

Power Grid Monitoring and Alerting System

**Adapting The Morning Report technology
for monitoring
the Electrical Power Grid**

**The Morning Report was originally developed
as part of NASA's Aviation Safety Program.**

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Overview of FY06 work and Vision for a Power Grid Monitoring and Alerting System

- ▶ Overview of Data Analysis Approach developed for the NASA Aviation Safety Program
- ▶ Review of results of analysis of PMU data for Western Grid
- ▶ Vision

**Overview of Data Analysis Approach
developed for
the NASA Aviation Safety Program**

How to do it?

The key elements of the approach

▶ Aviation Safety Program uses:

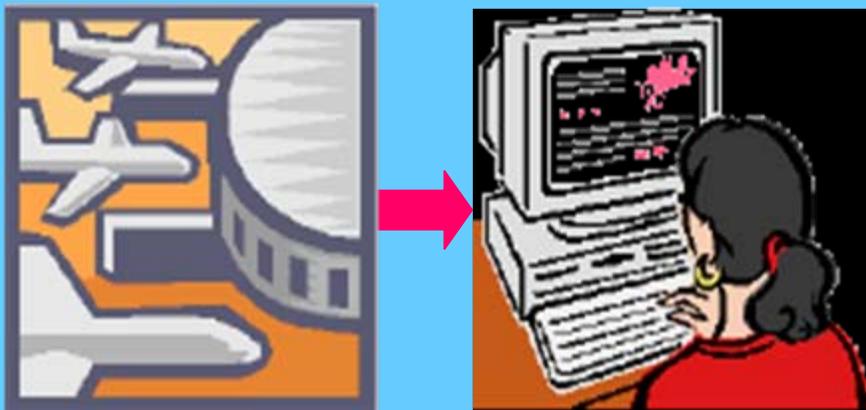
- On-board instrumentation to record hundreds of variables that monitor the aircraft throughout every flight.
- Sophisticated statistical analysis programmed into a workstation that analyzes the data to find:
 - Typical patterns, that characterize ~99% of the flights
 - Atypical events, that are worthy of individual inspection
- User-friendly software enables the aviation user to rapidly and effectively drill into the gigabytes of data to find the insight needed to:
 - Understand safety issues and formulate corrective plans if appropriate
 - Monitor typical patterns for trends
- Aviation Experts inspired by new insight proactively identify and correct safety issues affecting aviation safety

▶ Electrical Power Grid

- Instrumented system operation: PMU systems
- Adapt statistical analysis: Proof-of-concept in work
- User-friendly software: On-hold
- Expert review of results: Yuri Makarov

The Morning Report can be described in 12 Basic Steps

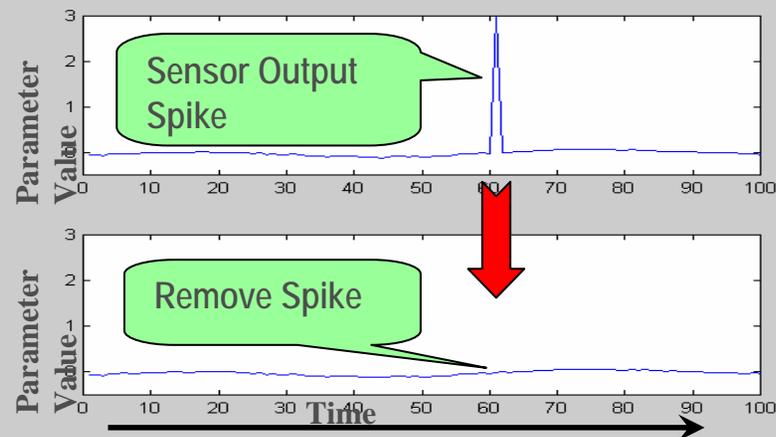
Step 1: Download Data



- ▶ Download daily or weekly
- ▶ From tapes, disks, or solid state devices
- ▶ Use commercially available playback software
- ▶ Insert data into commercially vended database

- PMU data continuously recorded
- > 400 variables from > 30 locations
- Data could be:
 - Live / real time
 - From archives

Step 2: Check the Data Quality



- ▶ Apply knowledge-based filters
- ▶ Identify "bad" data
- ▶ Remove the "bad" data
- ▶ Inform user of QA problems

Limited data checks to remove dramatically bad data.

Step 3: Conduct Pre-defined Exceedance Checks

- ▶ Airline experts define specific data comparisons to be made at specific routine events
 - Are the gear down while altitude is above 18,000 ft?
 - Are the flaps extended while airspeed is greater than 300 knots?
 - Etc.

Time (secs)	Param 1	Param 2	. . .	Param P	Routine Events
1	103.40	1		277.40	Start Takeoff
2	103.70	1		266.30	
...	
126	104.49	1		267.31	
127	104.98	1		268.19	
...	
129	105.45	0		269.12	Gear Up
...	
131	106.39	0		269.78	
...	
4021	106.82	0		270.71	
4022	107.33	0		270.78	
4023	107.89	0		270.85	10000 ft AFE
4024	108.40	0		271.14	
4025	108.53	0		271.53	
4026	109.38	0		272.03	
...	
N	110.68	0		273.70	Touchdown

