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Comparison of MIL-STD810G with real load cases of a VHF radio in a helicopter

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Realize Innovation.

Comparison of MIL-STD810G with real load cases of a VHF radio in a helicopter

Questions

Are the Standards for Vibration Testing sufficient to guarantee lifetime operation of a new Console in a police helicopter?

Can we perform vibration measurements in typical operating conditions to verify?

Is the current design of a new console robust enough to survive 30.000 hours of operation (=lifetime of helicopter)?

Project

New console for camera operator in a police helicopter

- Experimentel modal analysis
  - Identifying Resonance frequencies
- Operational modal analysis
  - Identifying Resonace frequencies installed in helicopter and during flight
- **Mission Synthesis**
  - **Validate vibration durability of current design**

Project
Mission Synthesis

Focus on VHF Radios of new console

Old console

New console

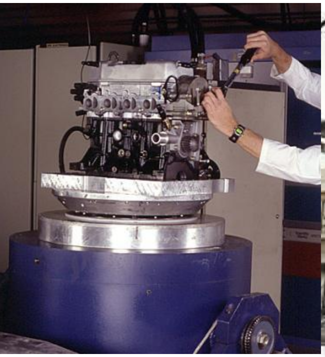
Mission Synthesis: Qualification of products under representative loading conditions

Materials undergo damage or do not completely fulfill their functions during day-to-day use

In the development cycle of a new product, it’s necessary to validate that the specimen remains operational in a representative environment during it’s intended lifetime

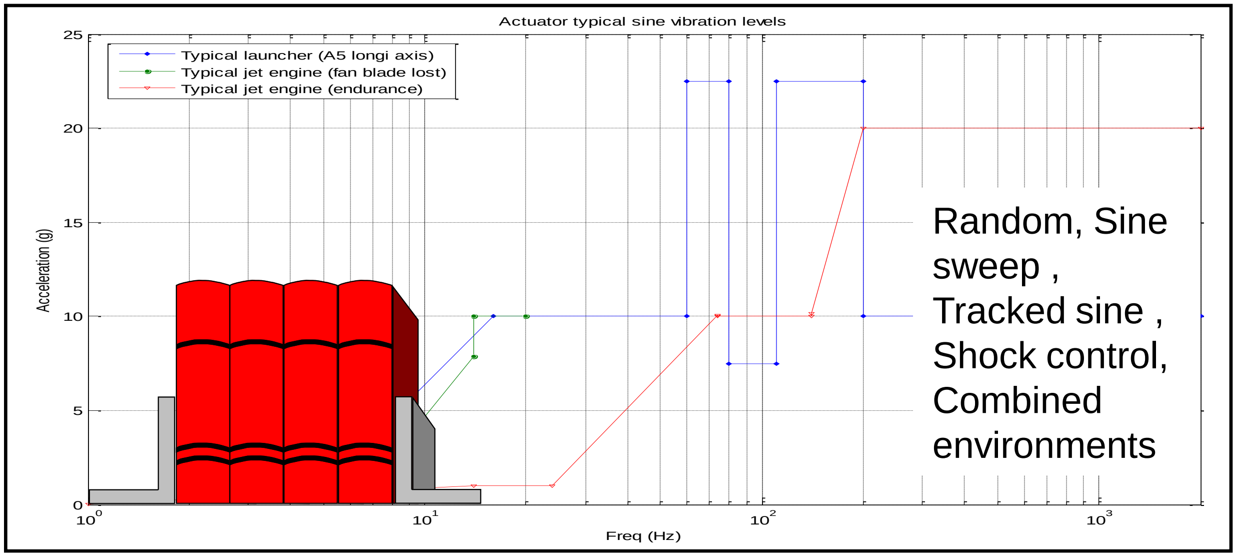
Standards exists for different vibration environments

Actual trend to tailor tests and reduce time and costs (Mission Synthesis)





