

***Atypical Event and Typical Pattern Detection
within Complex Systems***

**The Morning Report:
Advanced Pro-active Safety and System Monitoring Tool**

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March 2005

Why do we need:
*The Morning Report:
Advanced Pro-active Safety and
System Monitoring Tool*

▶ **Aviation Safety**

- Aviation is one of the safest ways to travel in the world.
- Why does it warrant efforts to monitor and improve?
 - Number of flights is expected to double in the next few years, which means the number of accidents is likely to double (or worse).
 - Changes in the airspace can have subtle and unenvisioned but significant impact on safety.

▶ **Monitoring 1000s of flights every day is almost impossible, but we can monitor**

- 10-20 typical patterns (with ~99% of the flights)
- 10-20 atypical flights

How to do it?

The key elements of the approach

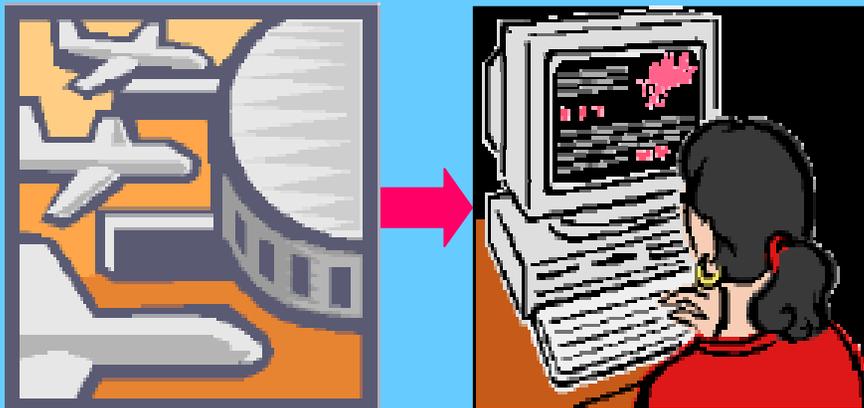
1. On-board instrumentation to record hundreds of variables that monitor the aircraft throughout every flight.
 - Roll, pitch, airspeed, engine temperature, vibrations, etc. are recorded every second from engine start to engine shut down
2. Sophisticated statistical analysis is programmed into a workstation that analyzes the data to find:
 - Typical patterns, that characterize 99% of the flights
 - Atypical events, that are worthy of individual inspection
3. 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
4. Aviation Experts inspired by new insight proactively identify and correct safety issues affecting aviation safety

The Morning Report invention enables this by providing:

2. **Sophisticated statistical analysis**
3. **User-friendly software**

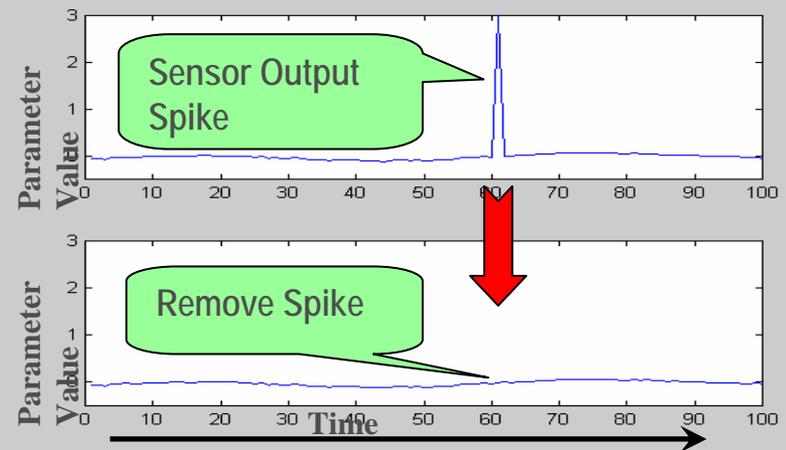
The Morning Report can be described in 12 Basic Steps

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

Step 2: Check the Data Quality



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

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.