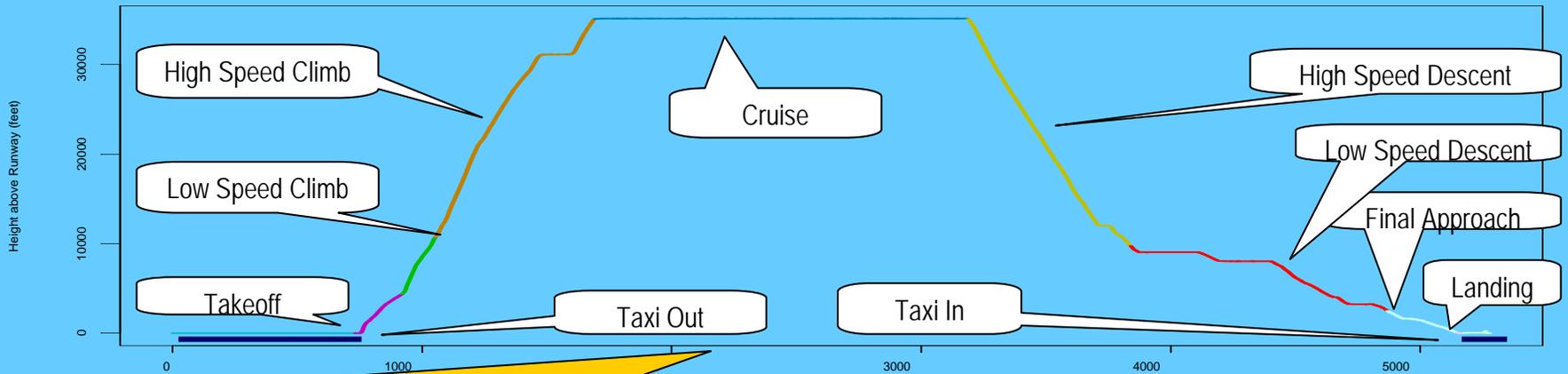
This requires that we envison the potential problems before they occur.

Power Grid Domain Experts could create Boolean Expressions for automatic monitoring. This effort is not part of the Proof-of-Concept investigation.

Step 4: Structure the Data

- ▶ Data are parsed into flight segments
- ▶ Flight Segments based on Event Markers, e.g.
 - Gear-up
 - Cross outer-marker
 - Descent through 1000 ft AFE
- ▶ Customizable to each air carrier phase definitions

Time (secs)	Param 1	Param 2	. . .	Param P	Event Marker	ACR Phase
151						
152	103.40	1		277.40	Rotate	Takeoff
153	103.70	1		103.70		
...		
335	105.13	1		105.13		
336	105.45	0		105.45	Gear Up	
337	105.73	0		105.73		
...		
1225	106.82	0		106.82		climb
1226	107.89	0		107.89	10000 ft AFE	
1227	108.10	0		108.07		
...		
3236	108.51	0		109.04		
3237	109.33	0		109.12	Max Altitude	Cruise
3238	110.25	0		109.74		
...		
6259	109.04	0		108.60		
6260	109.85	0		109.57	10000 ft AFE	
6261	109.87	0		110.39		
...		
6673	110.70	0		110.53		Approach
6674	111.19	0		110.68	Gear Down	
6675	111.90	1		111.29		
...		
7786	112.13	1		112.10		Landing
7787	112.91	1		112.43	Touchdown	
7788	113.63	1		112.90		



Data maybe partitioned into "60 second" observations.
 Observations may be grouped for comparison as function of Time-of-Day and Day-of-Week.

Step 5: Create Derived Parameters to Capture Physics Based Insights

- ▶ Aircraft heading with respect to runway
- ▶ Aircraft location with respect to runway
- ▶ Derived Energy Parameters
 - Total energy
 - Kinetic energy
- ▶ Others

Sin/Cos of Phase Angle
Deltas among various Bus locations
Physics based / Insightful Variables: TBD

Step 6: Calculate Preliminary Flight Parameter Signatures

- ▶ Continuous Variable
 - Air speed, roll, altitude, vibration, etc.
- ▶ Discrete Variables
 - Gear position, autopilot mode, reversers status, etc.
- ▶ Data Compression Signature

May use similar signature with multiple
temporal focuses:
X seconds / Y minutes

Step 7: Store the Signatures into the Database

For Proof-of-Concept, use
R&D convenient storage.

Step 8: Select the Data

- ▶ Select a subset of data:
 - Aircraft type
 - Airports
 - Flight Phase
 - Time Frames
 - Other Parameters

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4023	107.89	0		270.85	10000 ft AFE

May look at WECC as whole.
May look at subset (e.g.; Olympic Peninsula)

Step 9: Transform the Signatures

- ▶ Multivariate mathematical statistical techniques used enable:
 - Time series analysis
 - Characterization independent of phase duration
 - Flight mode transitions
 - Quantification captures values, trends, & noise

