# Stall and Unbalance Diagnostics by Vibration Methods

RSL Electronics LTD.

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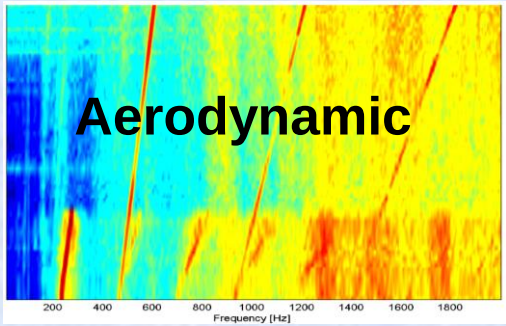
# Diagnostics by Vibration Methods

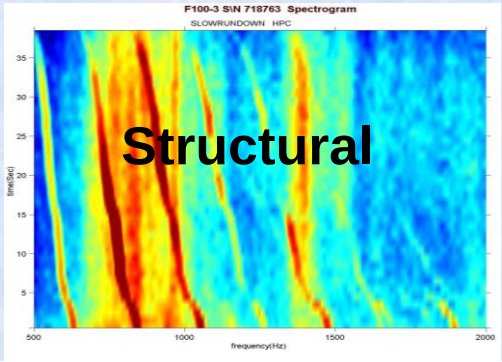
- **Non destructive methods for monitoring systems by vibration signatures.**
- **There exists a unique characteristic vibration signature for every mechanical part.**
- **Vibration sources:**
  - Rotation moving
  - Aerodynamic phenomena
- **Vibration signatures present dynamic, aerodynamic and structural characteristics of the system.**

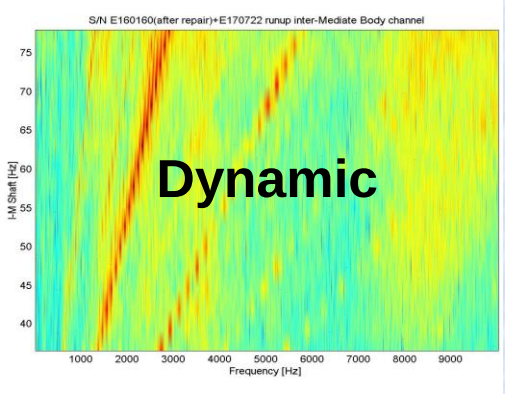
# Definitions

- The presented methodology is based on focal analysis of vibration signature that represents behavior of the mechanical part.
- The vibration signature is viewed in different planes – time, frequency, order, statistical moments.
- Focused analysis in the predefined point (e.g. specific frequency) for each mechanical part or fault. This point is called a POINTER.
- DIAGNOSTIC INDEX is a mathematical operator that compares the analyzed signature to a baseline signature and signifies difference in vibration signature.
- FEATURE is the diagnostic index value that solved for specified pointer.

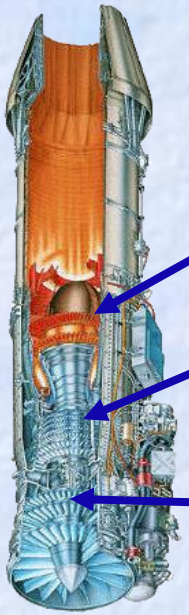
# Preliminary Stages of Vibration Methods




- Study and analysis of the system and its parts.
- Pointer identification.
- Analysis and classification of fault features.
- Selection of vibration signatures that may indicate the specific fault.
- Selection of a relevant diagnostic indexes.



| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| lmmoh_clutch | 1160850 | | 2 | | 2 | 10 | | 5 | 2 | 1 | 6 | 1 | 1 | | | | | | |
| lmmsh_clutch | 200720 | | 2 | | 2 | 10 | | 5 | 2 | 1 | 6 | 1 | 1 | | | | | | |
| lmmch_clutch | 082920 | | 2 | | 2 | 10 | | 5 | 2 | 1 | 6 | 1 | 1 | | | | | | |
| lmmg_clutch | 2101590 | | 2 | | 2 | 10 | | 5 | 4 | 1 | 6 | 2 | 1 | | | | | | |
| | | ges | 2 | | | 10 | | | | | | | | | | | | | |
| lmmb_clutch | 1504480 | | 2 | | 2 | 10 | | 5 | 4 | 1 | 6 | 2 | 1 | | | | | | |
| lmg_clutch | 756450 | | 2 | | 2 | 10 | | 5 | 4 | 1 | 6 | 2 | 1 | | | | | | |
| lmmcg_clutch | 107460 | | 2 | | 2 | 10 | | 5 | 4 | 1 | 6 | 2 | 1 | | | | | | |
| lmmis_cluste | 863590 | | 2 | | 2 | 10 | | 5 | 1 | 1 | 6 | 3 | 1 | | | | | | |
| | | ncgs | 2 | | | 10 | | | | | | | | | | | | | |
| lmmos_cluste | 613340 | | 2 | | 2 | 10 | | 5 | 1 | 1 | 6 | 3 | 1 | | | | | | |
| lmmss_cluste | 284570 | | 2 | | 2 | 10 | | 5 | 1 | 1 | 6 | 3 | 1 | | | | | | |
| lmmcs_cluste | 138330 | | 2 | | 2 | 10 | | 5 | 1 | 1 | 6 | 3 | 1 | | | | | | |
| lmmt_cluste | 769220 | | 2 | | 2 | 10 | | 5 | 1 | 1 | 6 | 3 | 1 | | | | | | |
| | | ncgs | 2 | | | 10 | | | | | | | | | | | | | |
| lmmot_cluste | 523090 | | 2 | | 2 | 10 | | 5 | 1 | 1 | 6 | 3 | 1 | | | | | | |
| lmmst_cluste | 239520 | | 2 | | 2 | 10 | | 5 | 1 | 1 | 6 | 3 | 1 | | | | | | |
| lmmct_cluste | 037360 | | 2 | | 2 | 10 | | 5 | 1 | 1 | 6 | 3 | 1 | | | | | | |
| lmmt_cluster | 855150 | | 2 | | 2 | 10 | | 5 | 1 | 1 | 6 | 3 | 1 | | | | | | |
| | | ncgs | 2 | | | 10 | | | | | | | | | | | | | |
| lmmot_cluste | 621770 | | 2 | | 2 | 10 | | 5 | 1 | 1 | 6 | 3 | 1 | | | | | | |
| lmmst_cluste | 284780 | | 2 | | 2 | 10 | | 5 | 1 | 1 | 6 | 3 | 1 | | | | | | |
| lmmct_cluste | 138880 | | 2 | | 2 | 10 | | 5 | 1 | 1 | 6 | 3 | 1 | | | | | | |
| lmmp_upper | 152860 | | 2 | | 2 | 10 | | 5 | 3 | 1 | | | | | | | | | |
| lmmop_upper | 100890 | | 2 | | 2 | 10 | | 5 | 3 | 1 | | | | | | | | | |
| | | nss | 2 | | | 10 | | | | | | | | | | | | | |
| lmmsp_upper | 045650 | | 2 | | 2 | 10 | | 5 | 3 | 1 | | | | | | | | | |
| lmmcp_upper | 011760 | | 2 | | 2 | 10 | | 5 | 3 | 1 | | | | | | | | | |
| lmmp_upper | 407020 | | 2 | | 2 | 10 | | | | | | | | | | | | | |
| | | nss | 2 | | | 10 | | | | | | | | | | | | | |
| lmmop_upper | 347160 | | 2 | | 2 | 10 | | | | | | | | | | | | | |
| lmmsp_upper | 147520 | | 2 | | 2 | 10 | | | | | | | | | | | | | |
| lmmcp_upper | 012720 | | 2 | | 2 | 10 | | | | | | | | | | | | | |
| lmmr_upper | 105990 | | 2 | | 2 | 10 | | 5 | 3 | 1 | | | | | | | | | |
| lmmsr_upper | 394720 | | 2 | | 2 | 10 | | 5 | 3 | 1 | | | | | | | | | |
| | | nms | 2 | | | 10 | | | | | | | | | | | | | |
| lmmsr_upper | 053970 | | 2 | | 2 | 10 | | 5 | 3 | 1 | | | | | | | | | |
| lmmcr_upper | 003210 | | 2 | | 2 | 10 | | 5 | 3 | 1 | | | | | | | | | |
| lmmh_upper | 085750 | | 2 | | 2 | 10 | | 5 | 3 | 1 | | | | | | | | | |
| | | hgs | 2 | | | 10 | | | | | | | | | | | | | |
| lmmoh_upper | 321290 | | 2 | | 2 | 10 | | 5 | 3 | 1 | | | | | | | | | |
| lmmsh_upper | 128170 | | 2 | | 2 | 10 | | 5 | 3 | 1 | | | | | | | | | |
| lmmch_upper | 010710 | | 2 | | 2 | 10 | | 5 | 3 | 1 | | | | | | | | | |
| lmmb_upper | 268930 | | 2 | | 2 | 10 | | 5 | 3 | 1 | | | | | | | | | |
| | | hgs | 2 | | | 10 | | | | | | | | | | | | | |
| lmmoh_upper | 234660 | | 2 | | 2 | 10 | | 5 | 3 | 1 | | | | | | | | | |
| lmmsh_upper | 125140 | | 2 | | 2 | 10 | | 5 | 3 | 1 | | | | | | | | | |
| lmmch_upper | 010670 | | 2 | | 2 | 10 | | 5 | 3 | 1 | | | | | | | | | |
| lmmt_center | 622020 | | 2 | | 2 | 10 | | 6 | 4 | 1 | | | | | | | | | |
| | | nms | 2 | | | 10 | | | | | | | | | | | | | |
| lmmot_center | 595250 | | 2 | | 2 | 10 | | 6 | 4 | 1 | | | | | | | | | |
| lmmst_center | 309240 | | 2 | | 2 | 10 | | 6 | 4 | 1 | | | | | | | | | |
| lmmct_center | 142520 | | 2 | | 2 | 10 | | 6 | 4 | 1 | | | | | | | | | |
| lmmt_center | 916930 | | 2 | | 2 | 10 | | 6 | 4 | 1 | | | | | | | | | |
| | | nms | 2 | | | 10 | | | | | | | | | | | | | |
| lmmot_center | 702820 | | 2 | | 2 | 10 | | 6 | 4 | 1 | | | | | | | | | |
| lmmst_center | 376230 | | 2 | | 2 | 10 | | 6 | 4 | 1 | | | | | | | | | |
| lmmct_center | 043930 | | 2 | | 2 | 10 | | 6 | 4 | 1 | | | | | | | | | |
| lmmg r l | 1391930 | | 2 | | 2 | 10 | | 5 | 4 | 1 | 6 | 2 | 1 | | | | | | |
| | | ges | 2 | | | 10 | | | | | | | | | | | | | |
| lmmbg r l | 356360 | | 2 | | 2 | 10 | | 5 | 4 | 1 | 6 | 2 | 1 | | | | | | |
| lmmcg r l | 713790 | | 2 | | 2 | 10 | | 5 | 4 | 1 | 6 | 2 | 1 | | | | | | |
| lmmcg r l | 106260 | | 2 | | 2 | 10 | | 5 | 4 | 1 | 6 | 2 | 1 | | | | | | |
| lmmbs_right | 317150 | | 2 | | 2 | 10 | | 6 | 2 | 1 | | | | | | | | | |
| | | aps | 2 | | | 10 | | | | | | | | | | | | | |