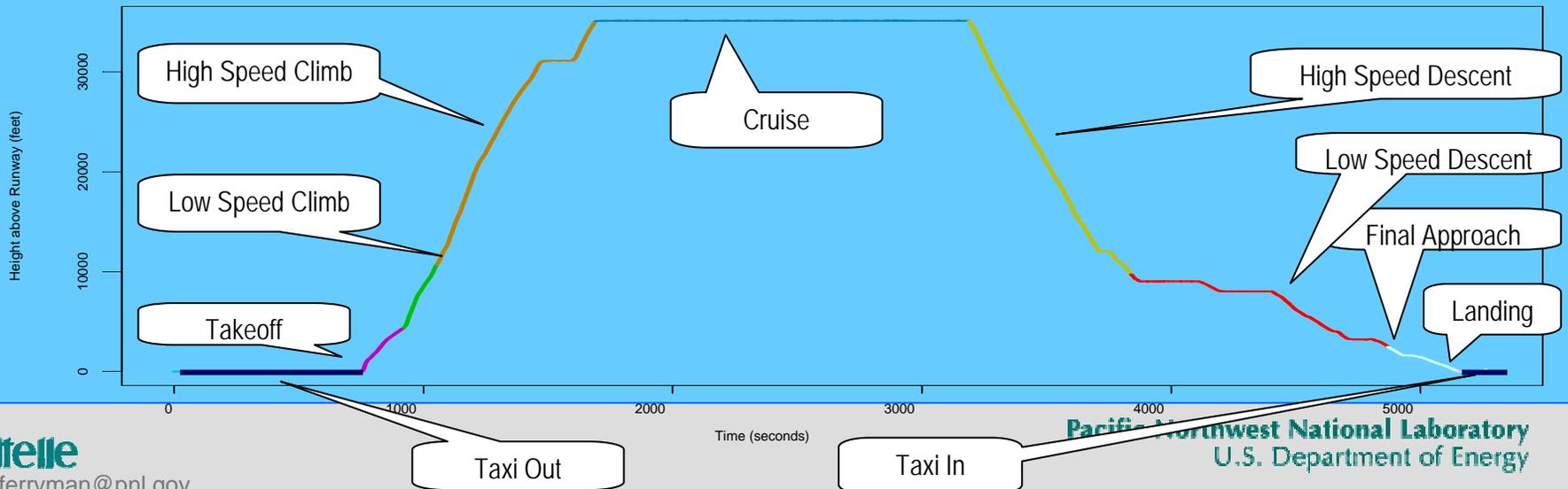
Time (secs)	Param 1	Param 2	. . .	Param P	Routine Events
1	103.40	1		277.40	Start Takeoff
2	103.70	1		266.30	
...	
126	104.49	1		267.31	
127	104.98	1		268.19	
128	105.45	0		269.12	Gear Up
129	105.78	0		269.78	
131	106.39	0		269.78	
...	
4021	106.82	0		270.71	
4022	107.33	0		270.78	
4023	107.89	0		270.85	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.

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		climb
...		
1225	106.82	0		106.82		
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		Approach
...		
6673	110.70	0		110.53		
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		



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
 - Location with respect to runway
 - ...
- ▶ Others

Step 6: Calculate Preliminary Flight Parameter Signatures

- ▶ Continuous Variables
 - Air speed, roll, altitude, vibration, etc.
- ▶ Discrete Variables
 - Gear position, autopilot mode, reversers status, etc.
- ▶ Data Compression Signature
 - Lossy compression for continuous variables
 - Lossless compression for discrete variables

Step 7: Store the Signatures into the Database

The Steps

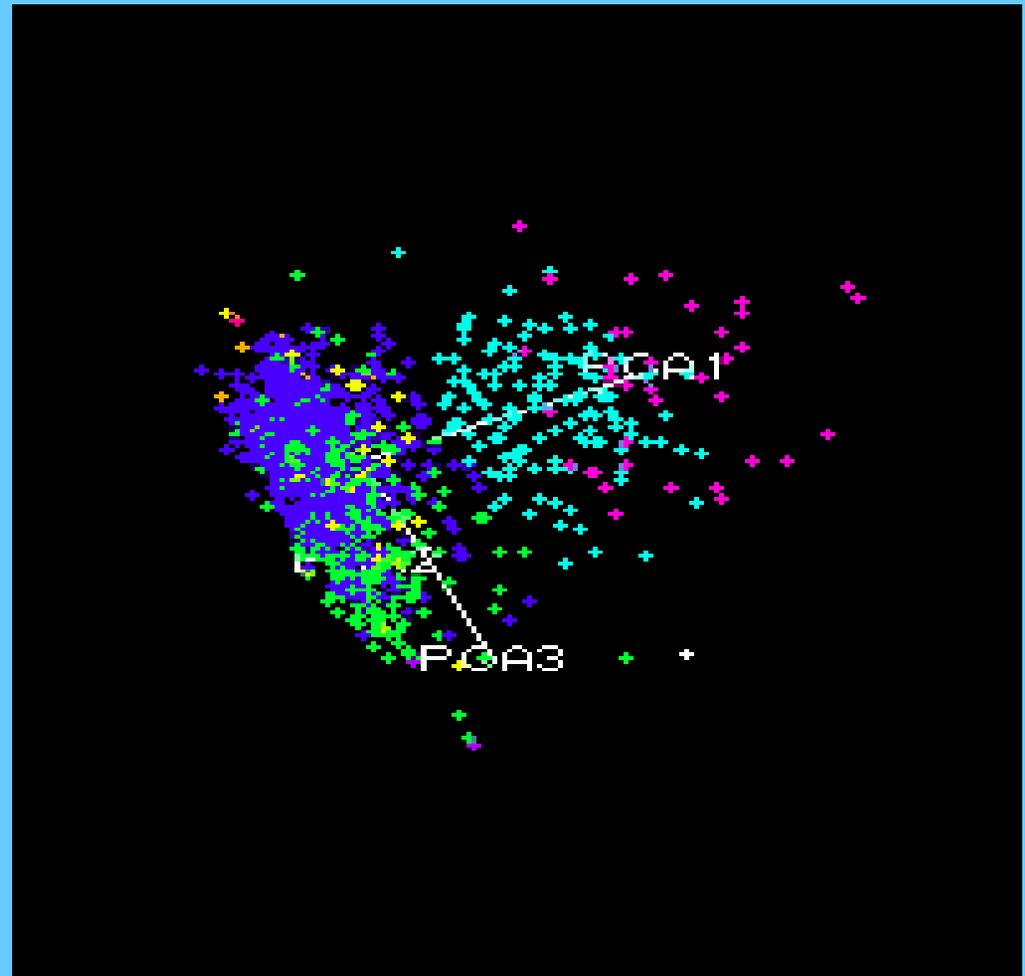
- ▶ **Steps 1-7. The previous steps are performed once for each flight**
 - Hands-off processing
 - CPU intensive