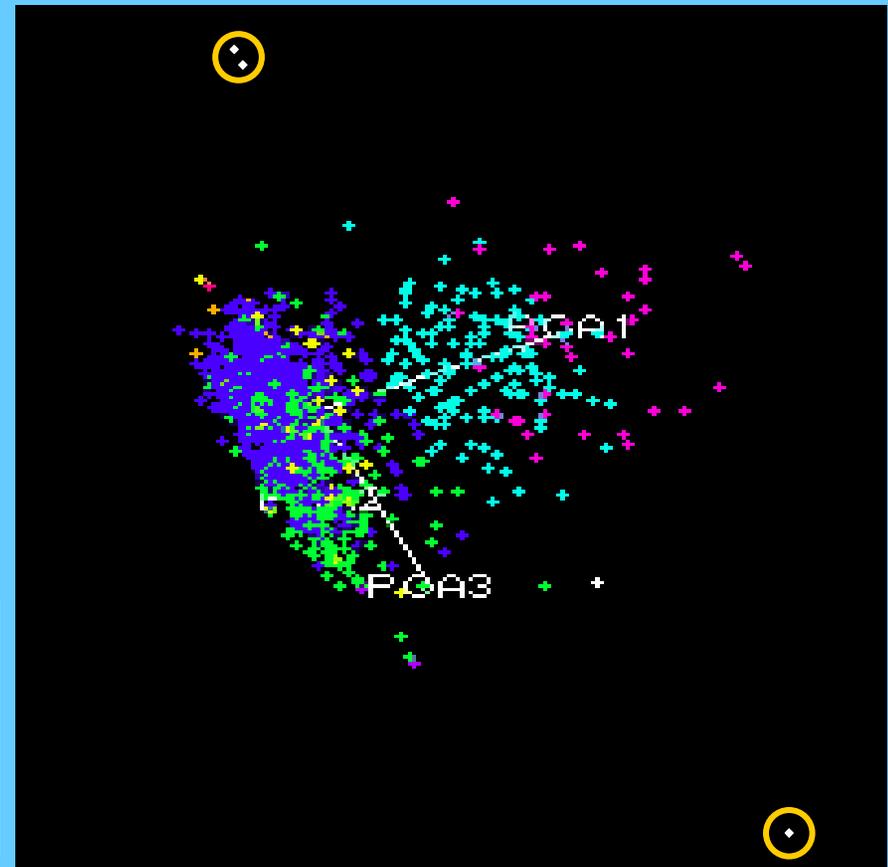
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May combine adjacent time periods for analysis (e.g.; 8-9am 9-10am, ... 3-4pm maybe combined)

Step 10: Cluster the Transformed Signatures

- ▶ Use several alternative clustering methods
 - Then, generate a consensus
- ▶ Typical patterns
 - Clusters of similar flights
 - Summarized in plain English via Storymeister
- ▶ Atypical flights
 - Singletons, clusters of one or two
 - Summarized in plain English via Rationale
- ▶ Performed for each user-defined and selected flight phase

- Each dot represents a observation.
- Dots are mapped to patterns with similar characteristics.
- Some observations may be mapped to very small clusters.



Step 11: Find the Atypical Flights

- ▶ Atypical flights are defined to be
 - Singletons
 - Very small clusters (atypical clusters)
- ▶ Differs from classic exceedance analysis
 - Which look for parameter values outside of pre-defined ranges within a flight phase
- ▶ Can be the impetus for further investigation
 - By operationally knowledgeable persons

- Atypical behavior of the Power Grid will be identified by the methodology.
- Domain Experts will assess the significance of the atypical behavior.
- If it represents insightful finding:

EUREKA !!!!

Finds the
unenvisioned.

End-users don't have to know
what they are looking for !!

The analysis finds
atypical events
never dreamt of !!

Step 12: Present the Findings

- ▶ Data processing occurs over night
- ▶ Morning report is ready by 7am every morning.
- ▶ Identifies most atypical flights
 - Excludes flights previously reviewed and dispositioned
 - Enables drill down to flight details
 - Allows capture images in Microsoft PowerPoint files for communication ease.

- Nature of the displays are TBD.
- Frequency of the displays are TBD.
- Display focuses on atypical events.

This may evolve to
The Minute Report.

