Creating Graphic Signatures of Analog Signals for Fault Detection and Situational Awareness – Three New Methods

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NASA Technology Goals

- **Minimize perceptual focus errors** – Form a Gestalt of system behavior using less console space i.e.
  - Pack more information in smaller areas through structured graphic patterns
  - Connect and arrange visual interrelationships to improve detection of abnormal conditions

- **Minimize user data saturation** - More efficiently capture and display analog information from multiple sources simultaneously
  - Compactly represent these analog signals – TESPAR Codes
  - Map to graphic symbols – Box Codes and Circle Codes
  - Fuse these symbols together – two different approaches
    - Transform analog signal magnitudes using time varying graphed math functions (ex. Rotorcraft Gearbox, Shuttle Foam Strikes)
    - Transform analog signal content using graphic patterns of 2D and 3D temporal strings (ex. Constructive Displays)

- **Generalize to multi state non linear systems** – current research
  - State Machines (wiring fault detection, software V&V)
  - Monotonic and non monotonic function consolidation
  - Blend human and machine pattern recognition strengths

Every Thing Old Is New Again

Images

Hieroglyphs
code images

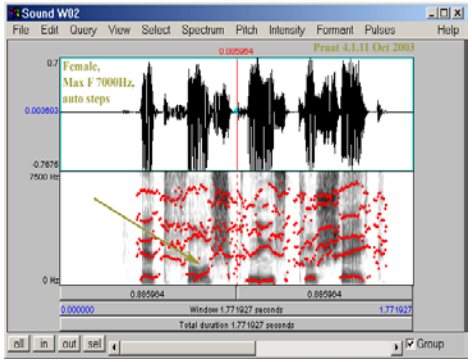
Bird Hawk

Glyph groups
code concepts

Word strings
code concepts

Alphabet strings
code words

Sounds code
images



Alphabets code
sounds

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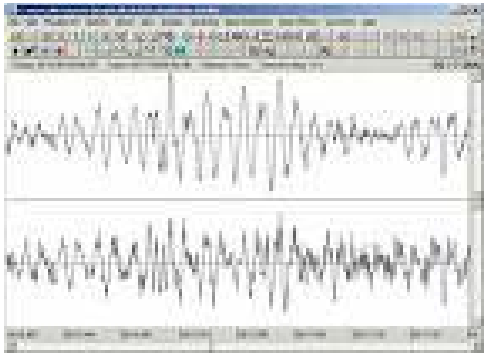
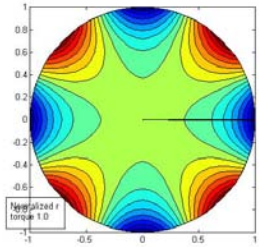
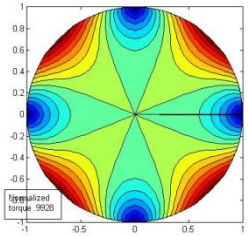
Approach One: Display Analog Information Directly Using a Math Function Graph Rather Than an Indicator

Signal Vibration Magnitudes Parameterize for example a Hyperbolic Cos Function

Original Analog Signals (Gearbox Vibrations)

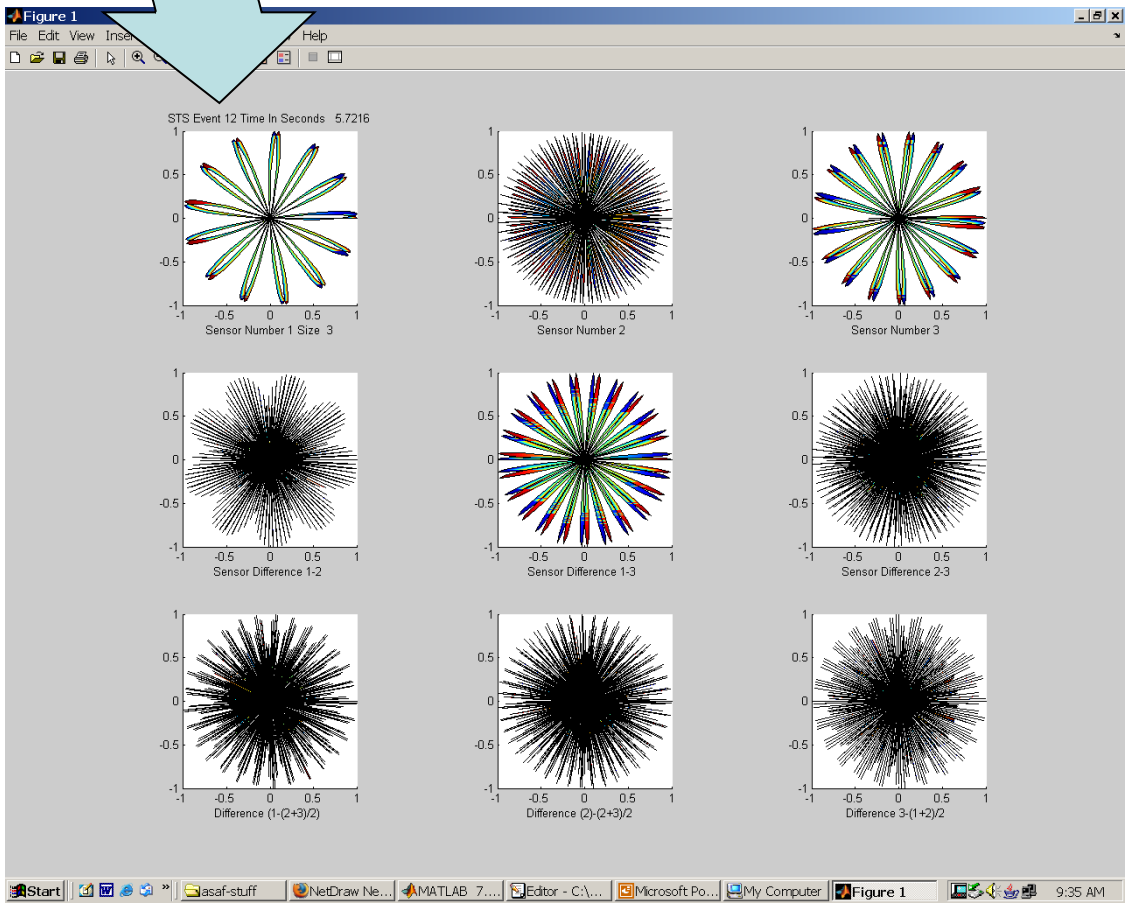






Visual Indications of a Helicopter Gearbox Fault and Shuttle foam strikes

Example 2: SST 121 Foam Strikes



Number of nodes is related to the Shuttle acceleration.

Graphic is from a weighted Cos of accelerometer values.

The upper left sensor fails intermittently.

A total failure causes a zero argument to the Cos function and a solid color (next slide).

Non symetric shapes are G's less than one.

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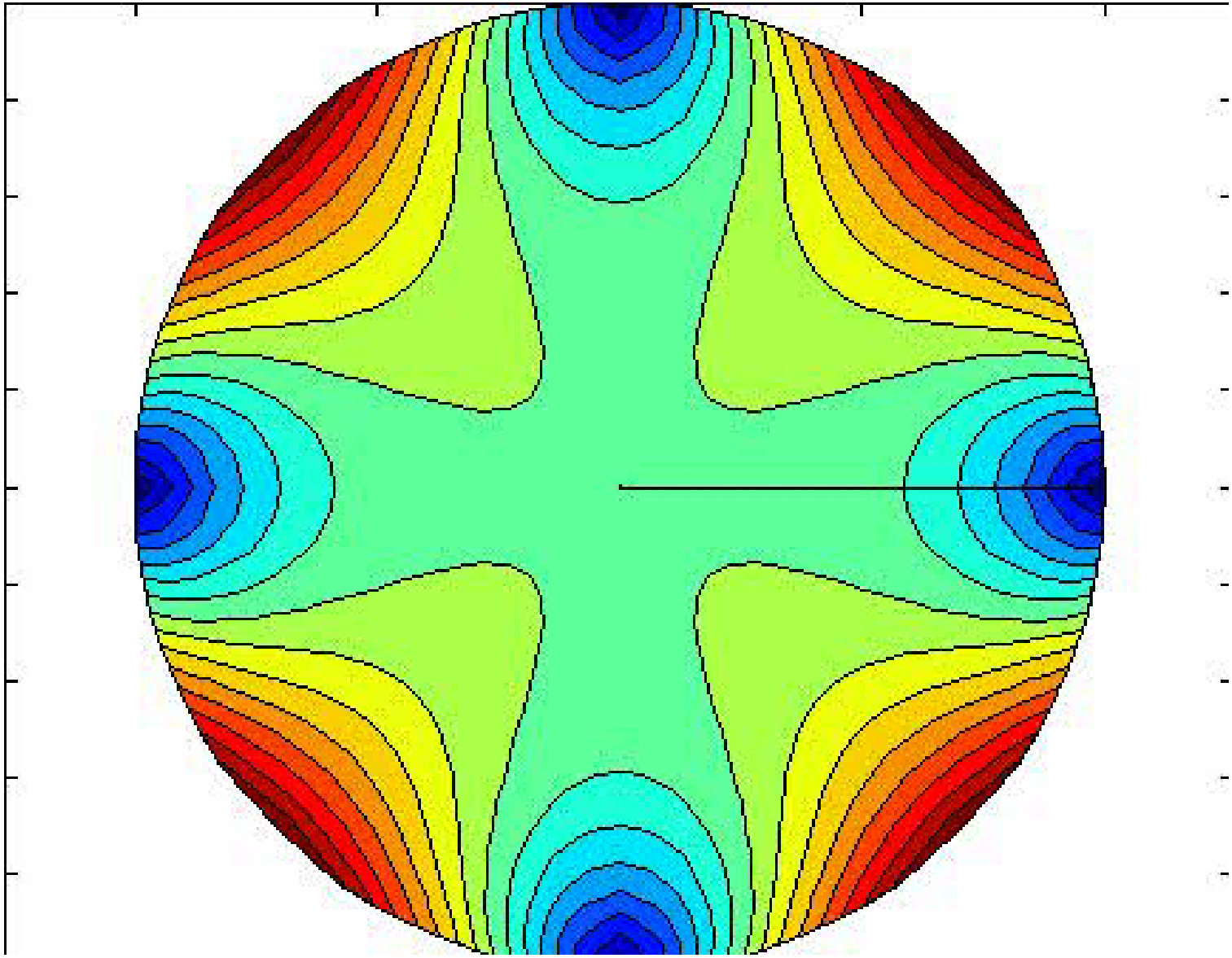

