with a particular component is indicated by a change in energy at a defect frequency related to the geometry of the particular component.

**Table 25 Gear and Drive Related Faults**

| Fault / Enhanced Features | Fault Symptoms |
|---|---|
| **Gear Tooth Fault** | |
| Enhanced kurtosis (from residual) | Above variance, growing –early.  Above and decreasing - advanced |
| Residual peak | Consistency unknown |
| Cepstral rahmonic at shaft period | Increasing with tooth breakage, leveling off until next breakage |
| Baseband shaft harmonic strength | Significantly increasing |
| RMS level | Increasing with advanced deterioration |
| Gear mesh level | No significant increase |
| **Gear Wear Fault** | |
| Enhanced kurtosis (from residual) | Stays around 3.0 |
| Gear mesh level | Significant increase |
| RMS level | Increase with severity |
| **Drive Shaft Fault** | |
| RMS level | Gradual, continuing increase |
| Shaft 1$^{st}$ and 2$^{nd}$ order SB's around gear mesh | Significant % of fundamental, increasing |
| Baseband shaft harmonic strength | Significantly increasing |
| Cepstral rahmonic at shaft period | Increasing toward failure (later indicator) |

### *4.2.5.2.4 Reduction Gear Box Processing*

Figure 65 shows the processing flow of the reduction gearbox ICHM. Vibration data is processed using the bearing and gear health monitoring approaches described previously (sections 4.2.5.2.2 and 4.2.5.2.3), and then fused with available temperature information to improve the confidence in identified bearing faults.

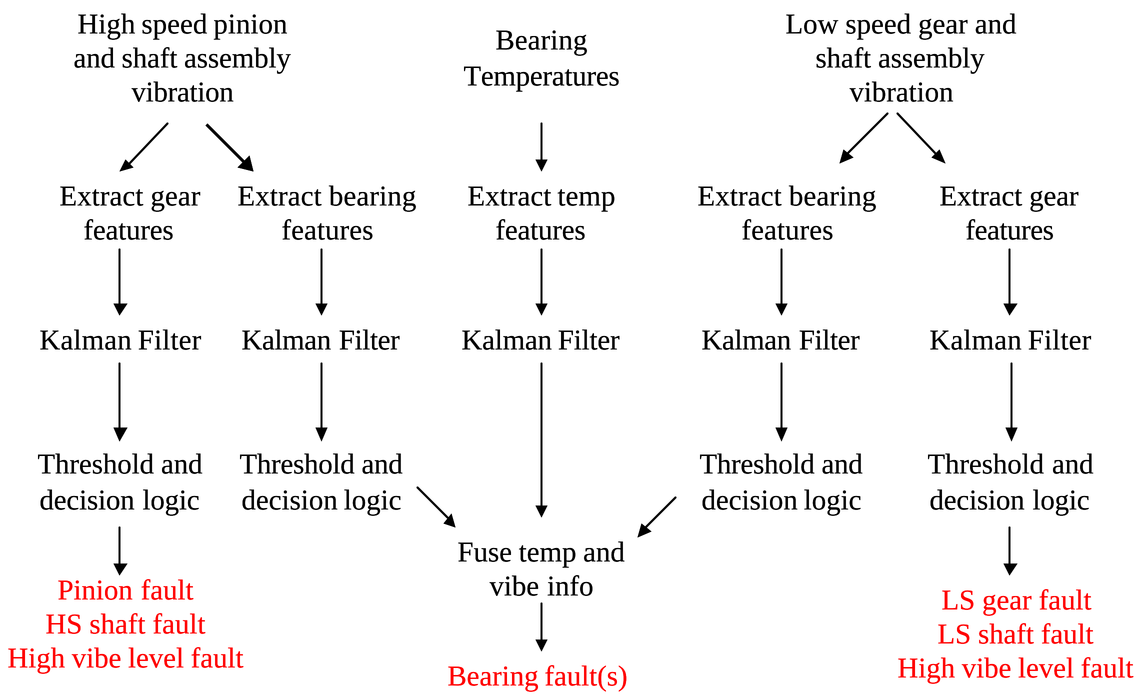



**Figure 65 RBG Processing Flow**

### *4.2.5.2.5 Accessory Gear Box Processing*

After computing the vibration related features, a Kalman filter is used to smooth the feature tracks and predict the future feature values within the alert time threshold. The processed features are then passed to the fuzzy-logic classifier to determine gear and shaft fault confidences - Figure 66. In the case of bearings, temperature data can be used to correlate damage to the component. Temperature data typically has less value in gear monitoring due to the relatively small contact area between components compared to bearings. In cases where accelerometers are installed in locations with high operating temperatures, temperature measurements can be used to assess potential sensor problems (e.g. changes in sensor sensitivity due to elevated operating temperature). All processing can be performed at the ICHM level. When the ICHM monitors several vibration sensors, the signals from the different sensors can be correlated to increase or decrease the confidence in the fault assessment or to identify potential sensor problems.

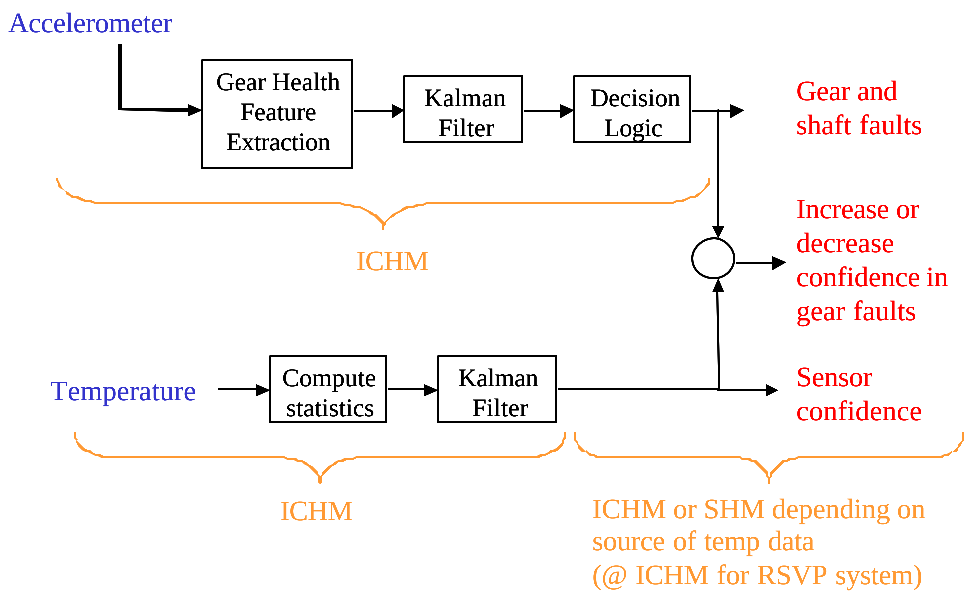



**Figure 66 AGB Processing Flow**

### 4.2.5.3 Data Processing and Analysis

#### *4.2.5.3.1 Approach/Software Structure*

Several feature extraction techniques were implemented on the four SSGTG subsystems monitored by the Machinery Health Monitoring System. These feature extraction techniques were developed by the Condition-Based Maintenance Department at Penn State ARL as part of the Condition-Based Maintenance (CBM) Features Toolbox. In addition to the analysis techniques, the Toolbox software structure and processing approach was adopted by the Integrated Component Health Monitors used in the RSVP ATD. The following description is, for the most part taken directly from the CBM Features Toolbox User's Guide.

The Condition-Based Maintenance (CBM) Features toolbox is a conglomeration of traditional features discussed in[1] along with a few non-traditional features developed at ARL. Developed in Matlab the toolbox provides a set of standard processing routines to help perform machinery diagnostics and prognostics. Toolbox flexibility supports the addition of features and input/output data file formats. By using an INI file interface, the user can easily change analysis parameters and process data with one Matlab command. The user may also pass data directly into any of the individual stand-alone feature

[1] Lebold, M., McClintic, K., Campbell, R., Byington, C., Maynard, K., "Review of Vibration Analysis Methods for Gearbox Diagnostics and Prognostics", 54th Meeting of the MFPT, Virginia, May 2000.

routines. The CBM INI file is a text file format that stores parameters and information about the accelerometers, signal conditioning, preprocessing parameters and the feature parameters. The flowchart in Figure 67 shows the data flow into and out of the CBM toolbox. To ensure that there are no issues on how the data was processed all of the parameters and information stored in the INI file are placed in the output data file along with the feature data.

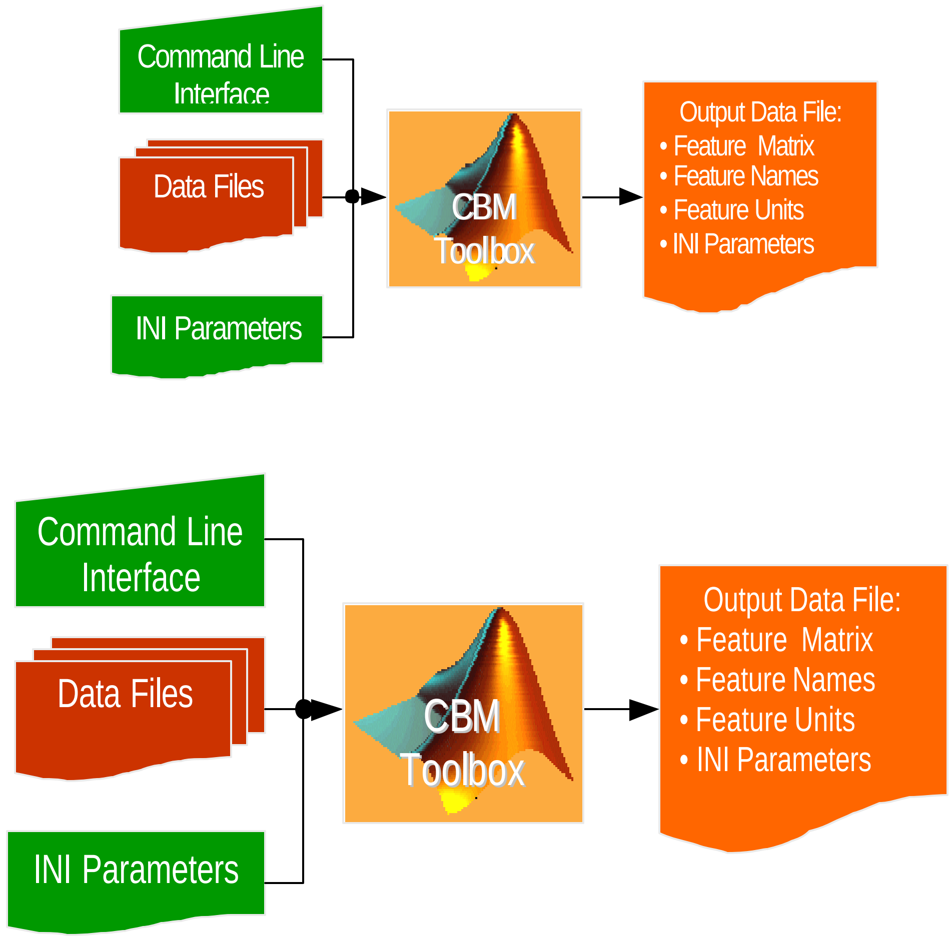



**Figure 67 Inputs and Output of the CBM Toolbox**

Eight (8) CBM Toolkit feature processing routines resulting in Figures Of Merit (FOM) were implemented in the RSVP HMS. Feature functions can produce multiple FOMs and be calculated in multiple preprocessing categories. The features and FOMs implemented on the Integrated Health Component Monitors in RSVP are identified in Table 26. All of the analysis features and input/output data files are controlled via a single command line to support batch processing.

**Table 26 Feature functions, the resultant FOMs, categorized by preprocessing level**

| | Function | FOMs Calculated within each Function | | | | | |
|---|---|---|---|---|---|---|---|
| | RMS | RMS | | | | | |
| | Kurtosis | Kurtosis | | | | | |
| RAW | Crest Factor | Crest | | | | | |
| | Enveloping | RMS | Kurtosis | STD Rect | Peak Amp | Peak Fq | |
| | Energy | Total | Peak (NB) | Broadband | NB/BB | | |
| | | | | | | | |
| TSA | Energy | Total | Peak (NB) | Broadband | NB/BB | | |
| | | | | | | | |
| | | | | | | | |
| RES | | | | | | | |
| | | | | | | | |
| | M6A | M6A | | | | | |
| DIF | M8A | M8A | | | | | |
| | FM4 | FM4 | | | | | |

### *4.2.5.3.2 Feature Extraction Overview*

Many types of defects or damage will increase the machinery vibration levels. These vibration levels are then converted to electrical signals for data measurement by accelerometers. In principle, the information concerning the health of the monitored machine is contained in this vibration signature. Hence, the new or current vibration signatures could be compared with previous signatures to determine whether the component is behaving normally or exhibiting signs of failure. In practice, such comparisons are not effective. Due to the large variations, direct comparison of signatures is difficult. Instead, a more useful technique that involves the extraction of features from the vibrational signature data could be used. Ideally, these features are more stable and well behaved than the raw signature data itself. Features also provide a reduced data set for the application of pattern recognition and tracking techniques.

Before any feature can be calculated on the raw vibration data, the data must be conditioned or preprocessed. Conditioning may range from signal correction, based on the data acquisition unit and amplifiers used, and mean value removal to time-synchronous averaging and filtering. A variety of signal processing techniques are used based on the feature being implemented. The features are divided into five preprocessing categories: 1) Raw signal (RAW), 2) Time synchronous averaged signal (TSA), 3) Residual signal (RES), 4) Difference signal (DIF), and 5) Band-pass mesh signal (BPM). The traditional processing flow for CBM feature extraction methods is shown in Figure 68. It is important to note that what is optimal for the one piece of equipment/ configuration, may not be optimal for other gearboxes or faults, and the INI file can be used to set the appropriate preprocessing parameters. Adjustment of these parameters for the SSGTG was accomplished after collection of data at the LBES

The RAW preprocessing denotes features that are calculated from the raw or conditioned signal from the sensor. The only preprocessing needed for these features is conditioning the signal or removing the mean of the signal. Signal conditioning is simply multiplying all of the data points by some calibration constant that is based on the accelerometer and amplifier used. The features in this group are: RMS, Kurtosis, Crest Factor, and Enveloping.

The TSA preprocessing entails time synchronous averaging of the raw data. Time synchronous averaging is a signal processing technique that is used to extract repetitive signals from additive noise. This process requires an accurate knowledge of the repetitive frequency of the desired signal or a signal that is synchronous with the desired signal. The raw data is then divided up into segments of equal length blocks related to the synchronous signal and averaged together. When sufficient averages are taken, the random noise is canceled, leaving an improved estimate of the desired signal. Before the signal is segmented, the number of data points in the series is increased by means of interpolation. This will provide a closer approximation when the signal is segmented and averaged. The sensor signal is segmented based on the synchronous signal. For example, a tachometer signal can be used as a synchronous signal for rotating machinery. Each segment will start based on the leading edge of a tach pulse and end on the corresponding data point that precedes the next tach pulse. Because of slight speed changes over the sample and inaccuracies in the tach pulse, the number of points in each segment might vary slightly. One method that has been used is to pick the segment with the lowest number of points and only average over this length. This may be thought of as justifying the data to the left and clipping off the data beyond the averaging length. The last step is to average all of the segments and decimate back to the original sampling rate.

There are three parameters involved with TSA that can affect the results: the interpolation factor, the number of revolutions concatenated together during the alignment, and the number of averages. Lebold, et al[1] describes these preprocessing parameters in more detail, and McClintic, et al[2] shows how these parameters affect the residual and difference analysis features when processed on Mechanical Diagnostics Test Bed (MDTB) data. A detailed description of the Applied Research Laboratory's MDTB can be found in reference [3]

The RES preprocessing calculates the residual signal, which consists of the time synchronous averaged signal with the primary meshing and shaft components along with their harmonics removed. What is unclear from the literature is how many harmonics to remove for the primary mesh and shaft components. For a time synchronous averaged

[1] Lebold, M., McClintic, K., Campbell, R., Byington, C., Maynard, K., "Review of Vibration Analysis Methods for Gearbox Diagnostics and Prognostics", 54th Meeting of the MFPT, Virginia, May 2000.

[2] McClintic, K., Lebold, M., Maynard, K., Byington, C., Campbell, R., "Residual and Difference Feature Analysis with Transitional Gearbox Data", 54th Meeting of the MFPT, Virginia, May 2000.

[3] Byington, C.S., Kozlowski, J.D., "Transitional Data for Estimation of Gearbox Remaining Useful Life", 51st Meeting of the Society for Machinery Failure Prevention Technology (MFPT), April 1997.

data over one revolution, this means that the smallest resolution in the frequency domain is the shaft frequency. Therefore, this would mean removing every point in the spectrum. What has shown to produce favorable results is to high pass the data about some frequency and only remove the meshing frequency and all harmonics. The cut-off frequency of the high pass filter will be system dependent, but it should lie somewhere between DC and the fundamental meshing frequency. Also, removal of five mesh harmonics has produced results very similar to the results produced by removing all the harmonics, but this may be system dependent.

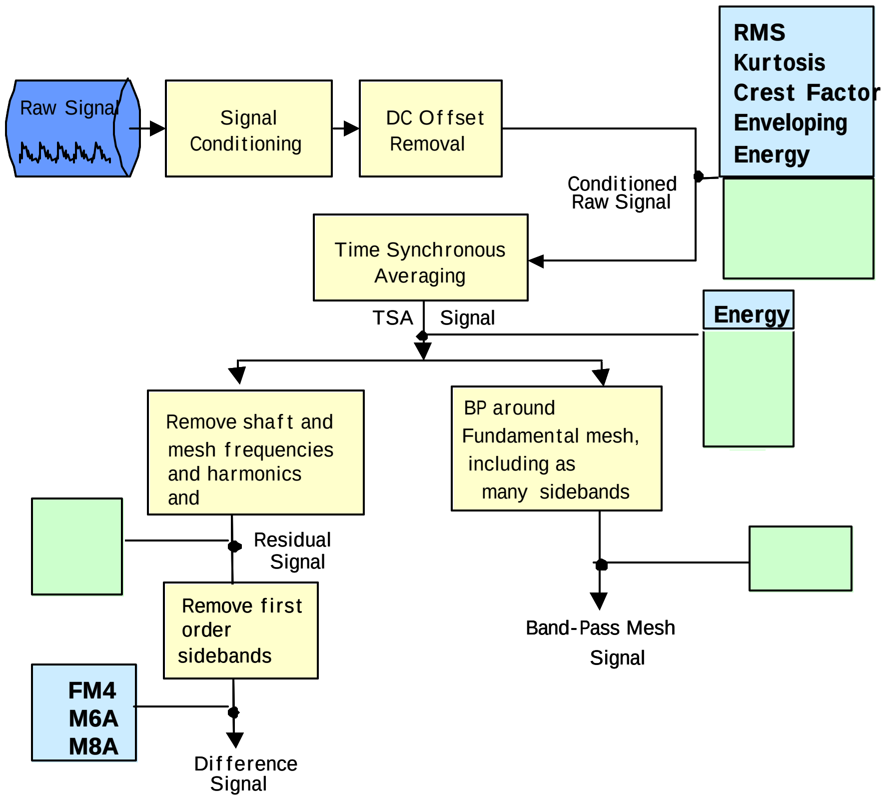



**Figure 68 Traditional Processing Flow for CBM Feature Extraction Methods**

The DIF preprocessing section calculates the difference signal by removing the regular meshing components from the time synchronous averaged signal. The regular meshing components consist of the shaft frequency and its harmonics, the primary meshing frequency and harmonics along with the first order sidebands. Since the residual signal is the result of removing the primary meshing and shaft frequencies and harmonics, the DIF processing section can consist of removing only the sidebands of the primary meshing frequencies from the RES signal. Assuming that a high-pass filter or a limited number of shaft frequency harmonics were removed, this will mean that only the sidebands of the meshing frequency and its harmonics need to be removed. For the case where time synchronous averaging is performed over one revolution, the sidebands will be one bin on either side of the meshing frequency. The features in the DIF group are: FM4, M6A, and M8A.

### *4.2.5.3.3 Feature Extraction Techniques Description*

#### 4.2.5.3.3.1 RMS

The root mean square (RMS) value of a vibration signal is a time analysis feature that is the measure of the power content in the vibration signature. This feature is good to track the overall noise level, but it will not provide any information on which component is failing. It can be very effective in detecting a major out-of-balance in rotating systems. Below is the equation that is used to calculate the root mean square value of a data series, $x_n$ over length N.

$$RMS = \sqrt{\frac{1}{N} * \sum_{n=1}^{N} x_n{}^2} \qquad (1)$$

#### 4.2.5.3.3.2 Kurtosis

Kurtosis is defined as the fourth moment of the distribution and measures the relative peakedness or flatness of a distribution as compared to a normal distribution. Kurtosis provides a measure of the size of the tails of distribution and is used as an indicator of major peaks in a set of data. As a gear wears and breaks this feature should react to the increased level of vibration [1]. The equation for kurtosis is given by:

$$k = \frac{\sum_{n=1}^{N}[y(n) - m]^4}{N*(s^2)^2} \qquad (2)$$

where y($n$) is the raw time series at point n, μ is the mean of the data, $\sigma^2$ is the variance of the data, and N is the total number of data points.

#### 4.2.5.3.3.3 Crest Factor

The simplest approach to measuring defects in the time domain is using the RMS approach. However, the RMS level may not show appreciable changes in the early stages of gear and bearing damage. A better measure is to use "crest factor" which is defined as the ratio of the peak level of the input signal to the RMS level. Therefore, peaks in the time series signal will result in an increase in the crest factor value. For normal operations, crest factor may reach between 2 and 6. A value above 6 is usually associated with machinery problems. This feature is used to detect changes in the signal pattern due to impulsive vibration sources such as tooth breakage on a gear or a defect on the outer race of a bearing. The crest factor feature is not considered a very sensitive technique. Below is the equation for the crest factor:

$$Crest\ Factor = \frac{PeakLevel}{RMS} \qquad (3)$$

where *PeakLevel* is the peak level of the raw time series, and *RMS* is the root mean square of the raw data.

### 4.2.5.3.3.4 Enveloping

Enveloping is used to monitor the high-frequency response of the mechanical system to periodic impacts such as gear or bearing faults. An impulse is produced each time a loaded rolling element makes contact with a defect on another surface in the bearing or as a faulty gear tooth makes contact with another tooth. This impulse has an extremely short duration compared to the interval between the pulses. The energy from the defect pulse will be distributed at a very low level over a wide range of frequencies. It is this wide distribution of energy that makes bearing defects so difficult to detect by conventional spectrum analysis when they are in the presence of vibrations from gears and other machine components. Fortunately, the impact usually excites a resonance in the system at a much higher frequency than the vibration generated by the other components. This structural energy is usually concentrated into a narrow band that is easier to detect than the widely distributed energy of the bearing defect frequencies. With tooth wear and breakage, the side band activity near critical frequencies such as the output shaft frequency is expected to increase. The entire spectrum contains very high periodic signals associated with the gear mesh frequencies.