APHS Morning Report
Morning Report - Tab
Summary | Flight List

Analysis Overview

Morning Report Name: After Re-Run Report Date: 5/24/2004

Summary of Flights

Number of new flights : 3199

Aircraft Model : B737-700

Date Range of New Flights : 3/18/2004 - 5/30/2004

Number of Level 3 Flights : 49

Number of Level 3 Phases : 178

Number of Level 2 Flights : 194

Number of Level 2 Phases : 610

Number of Level 1 Flights : 727

Number of Level 1 Phases : 1726

Go To Flight List

APHS Morning Report
Morning Report - Tab
Summary | Flight List

Morning Report Summary

New Flights : 3199 Fleet : B737-700 Level 3 Flights

Flight Dates : 3/18/2004 - 5/30/2004 Level 2 Flights

Morning Report Date: 5/24/2004 Level 1 Flights

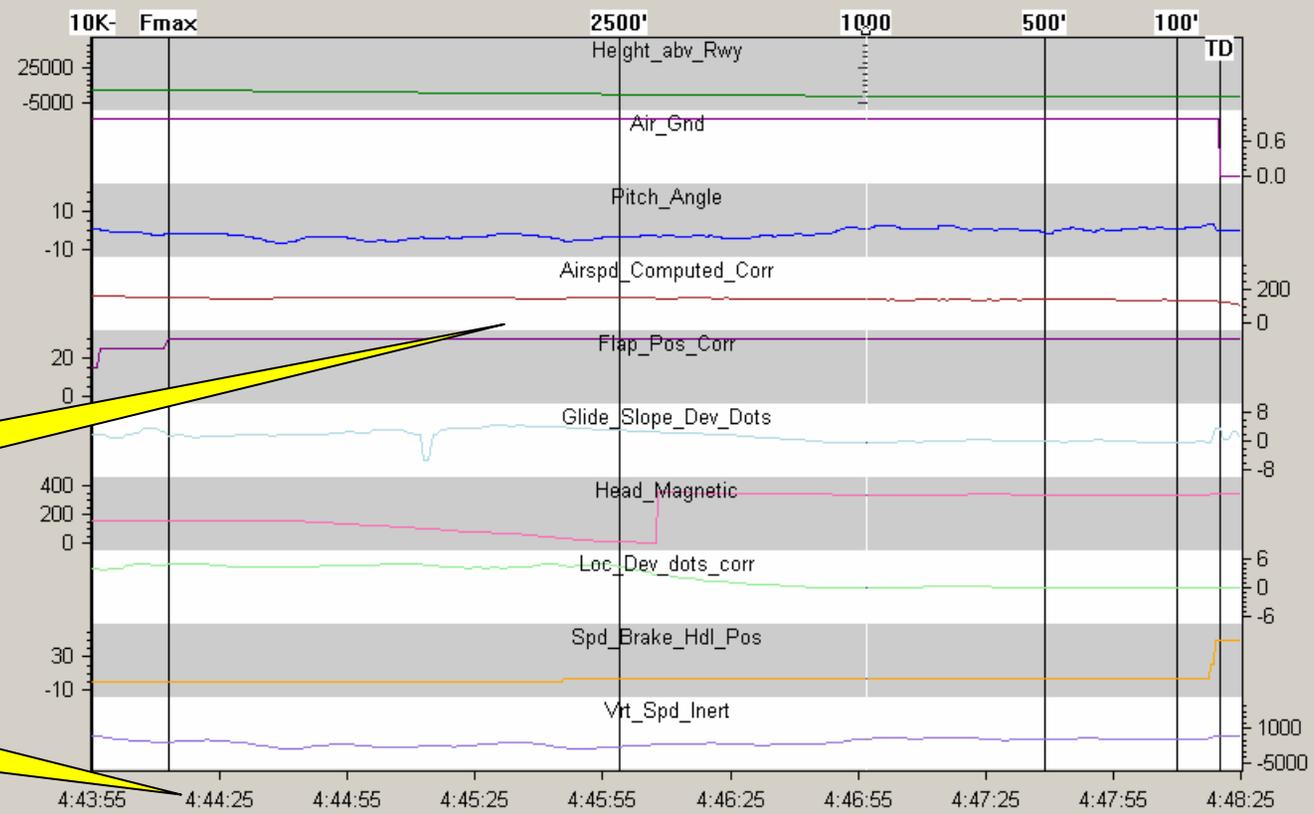
Explore Flight

Level	Flight	Tail Number	Analysis_ID	Phase	Origin	Destination	Validation	Rationale
3	3799_20040329_069	3799	5/24/2004 2:15:24 AM	3 - Landing	MW	ATL	Pending	(1)Angle_of_attack_L, (2)Comp_Pres
3	3799_20040329_024	3799	5/24/2004 1:21:50 AM	3 - Low Speed Climb	ATL	SAV	Pending	(1)Aldg_Gr_Sel_Dwn, (2)Angle_of_att
3	3712_20040322_052	3712	5/24/2004 1:04:07 AM	3 - Takeoff	ATL	DEN	Pending	(1)Aldg_Gr_Sel_Dwn, (2)Angle_of_att
3	3701_20040329_037	3701	5/24/2004 2:15:24 AM	3 - Landing	DAY	ATL	Pending	(1)Angle_of_attack_L, (2)Comp_Pres
3	3701_20040329_043	3701	5/24/2004 1:56:52 AM	3 - Final Approach	ADQ	ATL	Pending	(1)Aldg_Skop_Dev_Dots, (2)Aldg_Gr
3	3750_20040327_041	3750	5/18/2004 1:00:19 AM	3 - Low Speed Descent	IAD	ATL	Pending	(1)Aldg_Gr_Sel_Dwn, (2)Angle_of_att
3	3761_20040330_007	3761	5/24/2004 2:15:24 AM	3 - Landing	SAV	ATL	Pending	(1)Angle_of_attack_L, (2)Comp_Pres
3	3762_20040307_003	3762	5/24/2004 12:59:29 AM	3 - Takeoff	SLC	MCO	Pending	(1)Alt_Pres_Pos_Corr, (2)Spd_Brake
3	3707_20040301_018	3707	5/24/2004 2:10:57 AM	3 - Landing	BOE	SLC	Pending	(1)Aldg_Advisory, (2)Elevator_Pos_L, (
3	3748_20040328_037	3748	5/24/2004 2:15:24 AM	3 - Landing	MAD	ATL	Pending	(1)Angle_of_attack_L, (2)Comp_Pres
3	3751_20040331_015	3751	5/24/2004 1:04:07 AM	3 - Takeoff	ATL	ORD	Pending	(1)Aldg_Gr_Sel_Dwn, (2)Angle_of_att
3	3799_20040329_041	3799	5/24/2004 1:56:52 AM	3 - Final Approach	BHR	ATL	Pending	(1)Aldg_Gr_Sel_Dwn, (2)Angle_of_att
3	3763_20040307_008	3763	5/24/2004 1:52:00 AM	3 - Final Approach	MCO	SLC	Pending	(1)Aldg_Advisory, (2)Elevator_Pos_L, (