Shock and vibration levels



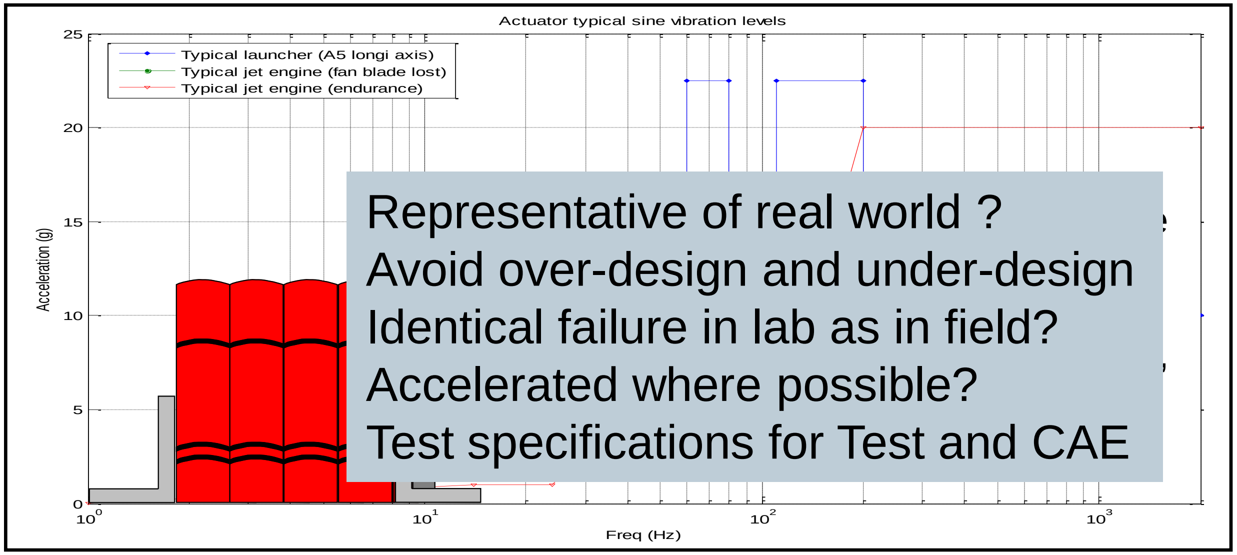
- Handbooks
- Standards
- Provided by manufacturers

Vibration control system

Is product fit for normal to extreme operating conditions?

Classical approaches
Qualification testing – what do we want ?

Shock and vibration levels



Representative of real world ?
Avoid over-design and under-design
Identical failure in lab as in field?
Accelerated where possible?
Test specifications for Test and CAE

- Handbooks
- Standards
- Provided by manufacturers

Vibration control system

Is product fit for normal to extreme operating conditions?