# Major Stages of Vibration Methods

- Validity checks of the vibration signals and engine rotation speed validation and analysis.
- Separation between stationary (steady-state) and non-stationary recordings, in order to adapt the type of analysis required.
- Validation of the vibration signatures-pointers correspondence.
- Graphical comparison between signatures of the engines at similar test conditions.
- Baseline calculation based on signatures of the production engines at different conditions.
- Calculation of diagnostic indexes that compare the signatures of the suspect and production engines at similar conditions versus the calculated baseline.

# Unbalance

- Unbalance is manifested in intensified vibration levels at the first harmony of the subject shaft rotating speed.
- When the unbalance is severe it may be manifested at higher harmonies of the shaft rotating speed.
- The most reliable results are expected to be obtained in the order domain of the phase average, but can be observed in the frequency or order domains.

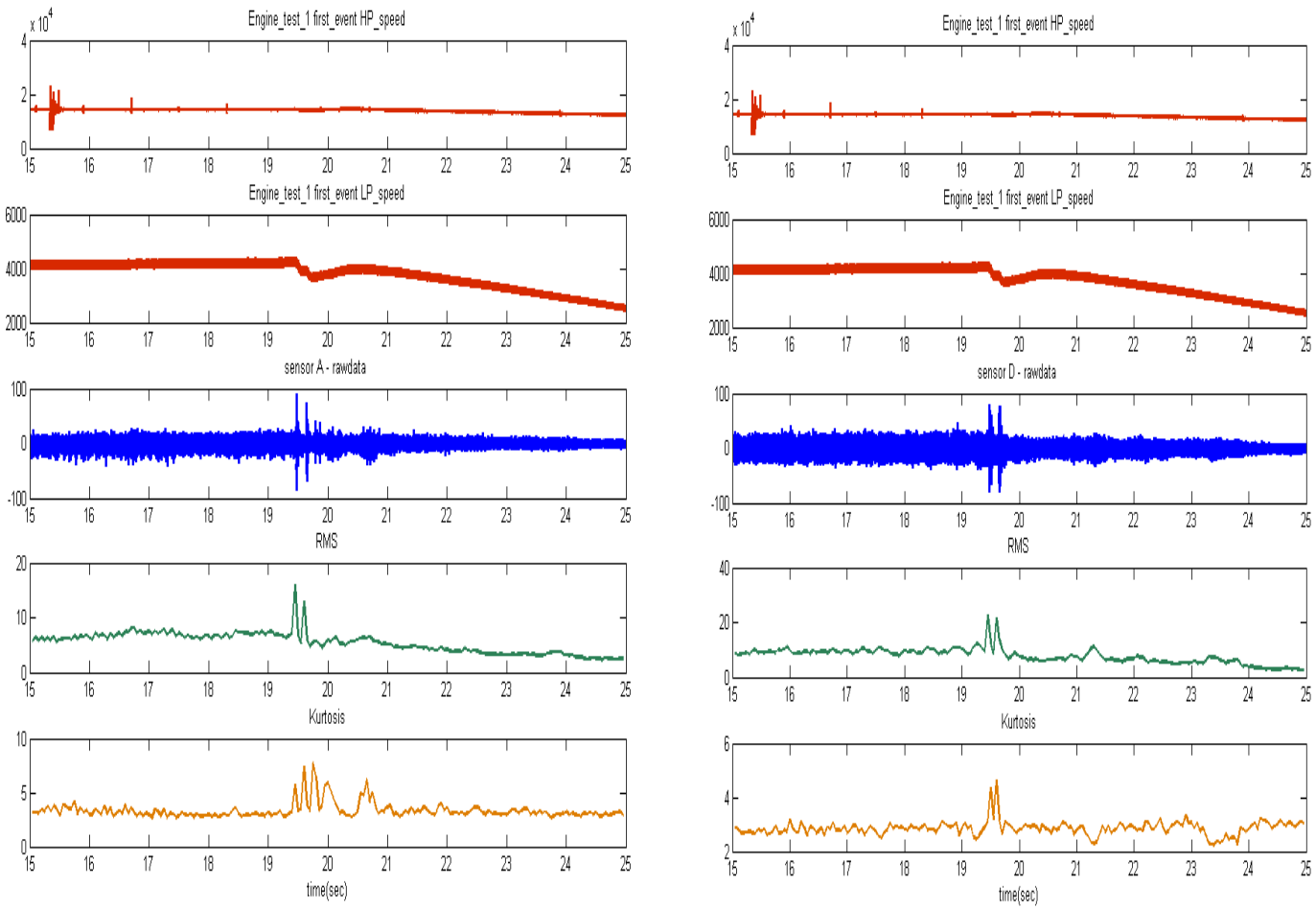
# Stall

- The stall is manifested in abnormal airflow through the compressor stage and results in a loss of engine power.
- The stall is identified by observing of rotating speed data of the both low and high pressure shafts and shock pulse in vibration sensors raw data that manifested in the second and fourth statistical moments of the vibrations signals (RMS and kurtosis).

# Tests 1 & 2 - Stall Events

- Signals from 6 accelerometers, LP and HP rotors speeds.
- These engine runs contain a stall during vibe survey with LP/HP rotor unbalances.
- Test 1 - two distinctive shock pulses generated by pressure waves initiated at the start of the each rotating speed step represent the stalls.
- Test 2 - three distinctive shock pulses generated by pressure waves initiated at the start of the each rotating speed step represent the stalls.