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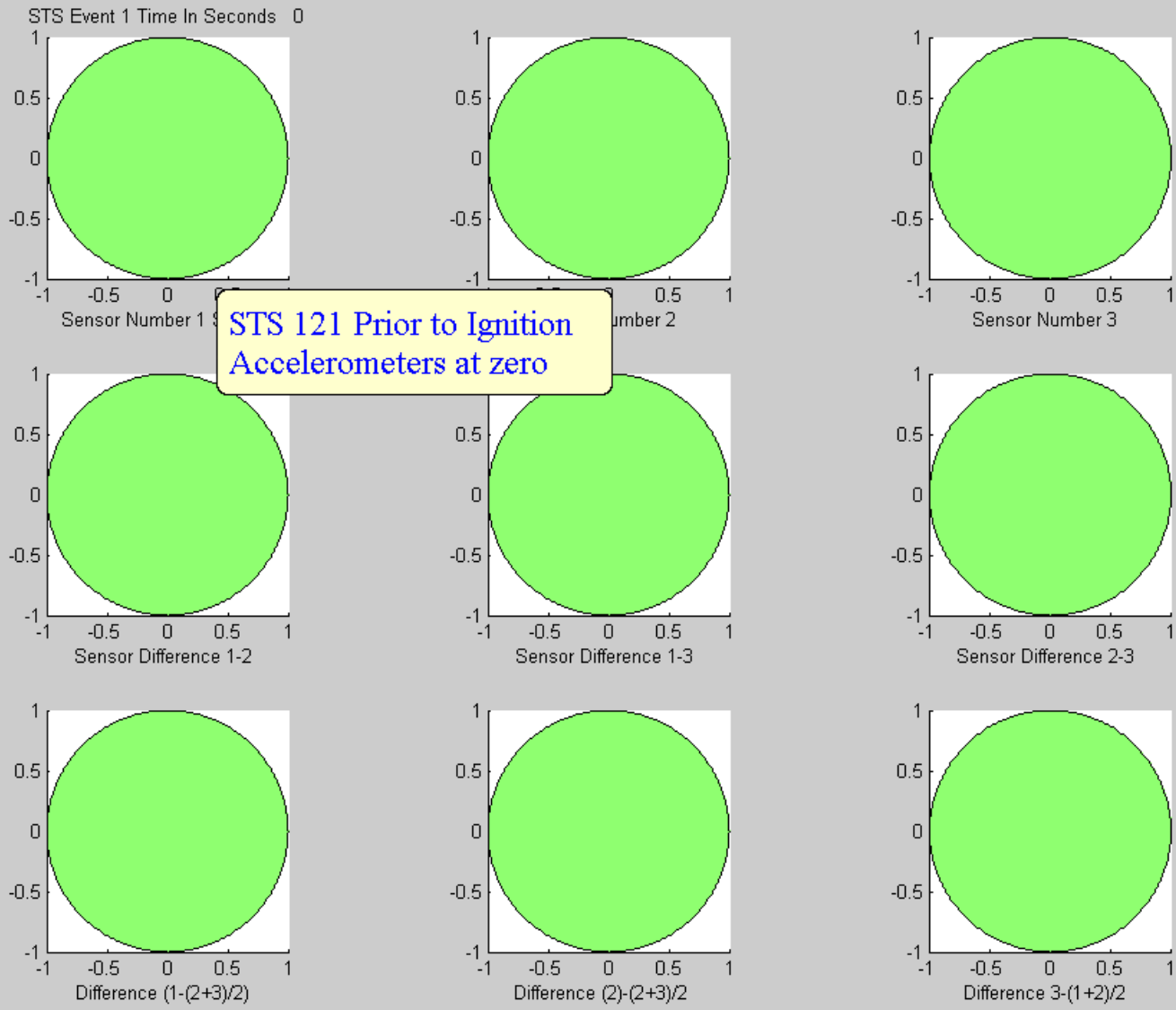
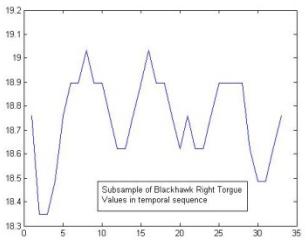
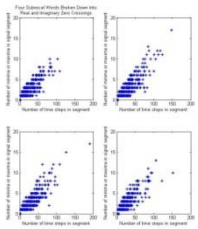


STS 121 Prior to Ignition
Accelerometers at zero

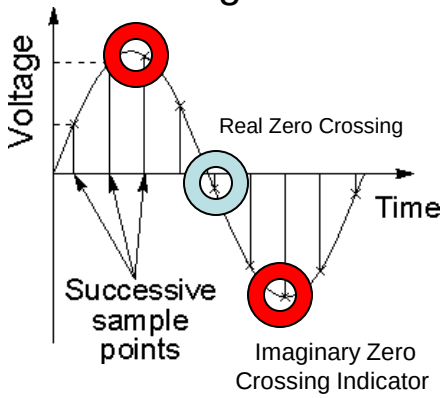
Approach 2: transform signal content into a unique graphic signature

Raw analog signal





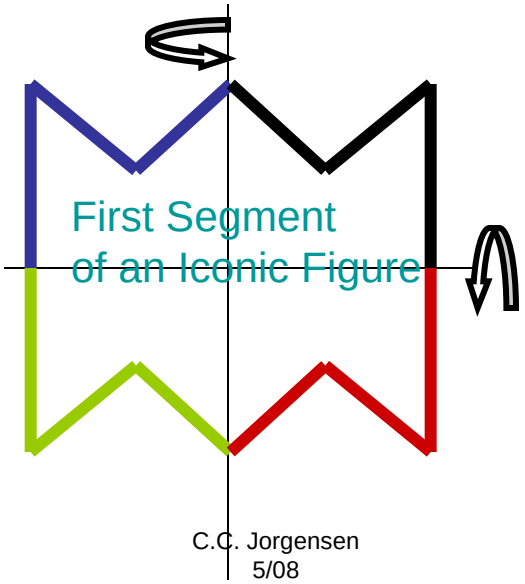
Tespar code of one signal event



Tespar codes' chained in a sequence

2 8 4 4 9 9 2 8 4 4

Box code "2" reflected and/or rotated on 4 axes

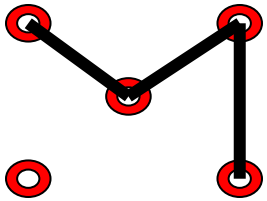


For each element in a sequence

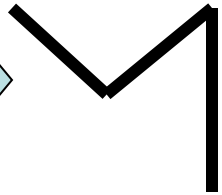
2

Map Code number to glyph

Box Code Frame



Box Code



Mapping Sequence Numbers to Box Codes

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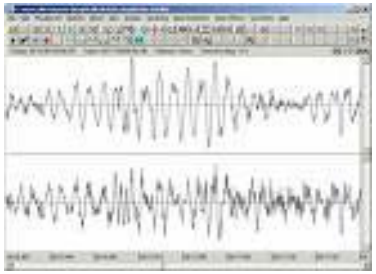
Create the signature from analog content

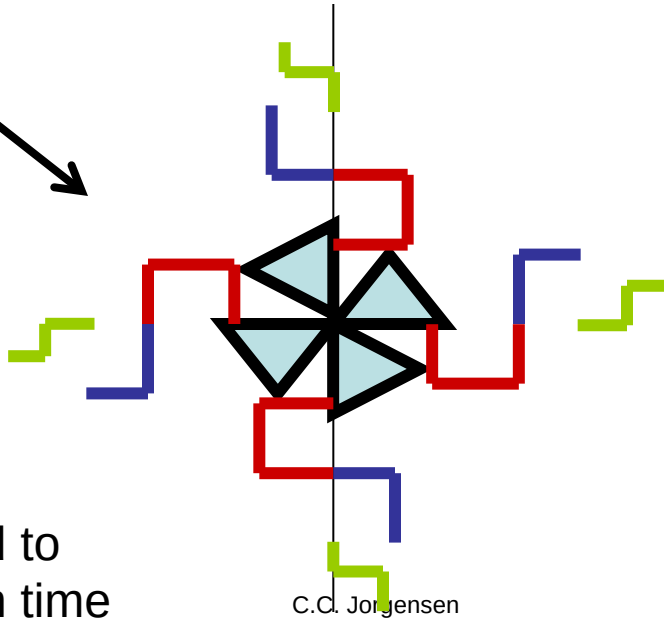
Analog Sensor Data

2 8 4 4 9 9 2 8 4 4



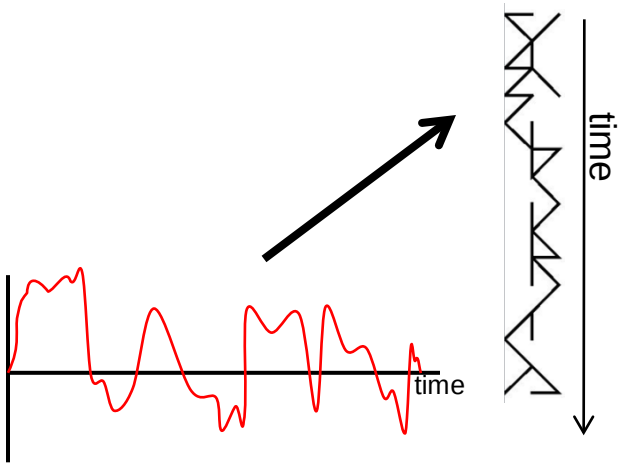
TESPAR Box Code Sequence:

Temporal Display

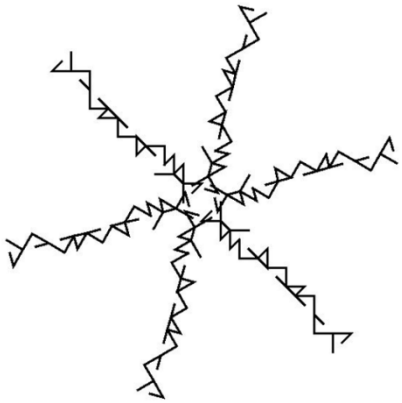


Distributions from signals are used to used to define an “alphabet” of signal describing areas. These regions are then mapped to different graphic icons and combined as patterns in time

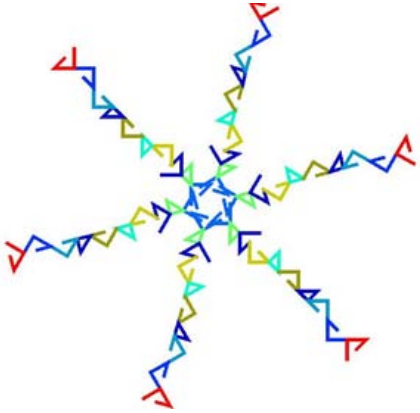
Enhance Change Detection Using Color, Thickness and Number of Axes



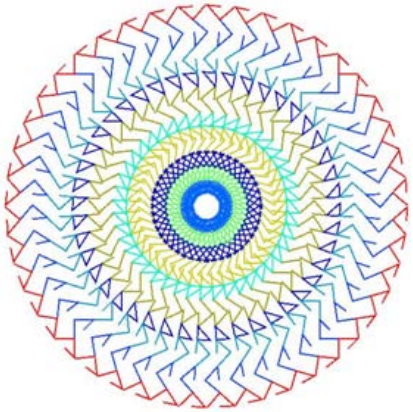
Ten symbols in black and white strung together in a vertical fashion



The same string of symbols arranged circularly repeating along 6 axes

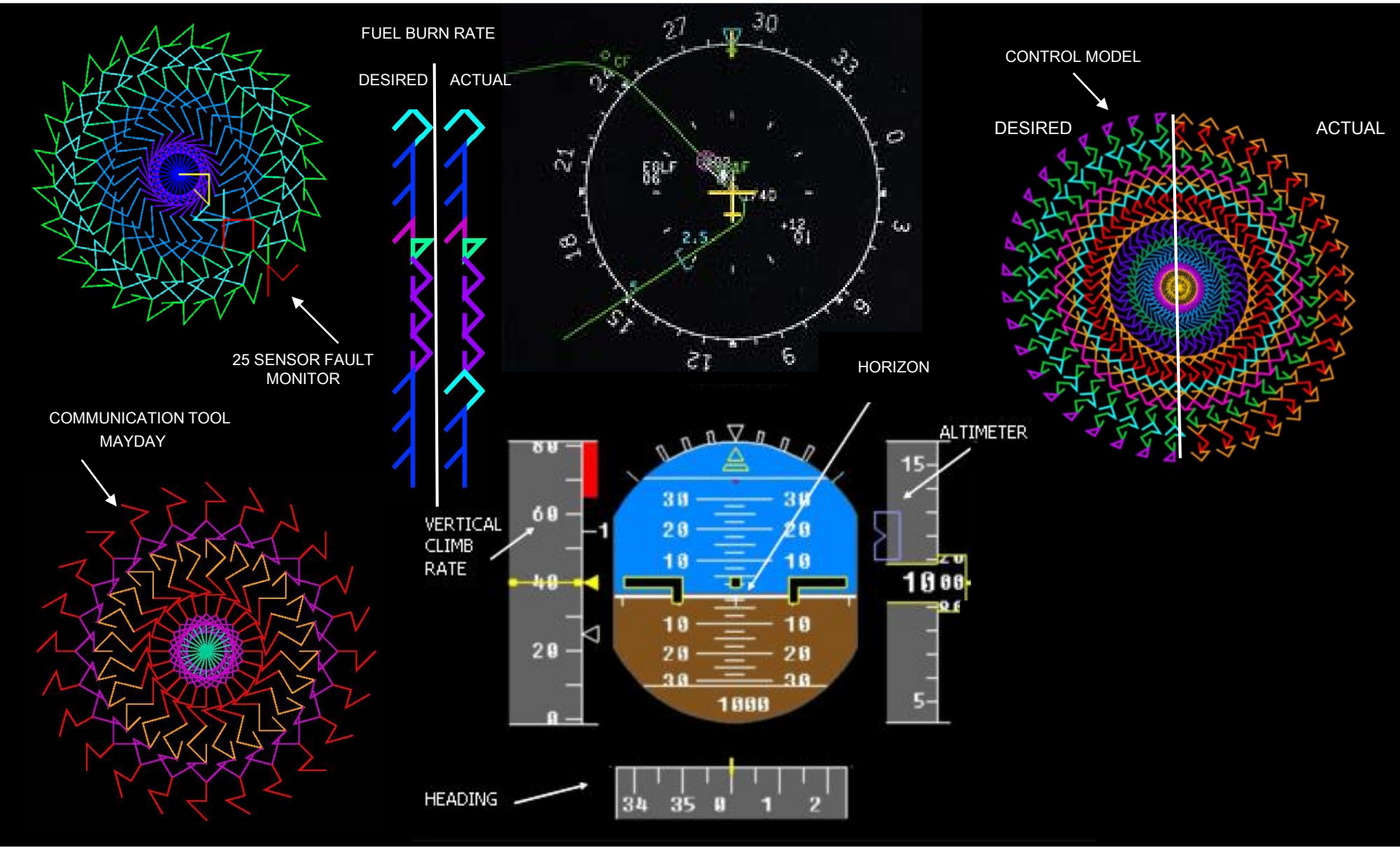


The same string of symbols now in color and with increased line thickness arranged circularly repeating along 6 axes



The string n color and with increased line thickness arranged circularly repeating along 44 axes

Combining Displays: Hypothetical New Pilot Display



Space Problem Example: Rocket Booster Case Breach Fault

- Create events using a 6 D.O.F. NASA MAVERIC (Marshall Aerospace Vehicle Representation in C) high fidelity simulation of the Orion crew launch vehicle first stage
- Study first 100 seconds of ascent looking at fault progression detection and coupled vehicle dynamics
- Compare current diagnostic panels and linear graphic plots with the new methods using a case breach fault scenario in terms of detection times and ease of use

Existing Orion Fault Display

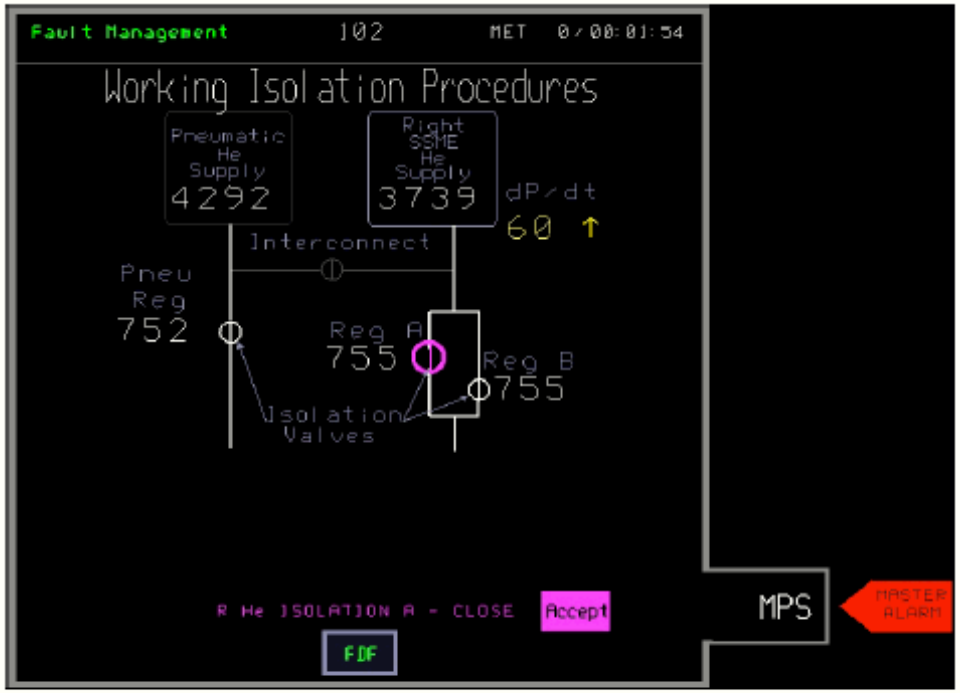
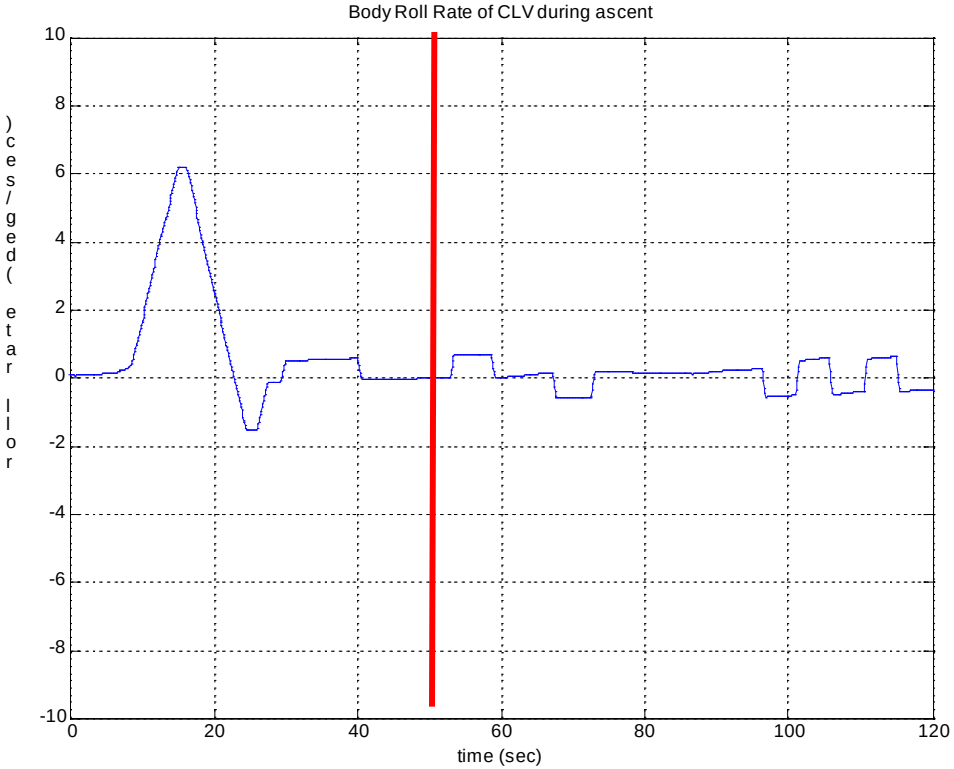


Figure 1.5. Fault Management Display as it appears immediately following C&W annunciation of anomalous rate of change (dP/dT) in Right Engine helium supply system tank pressure. FAMSS has already identified the problem as one requiring isolation procedures.