The envelope or high frequency technique focuses on the structure resonance to determine the health of a gear or the type of failure in a bearing. This technique consists of processing structure resonance energy with an envelope detector. The structure resonance is obtained by band-pass filtering the data around the structure resonance frequency. The band-pass filtered signal is then processed by an envelope detector, which consists of a half-wave (or full-wave) rectifier and a peak-hold and smoothing section. A simple envelope detector processing flow diagram is shown in Figure 69.

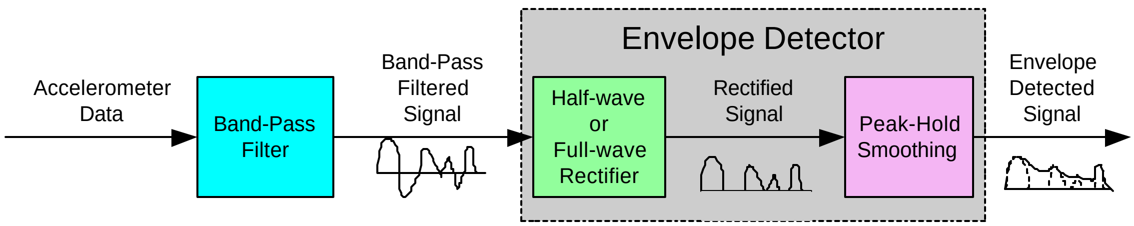



**Figure 69 Simple Envelope Detector Scheme**

The center frequency of the band-pass filter should be selected to coincide with the structure resonance frequency being studied. The bandwidth of the filter should be at least double the highest characteristic defect frequency. This will ensure that the filter will pass the carrier frequency and at least one pair of modulation sidebands. In practice, the bandwidth should be somewhat greater to accommodate the first two pairs of modulation sidebands around the carrier frequency.

The rectifier in the envelope detector turns the bipolar filtered signal into a unipolar waveform. The peak-hold smoothing section will then remove the carrier frequency by smoothing/filtering the fast transitions in the signal. The remaining signal will then consist of the defect frequencies.

This feature produces several figures of merit for analysis use. The primary figure of merit is the peak frequency and amplitude in the power spectral density of the enveloped data. Other figures of merit include the RMS and kurtosis values of the filtering section and the standard deviation of the output from the rectification and smoothing block.

The envelope technique has been widely used in numerous applications and has shown successful results in the early detection of bearing faults. Besides early detection, this process can help distinguish the actual cause of bearing failure by inspecting the actual bearing defect frequencies.

#### 4.2.5.3.3.5 FM4

FM4 was developed to detect changes in the vibration pattern resulting from damage on a limited number of gear teeth[2]. FM4 is calculated by applying the fourth normalized statistical moment to this difference signal as given in the equation:

$$FM4 = \frac{N\sum_{i=1}^{N}\left(d_i - \bar{d}\right)^4}{\left[\sum_{i=1}^{N}\left(d_i - \bar{d}\right)^2\right]^2} \qquad (9)$$

where $d$ is the difference signal, $\bar{d}$ is the mean value of difference signal, and $N$ is the total number of data points in the time record. A difference signal from a gear in good condition will be primarily Gaussian noise therefore resulting in a normalized kurtosis value of 3. As a defect develops in a tooth, peaks will grow in the difference signal that will result in the kurtosis value to increase beyond 3.

#### 4.2.5.3.3.6 M6A and M8A

M6A and M8A were proposed by Martin[4] to detect surface damage on machinery components. Both of these features are applied to the difference signal. The theory behind M6A and M8A is the same as that for FM4, except that M6A and M8A are expected to be more sensitive to peaks in the difference signal. The equations for M6A and M8A are as follows:

$$M6A = \frac{N^2\sum_{i=1}^{N}\left(d_i - \bar{d}\right)^6}{\left[\sum_{i=1}^{N}\left(d_i - \bar{d}\right)^2\right]^3} \qquad M8A = \frac{N^3\sum_{i=1}^{N}\left(d_i - \bar{d}\right)^8}{\left[\sum_{i=1}^{N}\left(d_i - \bar{d}\right)^2\right]^4} \qquad (10)$$

where $d$ is the difference signal, $\bar{d}$ is the mean value of difference signal, and $N$ is the total number of data points in time record.

[4] Martin, H. R., "Statistical Moment Analysis As a Means of Surface Damage Detection", Proceedings of the 7th International Modal Analysis Conference, Society for Experimental Mechanics, Schenectady, NY, 1989, pp. 1016-1021.

## 4.3 Personnel Status Monitoring System

The following section describes functionality of the Personnel Status Monitoring System (PSM).

### 4.3.1 ISU (Chest belt)

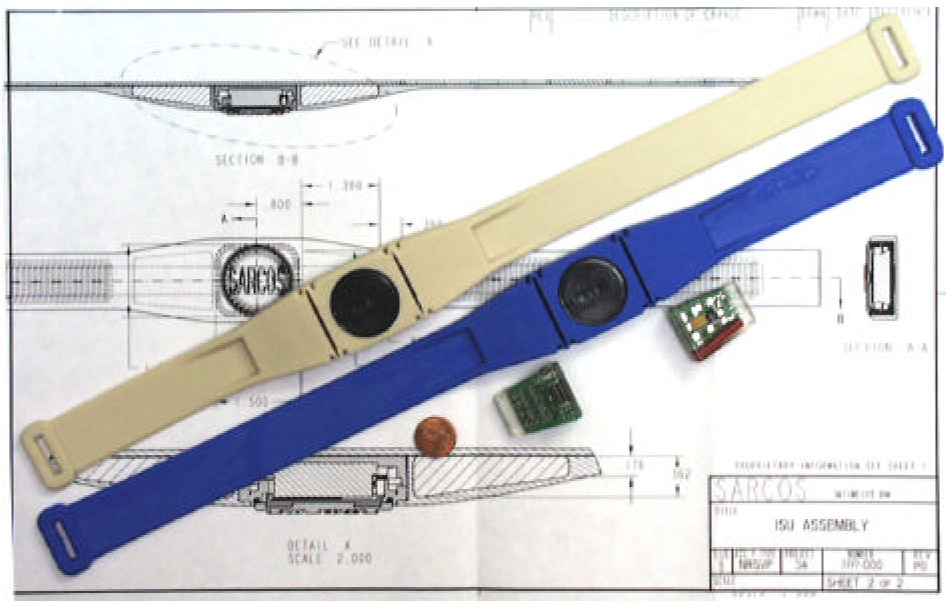



**Figure 70 RSVP Personnel Status Monitoring Belt**

The chest belt (Figure 70) is always on unless the battery has run down (estimated life 3 months) or removed. For the first belt unit, the accelerometer must be recalibrated when the battery is replaced. The unit is initialized by hanging vertically from one end as the battery is inserted and held that way for >60 seconds. (In this position, gravity will have no biasing effect on the accelerometer.) For the rest of the belts, no calibration is required when replacing the batteries. (Calibration constants were measured and stored in the Belt's nonvolatile memory.)

The ISU is worn across the chest with the long (two (rubber) electrodes on the left side of the body. The belt should be under the pectoral muscles and the end of the long arm in/below the left armpit (axilla). Electrode contact is enhanced by sweat or ECG electrode conductive gel. Excessive body hair may form a bad electrode contact. The belt should fit snugly.

The SARCOS logo is on the battery door. That door is bayonet mounted, rotate 1/8 turn or so anticlockwise and lift. There is an "O" ring seal for the door. The replacement cell is a CR2477N. Battery is inserted with the "+" facing down.

The ISU measures axillary temperature, shivering, position, motion, & heart rate derived from ECG signal. The short-range magnetic link to the CIU has a maximum range of 1 meter but depending on transmitting (ISU) and receiving (CIU) coil orientation that range may be reduced to about 30 cm. The ISU transmits a packet every 15 seconds.

### 4.3.2 CIU (Waist belt unit)


**Figure 71 RSVP RF-Communication Interface Unit**

The CIU (Figure 71) receives the ISU Bodylan packets, processes the ISU data, adds local information such as the CIU's temperature and relays data to the radio via the SPI interface. CIU operates in following modes:

1. Standby (message 82) CIU does not signal radio
2. 15 second update (message 84*) CIU signals radio every 15 seconds independent of ISU Packet
3. 60 second update(message 81) CIU signals radio every 60 second independent of ISU Packet
4. On ISU packet CIU signals radio only on reception of ISU packet

In the 15 and 60 second modes, the CIU will signal the radio with or without reception of a ISU packet. Since these two operations are asynchronous two each other, data may be delayed by one CIU packet cycle.

There are 3 status LEDs on the CIU Processor board. These are meant for quiet (visual) diagnostics. They are:

**Green - SPI active.**
Normally this LED will flash. The CIU turns this on when it signals the Radio (SPI Master) that it has a packet of data to send. The CIU turns it off when it is finished with sending data to the Radio.

**Yellow LED - Bodylan Power.**
This LED is powered by the same power running the Bodylan receiver electronics. When the CIU is first powered on, the Bodylan circuitry is powered up looking for a valid ISU packet. It will remain on until the CIU receives a valid

ISU packet. Once a valid packet is received, the CIU will synchronize its internal clock and power down the Bodylan electronics. If the CIU is in the 15 second mode, it will power up the Bodylan circuitry 1 second prior to receiving an expected ISU packet. If the CIU doesn't see any ISU packet (good or bad) it will power down and look again at the next expected ISU packet time. If the CIU fails to see ISU packets four consecutive times, it will leave the Bodylan powered on.

**Red LED - ISU Packet Error.**
This LED indicates the ISU packet was received with error(s). The CIU measures both the number of pulses and the duration between pulses in order to determine the values being sent. If a pulse is missing or the timing is incorrect, it will throw the packet out & light the Red LED. When this occurs, the Bodylan circuitry will remain on until it does receive a valid packet and the Red LED will also stay lit.

The CIU Black Box contains the CIU processor board (and battery package), Radio board, and Antenna board. The boards are stacked together with the Antenna board facing the opposite side of the belt clip. The CIU processor board (middle of the stack) has the battery package. The CIU operates using 3 AAA batteries. In order to gain access, the cover and the Antenna, must be removed.

**Switches**

There are two switches for the CIU. These are:

Power Switch
This is the main power switch and is located on the top side of the CIU box. On is towards the center of the box. When initially turned on, the Red and Green LEDs will flash 4 times, then with the Yellow LED staying on indicating the CIU is searching for an ISU packet. (The internal, on-board pushbutton switch is wired in parallel with the slider switch.)

Help Switch
This a button mounted on the CUI Processor board. A small extension has been added to bring the actuator flush with the surface of the lid. Pressing this will signal the CIU (via interrupt) that the user has requested help. Pushing the HELP button will force the CIU into the 15 second mode for 4 cycles. It will set a bit in one of the status registers (help flag bit) as well as setting the Sailor Status to RED. The CIU will send this status 4 consecutive times then clear the Help flag.

## 4.4 Access Point

**BSI FIELD GO PCATX-R9**
(STANDARD SHATTER-RESISTANT PROTECTION FOR LCD)

| PARAMETER | OPERATING | NON-OPERATING |
|---|---|---|
| SHOCK | 10G 11 MS ½ SINE | 30G 11 MS ½ SINE |
| TRANSIT DROP | 36" HIGH; 10 DROPS IN SHIPPING CARTON OR AIR CARGO CASE | CONSISTS OF 4 CORNER DROPS AND 6 SIDE DROPS |
| DROP AND TOPPLE | 5" DROP ON 4 CORNERS | UP TO 28 INCHES |
| VIBRATION (PER IEC 68-2-6) | 10-300 HZ 0.4G | 10-300HZ 1G PEAK |
| TEMPERATURE | 0 –TO + 50 C | -20 TO +60C |
| HUMIDITY | 5% TO 90% NON CONDENSING | |
| ALTITUDE | -1,000 TO +15,000FT | -15,000 TO + 40,000 FT |
| WATER/DUST | K/B IS NEMA 4/12 RATED | |
| APPROVALS | SAFETY= UL, TUV ON PS EMISSIONS= CE,FCC CLASS B | |

(INCLUDES BUILT IN CONVERSION BOARD AND G200 8 MB AGP VIDEO CARD)

**Figure 72 Access Point Hardware**

### 4.4.1 Hardware

An AP is an industrial grade IBM-clone PC running the Embedded Windows NT operating system. An illustration of an AP is shown Figure 72. Each AP consists of widely available components, ruggedized for shipboard use. They operate off of ship's power. Each Access Point will incorporate the follow accessory hardware items:

1. Video camera with audio
2. Video capture card
3. Ethernet card (100BaseT)
4. 3.5" floppy drive
5. CD-ROM writer drive
6. 2.2 GB EIDE removable media drive
7. Integral keyboard and LCD display

APs perform data logging and maintain a video loop recorder. Individual Access Points transmit real-time video or recorded video as commanded via the backbone. For sensed data, Access Points within a particular space exchange data with each other so each can make decisions based on all the data in the space. A COTS software package, NDDS (Network Data Delivery Service), have been selected as communication middleware. NDDS provides data/ information exchange and development environments between the environmental and structural sensors clusters, the Machinery Health Monitoring System and the Access Point and the Watchstation.

### 4.4.2 Software System and Development

Within a compartment, a LAN connects the Access Points (APs). Every Access Point is connected to a radio receiver via a serial line. In turn, the radio receiver connects to RF Sensor Cluster transmitters. All of the APs share identical software. However, one AP is identified as the "Primary" AP and has the additional responsibility of communicating with the Watch Station.

The principle of "Reliability Through Redundancy" extends to the AP software. All of the Sensor Cluster data must be available at every AP. Should RSVP lose an AP, the sensor cluster data should still be available, and other APs should shoulder the responsibility of the lost unit.

The state of a compartment is the sum of the information from all of the sensor clusters in the compartment. However, the radio receiver connected to an AP only receives communication from a few sensor clusters. Sensor cluster information, and indeed all AP state information, needs to be shared among all APs. Every AP needs to know the state of its peers, and the state of the compartment at all times. RSVP requires continuous and ubiquitous communication.

The two traditional LAN communication paradigms: client/server communication, point-to-point communication were investigated and rejected in favor of a publish/subscribe methodology. Publish/subscribe is built on client/server and point-to-point communication, but the lower level communication details are hidden. Since the communication details are hidden the developers can focus on substantive application matters.

#### 4.4.2.1 Publish/Subscribe Paradigm

The client/server model is appropriate when multiple clients need to communicate with a central server. The RSVP communication requirement could be addressed from the client/server model if every AP was considered both a client accepting connecting to other APs, and a server accepting connections from other APs. When a half dozen APs shared a compartment, each AP would be a client to each of the 5 remaining APs, and act as a server to them as well. Client/server model communication is doable but complex.

Point-to-point communication is useful when a system communicates with only one, or at most a few systems. The RSVP communication requirement could be addressed with the point-to-point model by connecting N Access Points with N! point-to-point paths. A half dozen APs in a compartment would require 720 communication paths. Again possible but complex.

The publish/subscribe paradigm is a higher-level communication paradigm. A publisher makes "topics" of information available to subscribers. For example, one publisher may broadcast topic "Temperature," and another publisher may broadcast topic "Humidity," and yet a third may publish “WindDirection.” One subscriber may request topics “Temperature” and “WindDirection,” while another subscriber may request topics “Temperature” and “Humidity.” The publish/subscribe software has responsibility for insuring that topics of interest are communicated between publishers and subscribers.

All of the APs in a compartment need data from all sensor clusters. RSVP shares Sensor Cluster data among all of the APs in a compartment using publish/subscribe. Each AP publishes the data it receives from its radio receiver and subscribes to all of its peer’s data. The publication topic for environmental sensor data is “COMP012/ENVDATA.” The topic is like a file path, separated into components with slashes. Subscribing to the topic “COMP012/ENVDATA” is a request for all environmental data from compartment 12. An AP both publishes Sensor Cluster data, and subscribes to Sensor Cluster data.

In addition, to simplifying data sharing, the publish/subscribe paradigm is also useful in determining the AP failure. Every AP publishes a periodic heartbeat with the topic, “COMP012/AP0xx/HEARBEAT.” Every AP also subscribes to its peer’s heartbeat with the subscription “COMP012/*/HEARBEAT,” where embedded asterisk is the wildcard character that means “any.” Thus, the subscriptions will include the publications “COMP012/AP012/HEARBEAT,” “COMP012/AP045/HEARBEAT,” etc. Since each subscription includes an optional timeout value, the failure of an AP to publish its heartbeat will trigger a subscription timeout, notifying its peers that it is inoperable. The peer cans then take the appropriate evasive action. If the unavailable peer is the Primary AP with responsibility for communicating with the Watch Station, the Primary AP’s Watch Station Communication responsibilities are taken over by another AP.

The RSVP system has about 25 different kinds of publications. The publications simplify data sharing and provide for notification on system failure. The publish/subscribe software used was NDDS purchased from Real-Time Innovations, 155A Moffett Park Drive, Sunnyvale, CA 94089. The product was reliable and well supported. The API was well thought out and the learning curve was short. Resource usage was minimal. NDDS was one of the major reasons the software was developed on time and on budget.

#### 4.4.2.2 Programming Language and Development

The RSVP software was developed using Microsoft Visual C++ 6.0 . The RSVP AP application was written in ANSI Standard C++, and is a “command line” application. It uses neither Windows, the Microsoft Foundation Class nor the application framework (afx). The Dinkumware (398 Main Street, Concord, MA 01742) Standard Template Library was used extensively.

The RSVP AP application is heavily multithreaded. Event, critical section, timer, and mutex synchronization were used extensivly. The delivery of publication information was asynchronous. On the arrival of publication information the application would place the information into a queue, an event would be signaled, and the delivery thread would return. The signal would unblock a waiting application thread that would read the queue and process the publication information.

C++ was used primary for encapsulation within classes. Inheritance played an important though secondary roll. The application contains 73 classes. Messages were passed between the classes via the Publish/Subscribe software, via synchronization primitives and intermediate queues, and via traditional method calls.

#### 4.4.2.3 Audio, Video and Video Compression

Every AP is equipped with a microphone and a video camera with pan-tilt-zoom. The cameras composite video and the audio feed to a Videm AV (PCI) video capture board manufactured by Winnov, 1043 Kiel Court, Sunnyvale, CA 94089. The video application at the AP captures the video at 5 frames per second. The video is compressed with a PICVideo Motion JPEG codec from Pegasus Imaging Corporation, 4522 Spruce Street, Suite 200, Tampa, Florida 33607. The audio and video are saved as avi files and are displayable with widely available media player software. Files including the most recent 24 hours of video are retained at the AP for retrospective examination.

After compression, a 320x240 video frame is about 10k in size. The slow frame rate, the small image size, and the efficient compression allow a real time video stream to be sent over the network to the Watch Station without unduly burdening the network. The publish/subscribe software is used to transfer the video. The video publisher application at the AP, and the video subscriber application at the Watch Station use Microsoft's Video for Window API, and are Windows applications.

On request from the Watch Station, a video stream is sent from the AP. The camera's pan-tilt-zoom is driven from the Watch Station video user interface. As the video is presented at the watch station, it is also retained as avi files. Thus the video system supports two types of retrospective analysis. Video shown at the watch station can be replayed. At every AP, the most recent 24 hours of video is available.

#### 4.4.2.4 Communication Between the Primary AP and the Watch Station

One is the APs in a compartment is given the responsibility of communicating with the Watch Station. This "Primary" AP is the first AP to be started in a compartment. When the first primary goes off-line, the AP with the highest serial number in a compartment takes its place as the Primary. Communications to the Watch station from the primary AP include environmental alarms and sensor data readings. Environmental alarms are triggered by high temperatures and water levels, as well as by the fulfillment of environmental criteria that indicate fire. In addition, the watch station may request continuously updated sensor readings. In this case, when the Primary AP receives data from a sensor of interest, it is forwarded to the Watch Station.

#### 4.4.2.5 Alarm Generation

Multiples times a minute, every AP examines compartment data searching for evidence of alarm conditions. RSVP alarm conditions include fire, flood, high temperature and abnormal structural strain. Every AP does a complete alarm analysis, but only the Primary AP presents the alarm information to the Watch Station. Flood, high temperature and abnormal structural strain alarms are determined by testing sensor values against preset values. When the values are exceeded in multiple sensor clusters, an alarm is generated. Fire detection is more complex.

Fire detection uses multiple variable discrimination. Sensor data was gathered from a series of test fires and used to build fire models. The test fires burned a variety of fuels including hydrocarbons heptane and #2 fuel oil, wood and wood derivatives including excelsior and paper, plastics characteristic of printed circuit boards, and edible polysaccharides like pop tarts and toast. Sensor data was also gathered on the ignition products of welding.

For each of these fires, a set of discrimination coefficients was generated that modeled the fire. The sum of the products of the discrimination coefficient and the transformed sensor reading determined the probability of fire. Every set of sensor readings was analyzed using all of the fire models. When multiple fire models produced a high probability of fire from the data on multiple sensors, the fire alarm was sent to the Watch station. Raw sensor readings were transformed to eliminate both the effects of sensor aging with a long term filter, and the effects of transients with a short term filter.

The major contributors to the success of the software effort were: the acquisition of the NDDS publish/subscribe software, the use of object technology, and the use of the Standard Template Library containers. The publish/subscribe software allowed the developers to bypass the complexity of network communications. Object technology provided the framework for developing a system of independent entities communicating via messages. The Standard Template Library's container classes were used as data repositories.

#### 4.4.2.6 RF Architecture

The low power radio frequency (RF) network is described in detailed in the RSVP formal report called "The Radio Network Communication Specification" [ref 13]. The technical report describes the hardware and protocols used to implement the custom, low-power wireless portion of the Reduced Ships-Crew by Virtual Presence (RSVP) system.
The areas to which this document is applicable are the environmental, structural and personnel monitoring functions. Coverage includes all functionality of the Access Point Communications Module (APCM), aspects of the sensor clusters that pertain to system communication, and all functionality of the personnel status monitor from the antenna to the processor-processor interface. The messages being sent throughout the RSVP system are covered by "Integrated Communications Specification Report" [ref 14].

# 4.5 Watchstation

## 4.5.1 Overview

The purpose of the RSVP Watchstation (WS) is to provide a means of demonstrating compartment level virtual presence based on the technologies and system developed during the RSVP ATD. The WS is a prototype example for demonstrating the underlying technologies; advanced distributed sensing capabilities (MEMS, power scavenging, distributed processing), wireless networking communication and a robust data to information fusion architecture in an integrated system. As such, the RSVP Watchstation is not intended to be a finished product for implementation. The Watchstation does provide an example of things to consider, including form and function, when developing and implementing the under lying technologies in the future. A properly designed human-centered interface will be essential in realizing the full benefits of reduce manning through technologies leading virtual presence.

The WS provides a means for interactive viewing of selected system data as well as asynchronous updates due to alarm conditions. The viewing of system data will be by hierarchical interaction with graphical screen objects. To facilitate rapid prototyping for the RSVP demonstration effort, a COTS software package, Sammi (Standard Application Man Machine Interface) and NDDS (Network Data Delivery System), have been selected to provide graphical user interface and data communication development environments.