# Test 1 – Stalls Identifiers




**Rotor speed HP**

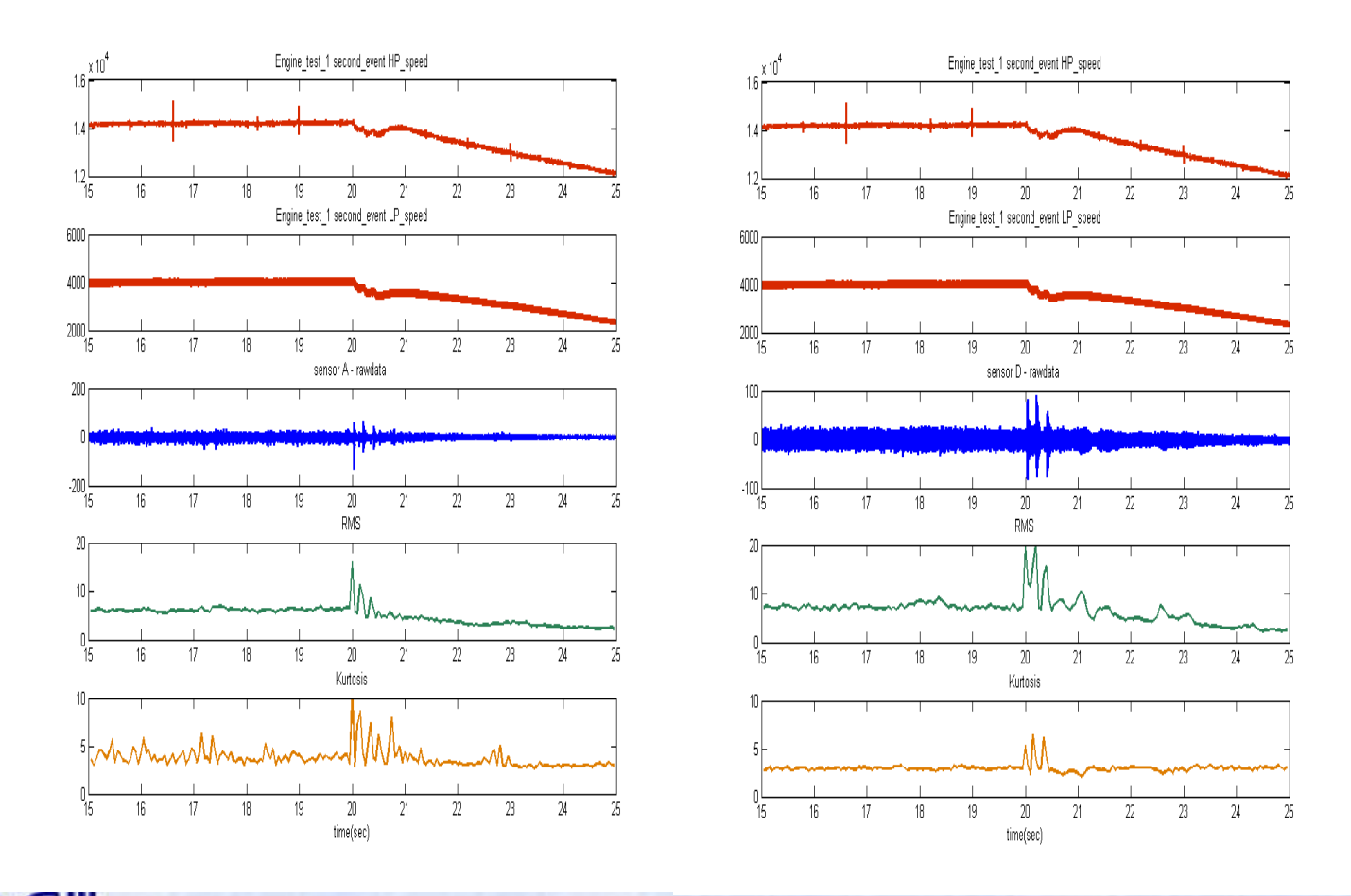
**Rotor speed LP**

**Raw data A/D**

**RMS**

**Kurtosis**

# Test 2 – Stalls Identifiers




**Rotor speed HP**

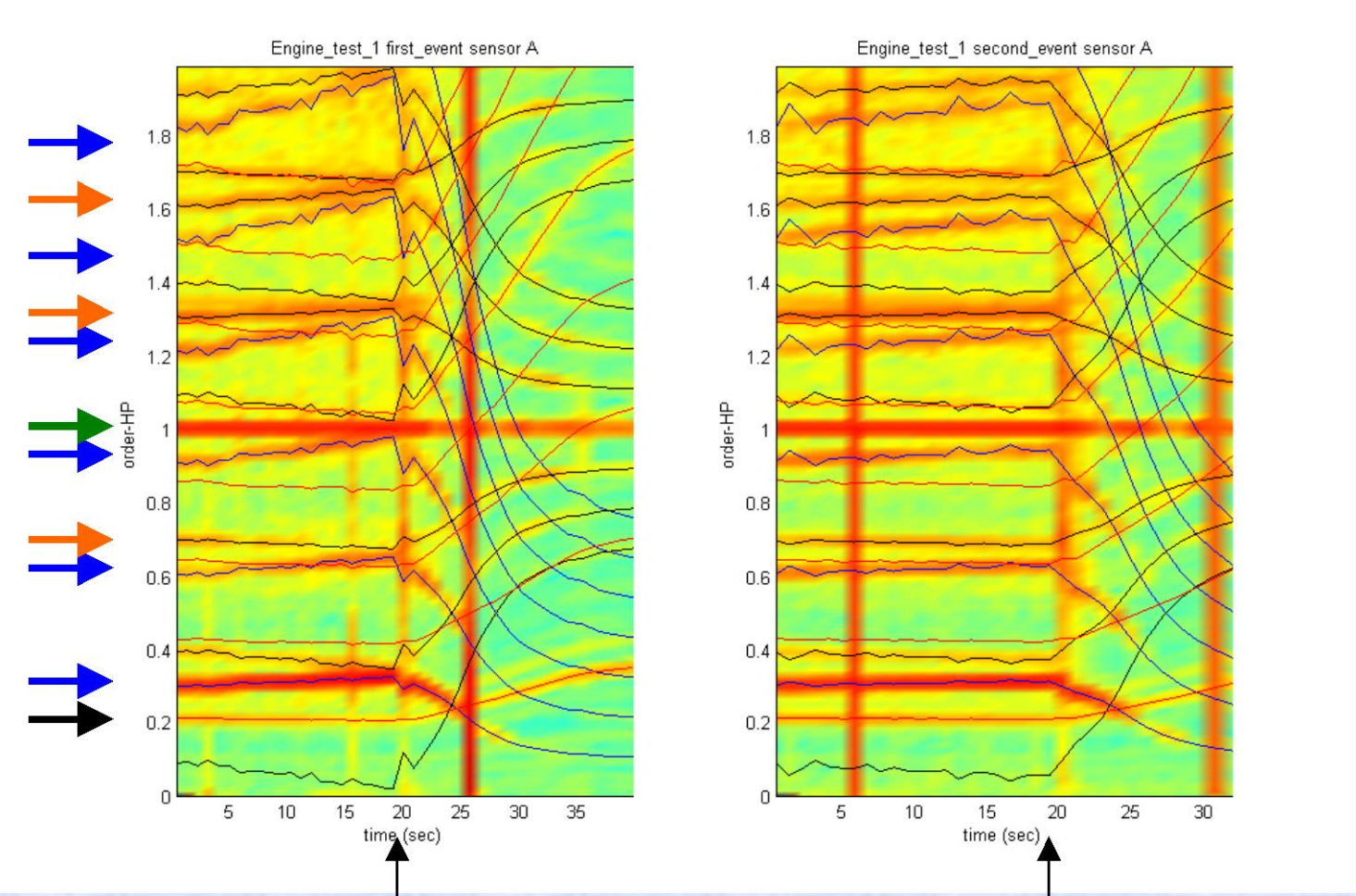
**Rotor speed LP**

**Raw data A/D**

**RMS**

**Kurtosis**

# Tests 1 & 2 – Stall Identifiers

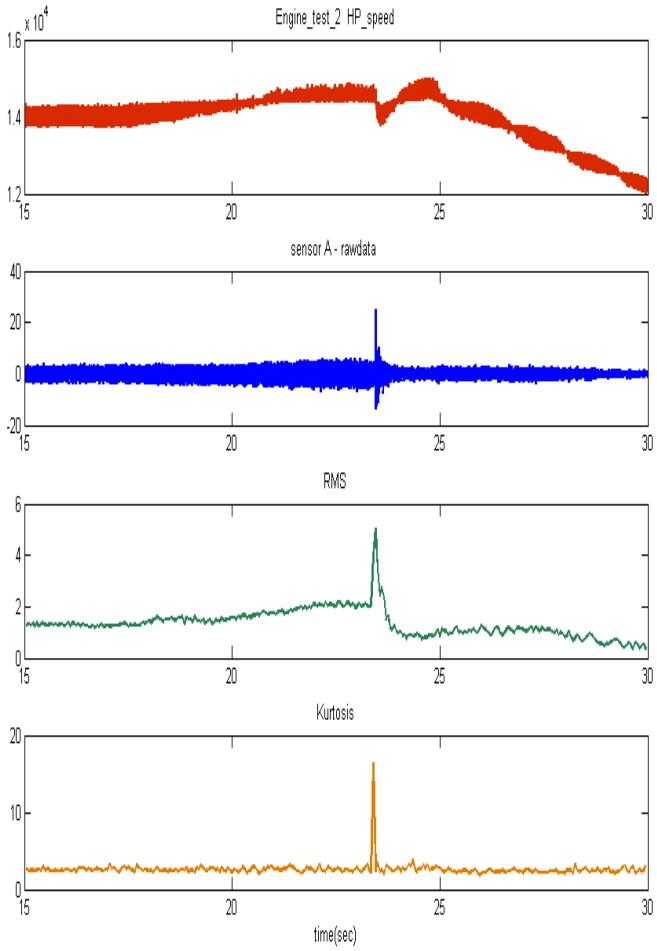


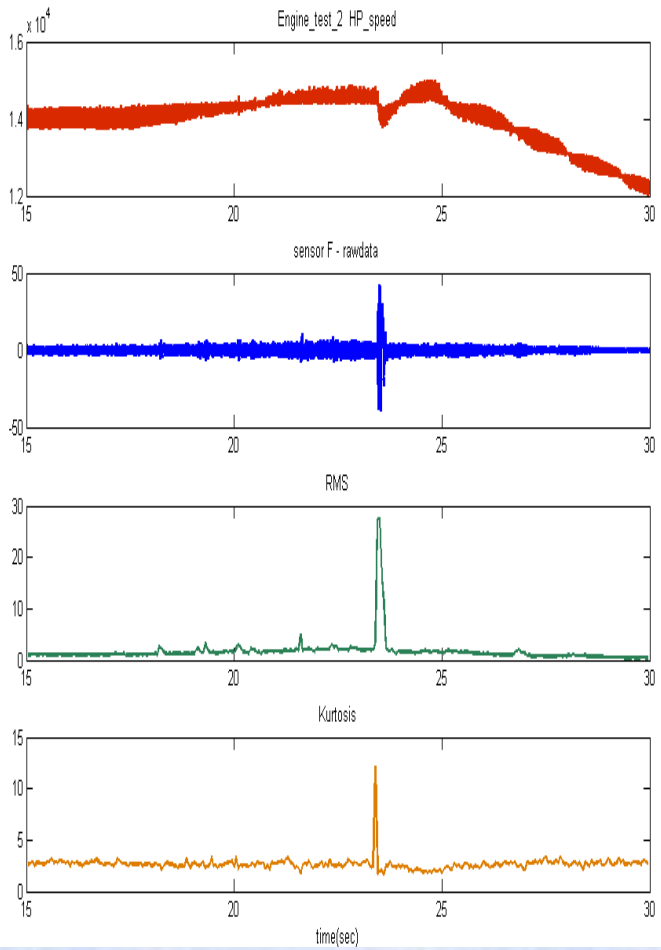

HP
HP sidebands (of LP)
LP harmonies
50 Hz

# Test 3 – Stall and Compressor Blade Out

- Signals from 3 accelerometers and HP RPM.
- The stall was identified using the methodology applied in test 1 (same phenomenon of a pressure wave at the beginning of the deceleration, i.e. a shock pulse initiated at the start of the step in the HP rotating speed).
- A blade out is expected to cause unbalance of the HP shaft.
- Vibration levels at the shaft rotating speed pointer decrease during deceleration → the sudden increase was associated with the unbalance generated by the blade out.