- ▶ **Steps 8-11. Performed over night or upon request on numerous flights. We compare the flights to each other and identify**
 - Typical patterns
 - Atypical events

- ▶ **Step 12. User Interaction**
 - Displays
 - Interactive exploration
 - Drill-down to any portion of any flight

Step 10: Cluster the Transformed Signatures

- ▶ Use several 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



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

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 user to capture images in Microsoft PowerPoint files for communication ease.

APMS 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 : 3/16/2004 - 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 Cancel

Finished.

APMS Morning Report
Morning Report - Tab
Summary | Flight List

Morning Report Summary

New Flights : 3198 Fleet : B737-700 Level 3 Flights

Flight Dates : 3/16/2004 - 5/30/2004 Level 2 Flights

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

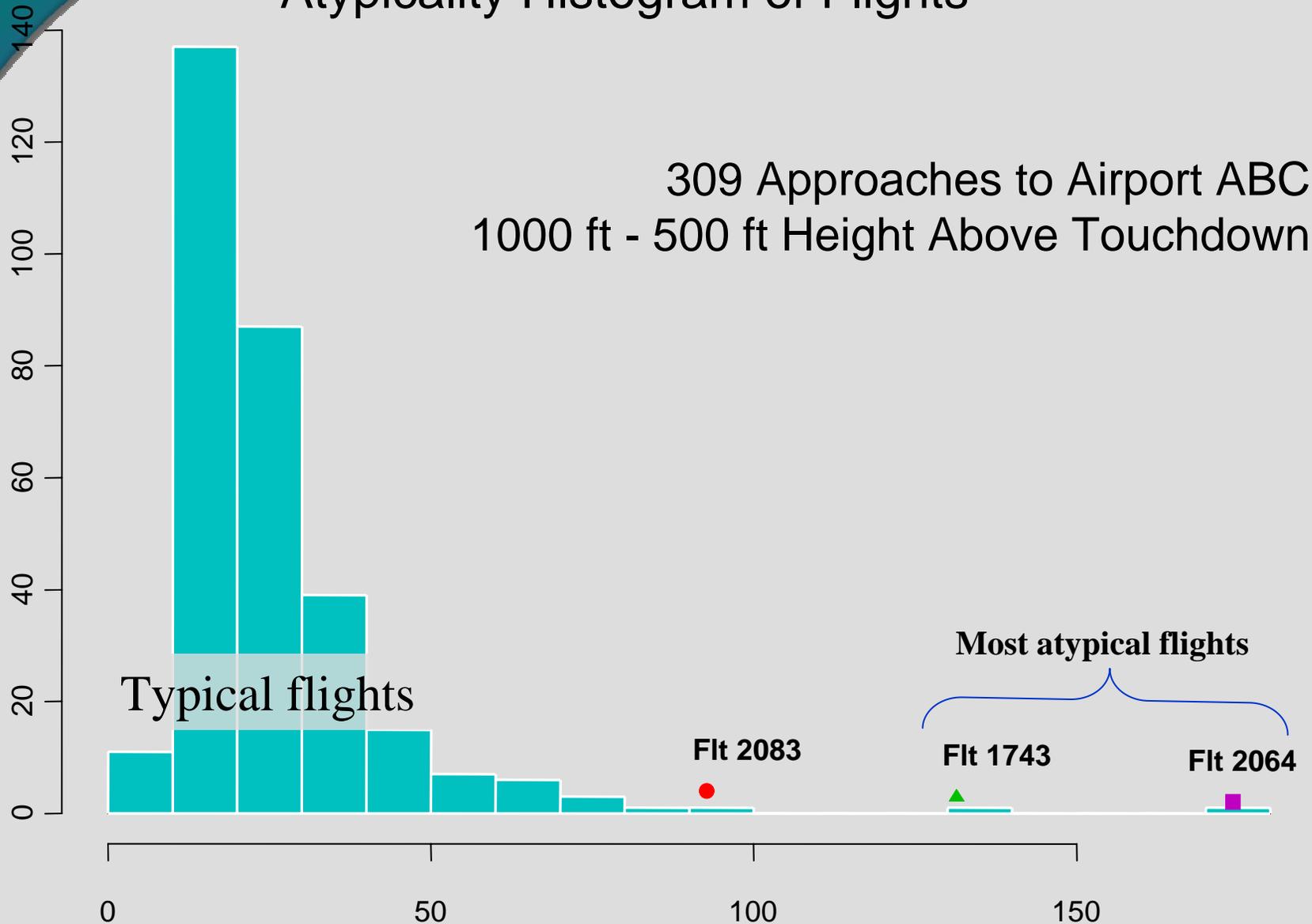
Explore Flight

Level	Flight	Tail Number	Analysis ID	Phase	Origin	Destination	Validation	External
3	3739_20040329_059.....	3739	5/24/2004 2:15:24 AM	3 - Landing	MDW	ATL	Pending	(1)Angle_of_attach_L, (2)Long_Pres...
3	3739_20040329_029.....	3739	5/24/2004 1:21:50 AM	3 - Low Speed Climb	ATL	SAV	Pending	(1)dg_or_sel_Dwn, (2)Angle_of_att...
3	3712_20040322_052.....	3712	5/24/2004 1:04:07 AM	3 - Takeoff	ATL	DNV	Pending	(1)dg_or_sel_Dwn, (2)Angle_of_att...
3	3703_20040329_037.....	3703	5/24/2004 2:15:24 AM	3 - Landing	DAY	ATL	Pending	(1)Angle_of_attach_L, (2)Long_Pres...
3	3703_20040329_043.....	3703	5/24/2004 1:56:52 AM	3 - Final Approach	ABQ	ATL	Pending	(1)Wide Slope Dev Data, (2)dg_or...
3	3750_20040327_044.....	3750	5/24/2004 1:38:19 AM	3 - Low Speed Descent	IAO	ATL	Pending	(1)dg_or_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_attach_L, (2)Long_Pres...
3	3762_20040307_003.....	3762	5/24/2004 12:59:29 AM	3 - Takeoff	SLC	MCO	Pending	(1)at_Pres_Pos_Corr, (2)Fuel_Flow...
3	3707_20040301_018.....	3707	5/24/2004 2:10:57 AM	3 - Landing	BOI	SLC	Pending	(1)Wen_Adv, (2)Height_Above_L0, (...
3	3748_20040328_027.....	3748	5/24/2004 2:10:57 AM	3 - Landing	MEM	ATL	Pending	(1)Angle_of_attach_L, (2)Long_Pres...