3	3712_20040322_051	3712	5/24/2004 1:08:19 AM	3 - Low Speed Descent	QAR	ATL	Pending	(1)Aldg_Gr_Sel_Dwn, (2)Angle_of_att
3	3724_20040329_014	3724	5/24/2004 2:15:24 AM	3 - Landing	CPW	ATL	Pending	(1)Angle_of_attack_L, (2)Comp_Pres
3	3748_20040328_023	3748	5/24/2004 1:04:07 AM	3 - Takeoff	ATL	BOE	Pending	(1)Aldg_Gr_Sel_Dwn, (2)Angle_of_att
3	3762_20040307_001	3762	5/24/2004 12:59:29 AM	3 - Takeoff	SLC	LAX	Pending	(1)Alt_Pres_Pos_Corr, (2)Spd_Brake
3	3750_20040325_034	3750	5/24/2004 1:21:50 AM	3 - Low Speed Climb	ATL	TUH	Pending	(1)Aldg_Gr_Sel_Dwn, (2)Angle_of_att
3	3762_20040307_003	3762	5/24/2004 2:10:57 AM	3 - Landing	SFO	SLC	Pending	(1)Alt_Pres_Pos_Corr, (2)Height_Above_G
3	3799_20040329_033	3799	5/24/2004 2:15:24 AM	3 - Landing	EWR	ATL	Pending	(1)Angle_of_attack_L, (2)Comp_Pres
3	3748_20040328_026	3748	5/24/2004 1:08:19 AM	3 - Low Speed Descent	SFO	ATL	Pending	(1)Aldg_Gr_Sel_Dwn, (2)Angle_of_att
3	3758_20040325_038	3758	5/24/2004 2:15:24 AM	3 - Landing	CPW	ATL	Pending	(1)Angle_of_attack_L, (2)Comp_Pres
3	3705_20040329_014	3705	5/24/2004 12:59:29 AM	3 - Takeoff	SLC	BOE	Pending	(1)Height_Above_TD, (2)Alt_Pres_Pos_C
3	3751_20040331_020	3751	5/24/2004 2:15:24 AM	3 - Landing	SEA	ATL	Pending	(1)Angle_of_attack_L, (2)Comp_Pres
3	3761_20040330_004	3761	5/24/2004 1:21:50 AM	3 - Low Speed Climb	ATL	OZL	Pending	(1)Aldg_Gr_Sel_Dwn, (2)Angle_of_att
3	3761_20040330_013	3761	5/24/2004 2:15:24 AM	3 - Landing	MFR	ATL	Pending	(1)Angle_of_attack_L, (2)Comp_Pres
3	3745_20040309_010	3745	5/24/2004 1:17:20 AM	3 - Low Speed Climb	SLC	SLC	Pending	(1)Elevator_Pos_L, (2)Spd_Brake, (3
3	3712_20040322_054	3712	5/24/2004 1:15:24 AM	3 - Landing	COS	ATL	Pending	(1)Angle_of_attack_L, (2)Comp_Pres
3	3758_20040325_049	3758	5/24/2004 1:04:14 AM	3 - Low Speed Descent	EWR	SLC	Pending	(1)Down_Ady, (2)Height_Above_TD, (3
3	3724_20040329_014	3724	5/24/2004 1:21:50 AM	3 - Low Speed Climb	ATL	IAD	Pending	(1)Aldg_Gr_Sel_Dwn, (2)Angle_of_att

Drill-down Example

Time at cursor from Liftoff : 4:36:35 to Touchdown : 0:01:23 in View : 0:04:05

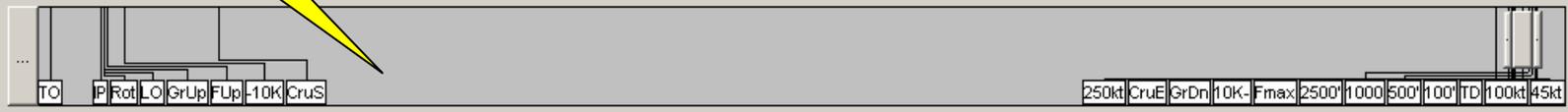
A	Height_abv_Rwy	996
B	Air_Gnd	1
C	Pitch_Angle	1.23047
D	Airspd_Computed_Corr	143.75
E	Flap_Pos_Corr	30
F	Glide_Slope_Dev_Dots	-0.428571
G	Head_Magnetic	337.5
H	Loc_Dev_dots_corr	0.0403226
I	Spd_Brake_Hdl_Pos	3.94077
J	Vrt_Spd_Inert	-715.671