# Test 3 – Stall Identifiers



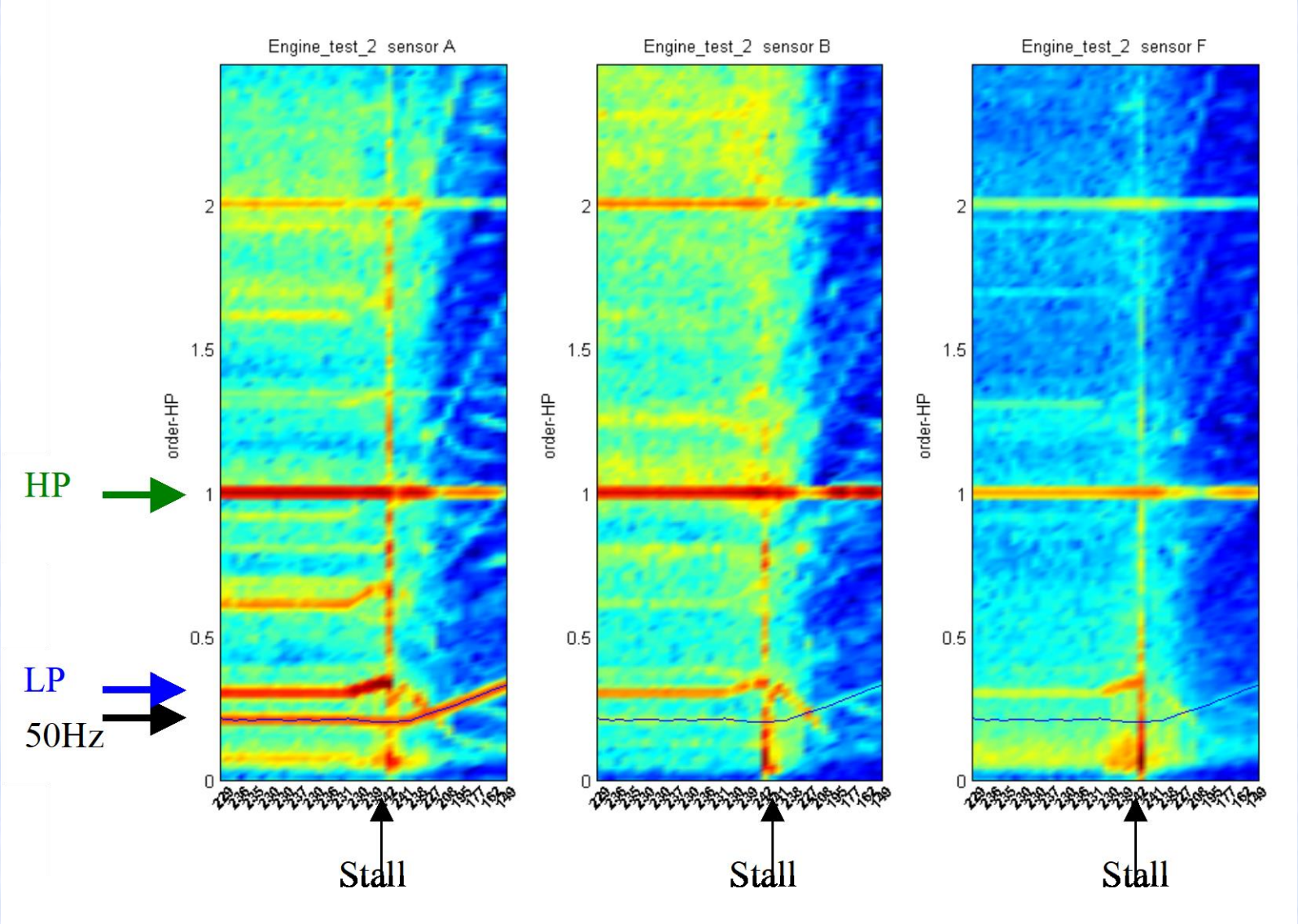

**Rotor speed HP**

**Raw data A/F**

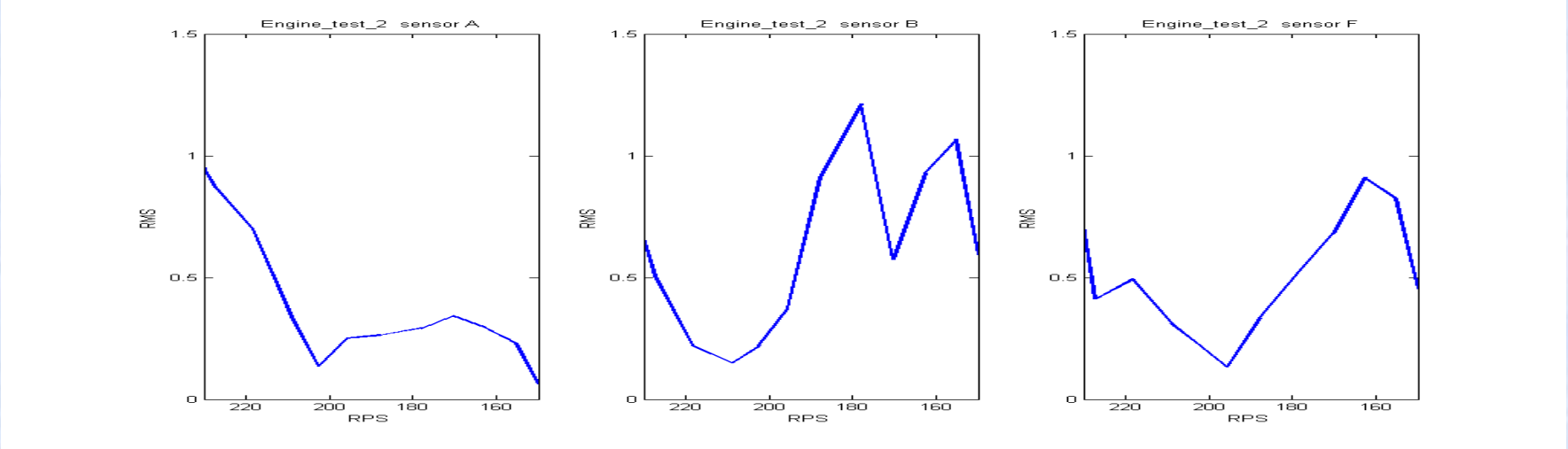
**RMS**

**Kurtosis**

# Test 3 – Sensor A, B & F – HP Order Spectrograms



# Test 3 – Unbalance Identifiers




**RMS as a function of HP rotating speed of sensors A,B and F**

# Test 4 – Medium and High Level Fan and LPT Unbalances

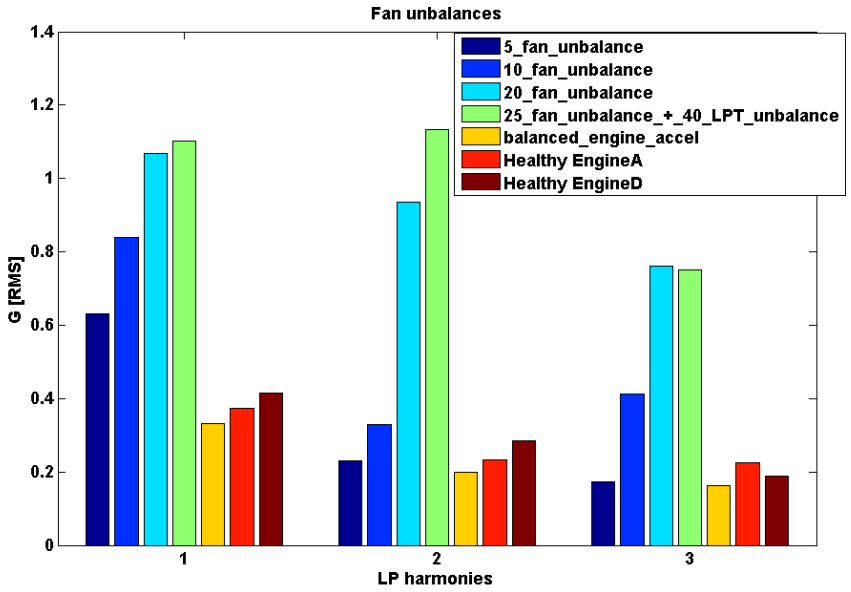
- **Signal from 3 accelerometers.**
- **RPM data for LP and HP shafts.**
- **Data sets for medium and high level fan and LPT unbalances:**
  - 5 fan unbalance
  - 10 fan unbalance
  - 20 fan unbalance
  - 10 LPT unbalance
  - 40 LPT unbalance
  - 25 fan and 40 LPT unbalance