Watchstation hardware consists of an industrial rack mount PC, two 20 inch touch screens, keyboard, mouse and associated interconnect cabling. Watchstation software consists of Windows NT operating system, NDDS communication software and a commercial graphical user interface software package.

Specific details of the hardware, software interface design and User Interface development are described in the following sections.

#### 4.5.1.1 Functional Requirements

Table 27 identified the functional requirements specified in section 3.1 of the Requirements for the RSVP Watchstation report, and notes which requirements were implemented. *Note: Identified requirements are for a final deployed system and as such, full compliance for the prototype demonstration system was not expected.*

**Table 27 Watchstation Functional Requirements**

| Requirement | Implementation | Comments |
|---|---|---|
| The watchstation shall meet the RSVP HCI requirements for consistency, navigation, visual appeal, terminology, organization, response time, reliability, feedback, error prevention, alerts, input devices, and output devices, general monitoring, machinery monitoring, environmental monitoring, personnel monitoring, structural monitoring, and user configuration. | Implemented in accordance with RSVP User Interface Requirements (10/99) | In a few cases, limitations of the graphical development software prevented full compliance with defined requirements. In general the requirements were met. |
| The watchstation shall receive alerts/alarms/data asynchronously and display them to the operator. | Implemented using SAMMI user interface; NDDS data management. | Alerts/alarms were pushed from lower levels in the system when an abnormal condition is detected. |
| The watchstation shall have the capability to display health vectors. | Implemented | Health information was provide in conjunction with alert/alarm message in the data view screen |
| The watchstation shall have the capability to display data from any sensor. | Implemented | Operator could 'drill down' to sensor data |
| The watchstation shall have the capability to display system configuration information. | Implemented | RSVP System View implemented allowing access to components of the RSVP monitoring system. Included system setup capability |
| The watchstation shall have the capability to permanently archive all information received at the watchstation with a timestamp. | Implemented separately at lower levels in the system. | Information was archived but not at the watchstation. Distributed archiving met the rationale for the requirement – evaluating effectiveness of the RSVP system |

| Requirement | Implementation | Comments |
|---|---|---|
| The watchstation shall have the capability to store and retrieve information. | Implemented | System configuration information stored in commercial database. Supported UI configuration |
| The watchstation shall have the capability to:<br>1. Obtain live or recorded video from an Access Point<br>2. Display what was obtained<br>3. Permanently archive what was obtained<br>4. Recover video from archive and replay at user request | 1. Implemented<br>2. Implemented<br>3. Partial Implementation – limited archive capability implemented at AP<br>4. Partial Implementation – Operator can request video recording | 1. Provided operator with telepresence.<br>2. Provided operator with telepresence.<br>3. Provided operator and investigators with near term/event video history<br>4. Demonstrated meeting requirement with the need for a large storage capacity |
| The watchstation shall have the capability to archive video automatically based on certain triggering events like a fire alarm. | Partial Implementation | Event triggered video recording not implemented. Operator record request option implemented. |
| The watchstation shall have the capability to display video from multiple Access Points (APs) simultaneously. | Implemented | Video feeds from 4 AP displayed simultaneously |
| The watchstation shall have the capability to transfer data and files to/from the APs and Machinery HMS. | Implemented | Lower level update capability from the WS allows for system wide modifications, upgrades, etc. at central location |
| The watchstation operating system shall be one with an extensive user base, familiarity, good Visual C++ tools, and compatibility with any COTS software that will run on the watchstation. | Implemented Considers total costs of OS selection including ability to use existing systems to demo watchstation software, learning curve for new users, compatibility issues. | Windows NT operating system on WS and Access Points, SHM and ICHMs. Rationale was for selection of OS included cost, demonstration portability, existing system compatibility and new user learning curve |

## 4.5.2 Hardware

In order to support a successful demonstration at LBES, aboard the USS MONTEREY and at the ex-USS Shadwell, performance, interface, environment and reliability requirements were established for the Watchstation hardware. Table 28, Table 29, Table 30, and Table 31 identify the requirements and their implementation status for the demonstrations. The Watchstation is a commercially available Pentium based computer running Windows NT, in a ruggedized rack mount housing.

### 4.5.2.1 Hardware Requirements

#### *4.5.2.1.1 Performance Requirements*

**Table 28 Watchstation Performance Requirements**

| Requirement | Implementation | Comments |
|---|---|---|
| The watchstation shall meet the RSVP HCI performance requirements. | Implemented in accordance with RSVP User Interface Requirements (10/99) | In a few cases, limitations of the graphical development software prevented full compliance with defined requirements. In general the requirements were met. |
| The watchstation shall have a means for loading from, and storing data to, a widely available, removable storage medium. | Implemented | 250MB Zip Drive, CDRW, 2GB Jazz Drive, 1.44MB Floppy |
| The watchstation shall have a high-speed means for loading software. | Implemented | Internal CDRW. |
| The watchstation shall have an internal or external data storage device with removable media. | Implemented | 2 GB Jazz drive, |
| The watchstation shall have a network interface card. | Implemented | 100 Base T Ethernet card |
| The watchstation shall have a modem. | Implemented | 3 Comm PCI 56K Voice Hardware Modem |

#### *4.5.2.1.2 Watchstation Interface Requirements*

**Table 29 Watchstation Interface Requirements**

| Requirement | Implementation | Comments |
|---|---|---|
| The watchstation shall meet the RSVP HCI input/output requirements. | Implemented | Touch Screen Displays, Keyboard w/ Integrated Track Ball, Mouse |
| The network interface protocol employed shall be a widely accepted, nonproprietary standard. | Implemented | TCP/IP Used. For detailed descriptions see RFC 793 for TCP, RFC 768 for UDP, RFC 791 for IP, and RFCs 894 and 826 for sending IP over Ethernet. |
| The watchstation software shall interface to the NDDS middleware used for data transport from the Access Points. | Implemented | NDDS Interface to Watchstation User Interface software developed |
| The watchstation hardware and software shall conform to the interface control documentation to be defined. | Implemented | Interface documents for Watchstation (Sammi) to AP (NDDS), AP (NDDS) to SHM (TCP/IP), and SHM (TCP/IP) to ICHM (TCP/IP) Interface Control Documents established |

#### *4.5.2.1.3 Watchstation Environmental Requirements*

**Table 30 Watchstation Environmental Requirements**

| Requirement | Implementation | Comments |
|---|---|---|
| Hardware operating temperature range shall be $0^0$-$45^0$ C without external cooling. The operating temperature range should be $0^0$-$60^0$ C without external cooling. | Industrial PC specification | Accepted vendor specs, unit not tested |
| Hardware shall withstand random vibration of up to 0.4 grms between 50 and 500 Hz. | Industrial PC specification | Accepted vendor specs, unit not tested |
| Hardware shall operate in an environment with relative humidity levels between 10 and 90 percent, non-condensing. | Industrial PC specification | Accepted vendor specs, unit not tested |

#### *4.5.2.1.4 Watchstation Reliability Requirements*

**Table 31 Watchstation Reliability Requirements**

| Requirement | Implementation | Comments |
|---|---|---|
| The watchstation shall meet the RSVP HCI reliability requirements. | Implemented in accordance with RSVP User Interface Requirements (10/99) | In a few cases, limitations of the graphical development software prevented full compliance with defined requirements. In general the requirements were met. |
| The watchstation hardware shall be rugged enough to last four months in a shipboard environment. | Industrial PC specification | Accepted vendor specs, unit not tested |
| The watchstation shall automatically reboot and re-establish connections to the Access Points in the event of a power failure. | Implemented | Auto Boot, User Interface Software auto load |
| The watchstation shall be operational upon loss of ship's power. | Implemented | Used ICAS uninterruptible power supply (UPS) co-located in rack with RSVP CPU. UPS meant to allow operation for short periods of power loss/orderly shutdown |
| The watchstation shall be electrically isolated from noisy ship's power. | Implemented | Used ICAS uninterruptible power supply (UPS) co-located in rack with RSVP CPU |

#### 4.5.2.2 Watchstation Installation – CG61 USS MONTEREY

The Watchstation hardware was located in the Central Control Station (CCS) aboard the USS Monterrey. The Watchstation CPU was rack mounted in the ICAS cabinet in a spare slot. The two touch sensitive screens, keyboard and mouse were located near the aft bulkhead in CCS on small work table designed, fabricated and installed to support the RSVP At Sea Demonstrations. The Watchstation hardware is shown in Figure 73 and Figure 74

**Figure 73 Watchstation Screens**

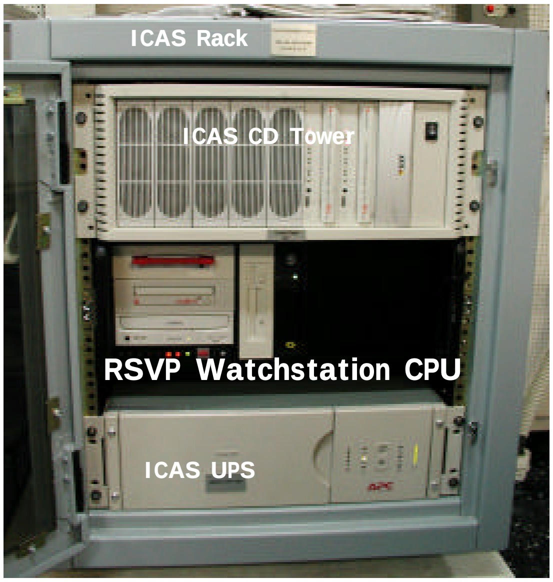



**Figure 74 Watchstation CPU Mounted in ICAS Rack**

## 4.5.3 Software

### 4.5.3.1 Overview

All communication between the watchstation user interface (WSUI) and subsystems is accomplished by either direct communication with APs or data flow routed through APs. Figure 75 presents an overview of the system hierarchy. The WSUI is designed to provide for interactive viewing of selected system data as well as asynchronous updates due to alarm conditions. The viewing of system data is by hierarchical interaction with graphical screen objects. To facilitate rapid prototyping for the RSVP demonstration effort, two COTS software packages, Sammi (Standard Application Man Machine Interface) and NDDS (Network Data Delivery System), were selected to provide graphical user interface and data communication development environments.

A commercially available graphical interface and communication development package manufactured by Kinesix was chosen to implement the WSUI objects necessary to present preprocessed information from the subsystems. Standards-based Advanced Man Machine Interface (Sammi$^{R}$) is a client/server and Web-based software development toolkit for creating graphical, networked or embedded applications that are data, event, and command driven. It consists of a graphical editor for creating user interfaces; multiple executable programs that manage the user interfaces and network communicat6ions during runtime; libraries and tools for developing distributed applications that communicate with the Sammi runtime programs and interact with end-users; and libraries and tools for customizing and enhancing the graphical editor and runtime programs. It is designed to facilitate control and monitoring in distributed networks and is suitable for the RSVP application. . Kinesix Corporation located in Houston, TX markets SammiR.

NDDS network middleware software manufactured by Real-Time Innovations (RTI) was selected to meet the requirements for real-time data exchange between APs and to allow both publish/subscribe and client/server request/reply paradigms.

The WSUI to AP interface design requires a definition of the interface between the Sammi and NDDS software as well as the structure of the interface between NDDS and the data for each subsystem.

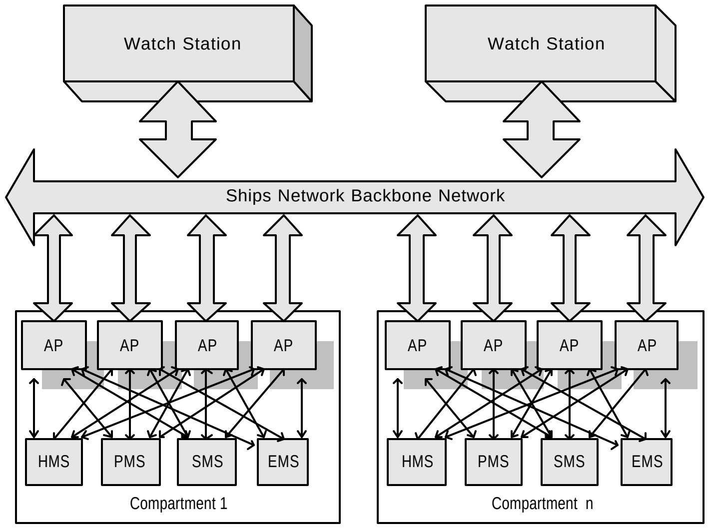



**Figure 75 RSVP System Architecture**

### 4.5.3.2 Sammi

The Sammi environment provides the capability to build graphical user interface (GUI) formats (screens) by using Dynamic Data Objects (DDOs). The interface screens are constructed by dragging and dropping an available set of DDOs. The DDOs contain extensions to allow data and commands to be sent to and from the GUI formats to distributed peer server processes. The Sammi Runtime Environment (RTE) manages the interactions between the DDOs and the server processes. DDOs for both data input and output are provided in the form of integers, floats, strings, charts, buttons, sliders, alarms, etc.
DDOs allow a server process to be specified such that bi-directional data communication can occur between a DDO element and a server located anywhere in the network. The communications are based upon underlying remote procedure calls (RPCs). Input DDOs allow one or more commands to be sent to either a specified server or the Sammi RTE. Commands sent to the RTE provide facilities to add and delete window formats and make layers within a format visible/invisible, among other features. Commands sent to user peer server processes are event driven, and several events can be initiated sequentially based upon DDO inputs such as button clicks. In addition, a peer server process can send commands to the RTE such that the peer server can affect change in the current state of the GUI.

There are two underlying methods to communicate information between a DDO and a server: polled and asynchronous. For each DDO, the protocol is specified as either polled or peer (the asynchronous method is provided by the peer protocol) along with the server name. For polled data, the server only sends DDO updates when requested to do so by the RTE, based on a rate specified by the DDO. The peer data protocol provides for asynchronous updates where the server process drives the update rate. The peer protocol is envisioned as the primary protocol to support the WSUI since much of the RSVP system data will arrive asynchronously. Figure 76 illustrates the Sammi structure.

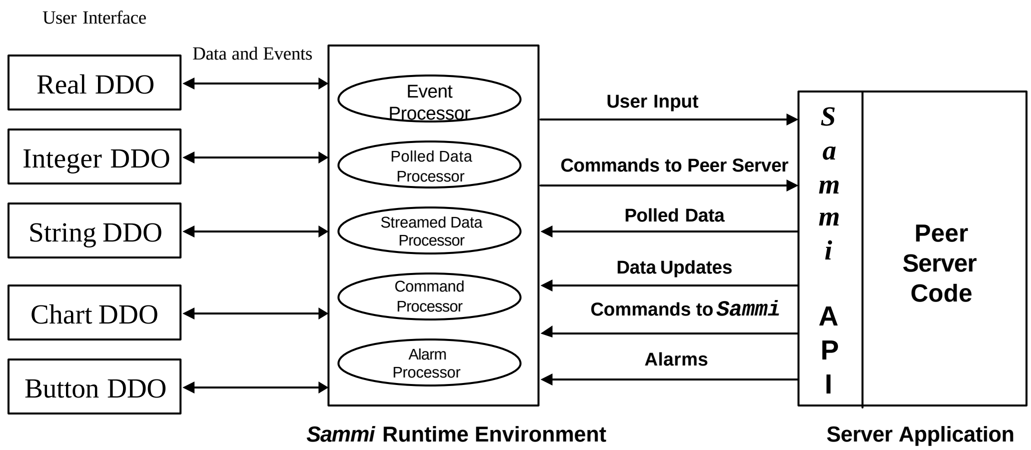



**Figure 76 Sammi Structure**

#### 4.5.3.3 NDDS

The NDDS environment provides a middleware component for communications between APs and the WSUI. It provides a standard client/server architecture as well as a publish/subscribe paradigm.
Client and server message object classes can be created anywhere in the network. These disjoint objects communicate by *client objects* initiating requests to NDDS *server objects*. The *client* can wait for the *server* to respond to the request or install a callback to provide notification. This structure is often referred to as a request/reply.

The NDDS publish/subscribe architecture allows publications to be registered over the network. Then the *subscription object* "subscribes to a message" which results in the *publication object* sending its message data to the *subscribing object*. Using this paradigm, no data is actually sent by a *publishing object* until requested by a corresponding *subscription object*. The publish/subscribe protocol allows data to be sent to a client process without the need for the client to issue requests (polling) each time data becomes available.

#### 4.5.3.4 Sammi/NDDS Interface (SNI)

The Sammi peer server code enabled the mapping of data between Sammi DDO objects and the NDDS message environment and is termed the Sammi/NDDS interface (SNI). The NDDS data is encapsulated in message classes, which provide data input and output via both publish/subscribe and request/reply protocols.

For each NDDS message, a data member called a topic is used to instantiate the object and to identify the particular data structure contained within the message. In addition, separate identifiers are used to identify the particular instance of the message and the location of the data in the network. An NDDS message can then be instantiated for several different topics, each containing different data structures corresponding to particular data sources. The peer server is also designed to facilitate the integration of database message classes to allow the integration of a local database into the watchstation software. Figure 77 illustrates the general interaction between DDOs, the Sammi RTE, the peer server, NDDS messages and database messages.

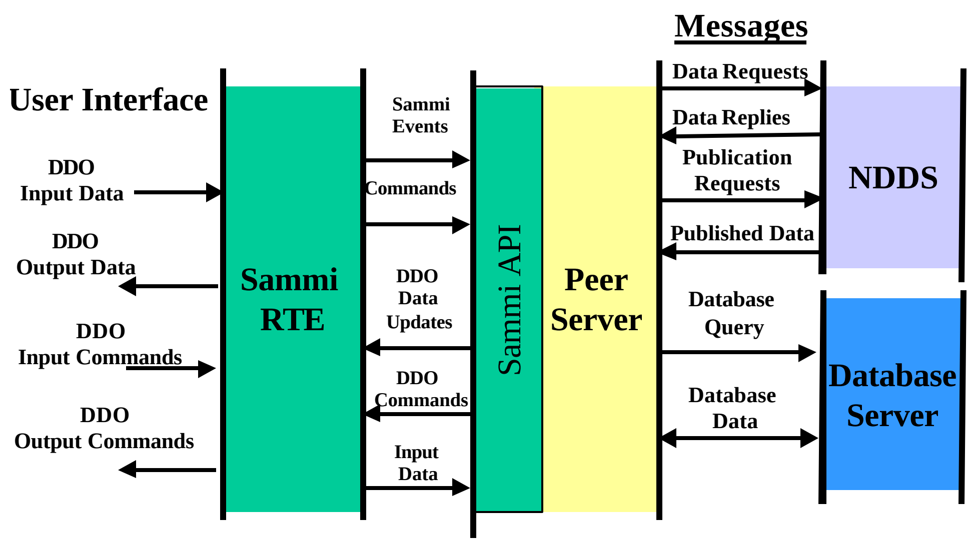



**Figure 77 Generalized Sammi/NDDS/Database Message Interaction**

Event services handled by the SNI peer server serve as the basis for coordinating the exchange of data between the WSUI and the APs. The event services process are notified in response to Sammi exposure, de-exposure and command events. These events are used to initiate dynamic subscriptions and publications, client/server requests or database requests. The generalized data flow is illustrated in Figure 78 Interface Data Flow.

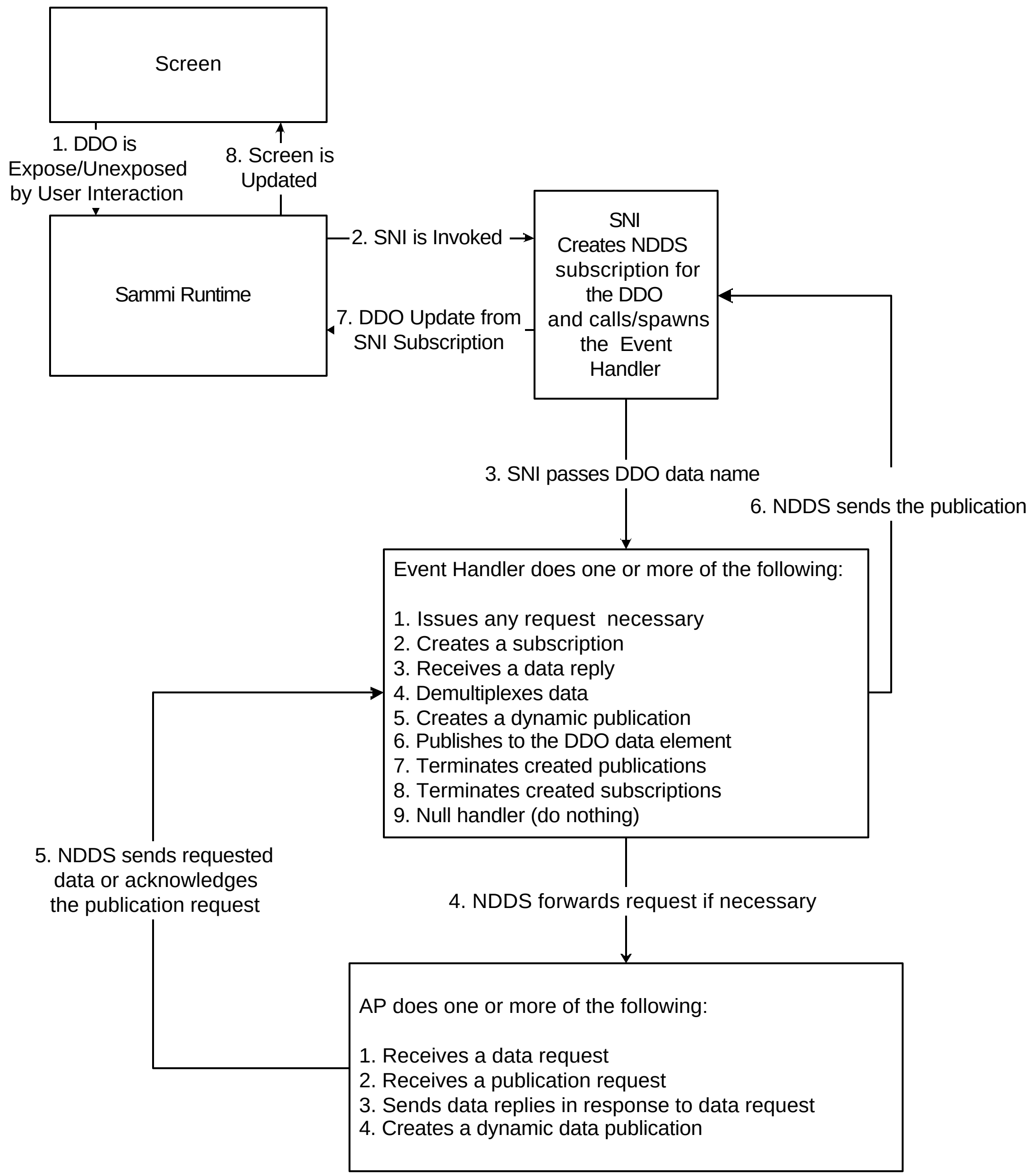



**Figure 78 Interface Data Flow**

## 4.5.4 User Interface Design

Development of the RSVP User Interface consisted of a series of tasks that included; requirements definition, concept development, design specification, screen development and User Interface documentation. Each of these tasks is described fully in the following reports. A brief synopsis of each is included in the sections that follow.