More realistic qualification testing
Use of recorded infield data

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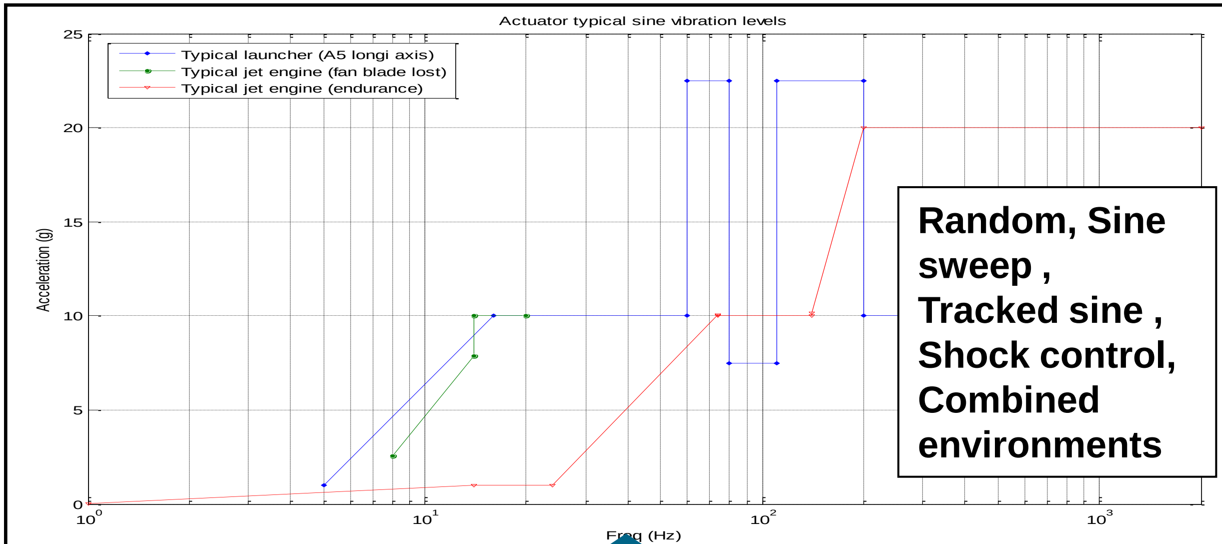
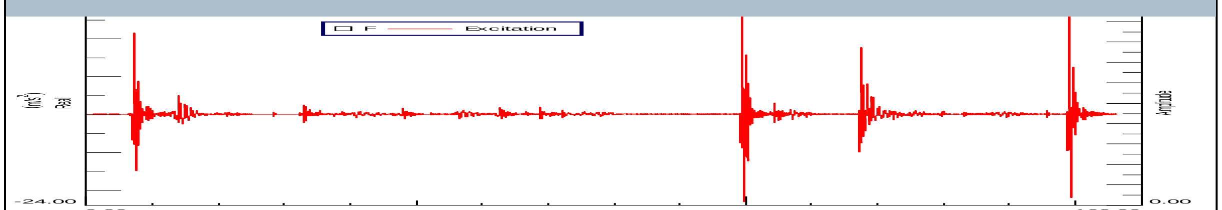
Representative shock and vibration levels



Random, Sine sweep , Tracked sine , Shock control, Combined environments

Mission Synthesis

Recorded infield data



Vibration control system

Is product fit for normal to extreme operating conditions?

Mission Synthesis

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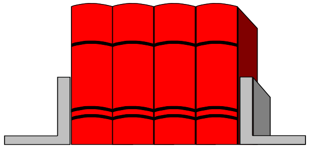
Goal of Mission Synthesis

- Derive vibration qualification specs based on measurements
- Compare to current standards
- Suggest evolution of standards

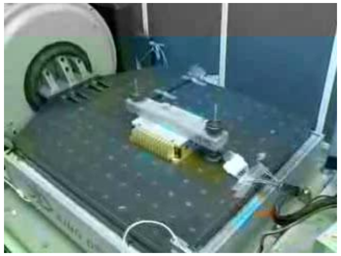
Real life

Recording

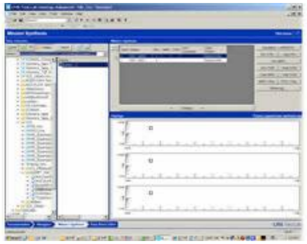
HOW ?



Standards



Shakertable



Analysis and Synthesis of the environments

Goal Mission Synthesis in this project

Goal

Validate if the VHF-radio’s on the new console survive the vibration environment of the police helicopter without additional shaker tests

Principle

- VHF-radio on original console survives all vibrations from helicopter (no issues reported)
- Compare damage due to vibrations between old and new console New console better or worse?
- What about MIL-STD810G standard? Needed or not?

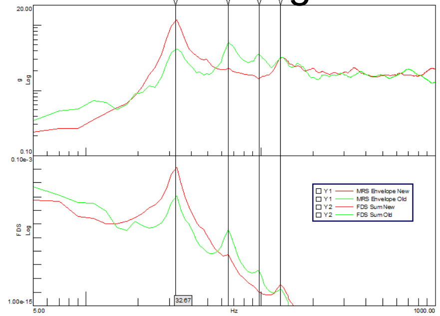
How?