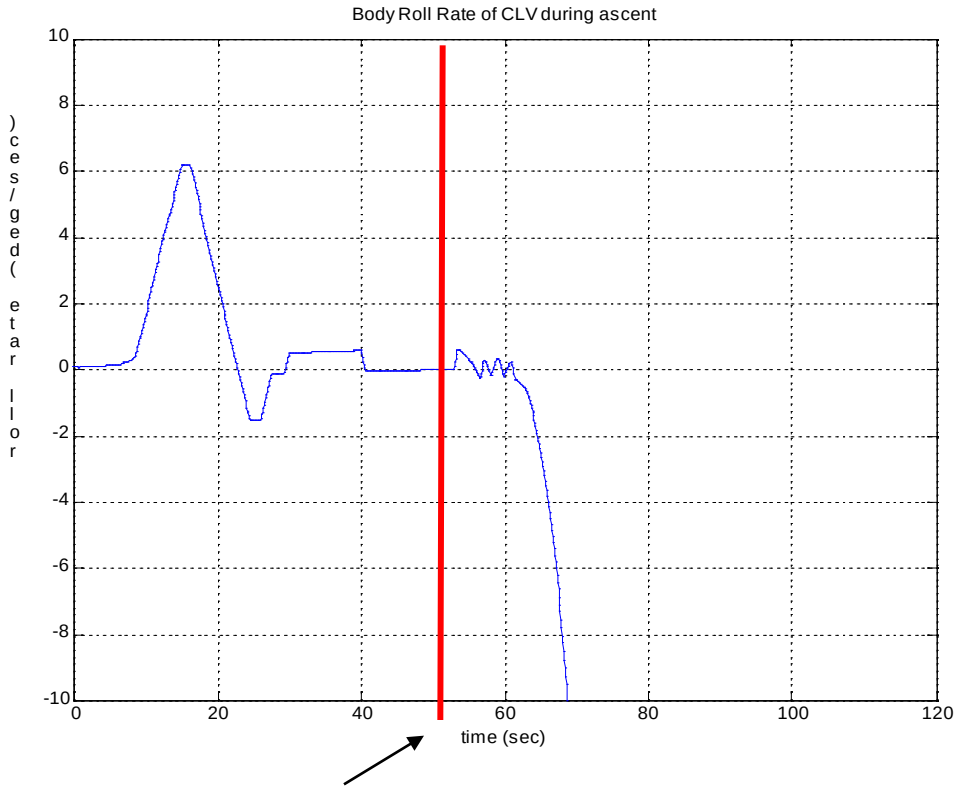
Evaluation of an Onboard Real-Time Fault Management Support System for Next-Generation Space Vehicles. (2006)
Intelligent Spacecraft Interface Systems Lab. Human Systems Integration Division. NASA Ames, Moffett Field.

Graphic Display of Launch Scenario: Nominal roll rate vs. case breach fault occurring at 50 sec

Note: most faults occurring before the max Q point (approximately at 59 seconds) lead to failure in reaching the target window during ascent. If a case breach were to occur after the 59 second mark the gimbaled nozzle can correct the trajectory of the vehicle

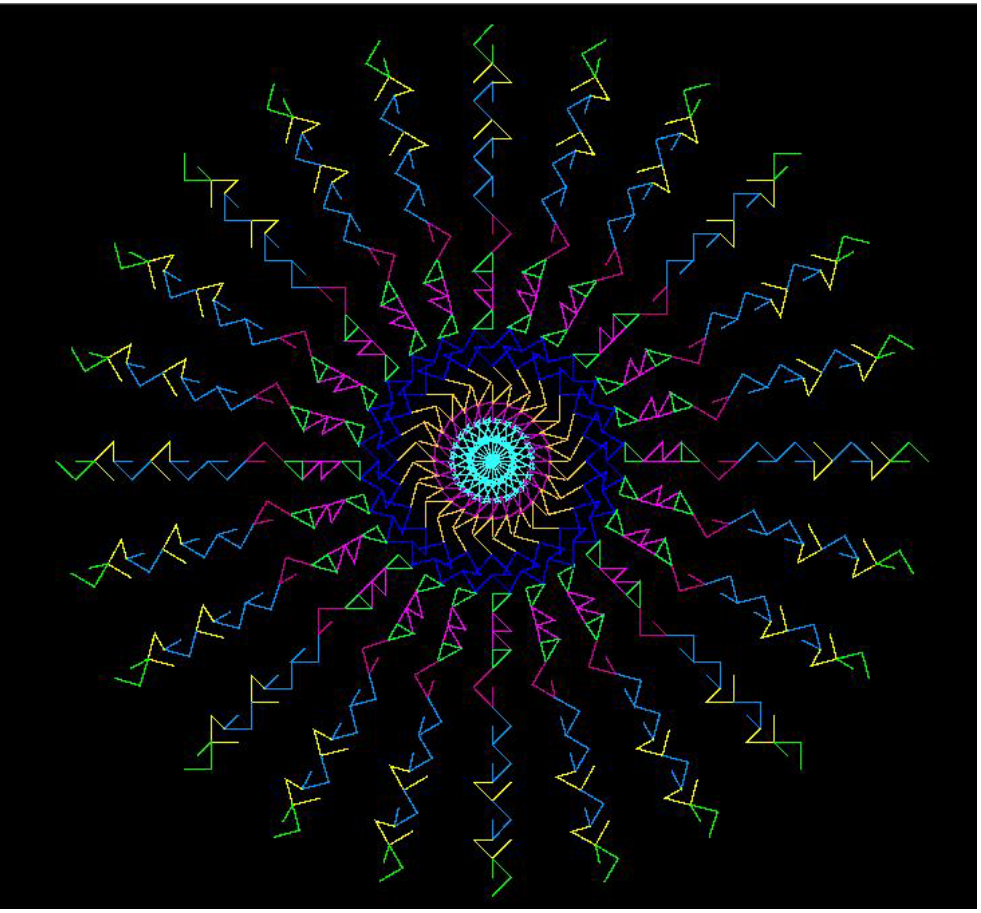


Nominal Ascent – no fault

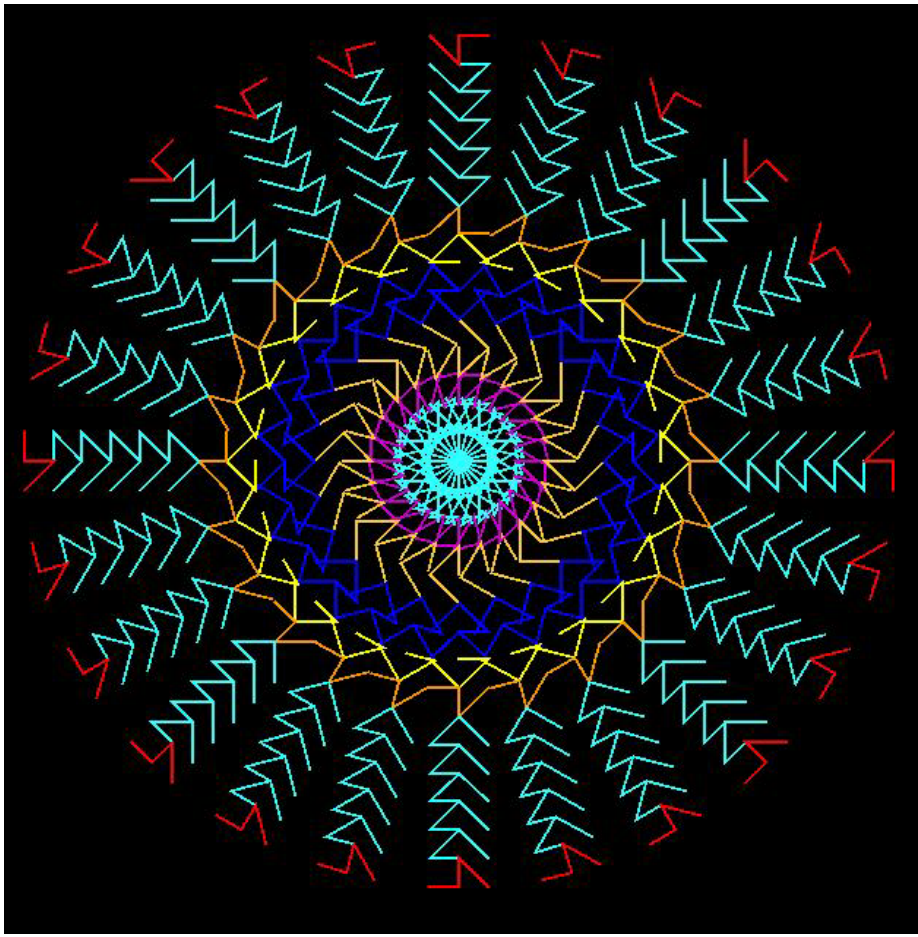


Actual Case breach fault - onset time 50 seconds

New Method: Nominal roll rate (left) vs. case breach fault roll rate (right) - onset at 50 sec