3	3751_20040331_015.....	3751	5/24/2004 1:04:07 AM	3 - Takeoff	ATL	ORD	Pending	(1)dg_or_sel_Dwn, (2)Angle_of_att...
3	3739_20040329_041.....	3739	5/24/2004 1:56:52 AM	3 - Final Approach	BREI	ATL	Pending	(1)dg_or_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)Wb_Advisory, (2)Elevator_Pos_L, (...
3	3712_20040322_051.....	3712	5/24/2004 1:38:19 AM	3 - Low Speed Descent	OAK	ATL	Pending	(1)dg_or_sel_Dwn, (2)Angle_of_att...
3	3724_20040329_014.....	3724	5/24/2004 2:15:24 AM	3 - Landing	DFW	ATL	Pending	(1)Angle_of_attach_L, (2)Long_Pres...
3	3748_20040328_023.....	3748	5/24/2004 1:04:07 AM	3 - Takeoff	ATL	BOS	Pending	(1)dg_or_sel_Dwn, (2)Angle_of_att...
3	3762_20040307_001.....	3762	5/24/2004 12:59:29 AM	3 - Takeoff	SLC	LAX	Pending	(1)at_Pres_Pos_Corr, (2)Fuel_Flow...
3	3758_20040325_034.....	3758	5/24/2004 1:21:50 AM	3 - Low Speed Climb	ATL	TUL	Pending	(1)dg_or_sel_Dwn, (2)Angle_of_att...
3	3762_20040302_003.....	3762	5/24/2004 2:10:57 AM	3 - Landing	SFO	SLC	Pending	(1)AR_CNR_Corr, (2)Height_Above_L...
3	3739_20040329_033.....	3739	5/24/2004 2:15:24 AM	3 - Landing	ENR	ATL	Pending	(1)Angle_of_attach_L, (2)Long_Pres...
3	3748_20040328_021.....	3748	5/24/2004 1:38:19 AM	3 - Low Speed Descent	SFO	ATL	Pending	(1)dg_or_sel_Dwn, (2)Angle_of_att...
3	3758_20040325_038.....	3758	5/24/2004 2:15:24 AM	3 - Landing	DFW	ATL	Pending	(1)Angle_of_attach_L, (2)Long_Pres...
3	3705_20040229_014.....	3705	5/24/2004 12:59:29 AM	3 - Takeoff	SLC	BOS	Pending	(1)Height_Above_TD, (2)AR_CNR_Cc...
3	3751_20040331_038.....	3751	5/24/2004 2:15:24 AM	3 - Landing	SEA	ATL	Pending	(1)Angle_of_attach_L, (2)Long_Pres...
3	3761_20040330_004.....	3761	5/24/2004 1:21:50 AM	3 - Low Speed Climb	ATL	QDL	Pending	(1)dg_or_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_attach_L, (2)Long_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)Pitch_Angle, (...
3	3712_20040322_054.....	3712	5/24/2004 1:16:24 AM	3 - Landing	COS	ATL	Pending	(1)Angle_of_attach_L, (2)Long_Pres...
3	3758_20040329_048.....	3758	5/24/2004 1:54:14 AM	3 - Low Speed Descent	ENR	SLC	Pending	(1)Wen_Adv, (2)Fuel_Burn_Rt_Avg, (...
3	3724_20040329_019.....	3724	5/24/2004 1:21:50 AM	3 - Low Speed Climb	ATL	IAO	Pending	(1)dg_or_sel_Dwn, (2)Angle_of_att...