Selectable variables

Elastic Time Scale

<< Prev Next >>



4:33:33 Time from Liftoff to left

Time to Touchdown from 0:00:20

Summary of Approach Characteristics

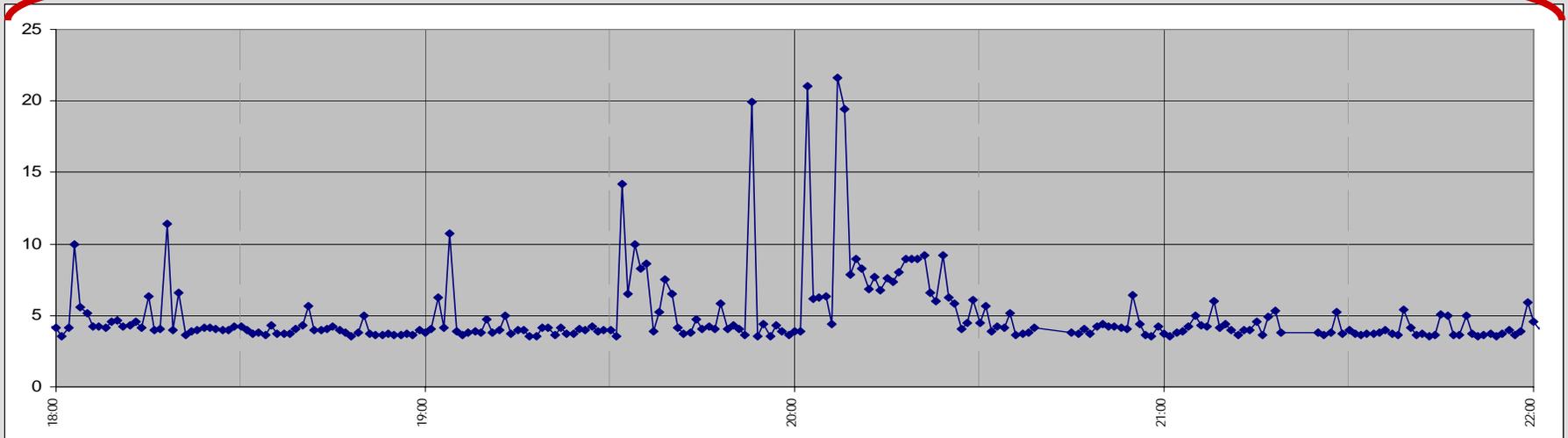
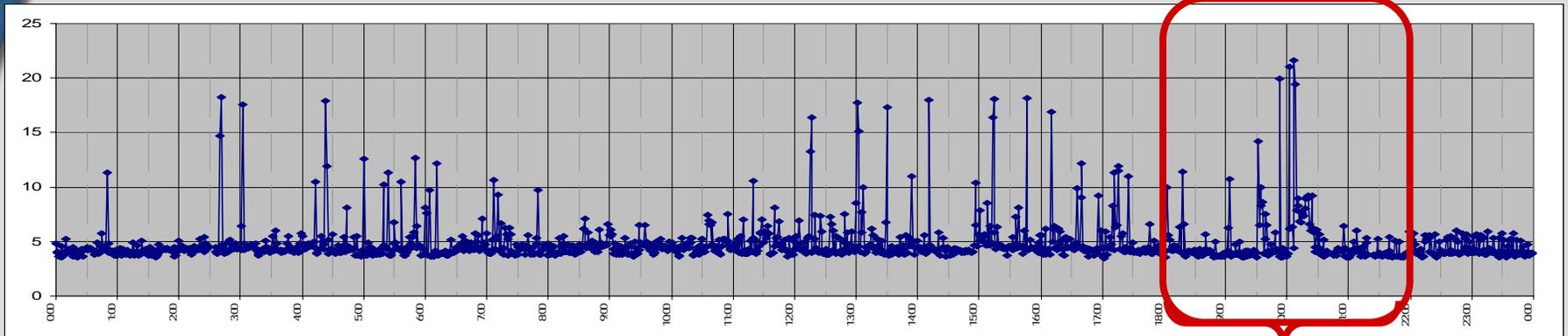
- ▶ NASA invested > \$6 million over 10 years to move beyond traditional Statistical Quality Control approaches.
 - This technology is multivariate data-driven, with an option to incorporate physics-based elements.
- ▶ This technology has won multiple prestigious awards:
 - R&D 100 award, one of the best 100 inventions world-wide, 2005
 - R&D 100 Editor's Choice Award, Invention with the Greatest Impact on Safety
 - Federal Laboratory Consortium award for transfer of technology developed at a federal lab to the community, 2007
 - American Statistics Association, Best Statistical Application 2006
- ▶ For more info and a 5-minute overview video:
 - <http://www.pnl.gov/statistics/RandD100.htm>

Review of results of analysis of PMU data for Western Grid

- 9/12/05
- 38 substations in Western Grid
- Voltage, Phase Angle, Frequency at 30 Hz

Atypicality Index for 1 day

Data is covered by NDA. Protect data. Proprietary data

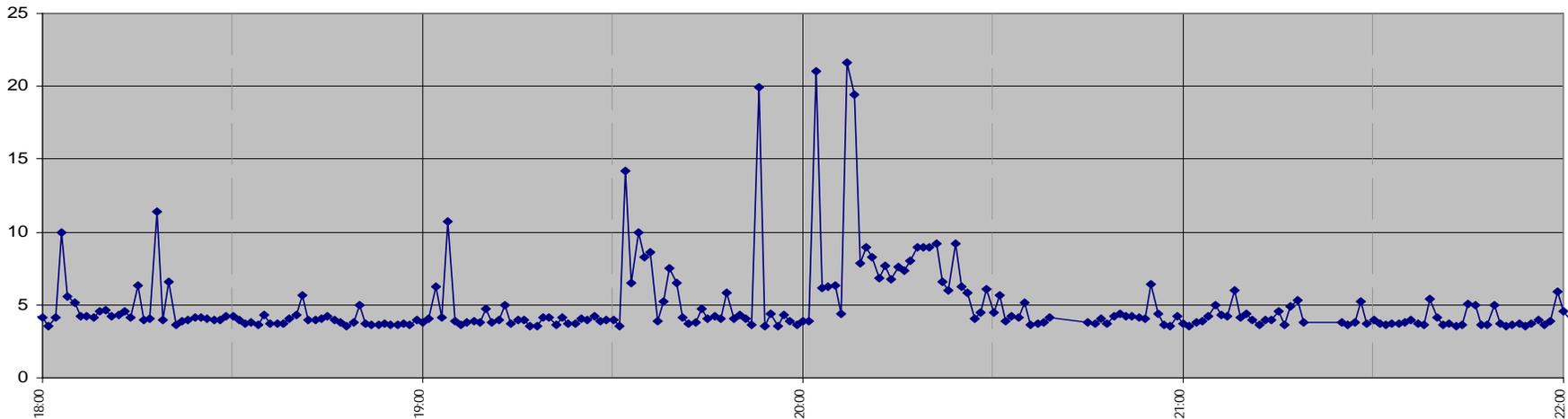


Atypicality Index for 1 day

Data is covered by NDA Protect data Proprietary data

Rationale identifies variables that contribute significantly to the Atypicality Index
And presents summary in plain English; e.g.:

Variable W is very low.
Variable X is low.
Variable y is high.
Variable Z is very high.