- Measure vibrations in different flightconditions on both consoles
- Calculate damage potential and compare

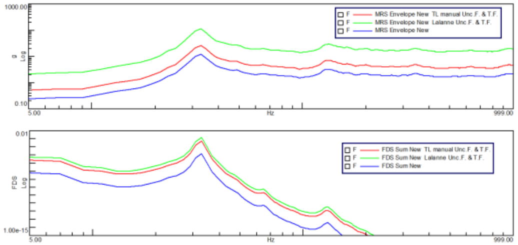
Procedure

Step 1: Define mission

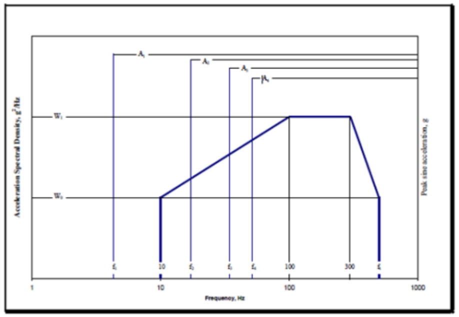
Step 2: Calculate damage info



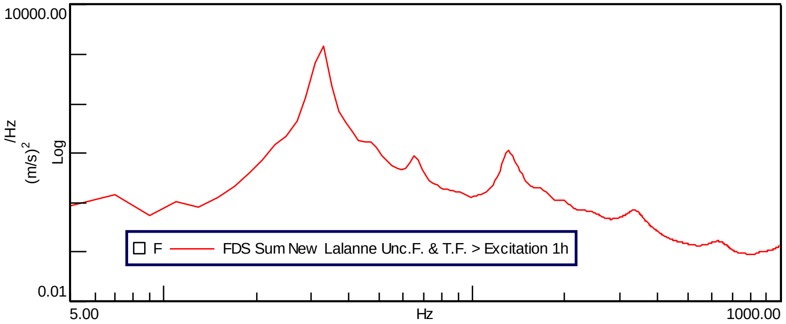
Step 3: Statistics Test & Unc. factor



Step 4: Compare with standard



Step 5: Test PSD



Step 1: Define mission

New console

- **Power up** (1% = 300h) → Run 9
  test: 88,6s → 12 190 repetitions
- **Hover on ground** (5% = 1500h) → Run 6
  test: 43,9s → 123 007 repetitions
- **Take off** (5% = 1500h) → Run 3
  test: 27,0s → 200 000 repetitions
- **Hover off ground** (18% = 5400h) → Run 11
  test: 82,4s → 235 922 repetitions
- **80 knot** (40% = 12000h) → Run 12
  test: 27,3s → 1 582 418 repetitions
- **120 knot** (25% = 7500h) → Run 13
  test: 41,2s → 655 340 repetitions
- **Landing + Power down** (6% = 1800 h) → Run 17
  test: 85,9s → 75 437 repetitions

Old console

- **Hover on ground** (6% = 1800h) → Run 01-ground
  test: 36,4s → 178 022 repetitions
- **Take off** (5% = 1500h) → Run 02-Take off
  test: 15,0s → 360 000 repetitions
- **Hover off ground** (18% = 5400h) → Run 04-hover off ground
  test: 61,9s → 314 055 repetitions
- **80 knot** (40% = 12000h) → Run 80 kts
  test: 61,5s → 702 439 repetitions
- **110 knot** (25% = 7500h) → Run 03-110kts
  test: 61,8s → 436 893 repetitions
- **Landing** (6% = 1800h) → Run 07-landing
  test: 42,9s → 151 049 repetitions

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Step 2: Calculate damage potential

Qualifiy different flightconditions on the potential damage creation due to vibrations

Damage related information needs to be extracted from the time measurements

Two important results:

- **MRS** – Maximum Response Spectrum
  Takes into account damage from high amplitude vibrations