# Test 4 – Processing & Diagnostic Methods

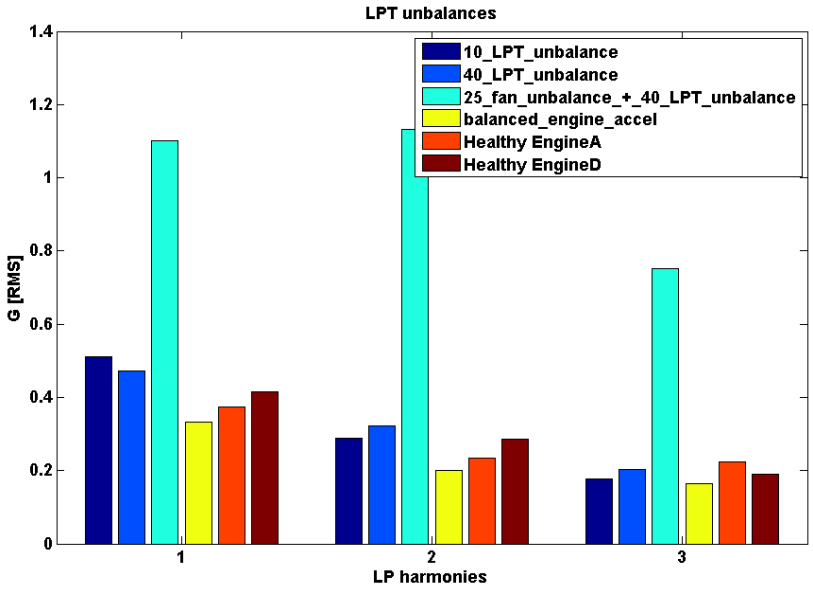
- Spectral analysis of vibration raw data (Power Spectral Density).
- Calculation of energy of first harmony of LP shaft.
- Spectrograms by time and RPM in non-stationary (acceleration) stage of engine work.
- Comparison with balanced/healthy engine.
- Analysis of different stationary and non-stationary engine work stages.