Nominal Ascent – no fault

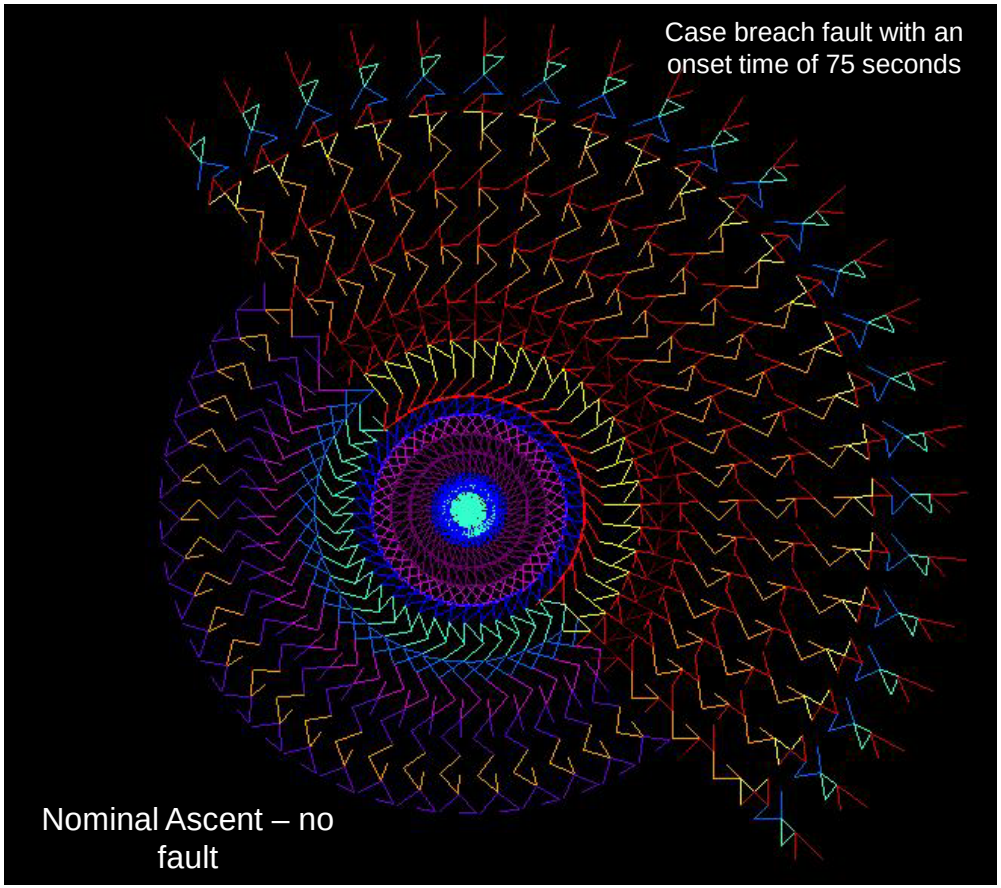


Case breach fault onset at 50 seconds

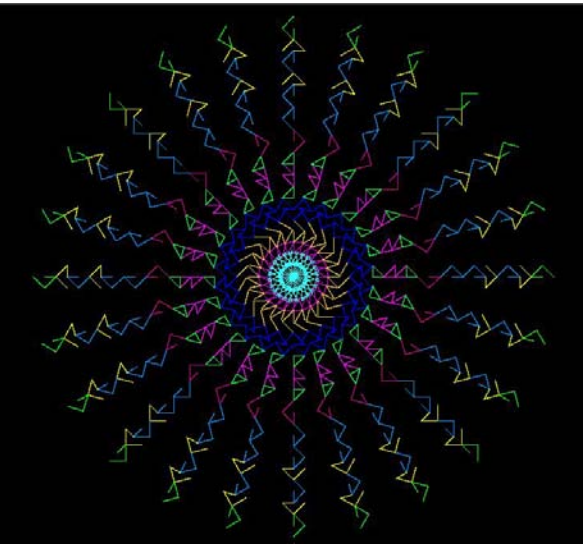
Split radial display for ease of use

Left half is nominal gimbal's pitch angle behavior - right half is a case breach fault at 75 sec

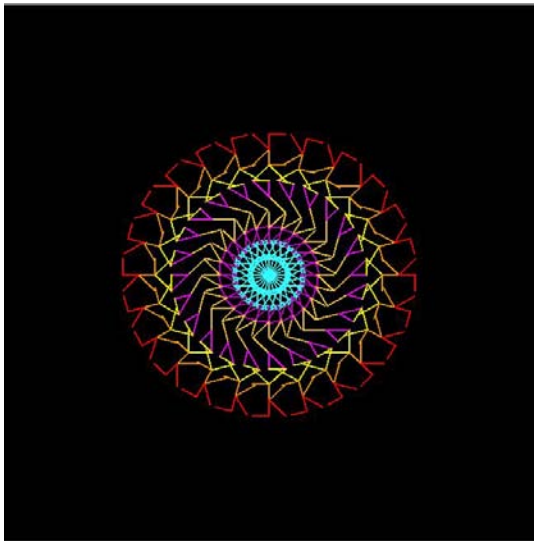
With increased dimensionality, the center of the image begins to compress reducing the ability to use a center as a sensor label



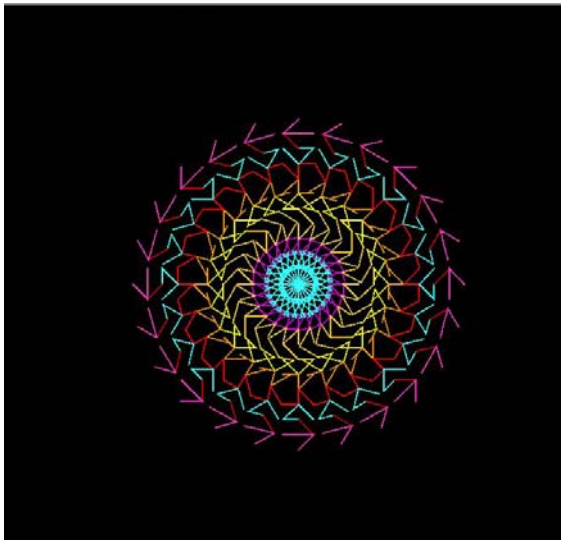
A fault's effect at the igniter versus its effect far away at the aft segment nozzle



Nominal Ascent – no fault



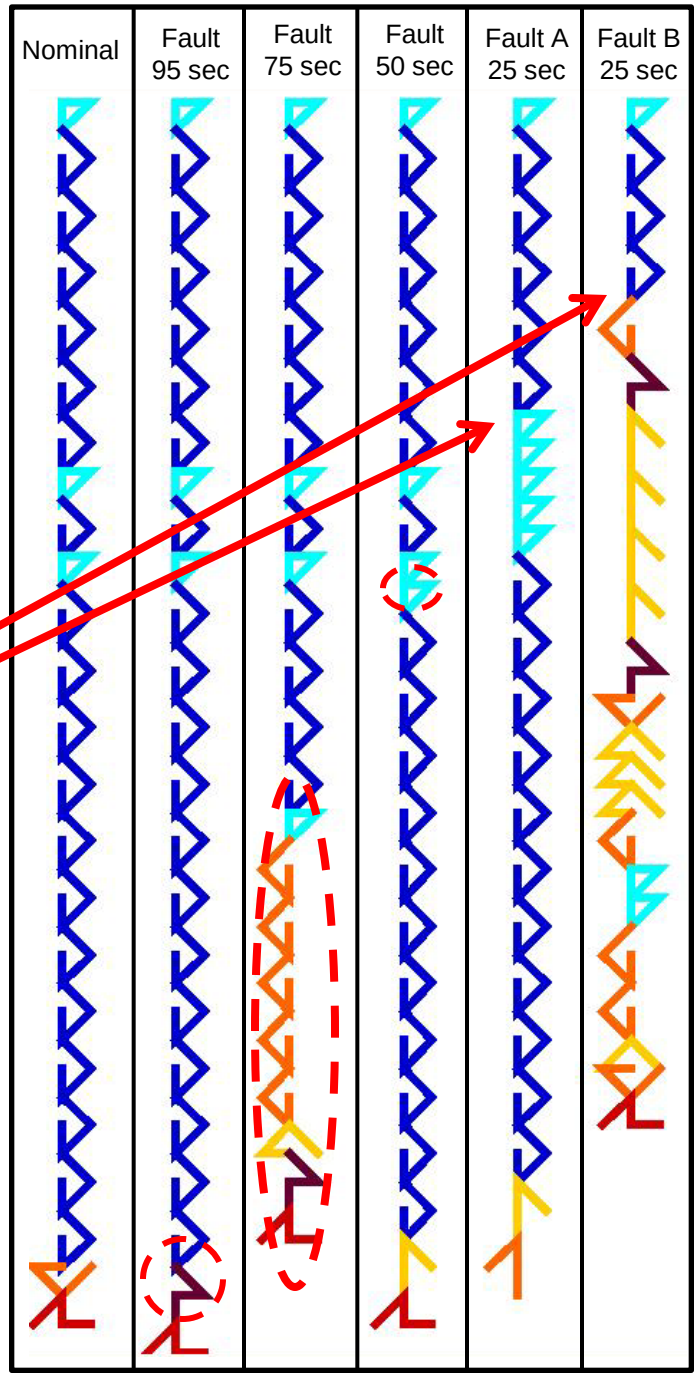
Igniter case breach fault with an onset time of 25 sec



Nozzle case breach fault with an onset time of 25 sec

Altitude Sensor Visualization In the Presence of an Engine Fault

This approach provides not only the visualization of rate of change of altitude of the SRB but also illustrates that small changes in the engine thrust may not effect the slope of the altitude but have a significant effect on how quickly or slowly altitude increases its rate of climb. The effects of an engine failure can be seen very well and even small changes occurring near the end of the ascent could be noticed with ease by the pilot.