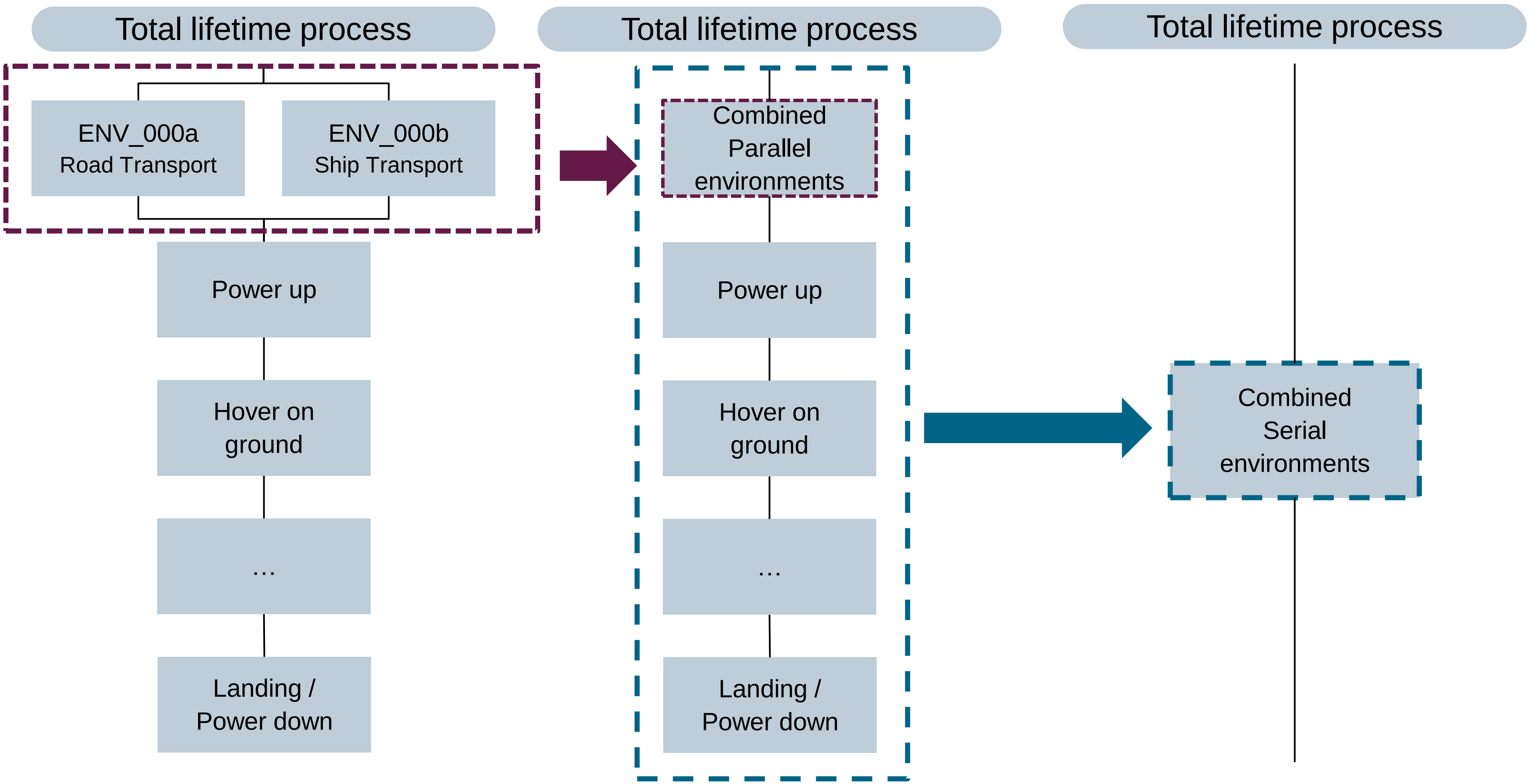
- **FDS** – Fatigue Damage Spectrum
  Calculates damage coming from low amplitudes but high number of cycles (long duration)