# Sensor A, Steady stage [5280-5400] RPM

## Fan unbalances

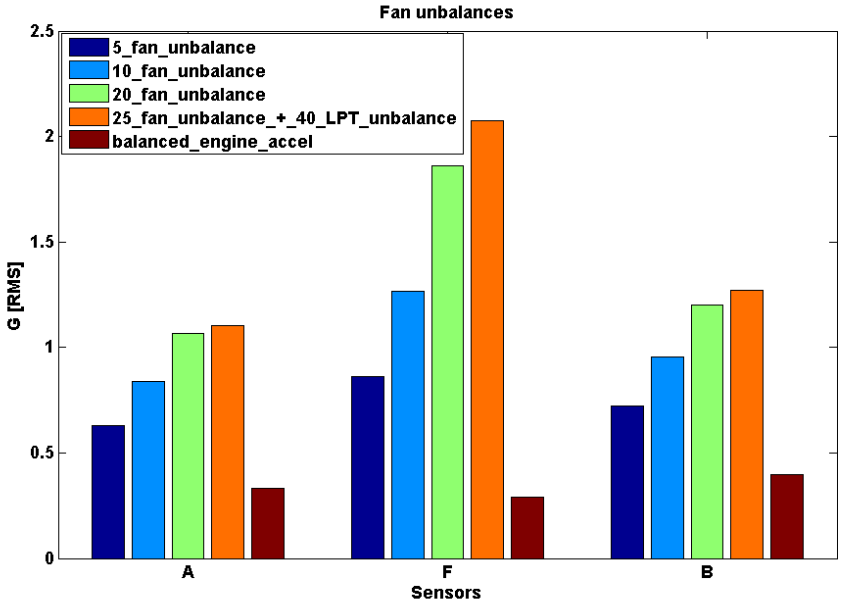



## LPT unbalances

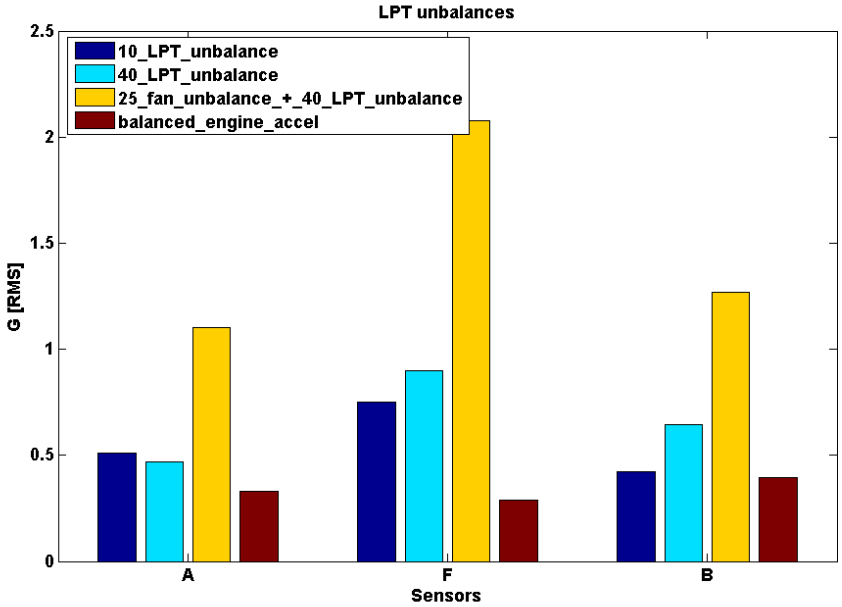


# 1st Harmony of LP Shaft, Steady stage [5280-5400] RPM

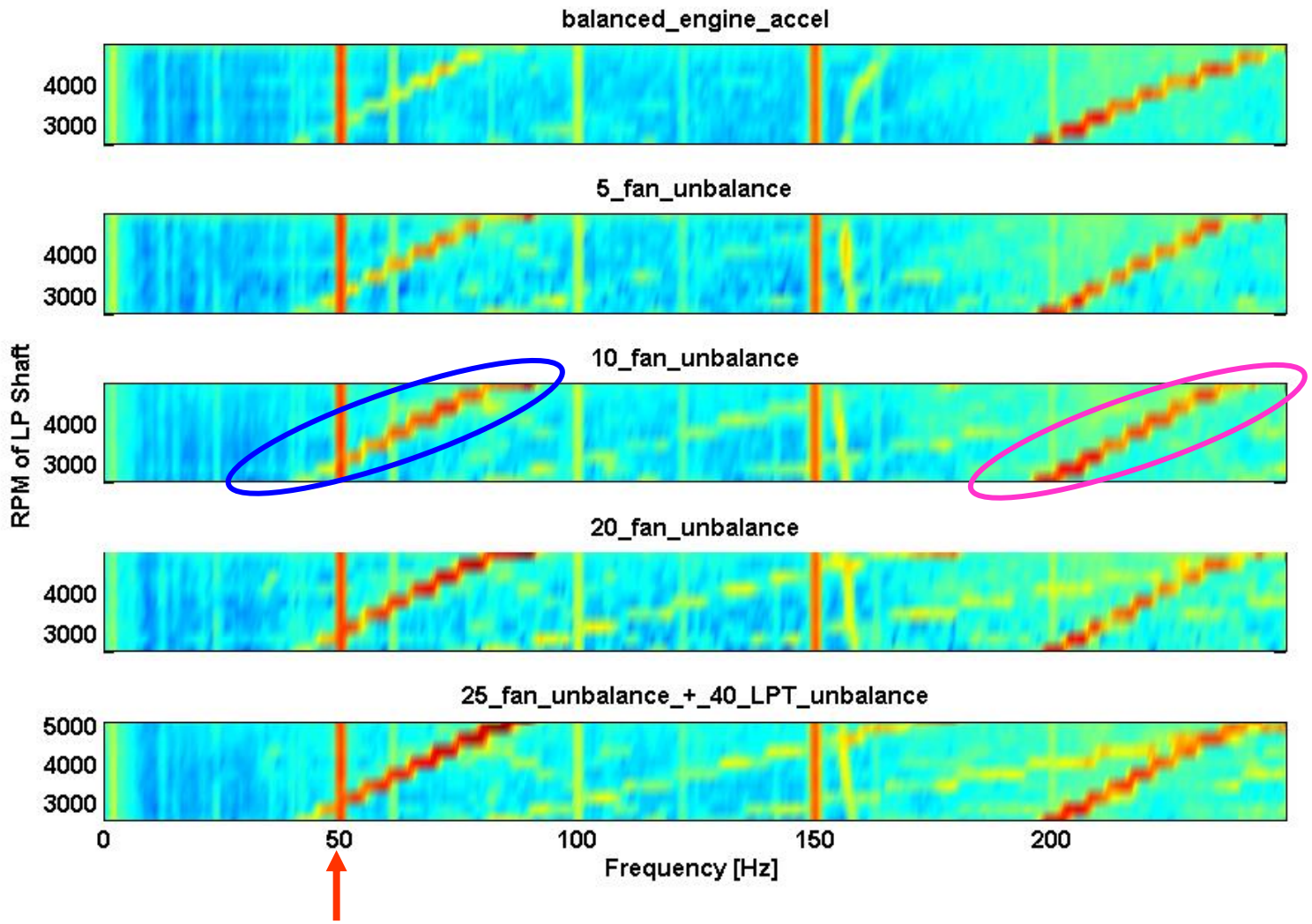
## Fan unbalances




## LPT unbalances



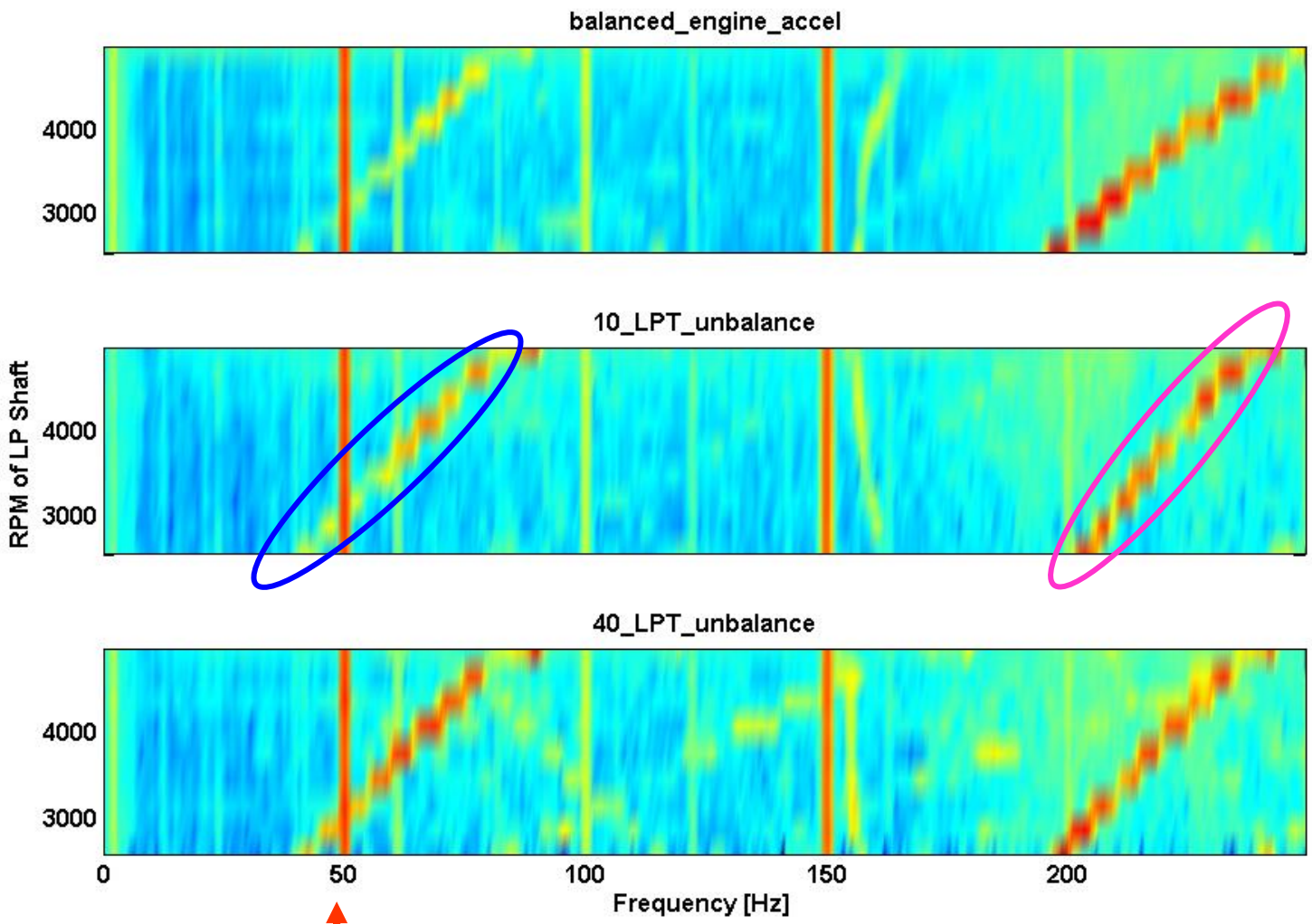
# Acceleration stage [2500-5000] Sensor F, Fan unbalances