- Definition of Data/Information Requirements to Support Virtual Presence
- Illustrative HCI Concept for Virtual Presence
- User Interface Design Specification
- User Interface Specification and Functional Operation Description Document
- User Interface Storyboard Graphics
- RSVP Watchstation Interface User Guide

The final User Interface layout consisted of two screens to support navigation and access to information/data requirements identified for the RSVP demonstrations. The multi-screen configuration was selected based the Multi-Modal Watch Station development efforts and the Integrated Command Environment (ICE) demonstration facility located at NSWC Dahlgren Division located in Dahlgren, VA. Once the requirements, design and basic layout were finalized, Navigation and Data screens were created for each of the four functional monitoring areas.

### 4.5.4.1 Approach

Based on the functional requirements identified in the systems engineering study to support situational awareness requirements for reduced crew ship operation a virtual presence concept and an implementation approach was developed.

In the developing the initial concept much of the effort focused on defining user interface requirements in terms of 'look and feel' and functional capabilities. This process involved; developing a set of common user interface requirements for use within RSVP, developing notional screens for discussion, describing an approach for integrating technology into systems and assessing user interface/ presentation techniques and technologies. These efforts were based on industry experience/ applications to develop efficient user interfaces to manage complex systems with fewer and fewer people. Additionally a definition for virtual presence was established to help provide context for requirements and system development.

### 4.5.4.2 Virtual Presence/ Situational Awareness

Dr. Dick Pew at BBN Technologies provided the following definition and information on Virtual Presence and Situational Awareness. Dr. Pew is an expert in human-factors engineering and human-centered design. Dr. Pew has authored a chapter "The State of Situation Awareness Measurement: Circa 1996," to appear in: <u>Experimental Analysis and</u>

<u>Measurement of Situation Awareness,</u> D. Garland & M. Endsley, Published by Lawrence Erlbaum Associates, Inc., Mahwah, NJ.

A very standard definition of Situational Awareness (SA) is: "The perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and projection of their status in the near future."

SA is a property of the operator, supported by the information sources available, not a property of the machine, system or the displays themselves. The human interface supports the development of SA but is not a part of it.

In Dr. Pew's book chapter, he breaks it into two parts, defining a "situation" and defining "awareness"

His definition of a situation is: "a set of environmental conditions and system states with which the participant is interacting that can be characterized uniquely by a set of information, knowledge and response options."

He goes on to distinguish information from knowledge. Information being the raw data that is coming in from the environment and is changing frequently. Knowledge being the stuff that is in the head of the operator, which he or she uses to interpret the information that is being received. This knowledge is based on training and experience.

Dr. Pew cautions not to define SA to be the sum total of everything one might possibly need to know, because SA is situation specific. When we ask whether an operator had adequate SA, we need to know what was needed at the time in question. This is important because the information required is constantly changing and it is impossible to know everything all the time.

Based on the definitions above, the elements of Awareness, 'Given the Situation' are:
- Current state of the system (including all the relevant variables).
- Predicted state in the "near" future.
- Information and knowledge required in support of the crew's current activities.
- Activity Phase
- Prioritized list of current goal(s)
  - Currently active goal, subgoal, task
  - Time
- Information and knowledge needed to support anticipated "near" future contexts.

The information sources can be of great variety, including:
- Sensory information from the environment
- Visual and auditory displays
- Decision aids and decision support systems
- Extra- and intra-crew communication
- Crew member background knowledge and experience

The following bullets summarize the definition of Virtual Presence in Support of Achieving Situational Awareness. This definition is applicable to any aspect of ship.

- Information and Knowledge Needed to Manage All Aspects of a Space, Machine, Environment or Situation in All Possible Scenarios (Multiple Contexts)

- Accomplished by Fusing Data from Multiple Sources to Determine The Operational State and Condition – Both Static and Dynamic

- Information/Knowledge that is Derived from the Raw Data Is Conveyed to the Operator in a Coherent, Navigable, Efficient Manner

- Supports the Management of Complex Systems with a Minimum Number of People

#### 4.5.4.3 UI Functional Requirements

User Interface Requirements documented in the Definition of Data/Information Requirements to Support Virtual Presence Report were designed to foster ease of use as well as user acceptance and trust in the RSVP system.

Requirements were divided into eighteen categories as follows;

- Form and function – 12
  - Consistency
  - Navigation
  - Visual Appeal
  - Terminology
  - Organization
  - Response Time
  - Reliability
  - Feedback
  - Error Prevention
  - Alert/Alarms
  - User Configuration

- Hardware – 2
  - Input Devices
  - Output Devices

- Monitoring Types
  - General
  - Machinery
  Environmental
  - Structural
  - Personnel

Ease of use had to be supported through consistent application of standards familiar to the users (e.g., the user interface guidelines for the Microsoft Windows graphical environment). Ease of use needed to be further supported by the presentation of a visually appealing user interface that provides a sense of control. Consistent user interface designs that incorporated direct manipulation metaphors, availability of context-specific help, streamlined navigation strategies, local language presentation, and minimal use of modes would help to induce a sense of user control. Consistency both with respect to users' task models and with respect to all functional areas within RSVP was desirable.

The UI design needed to maximize the interactive nature of the user interface to provide users with direct and intuitive means to accomplish their tasks. The user had to be able to navigate among functional areas and within functional areas in a direct manner. The interface also had to be visually appealing with easily interpretable visual elements and minimal visual clutter.

Information had to be presented in a form immediately usable by the user and arranged in a manner consistent with user expectations. Data/input to the user interface by the user would need to be validated in a timely manner and feedback provided in a direct, prompt, and appropriate manner. Positive, prompt, and direct feedback would be required to enhance the user's sense of control. Additionally, error avoidance techniques would be needed to reduce user errors and frustration and increase user productivity were included.

#### 4.5.4.4 UI Development

The introduction of advanced technology into a workplace does not in and of itself guarantee more efficient, safer, or easier to use systems. In many cases, the inclusion of advanced technology has increased system complexity without sufficiently reducing the potential for human error or mitigating the consequences of such error. Technology only provides an opportunity to enhance system effectiveness through its provisions of flexibility, increased functionality, and greater access to information.

The features that are deemed benefits of technology are the same features that create potential hazards for users. Thus, it is not the presence of technology but, how that technology is integrated into a system and used by the operators that will determine its effectiveness. Successful integration and use depends on knowledge of operators and their work environment, habits, tools, and tasks in addition to the design of a usable and friendly system interface.

##### *4.5.4.4.1 Successful Technology Integration*

The key to successful technology integration into complex systems is the use of a user-centered design process. Many design teams are familiar with human factors design principles. But few are aware of the importance of user-centered design processes, or even the distinction among the two. Where human factors design addresses user interface issues, user-centered approaches address underlying system issues. User interfaces that conform to human factors principles will have appropriate interaction mechanisms, page layout, labels, color coding, alarm presentation, etc. User interfaces that evolved from user-centered processes will have all of the preceding benefits as well as functional decompositions, navigation schemes, data visualization techniques, and information content that supports operator efficiency, accurate diagnosis, and appropriate decision making.

#### *4.5.4.4.2 User-Centered Design Process*

User-centered design is an iterative design process that has implications not only for user interface design, but also for system design. The process is intended to be used early in system development and continuously throughout the system development lifecycle. A user-centered design process guides the selection and development of system functionality. Functionality decisions based on this process help ensure the system provides features users need and thus will be more likely to accept and use.

As outlined below, the process encompasses many design and evaluation tools including the application of human factors principles to the development of user interfaces. A majority of the data collected in early steps of the process, comes directly from users. Their involvement early in the process fosters their acceptance of the final system in addition to increasing the likelihood that technology will successfully be integrated into the system.

Development of the RSVP User Interface followed a user-centered design process consisting of four steps; 1) Understand the users, 2) Develop design style guide, 3) Implement solution in accordance with style guide, 4) Establish continuous improvement process. This process was developed at Honeywell Technology Center Inc. and has been used successfully on a large scale to address issues affecting successful technology integration. The four steps are fully documented in the Definition of Data/Information Requirements to Support Virtual Presence Report

The RSVP team followed the four-step process, first by meeting with end users and conducting interview at the Aegis Readiness Training Center Detachment (ARTCD) located at the LBES at NSWCCD in Philadelphia. A total of 9 interviews were conducted with a wide range of ratings and ship experience as well as LBES trainers and engineers. Interview were also conducted with and questionnaires distributed to personnel knowledgeable in the area of structures to gain a ship level perspective of structural monitoring requirements as well damage control experts with respect to all four functional areas; machinery, environment, structure and personnel. An *Illustrative HCI Concept for Virtual Presence* was then developed, providing the basis for development of the *User Interface Design Specification, User Interface Specification and Functional Operation Description Document and User Interface Storyboard Graphics*. As the development of the RSVP system evolved, these documents were revised to reflect the RSVP implementation. Operation of the interface demonstrated aboard CG61 USS MONTEREY is documented in the *RSVP Watchstation Interface User Guide.*

#### 4.5.4.5 UI Design Specification

The User Interface Design Specification serves as the information content specification for the RSVP user interface – it describes the information contained in the interface. It describes the information presented on each screen along with a description of presentation format. The User Interface Storyboard Graphics document and the User Interface Specification and Functional Operation Description document describe the form (look) and functionality of the UI. The storyboard document illustrates interaction mechanisms, screen layout, formatting, and organization while the specification and operation document describes the interaction mechanisms employed in the interface and system behavior. The following figures were taken from the storyboard document.

The user interface described herein is based on a user workstation that contains two medium format (at least 1024x768) displays, a keyboard, and a cursor control device (e.g., a mouse). This document is divided into eight major sections – crew, environment, structure, machines, documentation, system, events, and navigation. The first seven sections comprise the content of the right-hand display screen (i.e. the task screen the navigation screen) and the eighth section a description of the left-hand display screen (i.e., the navigation screen) (Figure 79). The information requirements are described under each section.

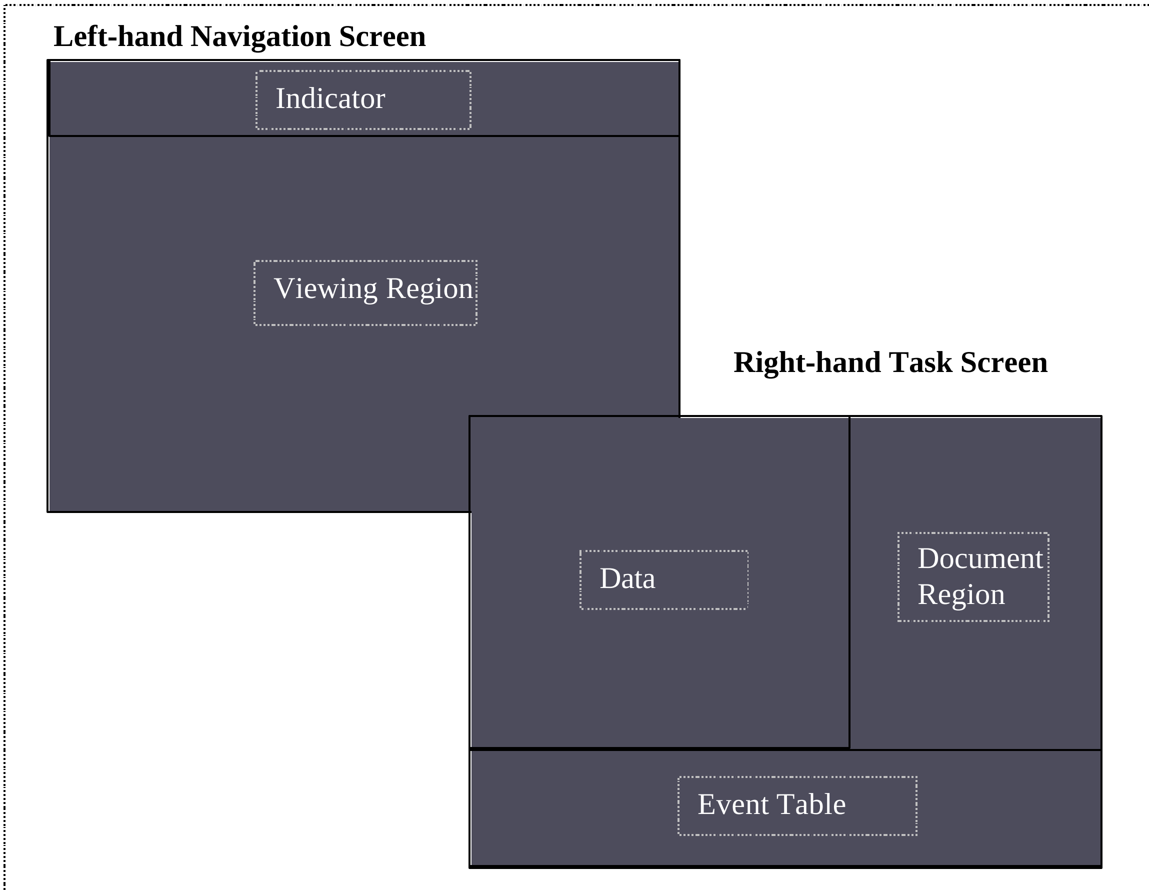



**Figure 79 User Interface Framework**

| |
|---|
| **Content**: description of required information including references or justification as necessary<br>**Format**: presentation format of information – text, icon, graphic, animation, button, etc. |
| **Region**: the region of the interface where the information will be displayed – condition indicator, hazard indicator, navigation, data, alarm, procedures, status bar, etc. |
| **Page**: the associated page number in the accompanying PowerPoint document of screen layouts. |

### *4.5.4.5.1 Navigation*

The design of the navigation screen is intended to provide both an at-a-glance status overview of the entire ship and selected compartments, as well as easy navigation throughout the compartments and systems of the ship. The steaming, hatch, and hazard icons maintain an overall context for the operator. Pulldown menus from hatch and hazard icons provide direct links to the relevant areas of the ship, as requested in expert interviews. Also based on interviews, the two methods of navigation—ship and list—mirror the differences in how damage control and engineering think about the ship. Icons in the compartment represent functional areas, providing event/alarm status and access to appropriate data pages. These icons are layered so that the operator controls the amount of clutter on the screen.

#### *4.5.4.5.2 Documents*

The document area provides a common area for procedures, manual pages, maintenance logs, and event histories. This kind of knowledge is often requested in expert interviews, and according to knowledge management experts, to be truly effective, it needs to be as integrated as possible with the user's actual task environment.

#### *4.5.4.5.3 Events*

According to our expert interviews, one of the biggest requests for alarms was that they clearly and specifically provide symptoms, diagnosis, and procedures in addition to basic notification. The operators don't want to "have to search for the fault." Our design provides this capability with a combination of an event list and event summaries. The event list is always visible. From each event entry, the operator can open a more detailed summary, or jump straight to the relevant data page, or source, to see the raw data related to the event. Each event summary provides information such as duration, symptoms, and prognosis, as well as direct links to appropriate maintenance logs, manuals, and event histories.

Another problem is information overload; therefore, the event list is sorted, and events are combined where possible. In interviews, experts were excited about the status/acknowledgement capabilities; they felt it could easily replace the currently tedious, paper-based event logs.

#### *4.5.4.5.4 Crew*

The crew section provides an at-a-glance overview of the crew members in a given compartment, as well as access to individual crew data. The design is intended to foster rapid decisions based on location, function, vitals, and mobility—Where are they? Is there something wrong? What can they do? For example, from interviews, damage control experts are interested in determining who's closest to a casualty, or in determining the optimal amount of time a firefighter can stay in a compartment. The compartment organization allows for such decisions.

Additional points:

- Alarms are combined so that only the "most important" alarm for each crew member is displayed. This is to keep an operator from being overwhelmed with multiple alerts, usually stemming from the same cause.
- According to interviews, heart rate is still the most practical measure of heat stress. Thus heart rate appears first in the health details group for each crew member.
- Station information gives expertise and work assignments for each crew member. This can help with crew management decisions. Who's the closest on-duty machinist to SSGTG 2? LCDR Miller is down, should a substitute medical team member be placed on-duty? Etc..

#### *4.5.4.5.5 Environment*

The environment section provides a status overview of each environmental parameter measured for a compartment, and direct access to raw sensor readings if necessary. Because a compartment can be large and contain multiple sensors, maximum and minimum readings are displayed in the overview along with status information. Habitability was habitually mentioned in expert interviews as another crucial aspect of environment, and wet bulb temperature was requested as an important decision aid.

#### *4.5.4.5.6 Machinery*

In interviews, experts mentioned that one thing they really like about a few of the current monitoring systems is the ability to see the most important parameters for multiple pieces of machinery at once. For instance, in "full-power" situations like fueling, engineers like to see data about all generators on one screen. The machinery overview screen provides this capability. Furthermore, the ranged bars allow an engineer to more quickly see which are parameters are high, and how parameters relate to each other.

The next level offers an overview of the sub-components of a single piece of machinery, including alarm status, important parameter readings, trending, and visualization of the machinery. Because there is some difference of opinion between engineers on which parameters are generally most important, operators can customize which parameters are displayed on both of these levels.

Finally, the last level of detail provides screens of every parameter monitored for a sub-component. However, with these screens, the operator should rarely have to search for desired parameters amongst all the data at this level.

#### *4.5.4.5.7 Structure*

Unlike the other functional areas, stress and shock relate more to the entire ship than to individual compartments. Therefore, the initial structure overview screen provides ship-wide readings, including a stress map to help operators visualize stress across the entire hull. At the compartment-level, an overview screen similar to the environment overview shows information about each structure parameter measured by a sensor in that compartment.

#### *4.5.4.5.8 System*

While important for configuration and maintenance, the typical watchstander doesn't care about the internals of the RSVP system, it only provides additional information overload and distracts from the day-to-day monitoring of the ship. In fact, the experts we interviewed already have a name for this kind of system-level data—*trivia*. Therefore, we've made this a separate area of the interface, ideally accessible only by authorized support engineers. Therefore, in the final system this section of the interface would not be visible. It would only appear if the user logging into the system was authorized to see this information. Once in this section of the interface, operators can see the location of all RSVP components (access points, sensor clusters, SHMs, ICHMs) in a compartment, using layers to help reduce clutter. Operators can then click on individual components and monitor details like battery levels, or modify thresholds.

### 4.5.4.6 RSVP User Interface

The general screen interaction is accomplished through a point and click interface. The system uses a dual touch screen setup; the left monitor is used as the selection screen and the right monitor is used to display selected information. The user interface contains two medium format (at least 1024x768) touch screen displays, a keyboard, and a cursor control device (e.g., a mouse). This section is divided into two major sections – the first being a description of the left-hand display screen (i.e. the navigation screen) and the second a description of the right-hand display screen (i.e., the task screen) The interaction mechanisms and tools associated with individual pages or screen regions are described under each section.

#### *4.5.4.6.1 Navigation Screens*

The initial Navigation screen layout consists of a series of condition and alarm indicators along the top menu bar and an elevation view of the ship.

Condition Indicator: This is a visual display tool that indicates the current condition of the ship and the current hatch/door conditions. Ships condition indicators are only illuminated when a condition is active. Only one condition is active at any given time. Inactive conditions appear un-illuminated (i.e., grayed-out). These indicators are presently inactive, but they are included to give the user an idea how a fully integrated console may appear.

Alarm Indicator: This is a visual display tool that indicates all alarm conditions currently present aboard ship. Symbols include fire, flood, medical, structural, machinery, acoustic, and temperature alarms. The alarm indicators are always presented in the same location. Inactive alarms appear grayed-out. Active alarms appear illuminated with the appropriate severity color code (red, yellow, blue, or silver) as illustrated in Figure 80.
The colors correspond to the severity of the alarm in the following manner:

- RED – Alarm (i.e. fire)
- YELLOW – Alert (i.e. machinery out of normal operating range)
- BLUE – RSVP System Alert (i.e. bad RSVP sensor)
- SILVER – Operator Notification (i.e. SSGTG offline)

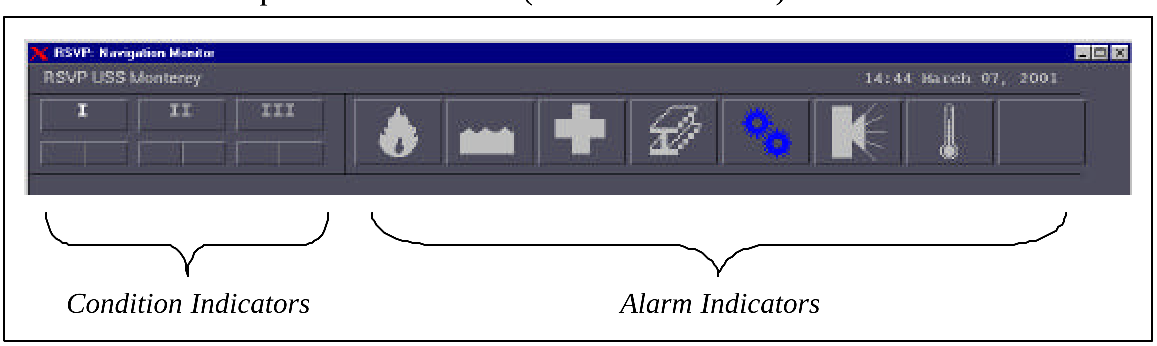



**Figure 80 Condition and Alarm Indicators**

Broadside Tool: This tool shows a broadside view of all decks aboard ship as shown in Figure 81. Users are able to point and click on a deck to select it. To select a particular compartment, position the mouse pointer on top any deck highlight in light gray, and click the mouse button. This will cause a plan view of the selected deck to be shown on the right hand side of the Navigation screen. When selected, the deck is outlined in white, the deck number appears to the right of the deck pointer, and the deck plate tool shows the plan view of the selected deck. If an event is active in a section of the ship, that section is filled with the appropriate severity color code (red, yellow, blue, or gray). Note that not all compartments or decks are configured in the software.