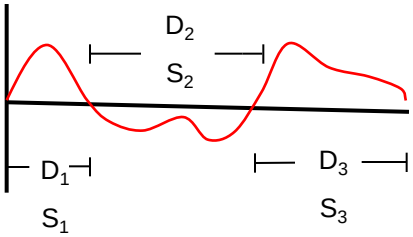


Here two faults were both applied at 25 seconds: fault A shows the change in the rate of altitude with a reduction in engine thrust to 95% of normal and fault B shows a reduction in thrust to 60% of normal. Not only can the fault be seen clearly in both situations with changes in the glyphs from the nominal display but the changes in the engine power can also be very clearly seen in rate of change of the altitude visualization.

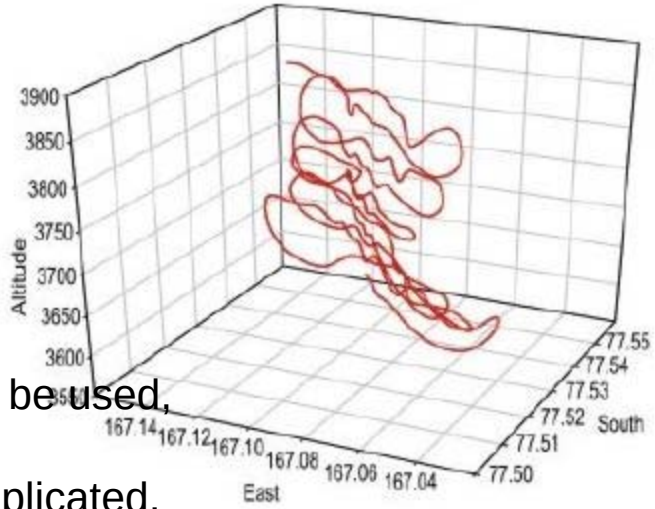
Approach 3: Monotonic Functions

The previous Tespar method allowed :

- osignal invert ability – a very unique display feature
- o a very compact use of memory space
- oan effective method of symbolically displaying information.



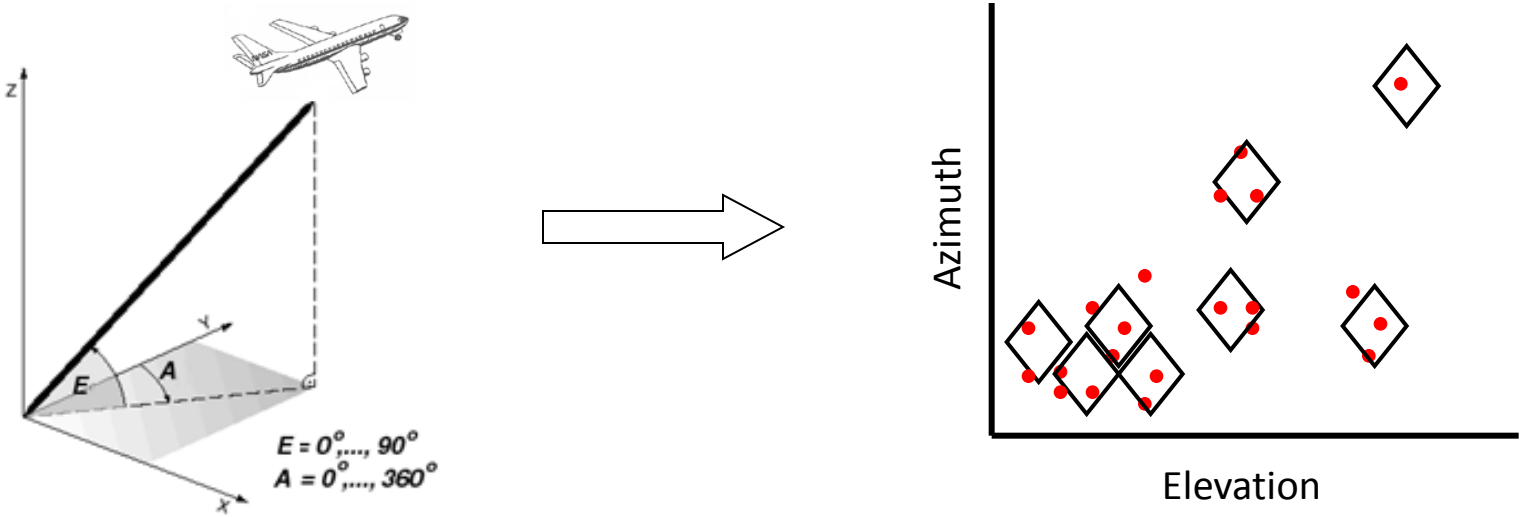
But some other signal types such as trajectories, altitudes, or general flight paths are described as monotonic signals, meaning they **no longer include zero crossings**, the Tespar method can not effectively identify the same features of this type of data.



To symbolically code these types an alternate algorithm had to be used, derived from handwriting analysis called a circuit code:

- o It is a technique that allows for the feature set of a complicated, closed function to be easily codified and reduced to a much smaller set of necessary slope change information
- o But, it now requires that a function be sampled at a given time interval
- o Relative slope between the intervals becomes the new feature set for connecting to the graphic symbols

Air Traffic Control : signals from Elevation and Azimuth Coordinates Rather than complex numbers



Instead of using S and D pairs based on zero crossing values this method uses pairs of azimuth and elevation along a flight path to create a data set.. This data can then be clustered to form an alphabet to create a TESPAR visual graphic as illustrated previously. Here each azimuth and elevation pair would correspond to a alphabet identifier as well as a graphic symbol – the size of the alphabet can then be increased or reduced depending on the amount of information desired regarding the flight path.

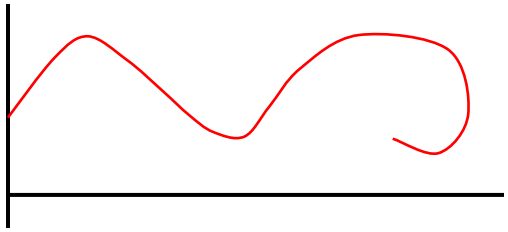
Circuit Coding Method

Methodology and Applying Graphics to the Alphabet

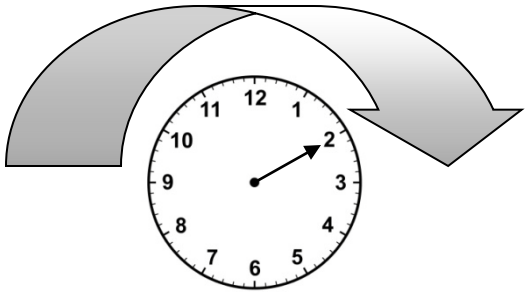
Define the signal using two descriptors:

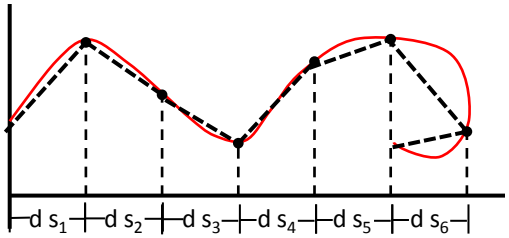
Using the circuit method a uniform interval length is chosen (d) and at every interval the slope of the line is determined and assigned a value (s). This slope here is based on the slope produced by the large hand on a clock face, this allows for ease in labeling each slope value and assigning an alphabet to the characteristics of the signal.

Given the following closed signal:



Circuit Method



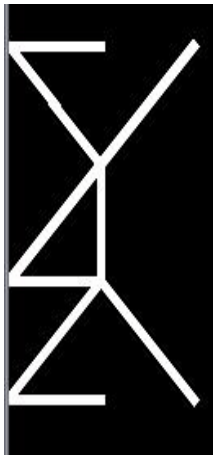


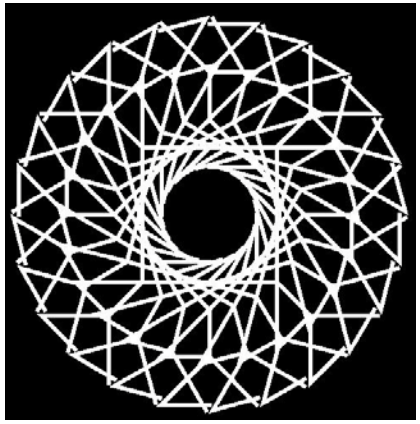
The alphabet for monotonic functions is easily created as each slope value corresponds to a time on the clock. The number of slope values possible on the clock face can be changed depending on the complexity of the signal and the size of the desired alphabet, this can be done by increasing the divisions between the numbered values on the dial

Creating Graphics out of the s and d Pairs

S and D Pair	Slope Based on Clock Face	Alphabet Identifier	Graphic Object
d s_1		1	
d s_2		4	
d s_3		5	

A combined graphic of the entire sequence of sensor data is created using a generation sequence based on reflection and symmetry