MRS and FDS

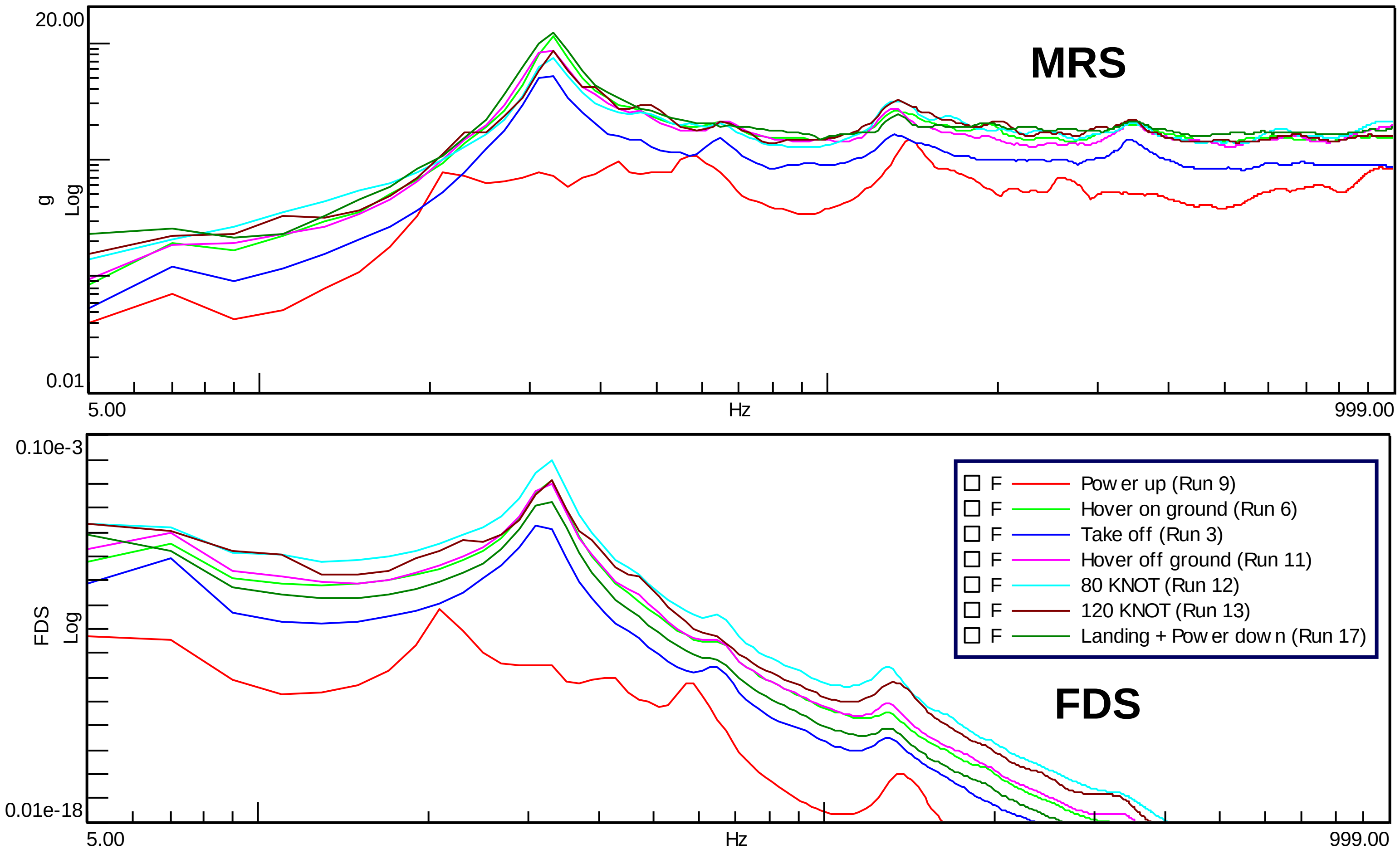
- Calculated seperately for each flight condition
- All results combined in one final MRS and FDS