- 1st harmony of LP shaft

- 1st harmony of HP shaft

# Acceleration stage [2500-5000] Sensor F, Fan unbalances



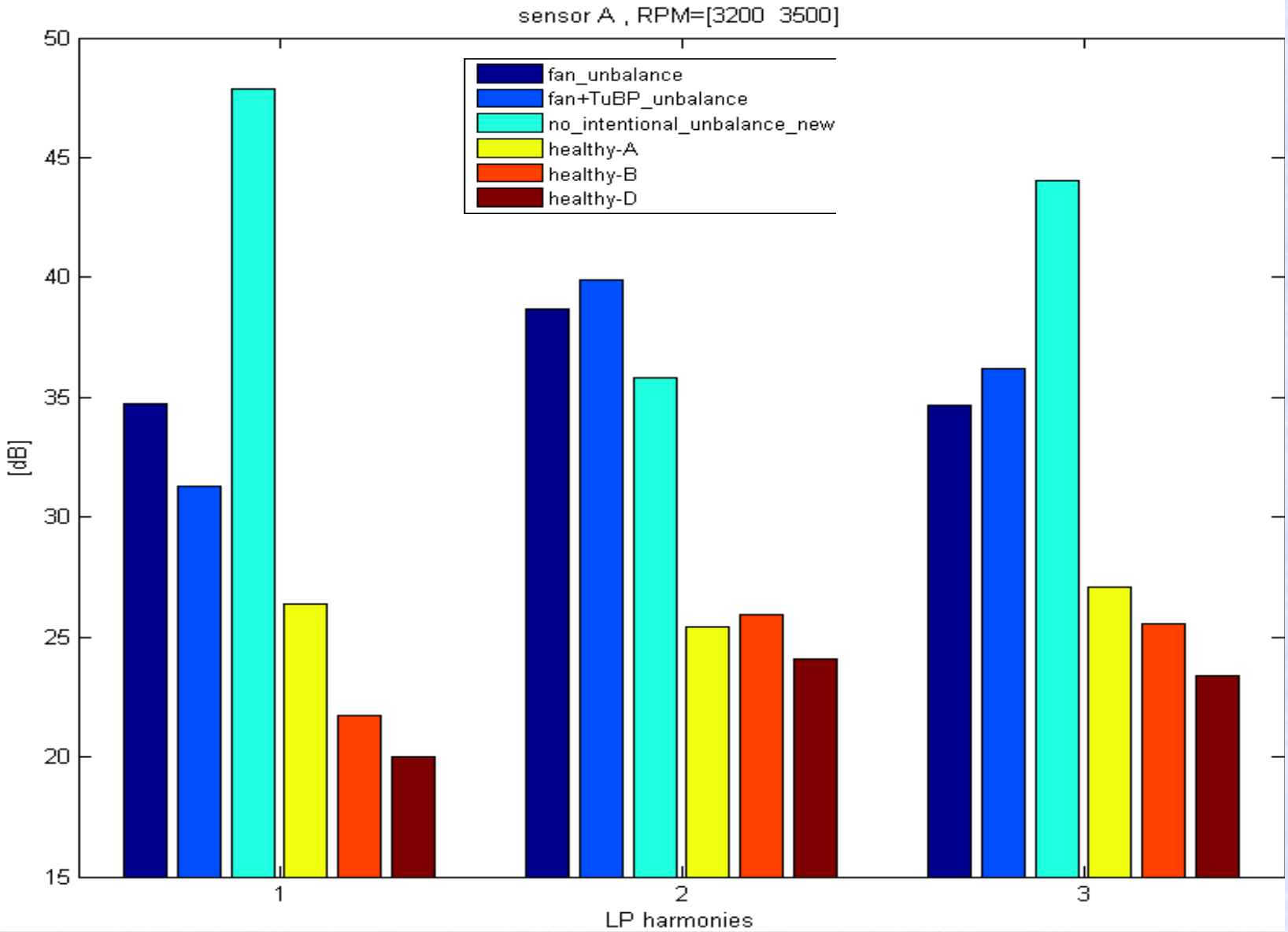

- 1st harmony of LP shaft

- 1st harmony of HP shaft

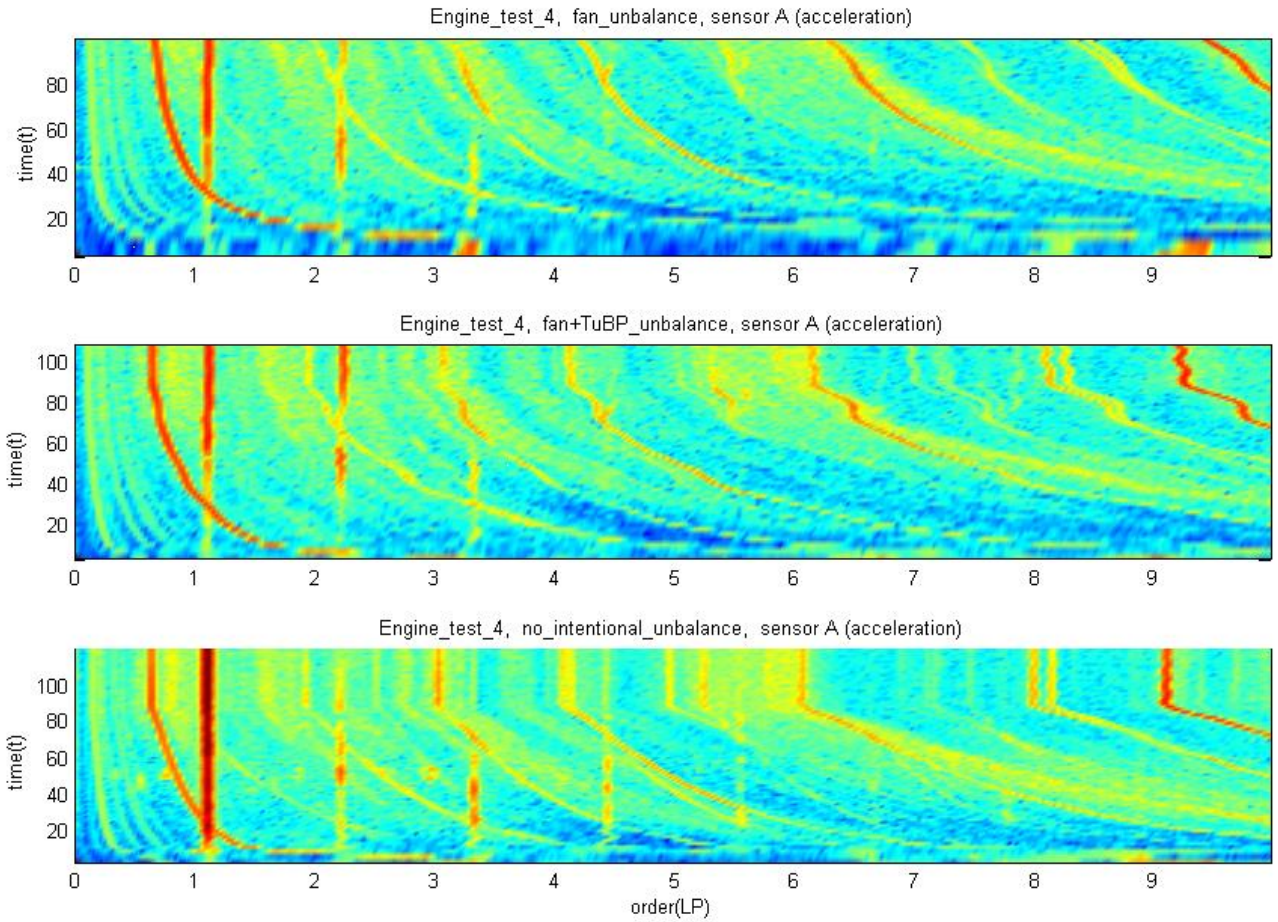
# Test 5 – Low Level LP Unbalances

- **Signal from 3 accelerometers and LP RPM.**
- **Three data sets of unbalanced configurations:**
  - without intentional unbalance
  - fan unbalance
  - fan and LPT unbalance

# Test 5 – LP unbalance pattern (3 LP harmonies) at [3200-3500] RPM



# Test 5 – Time-Order Spectrogram of Sensor A




**Fan unbalance**

**Fan & LPT unbalances**

**No intentiona unbalance**

# Conclusions

- The analysis presented proves the capability to detect the entire subject failures, including stalls, blade separation and different levels of unbalance.
- Tests 1 & 2 - The stalls have been detected in both events.
- Test 3 - Both the stall and the blade separation have been detected and the sequence of the events appears to be clear, i.e. the stall occurred at the deceleration start and the blade separation during the deceleration, after few seconds.
- Test 4 - In this test the analysis completed for steady and acceleration rotating speeds and for both the test events and for the healthy engines. A proposed methodology enables to detect the unbalance of LP shaft in different values of degradation.
- Test 5 - The analysis performed reveals the rotor unbalance during all the 3 events of the test data, when the unintentional unbalance seems to be in the more severe state.