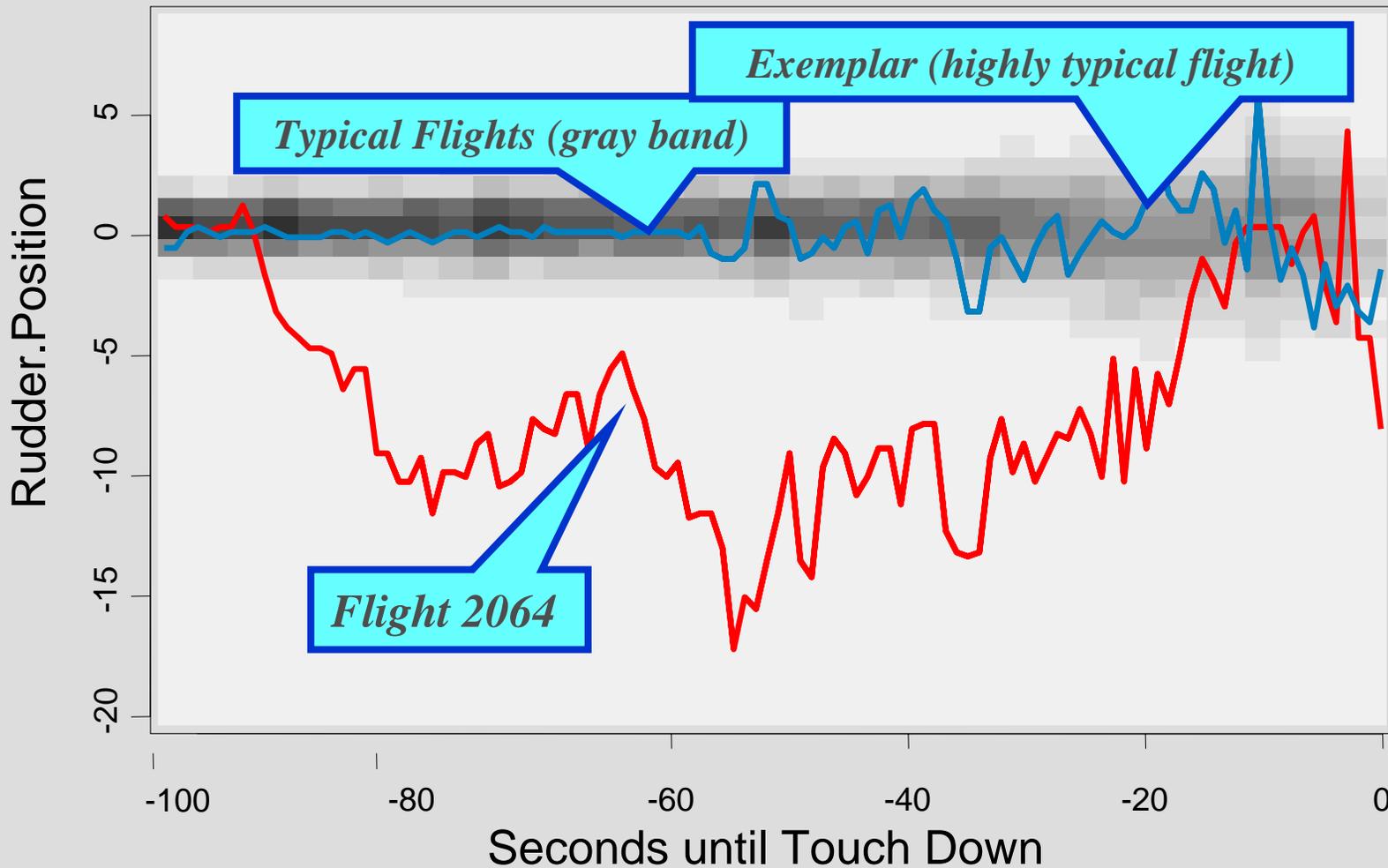
Finished.