[19:34] 230-kV Capacitor automatically energized to support voltages.

[19:36] Scattergood Unit #3 and #2 tripped; 2 125 MVAR 500-kV shunt reactors manually de-energized;

[19:53] 230-kV Toluca-Atwater Line 1 was closed. Line immediately relayed at Valley-GS due to phase imbalance that appeared as a ground fault

[20:02] 230-kV Tarzana-Olympic Line 3 faulted (Tree Contact); 115-kV PP2-Olive Line 1 line relayed. Line was at 165% of 2-hr emerg. rating

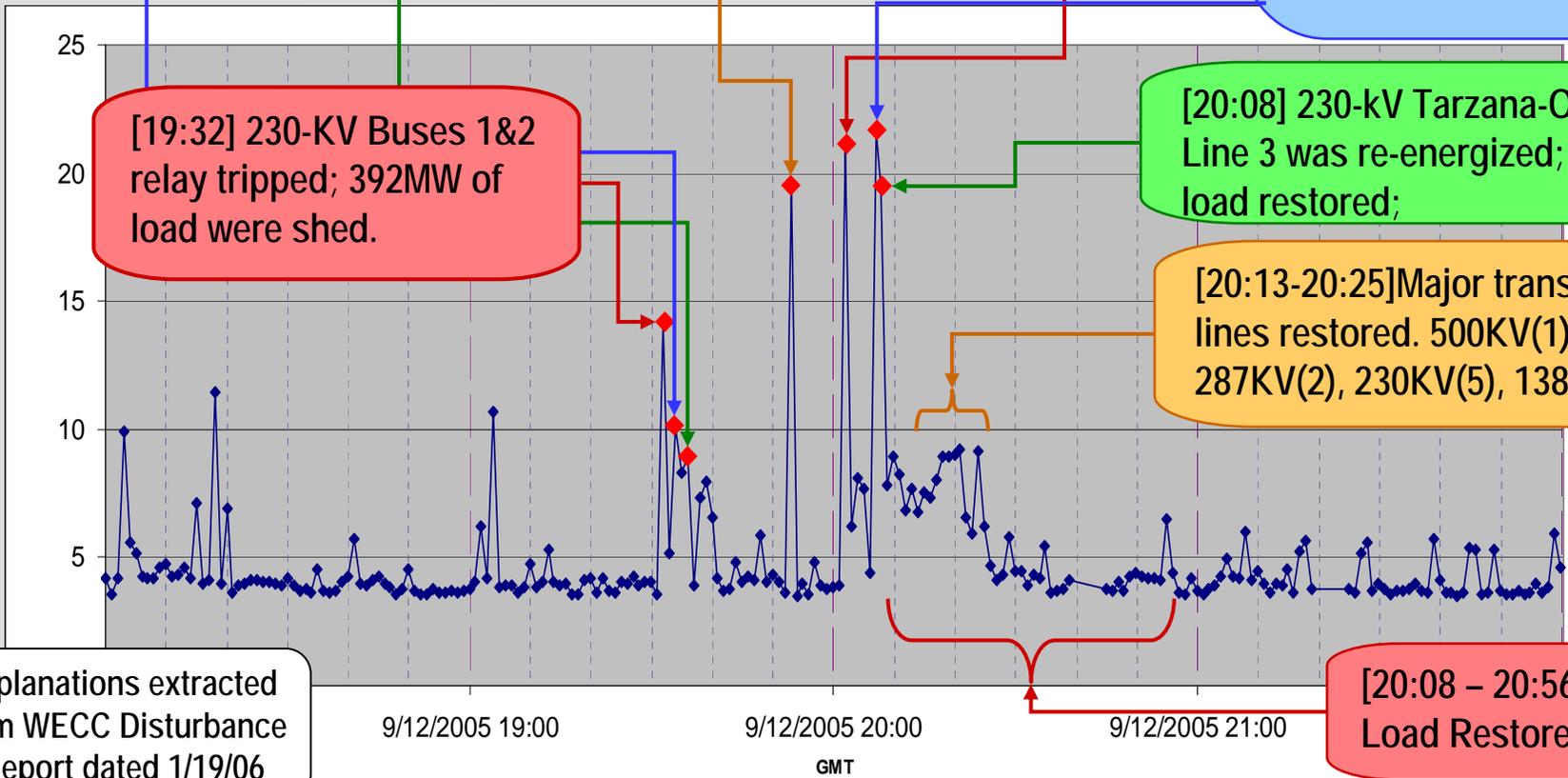
[20:07] 138-kV Tarzana-Olympic Line 1, 287-kV Victorville-Century Lines 1 and 2 transmission lines relayed; Islanding of the system south of RS-E; Southern system collapsed; 1,602 MW of load was shed.