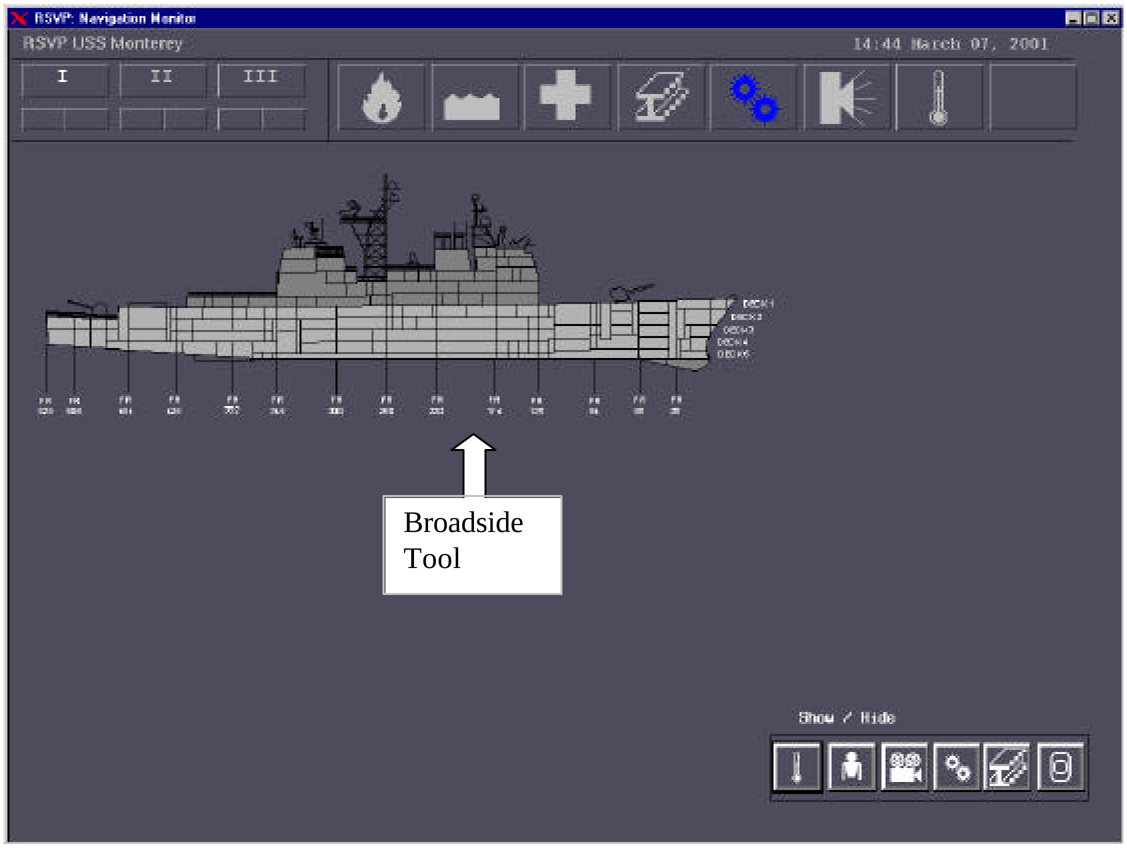



**Figure 81 Broadside Tool**

Deck Plate Tool: This tool shows a plan view of a single deck as shown in Figure 82. To select a particular compartment on that deck, position the mouse pointer on top any compartment on the deck plate tool highlighted in light gray, and click the mouse button. This will cause a view of that compartment to appear just left of center toward the bottom of the Navigation screen. When selected, the compartment is outlined in white and the compartment tool shows the perspective view of the selected compartment.

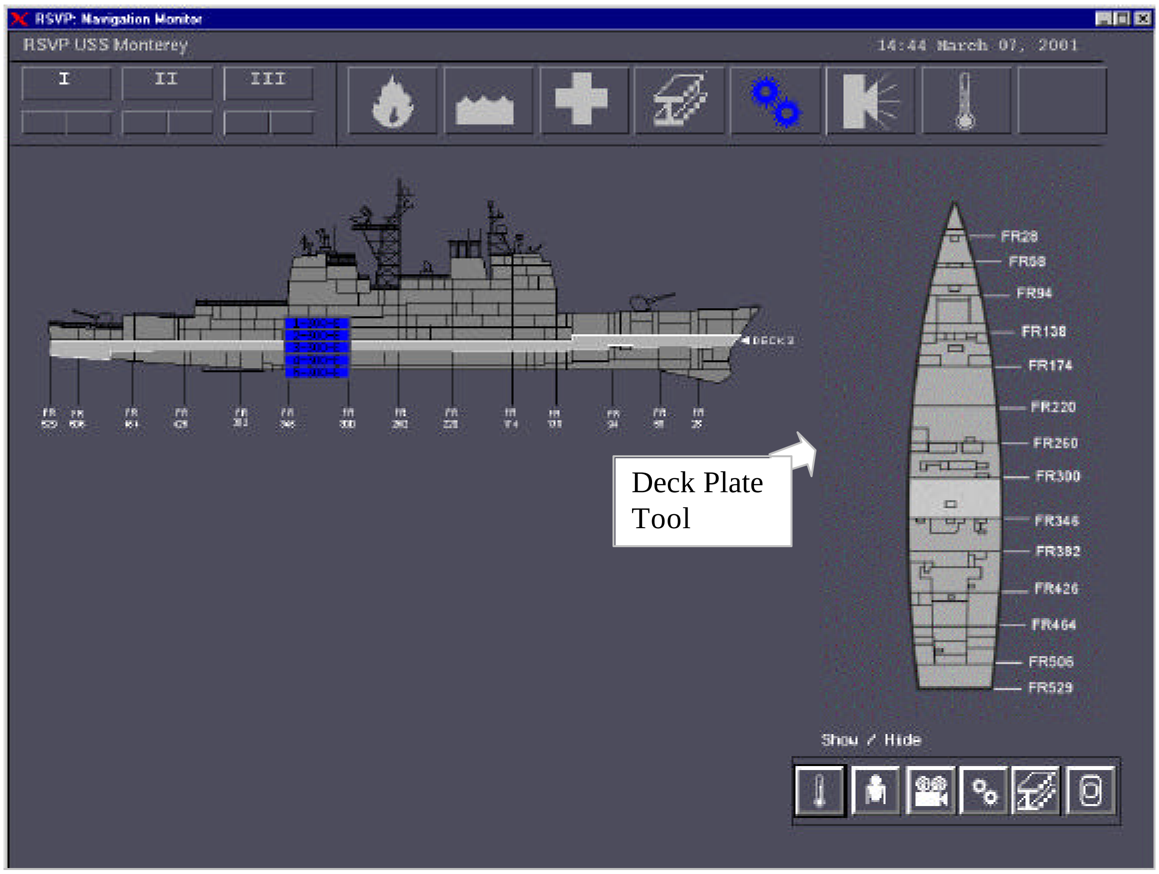



**Figure 82 Deck Plate Tool**

<u>Compartment Tool</u>: This tool shows a perspective view of a compartment as shown in Figure 83. The display is an illustration of the compartment and objects representing the sensor types located within that compartment. All active objects are color coded black to indicate to users that they can point and click to select it. Inactive objects are grayed out. When selected, the object name appears near the object, and the task screen on the right hand monitor shows all pertinent details for that object. If an event is active for an object, that object is filled with the appropriate severity color code (red, yellow, blue, or gray). In addition, hazard icons appear below the compartment name to indicate the events that are active in the compartment (e.g., if fire is present, a smaller version of the fire icon that appears in the hazard indicator is displayed underneath to the compartment). To obtain more information about a particular alarm condition, move the mouse curser over the sensor icon of interest on the compartment view and click the mouse button, and the data screen associated with that sensor will appear on the right hand monitor. For example, if the user selects one of the machinery icons from the compartment view of the Navigation screen, the software will automatically display the Machines page associated with the machine in the compartment the sensor is monitoring. The same applies to the other icons such as temperature, crew, environmental (video), crew, structure, and hatch. When sensors provide an alert or alarm, an icon corresponding to the sensor is displayed indicating the alarm the position of the alarm. For example, a fire alarm may be generated by two of the four sensors in the compartment. The sensor icons creating that alarm will be visible to indicate the fire is likely localized to that physical area.

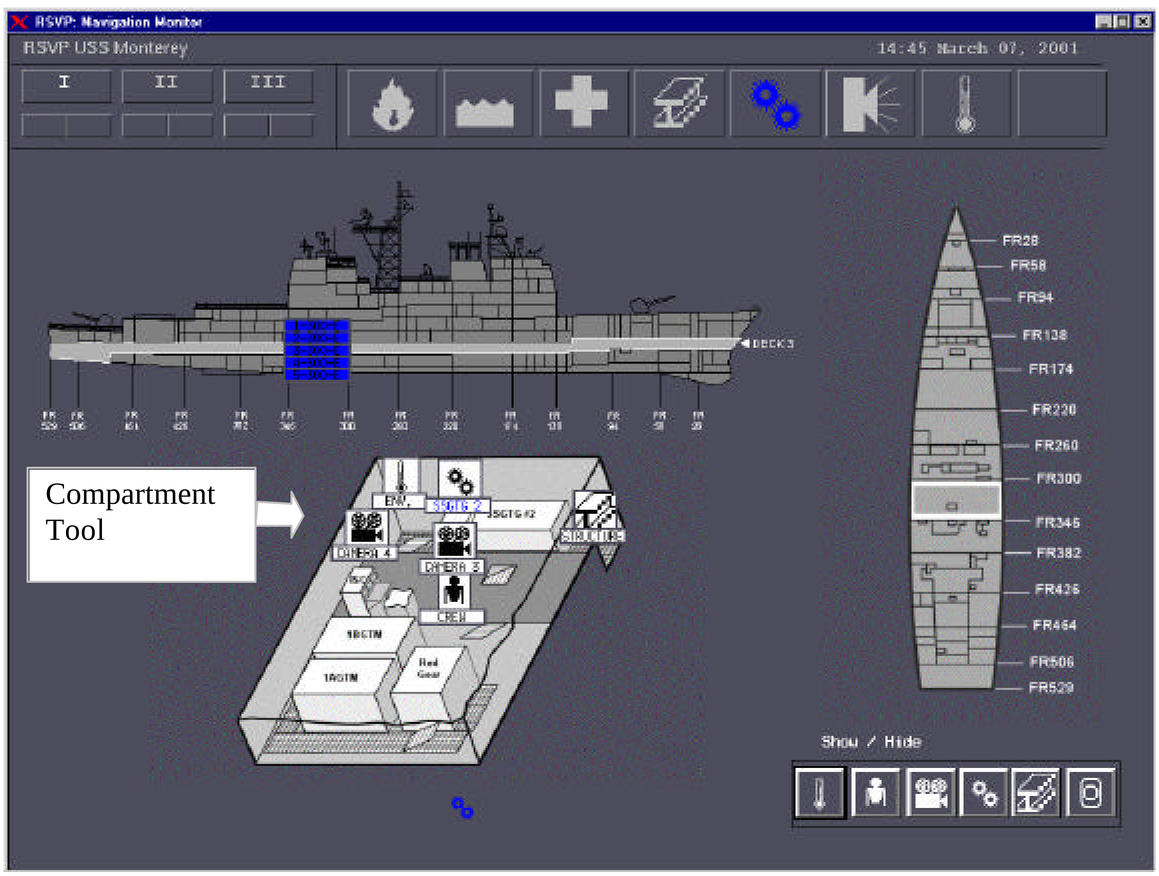



Figure 83 Compartment Tool

Layer Tool: To prevent clutter a layering tool has been included in the bottom right hand corner of the navigation screen. Six layers are presented – temperature, crew, camera (environment), machines, structure, and hatches/doors. A button is presented to hide or show all selectable objects of that type for each compartment shown. To show or hide any of these sensor icons, position the mouse pointer over the icon associated with the sensor type you wish to show or hide in the lower right hand corner of the Navigation screen and click on it with the mouse button. For example, Figure 84shows all sensor icons hidden with the exception of the machinery sensor icon.

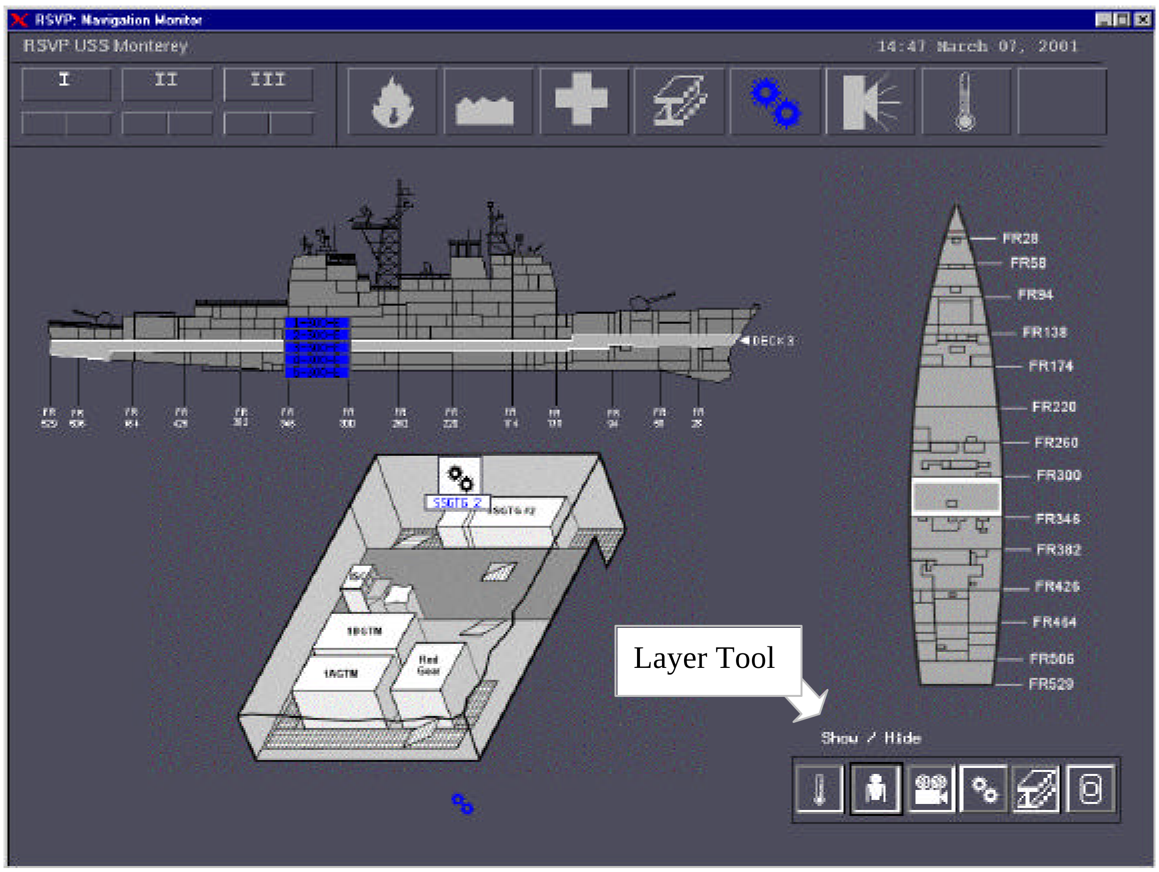



**Figure 84 Layer Tool**

#### *4.5.4.6.2 Task Screens*

The task screens contain details about the compartment selected in the navigation tool. Task screens consist of the following types:

- OVERVIEW -- No information is currently presented
- EVENTS – detailed information on the alarm and alert events for the ship
- STRUCTURE - hull stress and strain in a compartment
- MACHINES –information on the machines in a compartment
- ENVIRONMENT – environmental data in a compartment
- CREW – personnel information in a compartment
- SYSTEM – detailed information of the RSVP system components in a compartment

General Arrangement: The general arrangement of the task screens consists of a menu bar across the top, a data region where data associated with that screen type is displayed directly below the menu bar, a document region to the right of the data region, and an event table region at the bottom - Figure 85. It is possible to "navigate" from one task screen to another by using the mouse to click on the corresponding tab button on the menu bar at the top of the task screen. The type of data displayed in the data region of the task screen is unique to each page and is discussed is the appropriate sections below. *The document region is not functional at this time.* In general the task screens are displayed through the use of pull down menus and page buttons.

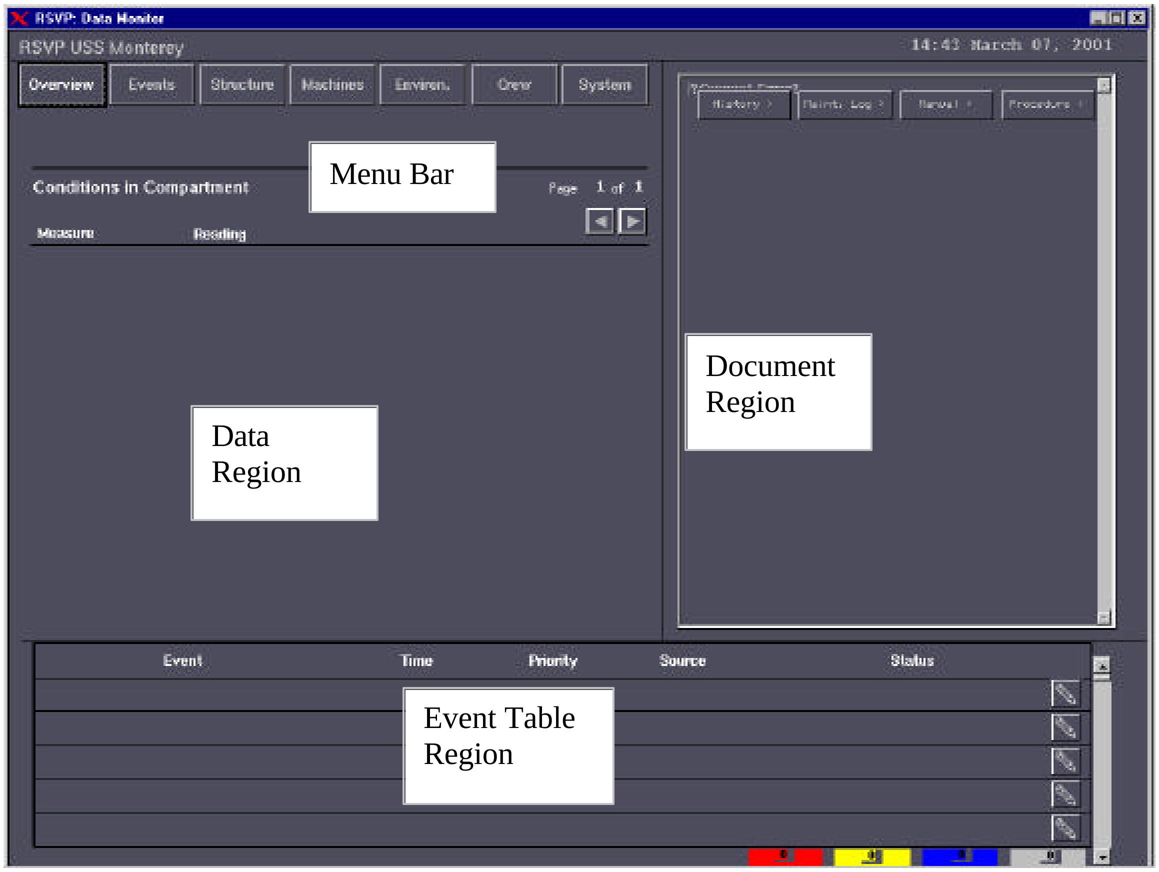



**Figure 85 General Arrangement of Task Screen**

The event table displays all pertinent event information including the event name, time of initiation, priority level, source of event trigger, and status of event. Table entries are presented by chronology. (Figure 86).

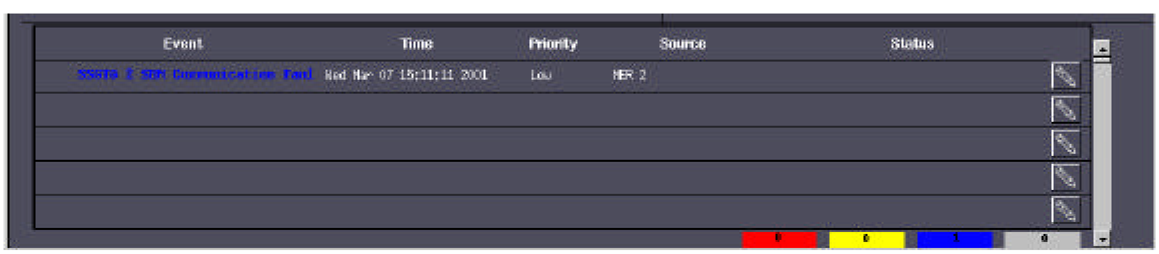



**Figure 86 Event Table**

The event table region also contains four indicators in the lower right hand corner of the screen that convey to the user the number of active, unacknowledged events for each category. A red/yellow/blue/silver bar with a # indicates there are # active alarms/alerts/system alerts/notifications. If there are no events of a certain type the indicator number will display "0". Indicators always appear in the same location. The pencil icons on the far right are currently inactive. Their intent is to allow the operator to make notes on an event such as acknowledging the alert or dispatch of repair team.

### *4.5.4.6.3 Event Data Pages*

This page provides detailed event information on events that have occurred. A standard set of information is presented including event location, duration, symptoms, diagnosis, confidence, prognosis, and impact - Figure 87. All sensors contributing to an event are listed after the "Description" label. The description name is color coded to indicate the severity level of the sensor event. The current sensor reading is displayed next to the symptom name and is followed by the time of event initiation. Depending on the subsystem not all of the fields below the Symptom are populated with data.

The first item in the Event Table is the default event page displayed when the "Events" button is selected. The page navigation tool cycles through multiple pages of a particular summary as necessary. To display another event in the event summary page users must select a new event from the Event Table or use the scroll bar.

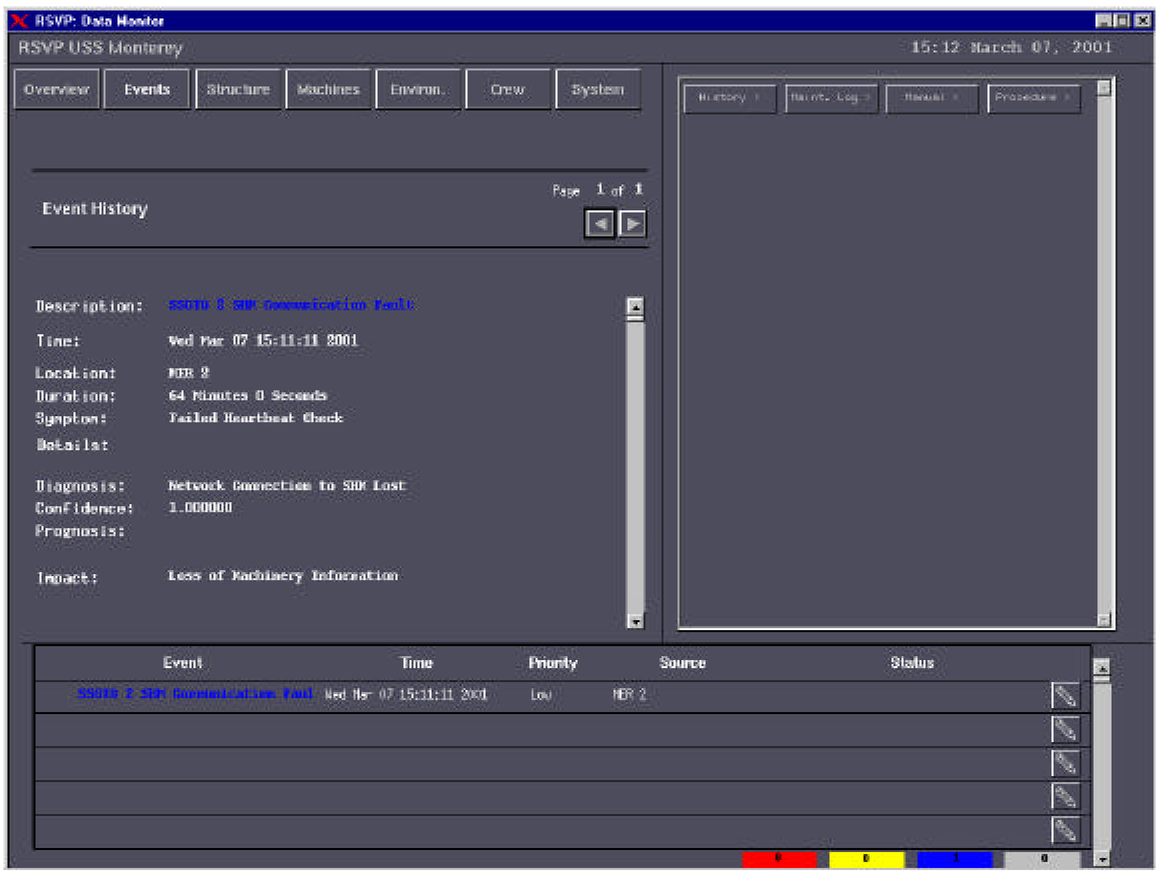



**Figure 87 Event Screen**

### *4.5.4.6.4 Structure Data Pages*

This page shows a visualization tool that displays a network of sensors to show hull-wide strain levels with port, starboard and keel views as shown in Figure 88. Events are color coded by severity and intensity. When the strains are normal the network appears black. Events are color coded by severity and intensity. Hue indicates severity level while saturation indicates intensity level. Below the visualization tool are three buttons (Strain, Seaway Shock, and High G Shock). Selecting any of these buttons will provide you with more detailed information about the parameter selected. Once one of these buttons has been selected, a page displaying detailed information related to that parameter is displayed.