Atypicality Histogram of Flights

309 Approaches to Airport ABC
1000 ft - 500 ft Height Above Touchdown

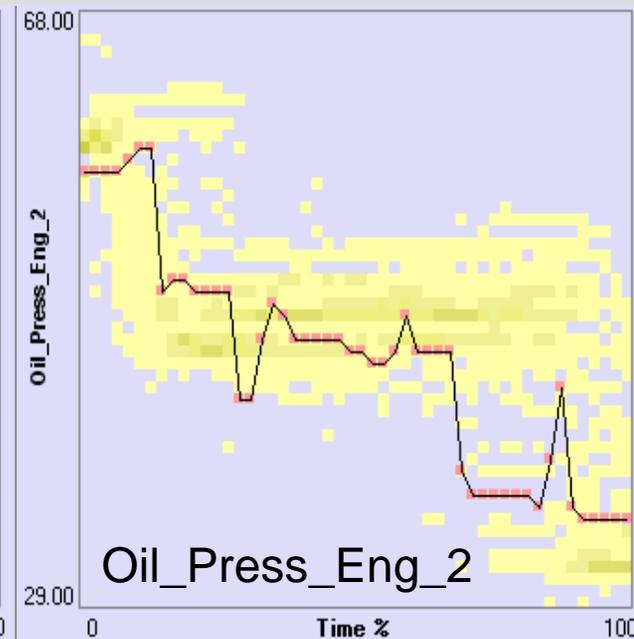
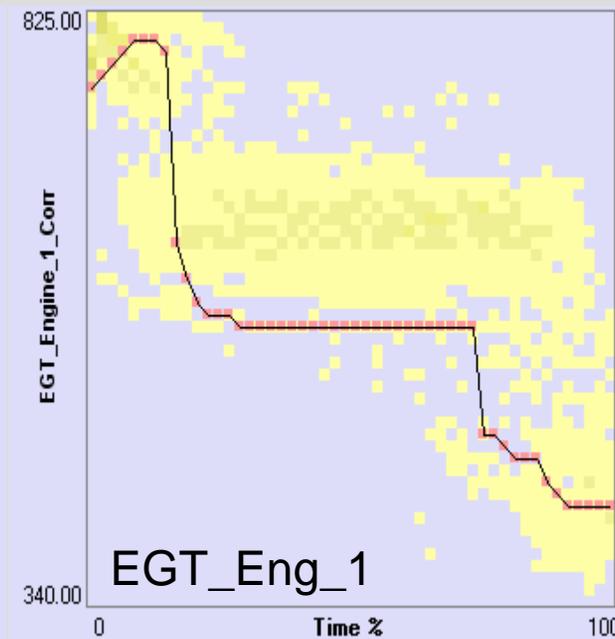
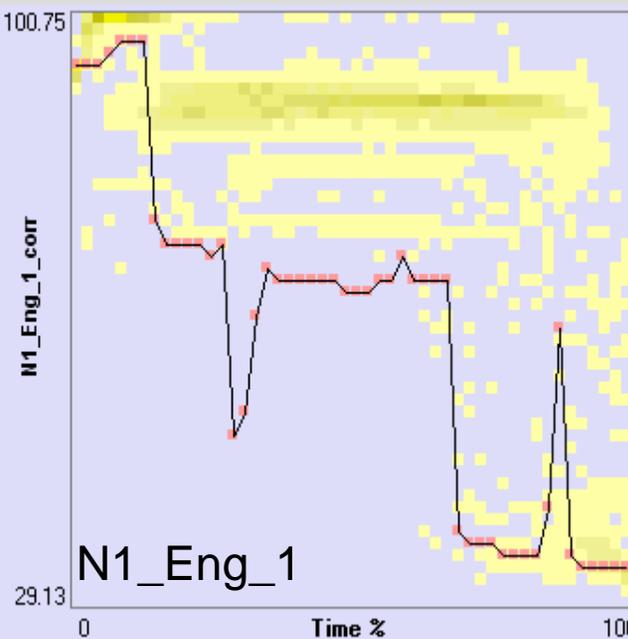


What made Flight 2064 Atypical?



Atypical Flight Rationale Example

- ▶ N1_Eng_1 on average is lower than normal during Cruise.
EGT_Engine_1 on average is cooler than normal during Cruise.
Oil_Press_Eng_2 is noisier than normal during Cruise.