[19:32] 230-KV Buses 1&2 relay tripped; 392MW of load were shed.

[20:08] 230-kV Tarzana-Olympic Line 3 was re-energized; 514MW load restored;

[20:13-20:25] Major transmission lines restored. 500KV(1), 287KV(2), 230KV(5), 138KV(1);

[20:08 – 20:56], Major Load Restored.

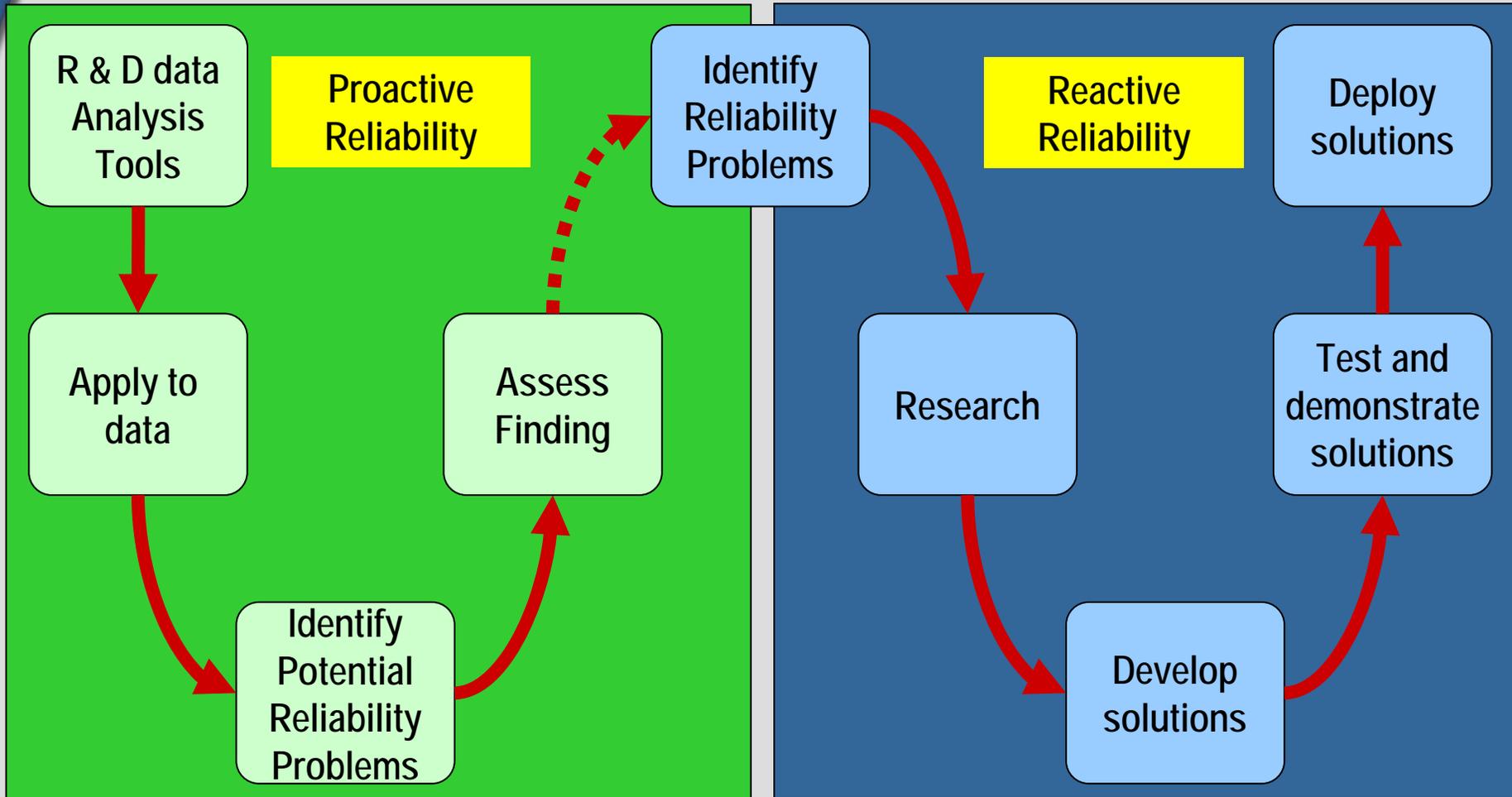


Explanations extracted from WECC Disturbance Report dated 1/19/06

Times are in GMT. 1932 GMT = 1232 West Coast time

Vision

Optimum Reliability comes from using both Proactive and Reactive Efforts



Goals

▶ Off-line Support (Morning Report):

- Automated identification, characterization and localization of atypical events
- Reconstruction of sequence of significant events
- Identification of typical patterns and sequence of transitions amongst typical patterns
- Identification of typical patterns exhibited as a result of intentional actions (e.g., grid re-configuration)



- ## ▶ Near-Real-Time automated operational support:
- Alert for abnormal events w/ characteristics & locations
 - Distinguish
 - expected and benign
 - problem indicators
 - Communication and coordination amongst grid operators



- ## ▶ Forecasting
- Pre-cursor identification of atypical events
 - Long-term and cyclic pattern detection
 - Expected Worst Case and uncertainty bounds for upcoming season and out-years
 - "What if" studies



- ## ▶ Misc.
- Extend to SCADA data and other information sources
 - Enhance with other analytical tools – existing and in R&D
 - Training aide
 - Communication and coordination across EI

Questions and Natural Next Steps