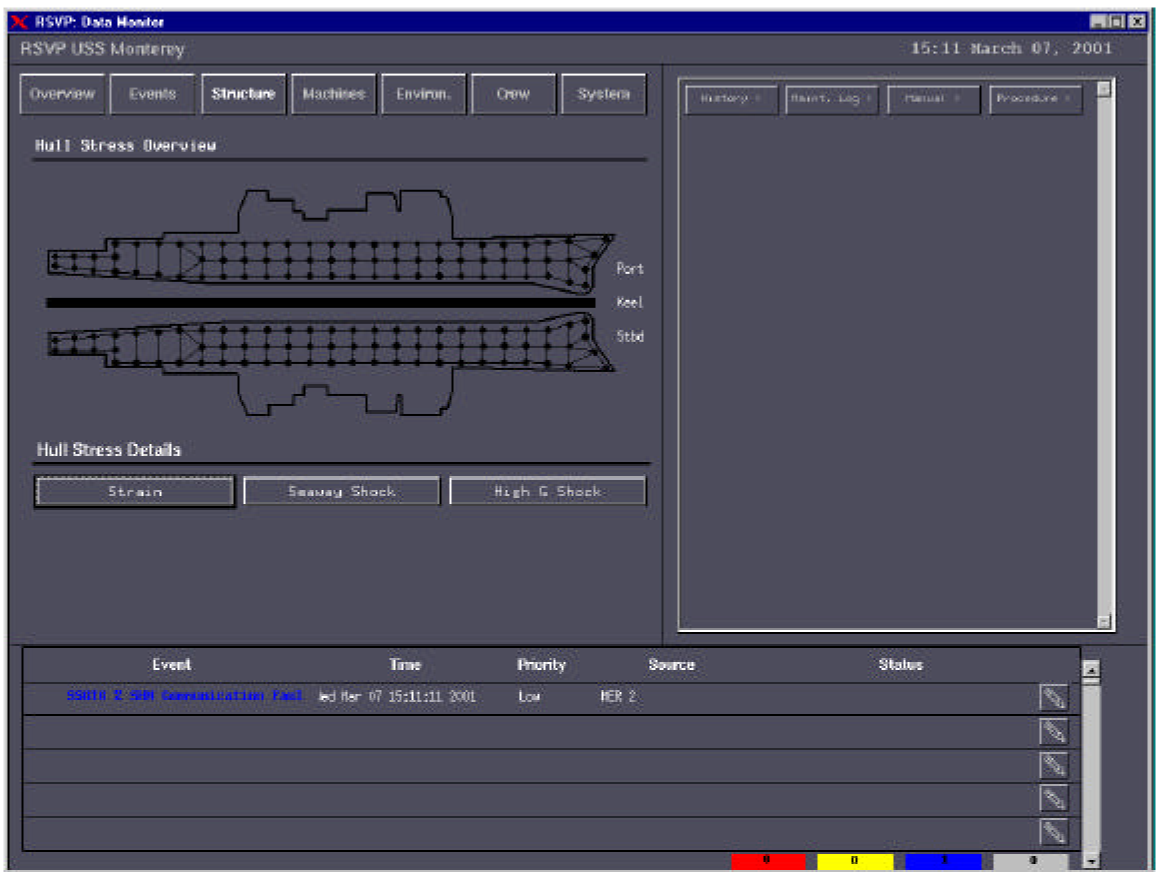



**Figure 88 Hull Stress Overview Page**

#### 4.5.4.6.4.1 Machinery Data Pages

This page, shown in Figure 89, presents an overview of the critical equipment classes for each of the major ship systems – electrical, propulsion, auxiliary, and damage control. At this time only the SSGTGs in the electrical machinery group are monitored. In a final system, operators would be able to navigate to different systems and subsystems from this page using the pull-down menus in the header. Currently only one SSGTG is implemented, therefore the other two SSGTGs are grayed out. Once the SSGTG has been selected, the data for the machine is presented in column format. The machine name button allows the operator to drill-down to detailed information that item. Health and operating status statements also are presented for each machine.

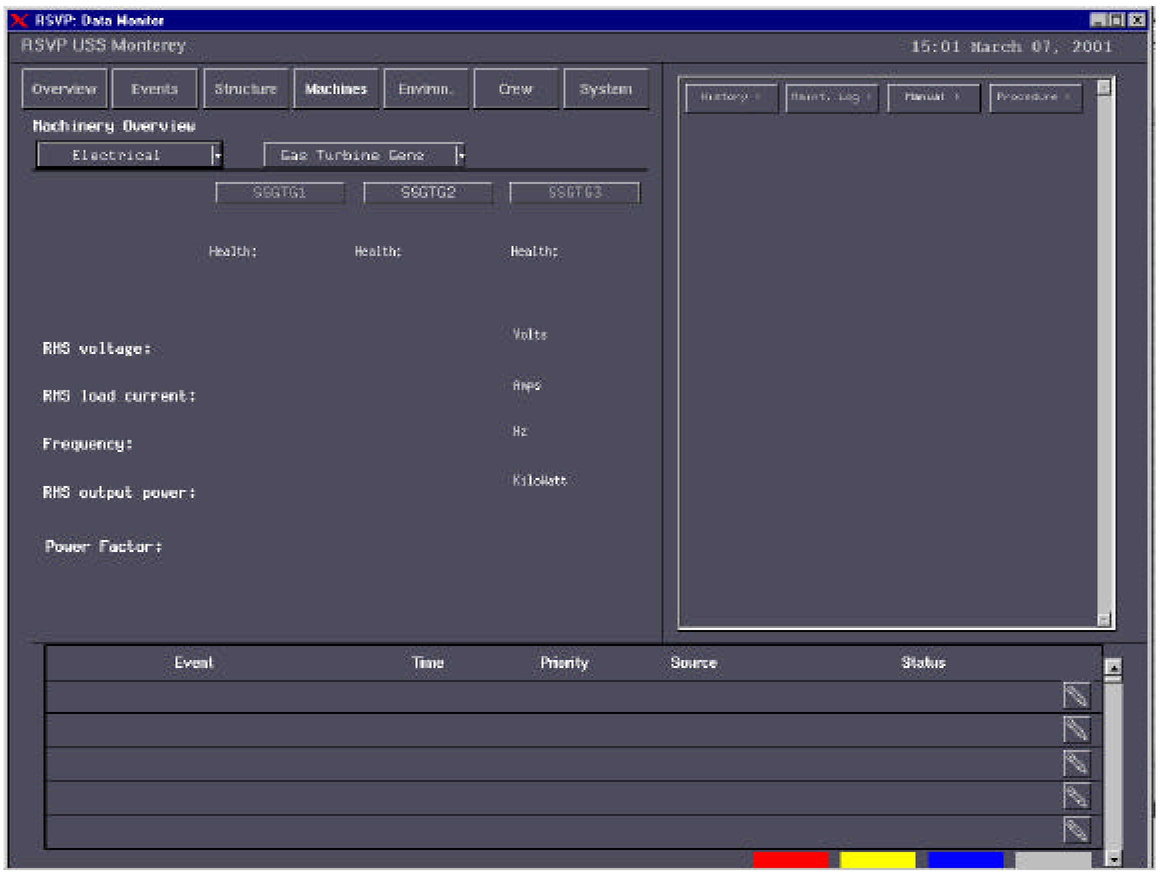



**Figure 89 Machinery Subsystem Overview Page**

Once a machinery button has been selected, a graphical representation of the machine is displayed, as shown in Figure 90, along with high-level data parameters. Next to each of the high level parameters is the current reading and a trend arrow indicating if levels are steady, increasing or decreasing, or rapidly increasing or rapidly decreasing. A dash indicates steady state, a single up or down arrow indicates levels are steadily increasing decreasing, and a double arrow up or down indicates levels are rapidly increasing or decreasing.

The names for the specific components of the machine (i.e., generator, reduction gear, and engine/accessory gear box) displayed above the high level data are buttons. When selected, these buttons open pages with detailed information for that particular component. The machinery detail pages are arranged in column format and include the current value, a relative scale (i.e., no scale is provided), a measure of the absolute rate of change, and the relative rate of change. The user can page through detailed information for that component as shown in Figure 91. A pull down menu allows the user to switch between generator, reduction gear, and engine/accessory gearbox detailed data. The user can page through to view trend data or access trend data directly using a pull down menu as shown in

Figure **92**. An example of a trend data page is shown in Figure 93.

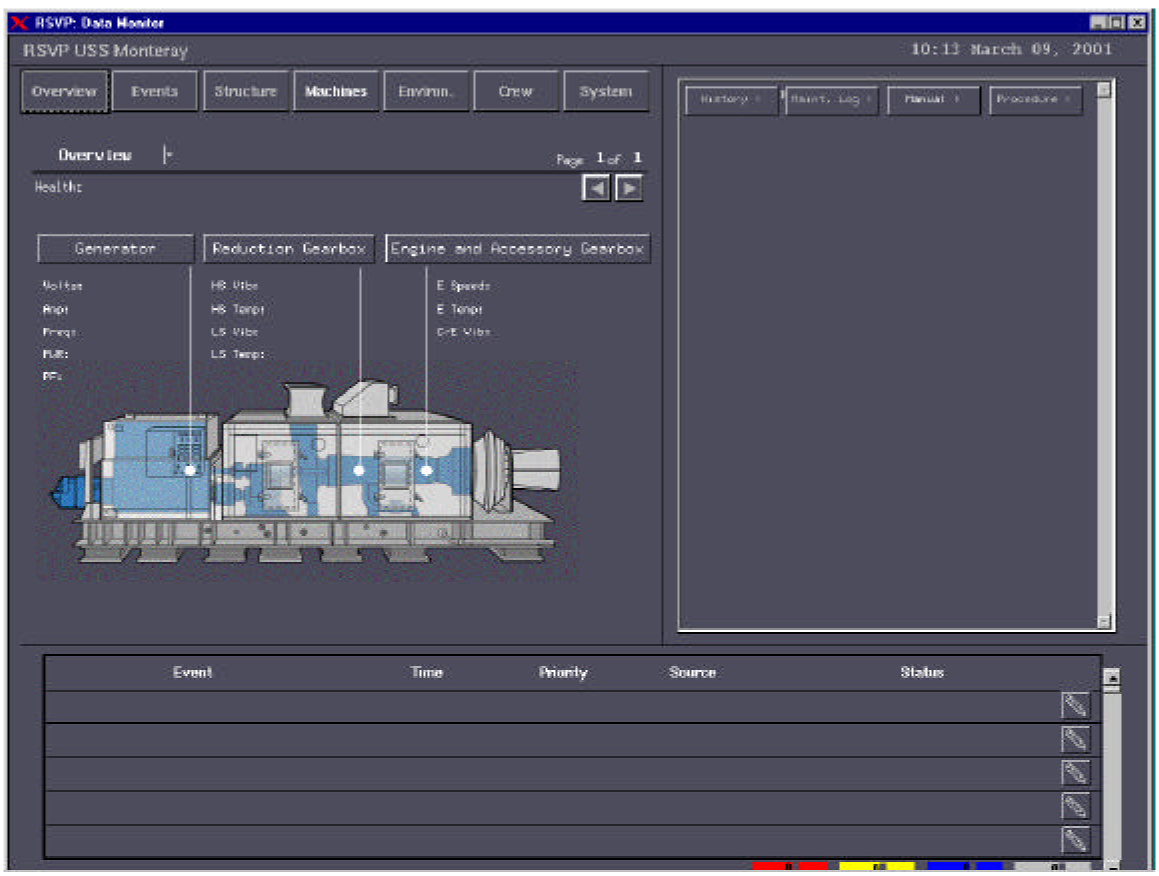



**Figure 90 SSGTG Overview Page**


**Figure 91 SSGTG Details Page**

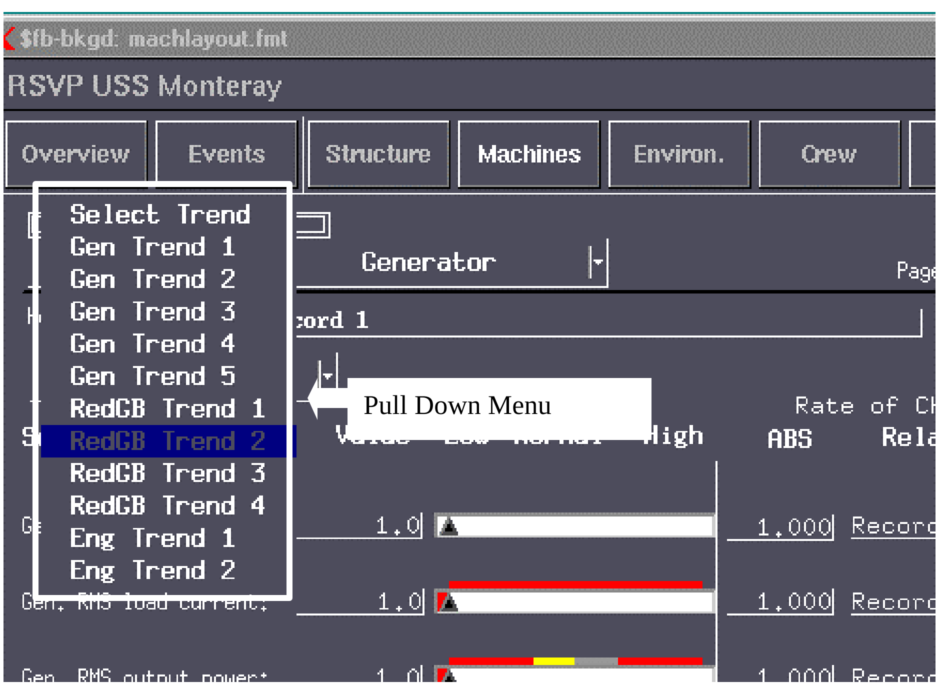


**Figure 92 SSGTG Select Trend Pull Down Menu**


**Figure 93 SSGTG Trend Data Page**

### *4.5.4.6.5 Environment*

This page presents a high level view of all measured environmental conditions in the active compartment in column format including condition name and values for each condition as shown in Figure 94. More detailed information for each environmental condition can be viewed by positioning the mouse button on top of the environmental condition name of interest and clicking. Environmental detail pages are arranged in column format and include the current value and a relative scale (i.e., no scale is provided) as shown in Figure 95. The user can page through detailed information for that sensor. A pull down menu allows the user to switch between sensors.


**Figure 94 Environmental Overview Page**


**Figure 95 Environmental Detail Page**

### *4.5.4.6.6 Crew*

This page presents a list of all personnel in the active compartment as shown in Figure 96. A table is used to display rank and name, health status, and station information for each person. Each name in column 1 is also a button that navigates to individual crew details. When events are active for a crewmember, the name is color-coded to reflect the appropriate severity level. When a name button is selected, the system presents detailed information about that individual as shown in Figure 97. The crewmember's name and navigation tool is displayed below the compartment name in the header. Next, health information and panic button status are presented under the header line. If health and panic button status are other than OK, the statement is color-coded to reflect the severity of the problem. Information about the individual's station and position and motion status also is displayed. The Details table displays a list of sensor-specific parameters, their current readings – in both text and graphic format.

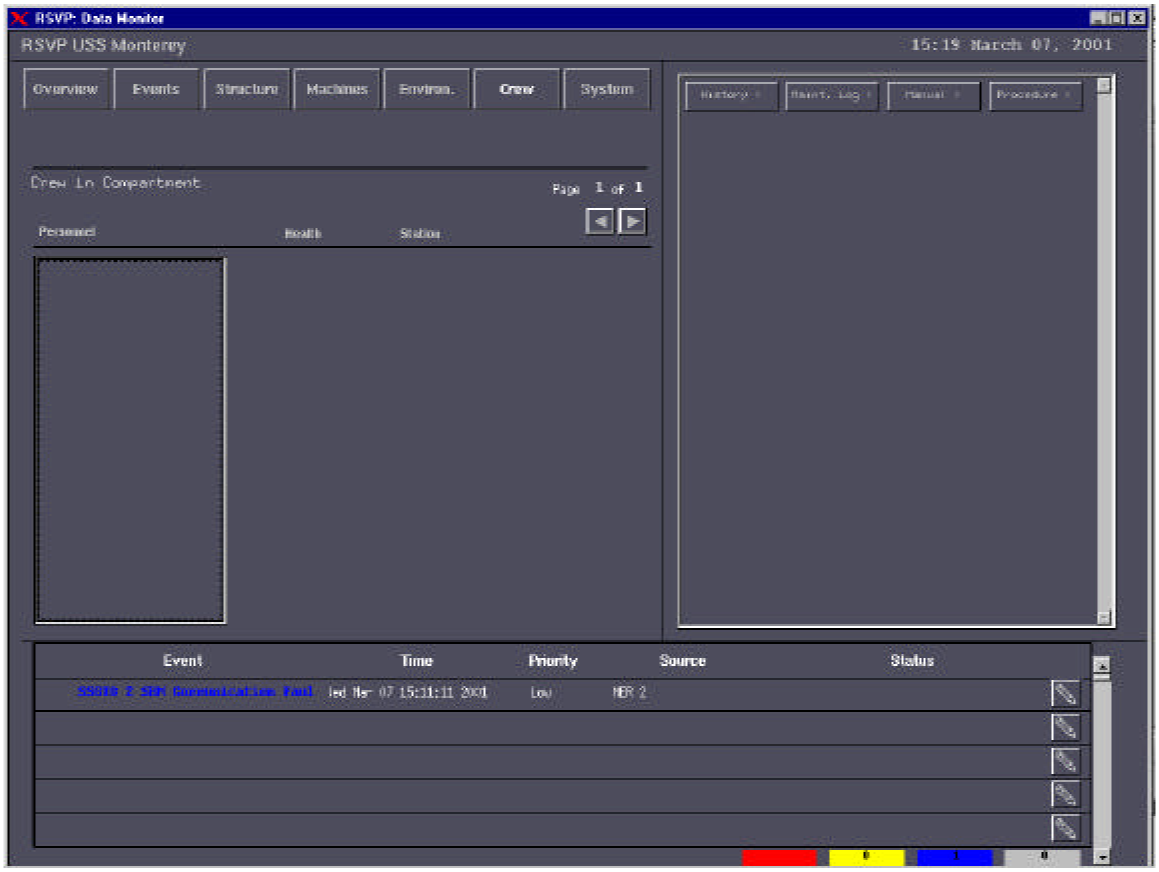



**Figure 96 Crew Overview Page**

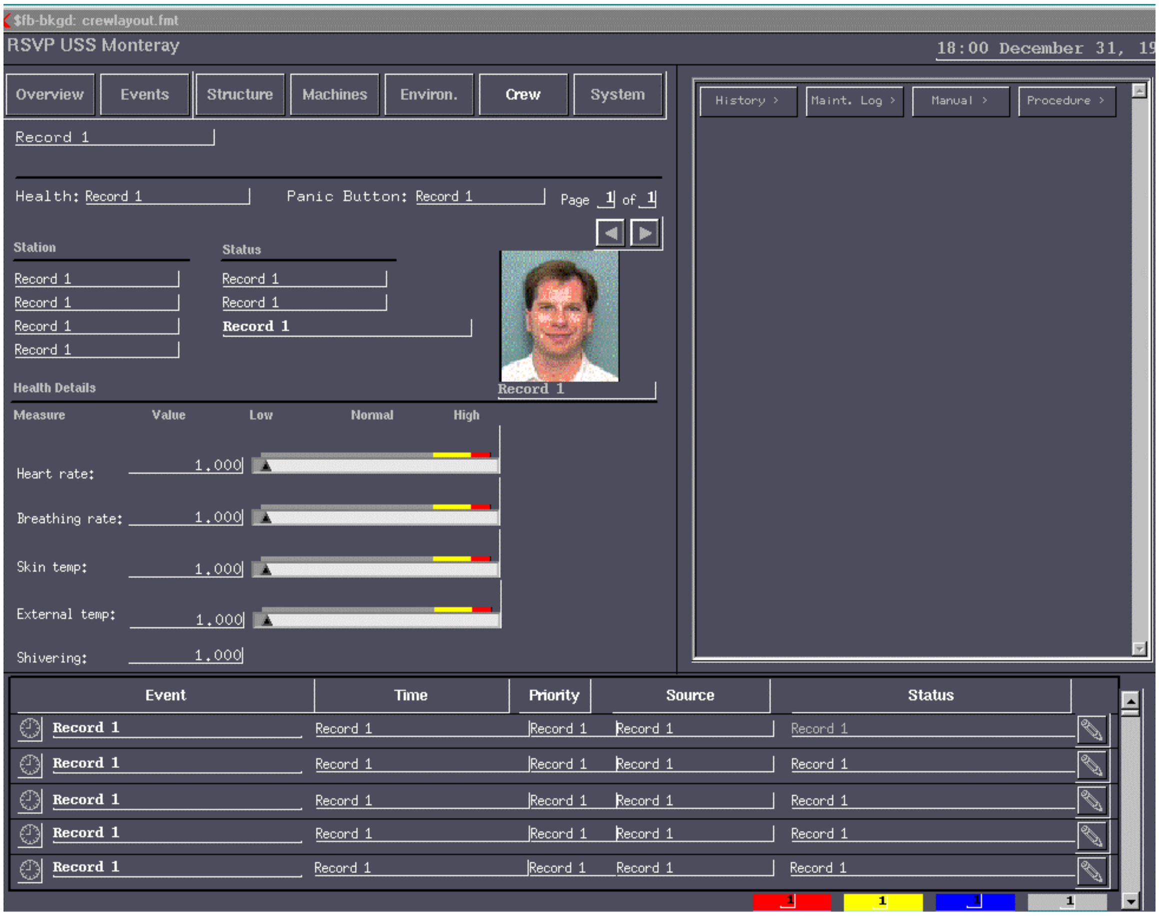



**Figure 97 Crew Detail Page**

### *4.5.4.6.7 System*

This page presents a graphical representation of the RSVP system components within the active compartment as shown in Figure 98. In a final system this field, these task screens would only be viewable by maintenance activities. They are not intended for general use by the operator. System components have unique iconic representations that can be selected to drill-down to more detailed information about the selected Personnel, Access Point, Sensor Cluster, SHM, or ICHM. In some cases, additional sensors located within the compartment may be available for viewing by paging to additional pages. Users can filter displayed content by selecting or de-selecting toggle buttons from the layer tool in the bottom right-hand corner of the page. When a toggle button is on, associated icons are visible on the graphic.