APMS Viewer Example

APMS Viewer

File Edit Grade

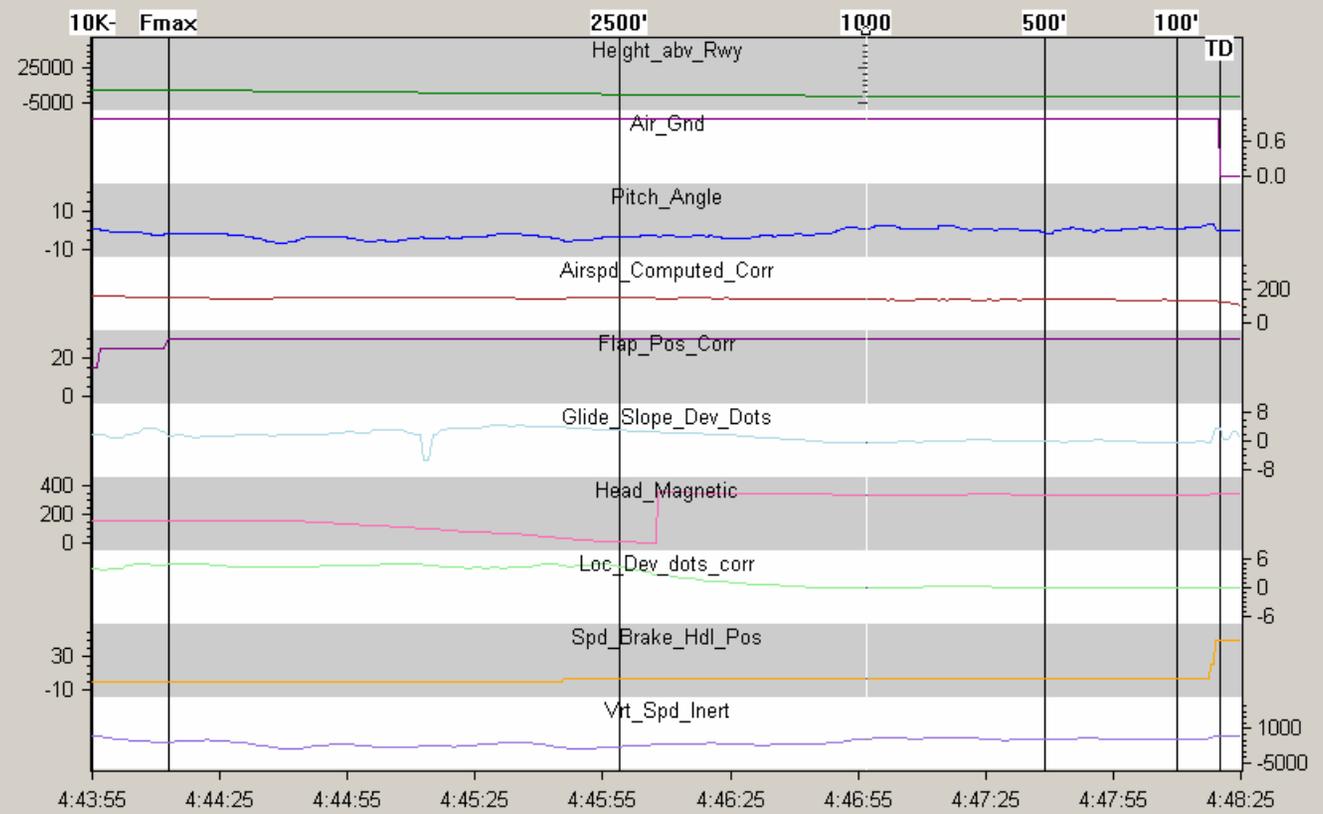
PowerPoint Reset View Show Grid

Data Exploration

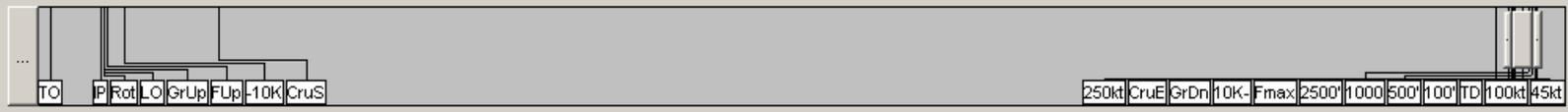
B737-700 3750_20040327_001.sffd

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



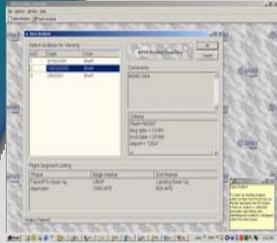
<< Prev Next >>



4:33:33 Time from Liftoff to left

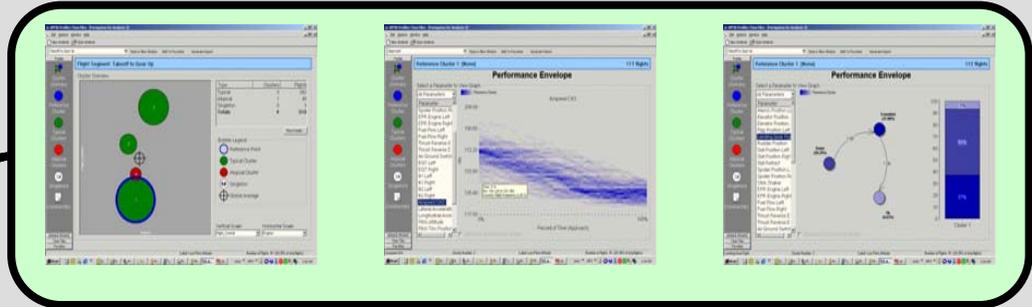
Time to Touchdown from 0:00:20

Profiler Tools

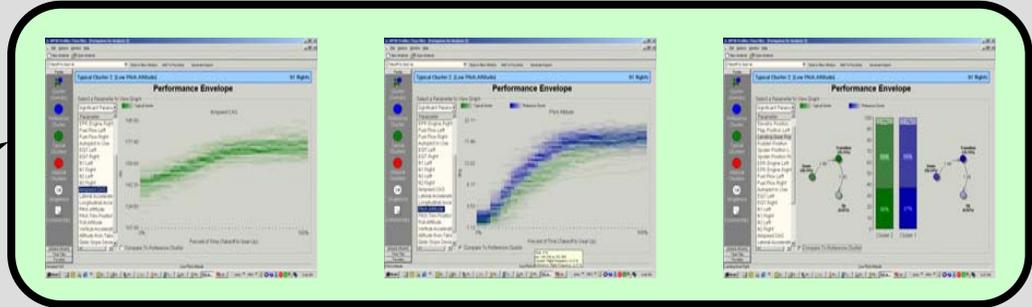


User defines the investigation

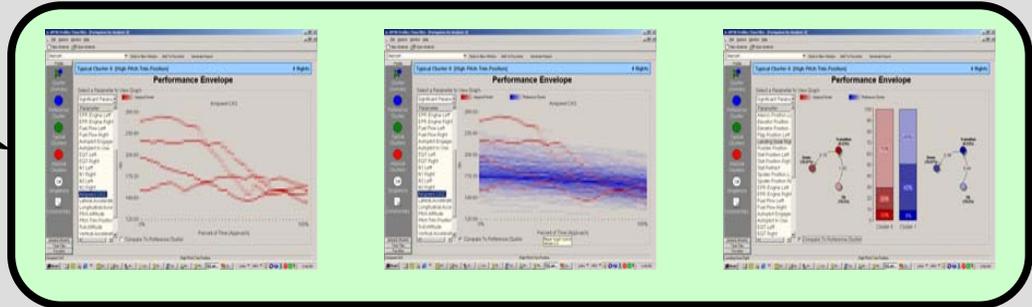
Computer analyzes the data;
Provides an overview of results



Clusters are examined and compared



Atypical clusters and singletons
are examined



Cluster Comparison

Automated cluster label

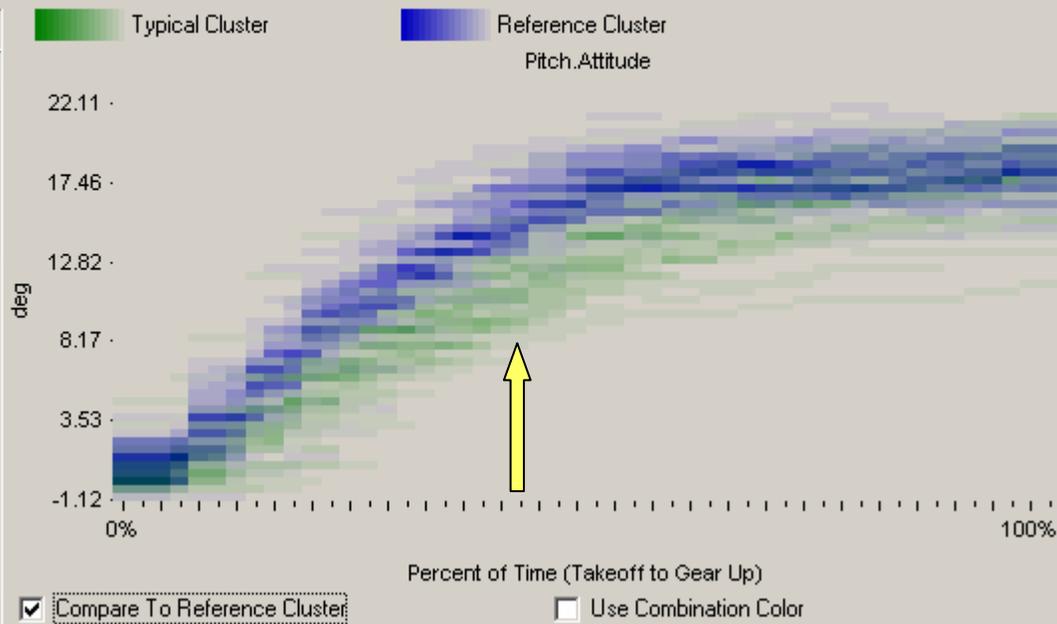
Typical Cluster 2: [Low Pitch.Attitude]

91 flights

Performance Envelope

Select a Parameter to View Graph

- Significant Parameters
- Parameter
 - Elevator.Position.Right
 - Spoiler.Position.Right.In
 - Spoiler.Position.Left.Out
 - Longitudinal.Acceleration
 - Lateral.Acceleration
 - Vertical.Acceleration
 - Roll.Attitude
 - Pitch.Attitude
 - Fuel.Flow.Right
 - Fuel.Flow.Left
 - N2.Right
 - N2.Left
 - N1.Right
 - N1.Left
 - EPR.Engine.Right
 - EPR.Engine.Left
 - Flap.Position.Left
 - Airspeed.CAS



Storymeister Example

Numeric characterization in plain English

- ▶ Cluster 8 contains 18 flights. It has highly unusual values in the engine parameter set during the 5000 ft to 2500 ft approach phase. It also has moderately unusual values in the flight controls parameter set during this phase.
- ▶ Cluster 8 has extremely large N1.Left (mean value of 96 PCT) and N1.Right (mean value of 97.1 PCT) values during the 5000 ft to 2500 ft approach phase. It also has unusually low flap.position.left (mean value of 3 degrees) values and extremely high noise in Airspeed.CAS (mean noise of 1.5 knots). The Rudder.Position rate of change was moderately high (mean rate of change of 0.25 degrees).

In Summary

- ▶ The Morning Report uses:
 - Multivariate statistical analysis and
 - User-friendly software
- To enable the user to understand:
 - Understand typical patterns observed in the operation of 1000s of flights
 - Identify Atypical events
 - Identify flights and their flight characteristics associated with safety issues
 - Share the information with a community of aviation experts, thus enabling them to formulate improve aviation policies and action plans.
- ▶ A very important characteristic about the Morning Report is the basic approach is extendable to numerous other domains, including:
 - Air traffic control
 - U.S Customs
 - Cyber Security
 - NASA Exploration of Space

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