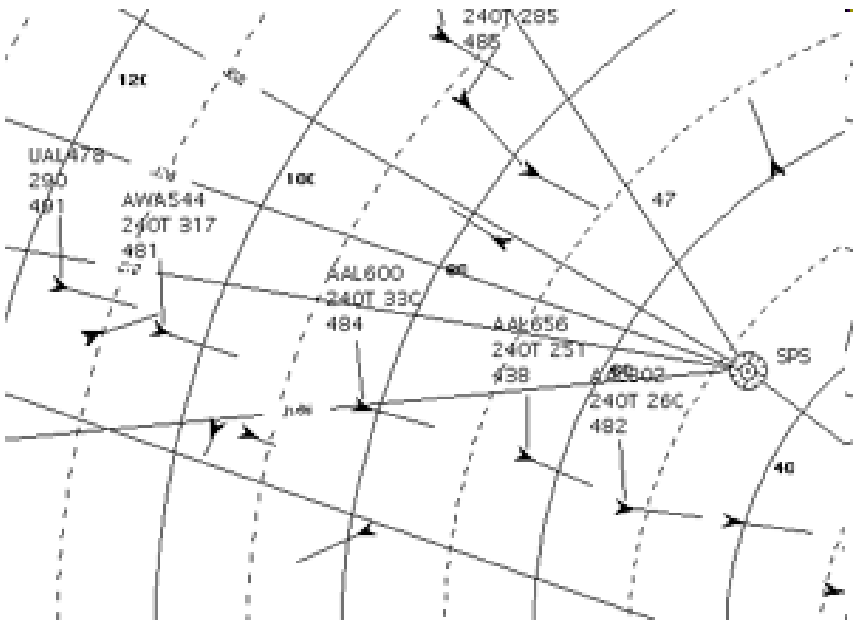


Increasing the dimensionality of the previous image in a circular pattern

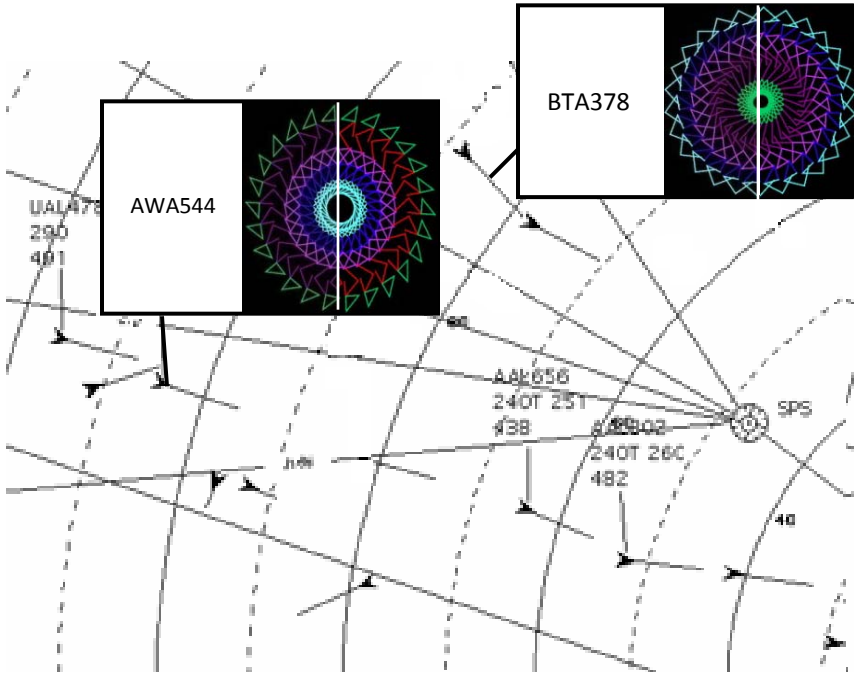
Air Traffic Control Applications: Flight Path Information Alternate Display Concepts

By using TESPAR codes to show the azimuth-elevation alphabet we can create a graphic that displays the current aircraft position and at the same time compare this data with the desired flight path details known before takeoff. Essentially the graphic accompanying the traditional display will allow the user to immediately detect any deviations in an aircraft's flight plan.

Flight Number	Actual Flight Information (Elev/Azim)	Desired Flight Information (Elev/Azim)



Using TESPAR Graphics



State Visualization

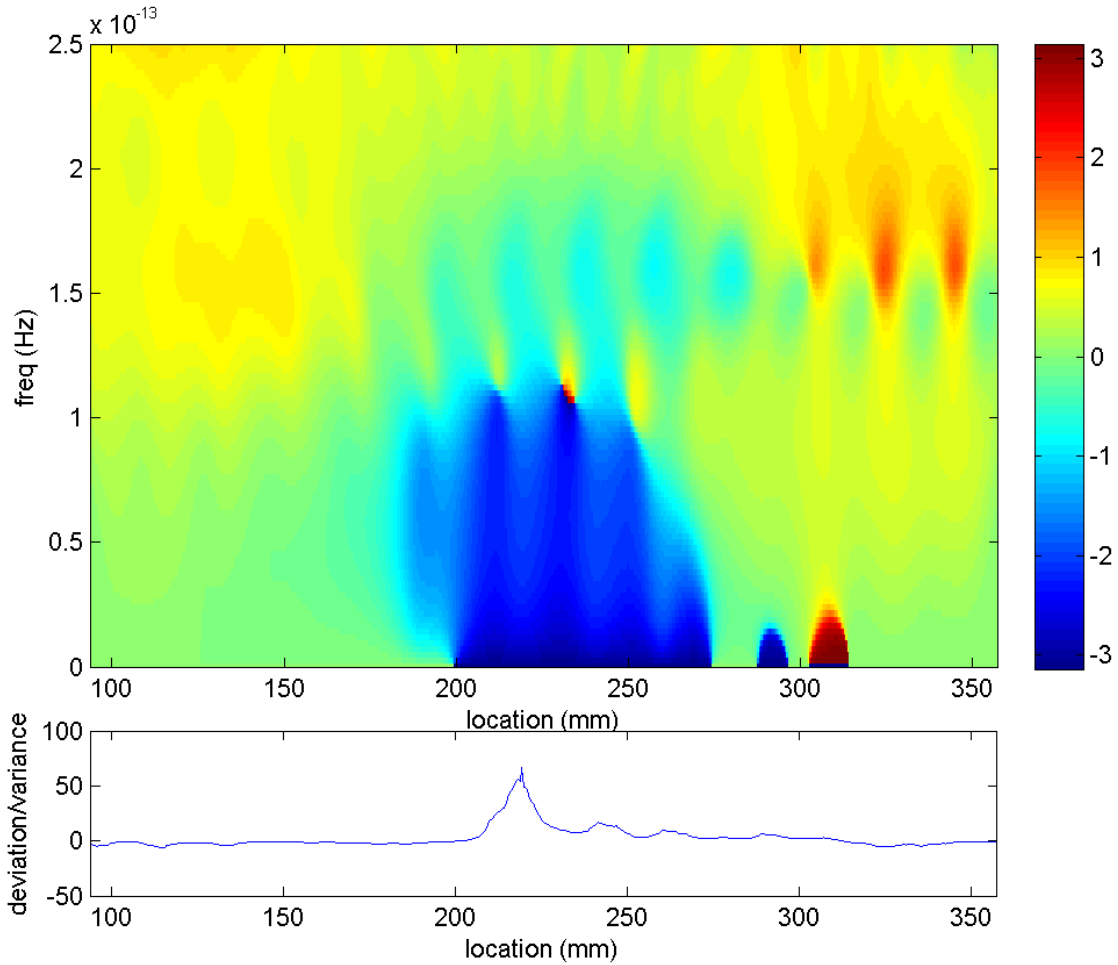
- Most complex systems can be defined as state machines

- State machines are particularly well suited for characterizing temporal processes

- An evolving graphic structure like a display is also a temporal process but would grow too large if not constrained

- Methods used to visualize state processes may be useful for recognizing changes in complex systems – such as visual fault detection and situational awareness
  - Integrity graphs
  - Circos and Extravis plots
  - Phase plots

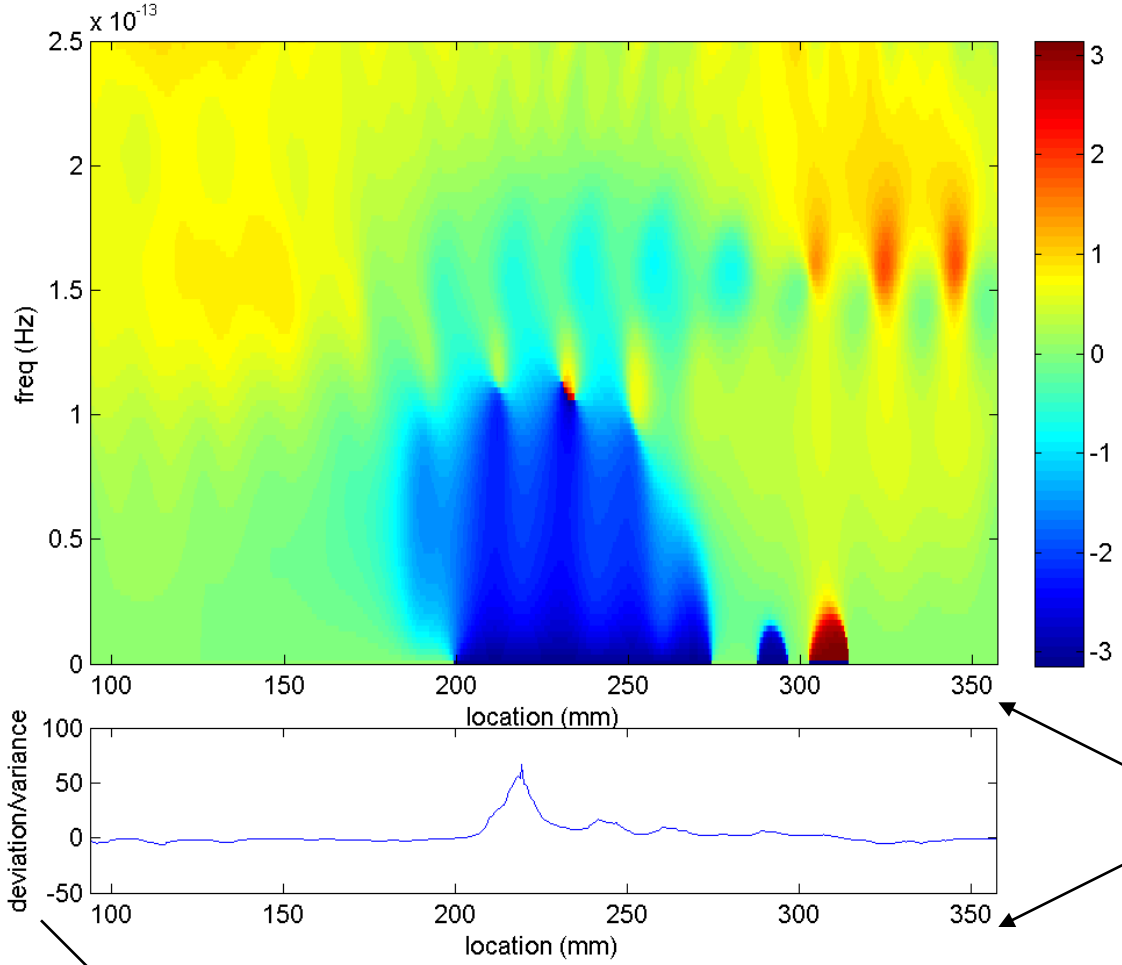
Phaseogram Interface



Comparison of a chirp down a chafed wire with a chirp down the same wire prior to chafing.