Each Personnel, Access Point, Sensor Cluster, SHM, or ICHM detail page is arranged in column format and includes a listing of the parameters measured by the sensor and the current value as shown in Figure 99. A drop down menu provides the user with the ability to select detail information for any of the sensors within the selected compartment.

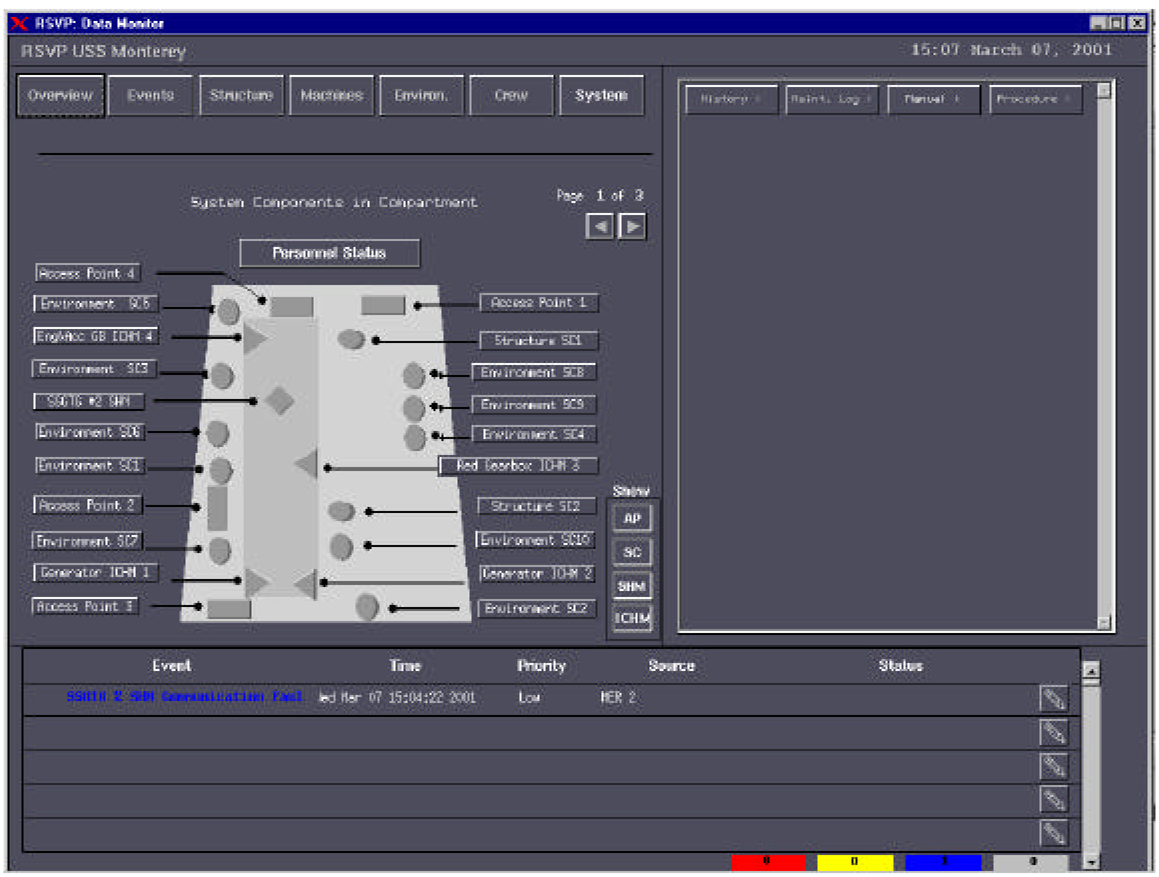



**Figure 98 System Components in Compartment**


**Figure 99 System Details Page**

# 5.0 Demonstrations

## 5.1 LBES

The purpose of the LBES demonstration was to perform a bottom-to-top Verification and Validation (V&V) of RSVP system component functionality and system integration while installed on the LBES DG-51 class engine plant. Assessment of data validity, data accuracy, and optimum system configuration was not performed in this demonstration. The installation, testing and removal of the RSVP equipment occurred January 19 through February 1, 2001

### 5.1.1 Primary Goals:

1. Complete subsystem and system integration checkout and operation.
    a. V&V of each subsystem.
    b. All subsystems functioning concurrently.
    c. Subsystems functionally integrated.
2. Validate operation and interface with Navy ship machinery and engine plant systems.
    a. Sensor data acquisition and information fusion of available environmental machinery and structural data.
    b. ICHM and SHM operation and interface/installation on the Allison K17 Generator set.
    c. Wireless data transmission.
    d. HCI functionality utilizing available sensor data and information fusion.
3. Mitigate risk of major demonstrations
    a. Resources to modify or repair will be limited during shipboard tests.

### 5.1.2 Approach:

1. Install fully constructed and fully functional Environmental Sensor Cluster, Machinery ICHMs and SHMs, and Access Points (APs) into a configuration as similar as possible to the planned CG-47 class installation.
2. Install the Watchstation on the LBES and run the RSVP HCI software.
3. Connect the Watchstation to the APs using an RSVP Local Area Network (LAN).
4. Verify RSVP components function as intended.
    a. SC/ICHM/ SHM sensors acquire data.
    b. SC/ICHM/SHM data fusion performs as designed.
    c. SC/ICHM/SHM data is successfully wirelessly transmitted to APs.
    d. AP data acquisition software functions as designed.
    e. AP data fusion software functions as designed.
    f. APs successfully transmit the correct information to the Watchstation over the LAN.
    g. HCI software receives, displays and reacts to AP information as designed.

### 5.1.3 Equipment

The LBES demonstration consisted of the following system components:

- Watchstation - 1
- APs - 4
    - APCM - 4
    - Cameras - 4
- Environmental Clusters - 10
- Hubs - 1
- Machinery Health Monitoring System - 1
    - SHM - 1
    - ICHM - 4
    - Instrumentation Box - 1
    - Power Supply Box - 1

### 5.1.4 Normal Operation Tests

Normal operation tests were executed to verify that the RSVP system and its components were operating in a proper fashion. The following sections describe the various test procedures that were executed.

#### 5.1.4.1 Environmental Sensor Cluster (ESC)

The ESC is a self-contained unit that senses its local environmental situation, autonomously determines if some level of casualty situation exists, and reports the information to an AP. The ESC monitors the following parameters:

1. Habitation temperature
2. Casualty temperature range
3. Smoke density
4. Carbon monoxide
5. Flooding
6. Hatch closure
7. Compartment pressure
8. Oxygen
9. Humidity
10. Sound

An ESC is considered operating properly if the ESC can successfully perform all of the following scenarios.
Scenario 1: ESC Acquisition
Scenario 2. ESC Data Uplink
Scenario 3. ESC Sound Uplink
Scenario 4. Retrieve ESC Diagnostic Data
Scenario 5. Retrieve ESC Calibration Data
Scenario 6. Retrieve ESC Threshold Data
Scenario 7. Retrieve ESC Location Data
Scenario 8. Retrieve ESC Frequency Data
Scenario 9. Change Single ESC Threshold
Scenario 10. ESC Downlink
Scenario 11. Single ESC Kickoff
Results:
All 10 ESC units passed the 11 scenarios described above. Initially, there was a software error for the Scenario 5: Retrieve Calibration Data test. A solution was determined and implemented. Based on the solution all of the ESC passed all 11 scenarios.

#### 5.1.4.2 Machinery HMS (ICHM and SHM)

The HMS is considered operating properly if after installed on the SSGTG, the following steps can successfully be performed autonomously;

- The ICHM and SHM boot up when connected to power
- Preinstalled operational configurations are established
- Communications are established between the SHM and ICHM
    - Radio link are established and maintained
    - Communication messages are sent and received
- The ICHM begins data collection, processing and reporting data/information to the SHM.
- The SHM receives information from the ICHM in the form of messages, converts the messages from TCP/IP to NDDS format and transmits to the AP
- The SHM services requests from the Watchstation through the AP and provides data/information in response to operators requests.

General Results:

The four ICHMs and SHM were installed on the K17 SSGTG on the LBES and stepped through a series of tests to verify proper operation and functionality according to the five (5) test requirements identified above. Autonomous operations of the ICHMs and SHM were remotely monitored using several communication and software debug programs that allowed monitoring of the ICHM and SHM operations without direct interaction.

Specific tests and results are as follows;

**Installation** - install and operate all of the HMS hardware and software on the K17 SSGTG at LBES prior to ship installation to ensure

the proper installation procedures are established and documented
the HMS does not interfere with the SSGTG operation
the HMS operates properly when installed on the SSGTG

<u>Results</u> – NSWCCD code 9332 verified the installation procedures ands installed the HMS hardware. The SSGTG was run over the course of several days, the HMS had no impact on the SSGTG operation. Based on the test and hardware installed, installation procedures were established by the NSWCCD Gas Turbine Life Cycle code in accordance with GTB14.

**Power On** – test for autonomous boot operation

<u>Results</u> – all ICHMs and SHM booted properly in accordance with preinstalled operating configuration files

**Communications Link (SHM to ICHM)** – determine if bi-directional communications are reliably and adequately established in the LBES environment

<u>Results</u> – communication between the ICHMs inside and outside the SSGTG module were automatically established and maintained with the SHM located in the RSVP HMS power supply enclosure

**Communications Link (SHM to WS)** – determine if bi-directional communications, including multiple protocol translations, from the SHM through the AP to the WS and vice versa WS-AP-SHM are reliably and adequately established in the LBES environment.

<u>Results</u> – communication between the SHM and WS *(TCP Server (SHM) to TCP Client (SHM) to NDDS Server (SHM) to NDDS Client (WS))* and WS to SHM communication *(NDDS Client (WS) to NDDS Server (SHM) to TCP Client (SHM) to TCP Server (SHM))* were automatically established and maintained. Publications and subscriptions were started and stopped using the Machine/NDDS interface (MNI) client test program to verify operation

**Sensor Connectivity and Operation** – verify sensor connectivity and the accurate collection and processing of data from all sensors connected to the ICHMs

<u>Results</u> – Each sensor signal value was compared to locally available readouts for the same parameters. Some variation in electrical parameters were identified. Variations were attributed to filter card settings and adjustment of calibration files – particularly electrical CT's. On-site adjustments were made correcting variations for a majority of the differences. Post LBES tuning of the filter cards will be conducted prior to the Ship install to correct remaining variations.

**Sensor/Parameter Data Mapping**– verify data/information from the ICHMs and SHM is correctly being sent to the WS

<u>Results</u> – Using the remote DIVA program, parameters and messages from both the ICHMs and SHM were monitored and corroborated with the messages sent to the watchstation. Sensor parameters generated by the ICHMs/SHM and respective messaging were verified.

**Data Mapping to Watchstation**– similar to that described above, verify data/information from the ICHMs and SHM is correctly being displayed at the WS and operator requests are executed with expected results.

<u>Results</u> – Using the remote DIVA program, parameters and messages from both the ICHMs and SHM were monitored for correct display at the watchstation. The User Interface (UI) was exercised and discrepancies identified. Several were corrected during the course of the test. Remaining corrections are to be accomplished off-site prior to the ship install.

#### 5.1.4.3 Radio Bit Error Rate (BER) Testing

BER tests were run while the equipment was install on the LBES plant. The initial BER test indicated a BER of 12%. 12% is significantly higher than was expected. A BER of <1%was anticipated. Draper engineers investigated the radio boards and found the new board assemblies had a slightly lower attenuation than the previous assemblies even with the same component. The engineers changed a resistor value to better align the radio. The radio was further tested and found to have BER of <1%. All the radios were modified during the LBES installation period and the BER tests were rerun yielding BER results of <1%.

#### 5.1.4.4 APs

The AP startup and network software is designed so that AP, when initially turned on, will automatically initiate, configure and establish communications with the other APs in the same compartment. If the a particular AP is the first to be powered on in a compartment it then becomes the Primary AP and controls all the data flow in and out of the compartment.
Results: All 4 APs successfully performed the above requirements

#### 5.1.4.5 Algorithms

##### *5.1.4.5.1 Environmental Sensor Cluster*

Fire:
The environmental sensor cluster typically samples its sensors once a second and transmits a data message every 10 seconds. If a cluster detects rapid changes and/or thresholds have are exceeded then the cluster will transmit the data to the AP at a rate of

once a second for further processing. When the source of the changes has dissipated the sensor cluster return to its normal mode of operation.
Results: Due to limited capability of the LBES facility the fire algorithm was reduced to a temperature reading. Once the Sensor Cluster had detected this event it behaved similarly as if the real fire algorithm were implemented. The 2 ESC units performed the fire demonstration as planned.

Flood:
Due to the limited capabilities of LBES facility, the flooding algorithm will comprise of multiple sensor clusters monitoring the water level of buckets of water. The sensor cluster typically samples its flooding sensor once a second and transmits a data message every 10 seconds. If a cluster detects rapid change and/or a “high” level the cluster will transmit the data to the AP at a rate of once a second for further processing. AP algorithms will provide higher level processing to determine whether or not to issue an alarm
Results: The 2 ESC units used during the demonstration operated as designed.

High Temperature:
The high temperature algorithm has been designed to indicate a single point temperature threshold that has been exceeded. If a cluster detects a rapid change and/or a “high” level the cluster will transmit the data to the AP at a rate of once a second for further processing. AP algorithms will provide higher level processing to determine whether or not to issue an alarm
Results: The 2 ESC units used during the demonstration operated as designed.

***Machinery HMS (ICHM and SHM) LBES Testing***

**5.1.4.5.1.1 Testing Approach**

Three classes of machinery HMS faults were simulated as part of the LBES testing. These faults were

1. Component faults – detect deterioration of key SSGTG mechanical and electrical components (bearings, gears, windings)

2. Limit faults – notification to the operator that and out-of-limit condition exists (voltage, current, vibration)

3. HMS faults – self monitoring provide operator with health of monitoring system (ICHM, accelerometers)

Scripted scenarios run for each ICHM/class of fault are described below;

**ICHM #1 Generator Electrical**

**Component faults** – Modify associated processed data at ICHM level to trigger generation of alert and alarm messages.

1) RECTIFIER_DIODE_COMP_FAULT
2) STATOR_WINDING_COMP_FAULT
3) FIELD_WINDING_COMP_FAULT

**Limit faults** – Running plant or inject voltage signal directly into ICHM. Adjust channel sensitivity to increase or decrease associated parameter level reported by ICHM and trigger alert and alarm generation.

1) VA_RMS_LIMIT_FAULT - high or low
2) VB_RMS_LIMIT_FAULT - high or low
3) VC_RMS_LIMIT_FAULT - high or low
4) VOUT_RMS_LIMIT_FAULT - high or low
5) VEXC_RMS_LIMIT_FAULT - high or low
6) IA_RMS_LIMIT_FAULT – high
7) IB_RMS_LIMIT_FAULT – high
8) IC_RMS_LIMIT_FAULT – high
9) IOUT_RMS_LIMIT_FAULT – high
10) IEXC_RMS_LIMIT_FAULT – high
11) GEN_FREQ_LIMIT_FAULT - high or low
12) POUT_LIMIT_FAULT – high

**System faults** – Adjust channel sensitivity to increase reported ICHM temperature and trigger system alert generation

1) ICHM_SYSTEM_FAULT – high

## ICHM #2 Generator Mechanical

**Component faults** - Modify associated processed data at ICHM level to trigger generation of alert and alarm messages.

1) DE_BEARING_COMP_FAULT
2) PMA_BEARING_COMP_FAULT

**Limit faults** – Running plant or inject voltage signal directly into ICHM. Adjust channel sensitivity to increase or decrease associated parameter level reported by ICHM and trigger alert and alarm generation.

1) ARMS_DE_1_LIMIT_FAULT – high
2) ARMS_PMA_1_LIMIT_FAULT – high
3) ARMS_DE_2_LIMIT_FAULT – high
4) ARMS_PMA_2_LIMIT_FAULT – high

**System faults** – Adjust channel sensitivity to increase reported ICHM or accelerometer temperature and trigger system alert generation. Disconnect accelerometers to trigger accelerometer system alert or alarm.

1) ICHM_SYSTEM_FAULT - high temp
2) A_DE_1_SYSTEM_FAULT - temp high, shorted or disconnected
3) A_PMA_1_SYSTEM_FAULT - temp high, shorted or disconnected
4) A_DE_2_SYSTEM_FAULT - temp high, shorted or disconnected
5) A_DE_2_SYSTEM_FAULT - temp high, shorted or disconnected

## ICHM #3 Reduction Gear Box

**Component faults** - Modify associated processed data at ICHM level to trigger generation of alert and alarm messages.

1) HS_DE_BEARING_COMP_FAULT
2) HS_NDE_BEARING_COMP_FAULT
3) LS_DE_BEARING_COMP_FAULT
4) LS_NDE_BEARING_COMP_FAULT
5) RBG_GEAR_FAULT

**Limit faults** – Running plant or inject voltage signal directly into ICHM. Adjust channel sensitivity to increase or decrease associated parameter level reported by ICHM and trigger alert and alarm generation.

1) ARMS_HS_DE_LIMIT_FAULT – high
2) ARMS_HS_NDE_LIMIT_FAULT – high
3) ARMS_LS_DE_LIMIT_FAULT – high
4) ARMS_LS_NDE_LIMIT_FAULT – high

**System faults** – Adjust channel sensitivity to increase reported ICHM or accelerometer temperature and trigger system alert generation. Disconnect accelerometers to trigger accelerometer system alert or alarm

1) ICHM_SYSTEM_FAULT - high temp
2) A_HS_DE_SYSTEM_FAULT - temp high, shorted or disconnected
3) A_HS_NDE_SYSTEM_FAULT - temp high, shorted or disconnected
4) A_LS_DE_SYSTEM_FAULT - temp high, shorted or disconnected
5) A_LS_NDE_SYSTEM_FAULT - temp high, shorted or disconnected

## ICHM #4 Accessory Gear Box

**Component faults** – Modify associated processed data at ICHM level to trigger generation of alert and alarm messages.

1) COMP_BEARING_COMP_FAULT
2) TOWER_BEARING_COMP_FAULT

**Limit faults** – Running plant or inject voltage signal directly into ICHM. Adjust channel sensitivity to increase or decrease associated parameter level reported by ICHM and trigger alert and alarm generation.

1) ARMS_ENGINE_LIMIT_FAULT – high
2) ARMS_AGBX_LIMIT_FAULT - high
3) ARMS_AGBY_LIMIT_FAULT - high
4) ARMS_AGBZ_LIMIT_FAULT - high
5) T_MODULE_LIMIT_FAULT – high

**System faults** - Adjust channel sensitivity to increase reported ICHM or accelerometer temperature and trigger system alert generation. Disconnect accelerometers to trigger accelerometer system alert or alarm

1) ICHM_SYSTEM_FAULT - high temp
2) A_ENG_SYSTEM_FAULT - temp high, shorted or disconnected
3) A_AGBX_SYSTEM_FAULT - shorted or disconnected
4) A_AGBY_SYSTEM_FAULT - shorted or disconnected
5) A_AGBZ_SYSTEM_FAULT - shorted or disconnected

These scenarios were simulated by artificially altering data as it was collected using the ICHM script file. This was done prior to execution of the analysis/ feature extraction routines. In most cases this was done adding gain to the signal. For the limit faults, this was straight forward, simply increasing the level of the measured parameter in question, until a preset limit was exceeded. For the RGB component fault, specific frequencies associated with the gear geometries and operating conditions were altered to simulate an evolving gear defect and stimulate the data processing and feature extraction capabilities of ICHM #3. The simulated gear vibration signatures would not be detected using standard RMS vibration measurements, thereby demonstrating the advanced warning analysis capabilities of the HMS. HMS faults were simulated by loosening the cable to each accelerometer to simulate a faulty sensor or wire. Communication faults were simulated by turning the ICHM and/or SHM off.

#### 5.1.4.5.1.2 Testing Process

The following is a summary of how the machinery scenarios were implemented and the verification process for the simulated faults. Timely detection of the simulated faults at the ICHM, generation of the corresponding fault message, receipt of the fault message at the SHM and accurate display of the condition at the Watchstation formed the basis of the test criteria. Testing was conducted in two phases. Phase one focused on the HMS system only. Generation and receipt of the proper message by the ICHM and SHM respectively was verified by using diagnostics software resident on the SHM. Virtual Network Computing (VNC) software allowed the test engineer to access and run programs on both the SHM and ICHMs using a laptop and wireless Network Interface Card (NIC). This configuration is shown in Figure 100

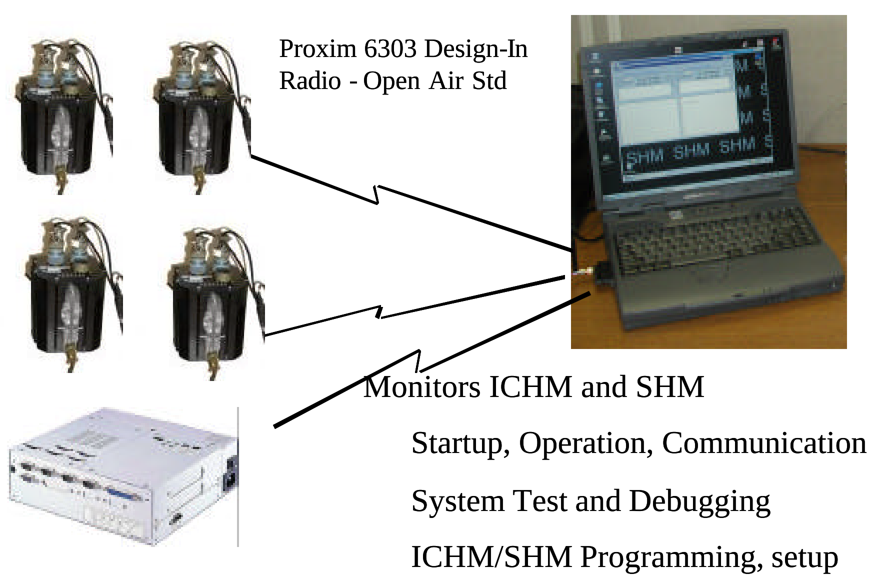



**Figure 100 ICHM and SHM Test Software/Laptop**

In this manner, the test engineer was able to; review the ICHM process, ICHM/SHM/NDDS communication interface and messaging in 'real time' in the NDDS Parameter Data Structure Display. As shown in Figure 101the left side of the display will show what ICHMs are connected and communicating with the SHM. The right hand side of the display shows the messages the Watchstation is subscribed to. Since the watch station is always attempting to subscribe to the alert and alarm messages, any subscriptions present on the right hand side verifies that the SHM is communicating with the access point. Phase two involved verification that the alert and alarm messages sent by the SHM to the Watchstation were display accurately in a timely manner.

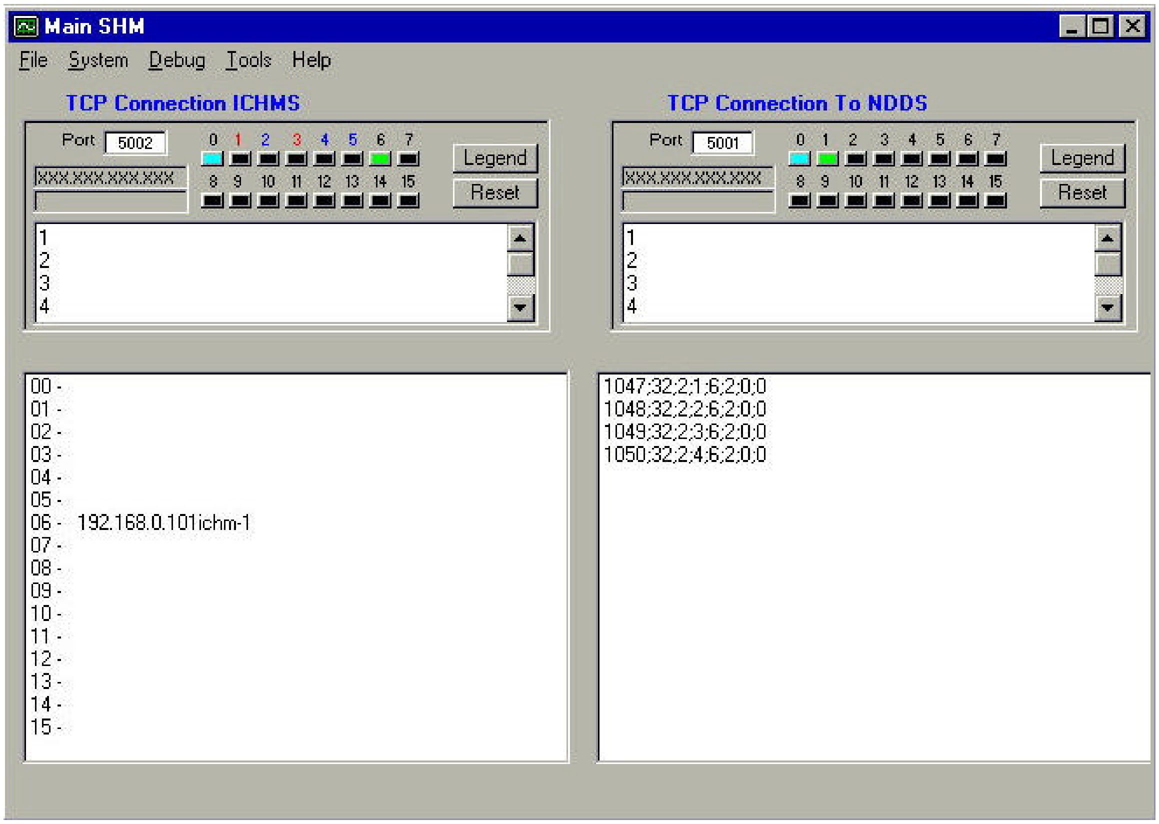



**Figure 101 SHM Connections Display**

Several additional debug ‘windows’ that supported detailed assessment and troubleshooting during LBES testing are identified in Table 32 and shown in Figure 102, Figure 103, Figure 104, Figure 105, and Figure 106.

**Table 32 HMS Debug Windows**

| | |
|---|---|
| **"Header Watcher"** | displays the message headers that each ICHM is sending the SHM |
| **"Parameter Data Structure Display"** | displays all of the parameter data that each ICHM is generating. |
| **"Fault Data Structure Display"** | displays all of the generated fault data |
| **"NDDS Parameter Data Structure Display"** | displays all of the parameters sent over NDDS to the Watchstation by the SHM. |
| **"Info Display"** | displays information messages that are put into the ICHM processing script by the programmer as diagnostic information. This allows rapid identification of the current location within the ICHM process/diagnostic script. |
| **"Debug Display"** | displays a real-time running display of the ICHM processing script. |

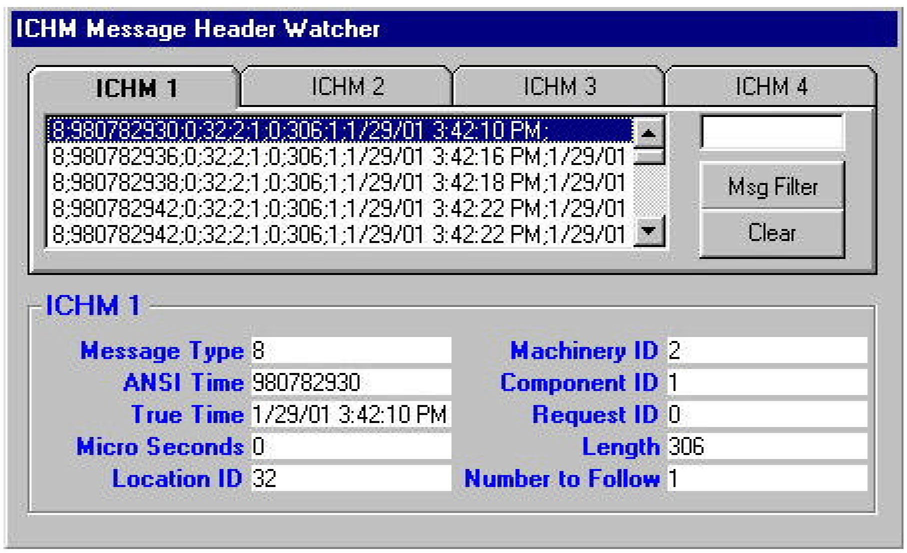



**Figure 102 ICHM Message Header Watcher**

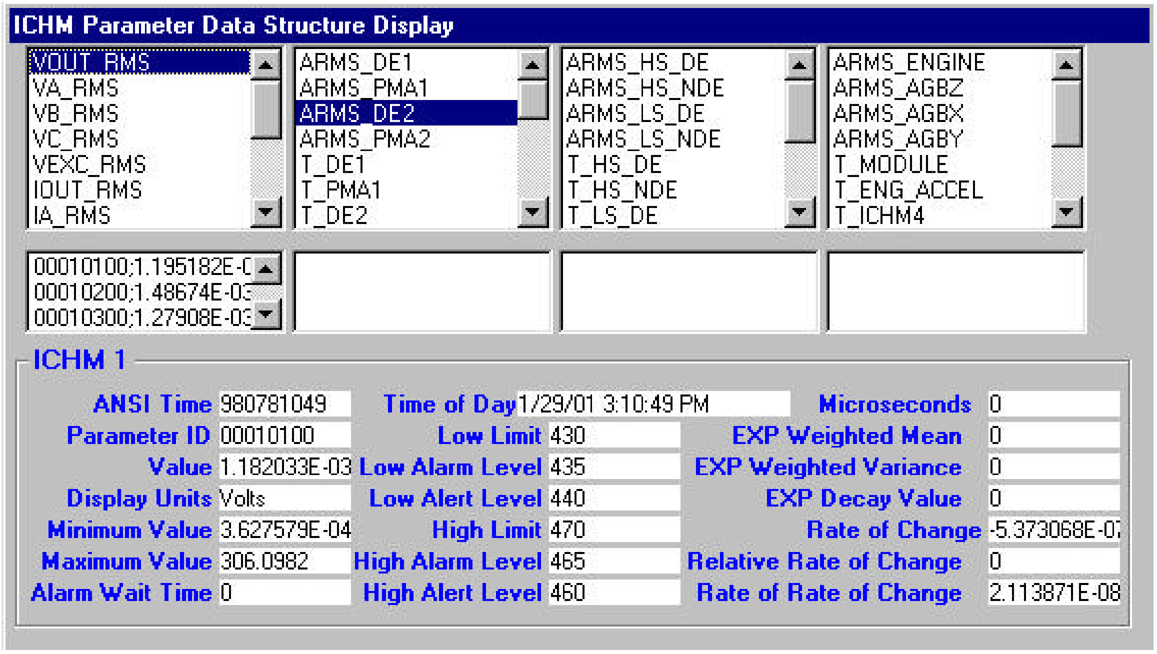



**Figure 103 ICHM Parameter Structure Display**

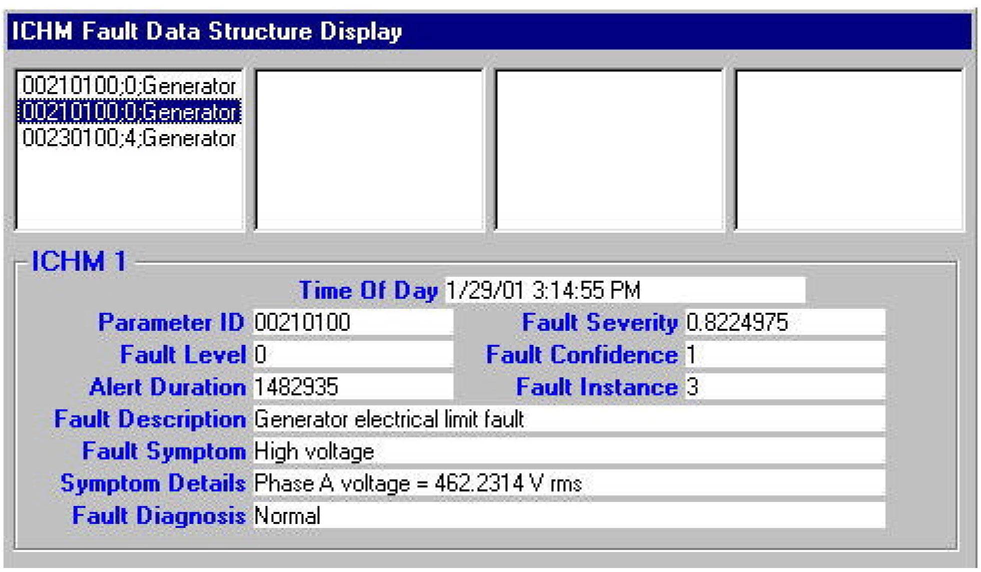



**Figure 104 ICHM Fault Data Structure Display**

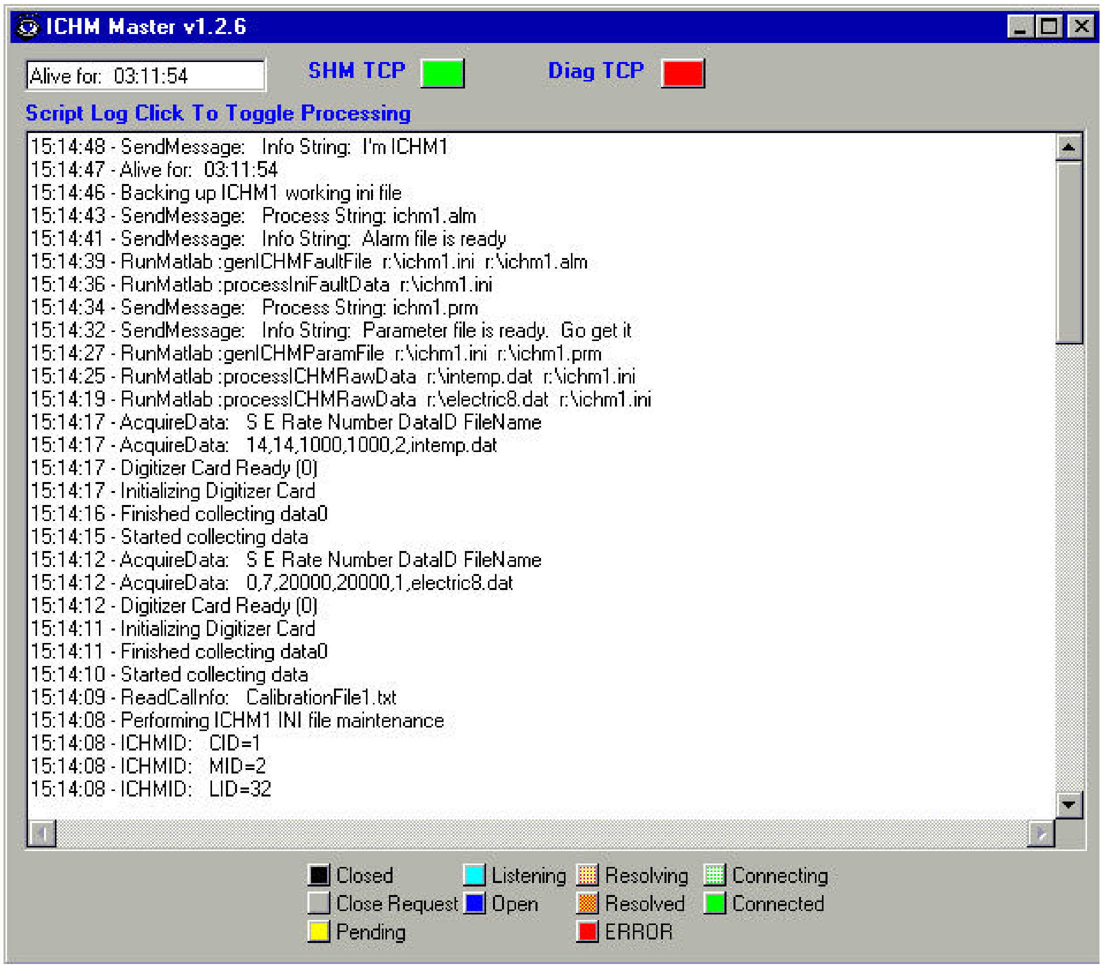



**Figure 105 ICHM Info Display**


**Figure 106 ICHM Debug Display**

#### 5.1.4.5.1.3 Results

A series of simulated fault conditions (section 5.1.4.5.1.1) were tested with the HMS installed on an operating 501K17 SSGTG. The following is a summary of processing, data fusion, classification algorithm and messaging modifications that were made based on operation of and data collection with the ICHMs and SHM at the LBES. Data collection, processing and communication operations at both ICHM and SHM functioned as expected with no problems or degradation for the duration of the LBES test. A final set of fault simulation scenarios were conducted as part of the LBES demonstration/VIP day.

ICHM1 (Generator Electrical) LBES testing did not indicate any required changes in the processing, data fusion, or classification algorithms on ICHM1.

ICHM2 (Generator Mechanical) Data from LBES testing were used to adjust inputs to the feature extraction algorithms, thresholds used in the data fusion and pattern classification algorithms, and alert and alarm message thresholds. The result was a significant reduction in the number of false alert and alarm messages sent to the SHM and Watch Station.

ICHM3 (Reduction Gearbox) Data from LBES testing were used to adjust inputs to the feature extraction algorithms, thresholds used in the data fusion and pattern classification algorithms, and alert and alarm message thresholds. The result was a significant reduction in the number of false alert and alarm messages sent to the SHM and Watch Station. LBES test data for this ICHM and ICHM4 also showed that the ICHM internal temperatures were well within acceptable operating ranges while the engine was running.

ICHM4 (Accessory Gearbox) Data from LBES testing were used to adjust inputs to the feature extraction algorithms, thresholds used in the data fusion and pattern classification algorithms, and alert and alarm message thresholds. The result was a significant reduction in the number of false alert and alarm messages sent to the SHM and Watch Station. LBES test data for this ICHM and ICHM3 also showed that the ICHM internal temperatures were well within acceptable operating ranges while the engine was running.

SHM LBES testing revealed several unresolved message format problems between the SHM and the ICHMs and between the SHM and the Watchstation. These were all resolved satisfactorily during LBES testing.

Table 33 summarizes the three classes and types of simulated fault testing conducted during the final LBES demonstration/ VIP day. Table 33 is representative of the full test matrix described in section 5.1.4.5.1.1 above

**Table 33 LBES ICHM and SHM Simulated Fault Testing**

| Fault Class | Node | Fault | Fault Condition | ICHM Detection | SHM Notification by ICHM | Watchstation Notification by SHM | Display of Condition at Watchstation |
|---|---|---|---|---|---|---|---|
| **Component Fault** | ICHM#3 reduction gear box | Progressive bearing fault | Bearing frequency anomalies assoc. with tower shaft bearing – normal to alert to alarm and back to normal | Yes – Alert and alarm conditions as simulated. Returned to normal after simulated condition removed | Yes – Message transmission and receipt verified | Yes – Transmission of message verified | Yes – 1) Receipt of SHM message verified. 2) Display of alert/ alarm message and correct fault information at WS. 3) Display of correct support info. and data |

| Fault Class | Node | Fault | Fault Condition | ICHM Detection | SHM Notification by ICHM | Watchstation Notification by SHM | Display of Condition at Watchstation |
|---|---|---|---|---|---|---|---|
| **Limit Fault** | ICHM #1 Generator Electrical | Output Voltage | High Voltage Level | Yes – Alert and alarm levels associated with pre-set limits. Returned to alert and then normal consistent with simulated input | Yes – Message transmission and receipt verified | Yes – Transmission of message verified | Yes – 1) Receipt of SHM message verified. 2) Display of alert/ alarm messages and correct voltage values 3) Correct graphical indication on bar graph assoc. w/ alert(yellow) and alarm(red) conditions |
| **Limit Fault** | ICHM #4 Accessory Gear Box | High Vibration | High RMS Vibration Level | Yes – Alert and alarm levels associated with pre-set limits. Returned to alert and then normal consistent with simulated input | Yes – Message transmission and receipt verified | Yes – Transmission of message verified | Yes – 1) Receipt of SHM message verified. 2) Display of alert/ alarm messages and correct vibration level 3) Correct graphical indication on bar graph assoc. w/ alert(yellow) and alarm(red) conditions |

| Fault Class | Node | Fault | Fault Condition | ICHM Detection | SHM Notification by ICHM | Watchstation Notification by SHM | Display of Condition at Watchstation |
|---|---|---|---|---|---|---|---|
| **System Fault** | ICHM #2,#3,#4 | Sensor Fault/Failure | Signal Loss/ Short | Yes – Sensor (accel.) signal change detected | Yes – Message transmission and receipt verified | Yes – Transmission of message verified | Yes – 1) Receipt of SHM message verified. 2) Display of system fault message at WS. 3) Display of correct support info. and data |
| **System Fault** | ICHM #1,#2,#3,#4 | Comm Link Loss | No ICHM Response to SHM Poll (ICHM Powered Down) | N/A | N/A | Yes – Transmission of message verified | Yes – 1) Receipt of SHM message verified. 2) Display of system fault message at WS. 3) Display of correct support info. and data |
| | SHM | Comm Link Loss | No SHM Comms with Ws for Set Time Period (SHM Powered Down | N/A | N/A | N/A | Yes – 1) Watchstation timeout cycle triggered 2) System alert message displayed 3) Display of correct support info. and data |

#### *5.1.4.5.2 Access Point*

Fire:
Due to the limited capabilities of LBES facility, the fire algorithm has been stripped down to a single parameter, temperature. The fire algorithm will comprise of the temperature sensors from multiple sensor clusters. The AP will monitor the sensor cluster readings for high level or rapid changes. Based on known sensor cluster locations the AP will determine whether or not an alarm will be issued. 2 adjacent sensor clusters sensing a high temperature will be viewed as an alarm. 2 non-adjacent clusters detecting a high level will not be viewed as an alarm.

Results:
The location discrimination feature of the algorithm was disabled due to the LBES/CG-61 physical differences. The APs shared the Sensor Cluster fire data across the individual APs to develop a compartment wide assessment of the Sensor Cluster data. The Primary AP then issued a FIRE alarm to the watchstation.

Flooding:
The flooding algorithm will comprise of multiple sensor clusters monitoring the water level of buckets of water. The AP will monitor the sensor cluster readings for high level or rapid changes. Based on known sensor cluster locations the AP will determine whether or not an alarm will be issued. 2 adjacent sensor clusters sensing a high water level will be seen as an alarm. 2 non-adjacent clusters detecting a high level will not mean an alarm.

Results:
The location discrimination feature of the algorithm was disabled due to the LBES/CG-61 physical differences. The APs shared the Sensor Cluster flooding data across the individual APs to develop a compartment wide assessment of the Sensor Cluster data. The Primary AP then issued a FLOOD alarm to the watchstation.

High Temperature:
The high temperature algorithm is design to minimize the number of false alarms. The algorithm will filter the temperature readings for unacceptable readings. An alarm is issued when a single cluster's data has successfully passed the filtering process.

Results:
The APs shared the Sensor Cluster flooding data across the individual APs to develop a compartment wide assessment of the Sensor Cluster data. The Primary AP then issued a HIGH TEMPERATURE alarm to the watchstation.

### 5.1.5 Fault (loss of communications) Recovery Exercises

Fault recovery exercises are design to flex the RSVP architecture and its associated system components and to illustrate many of the unique features of the RSVP system.

The following sections describe the various recovery schemes inherent in the RSVP architecture.

#### 5.1.5.1 APs

##### *5.1.5.1.1 Loss Of Network Communications Between AP And WS*

Action: The AP will issue a "kick-off" command to all connected Sensor Clusters.
LBES Results: All 4 APs issued a "kick-off" command to the APCM units causing the Sensor Cluster to migrate to other APs.

##### *5.1.5.1.2 Loss Communication between AP to APCM*

Action: The AP will issue a "kick-off" command to all connected Sensor Clusters.
LBES Results: The serial line connecting the AP and APCM was disconnected and the APCM recognized the lose of communication and issued a "kick-off" message to the Sensor Clusters forcing them to migrate to other APs.

#### 5.1.5.2 Sensor Clusters

##### *5.1.5.2.1 Loss of Communications between Environmental Sensor Cluster and AP*

Action: If the Sensor Cluster fails to hear a down link message from the AP 3 consecutive times then the Sensor Cluster will sequence to the next frequency channel in its AP frequency table. The sensor cluster will then try to establish communication with the new AP.

LBES Results: The testing consisted of shutting down APs that were connected to Sensor Clusters. The Sensor Clusters would then migrate to an operational AP. All the Sensor Clusters operated very well during the tests. No Sensor Cluster failed to switch.

##### *5.1.5.2.2 Loss Of Communications Between SHM To AP*

Action: If communications between the SHM and an AP fails, then the SHM will automatically switch to another AP unit in that given compartment and try to establish communications.

LBES Results: The testing consisted of shutting down APs that were connected to the SHM. The SHM would sense the loss of communication with the AP and then immediately migrate to an operational AP.

##### *5.1.5.2.3 Loss of Communications between SHM to ICHM*

Action: If communications between the SHM and an ICHM fails, then the SHM after a set period of time will report the communications loss to the Watchstation user interface as a system fault in the alert/alarm region of the Data screen. Additionally, loss of