Phaseogram Interface

Frequency Bands



Phase Shift:

$+\pi$

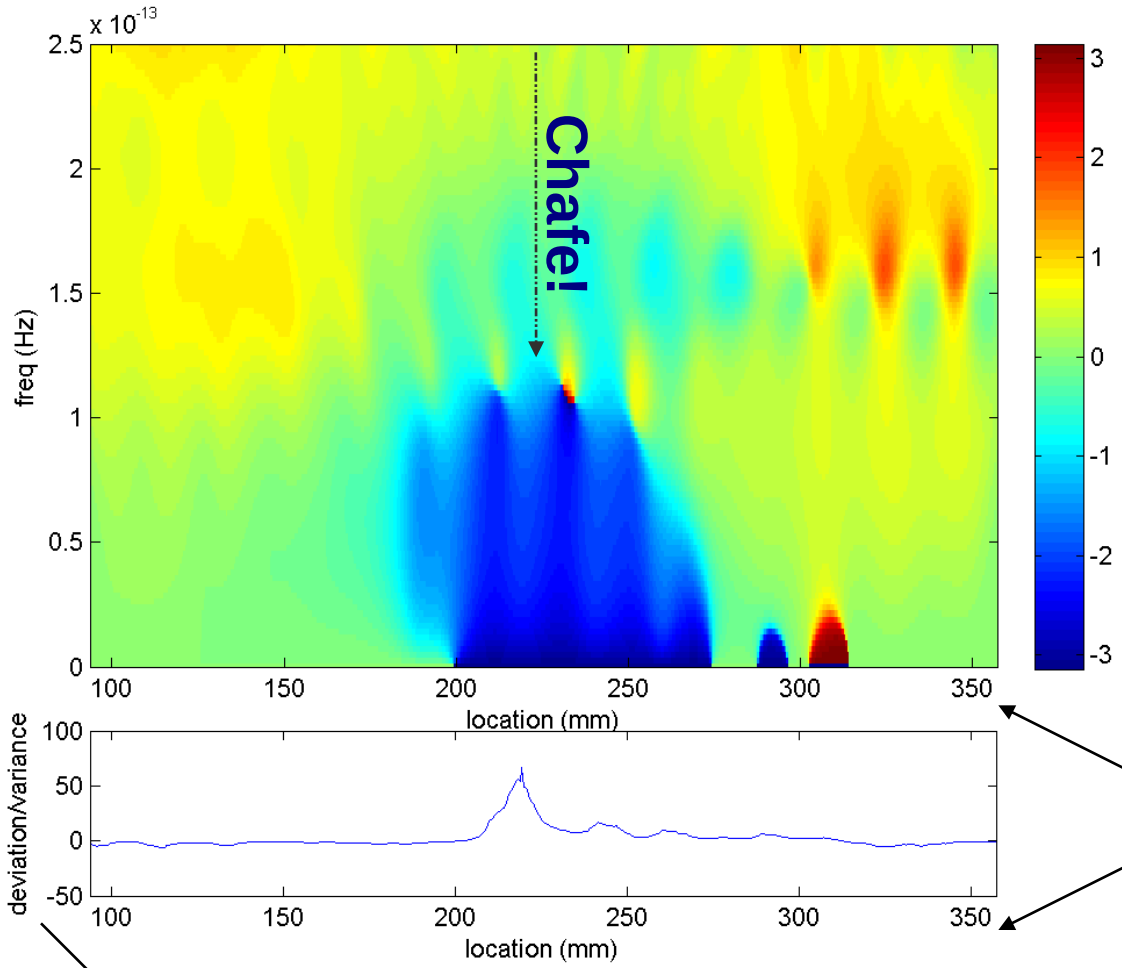
$-\pi$

Where is the chafe?

(Signal – norm)/(local standard deviation of norm)

Phaseogram Interface

Frequency Bands



Phase Shift:

$+\pi$

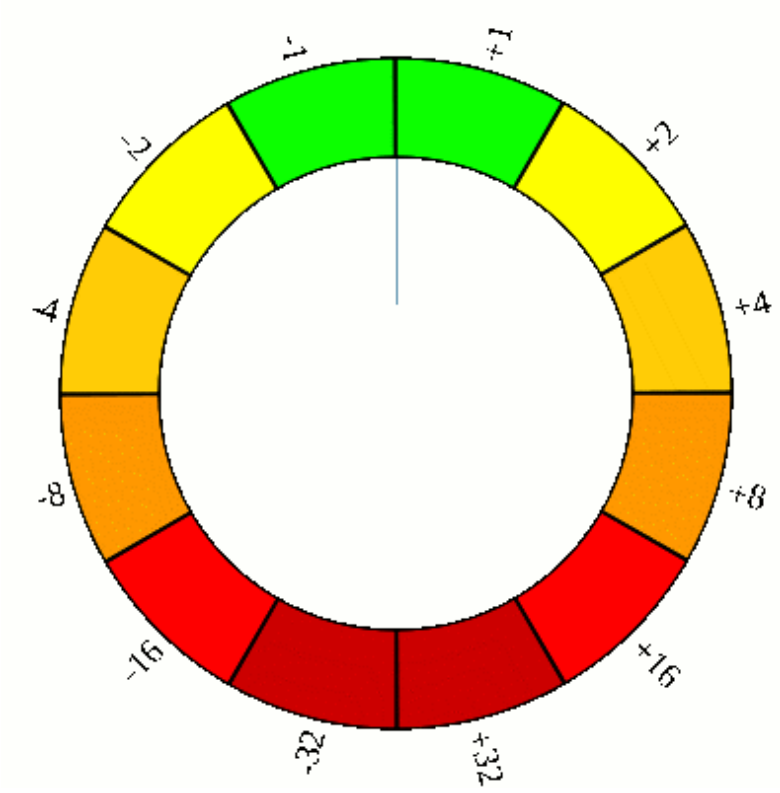
$-\pi$

Where is the chafe?

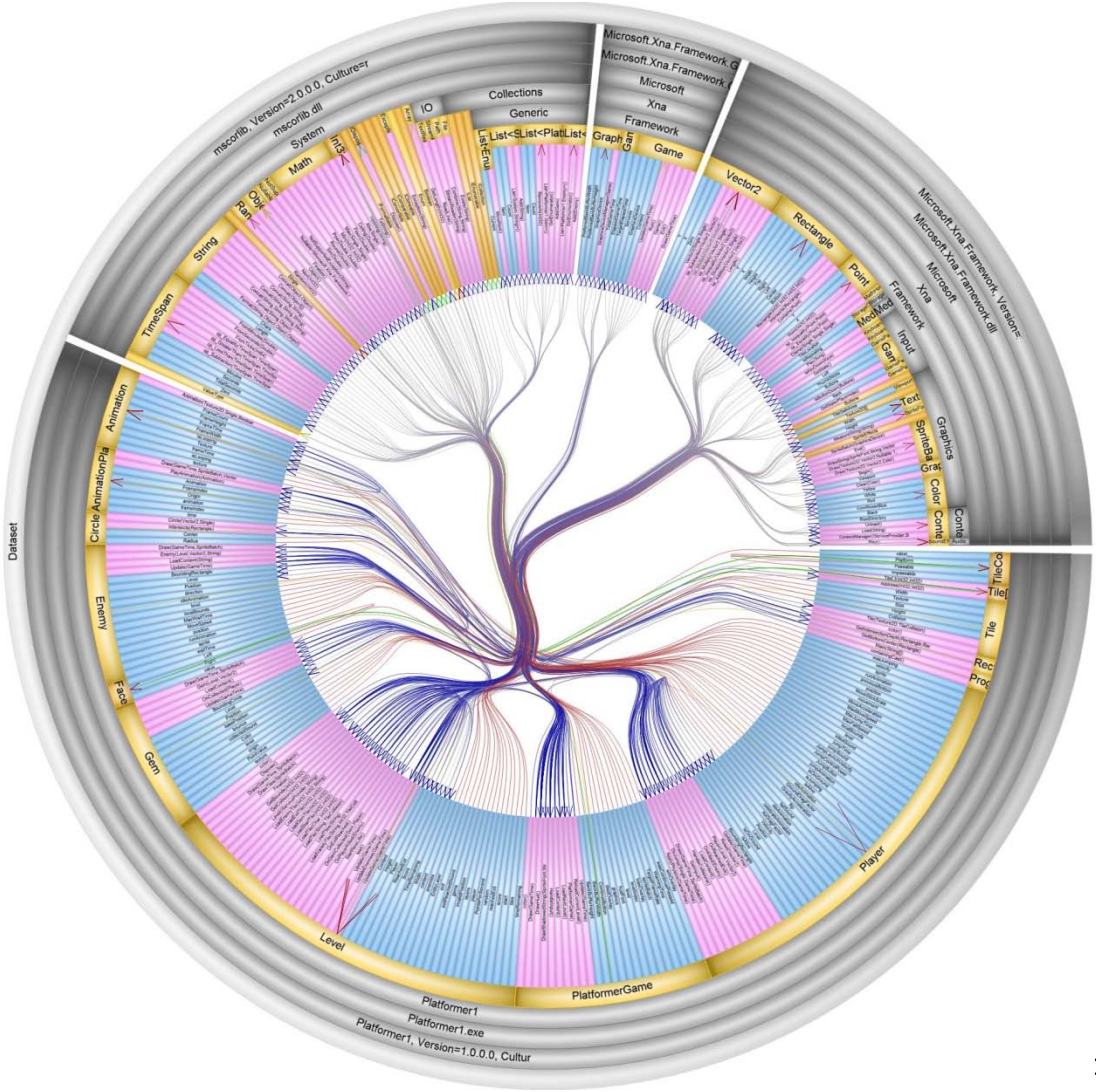
(Signal – norm)/(local standard deviation of norm)

Circos “Clock-Plot”

- Each segment represents the entire wire length
- Deviation Ratio = (Signal – norm)/
  (local standard deviation of norm)
- Deviation Ratio is rounded to nearest power of two to weigh chafe location more than severity
- Green zones = wire is normal



Example of code activity state traces in software - Extravis



:.C. Jorgensen