Step 2 : Calculation of overall damage

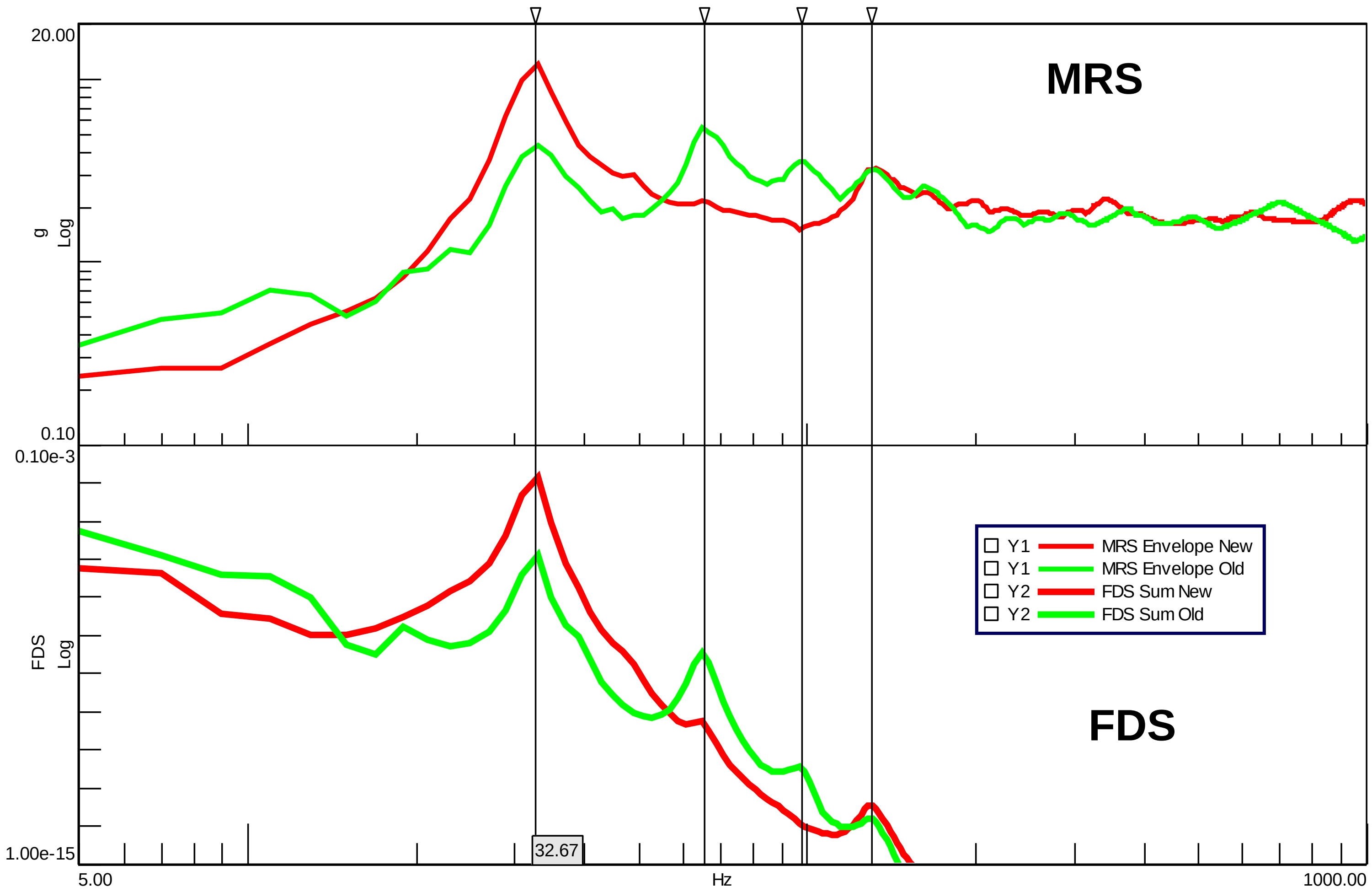
- Combine spectra (MRS/FDS) of the different situations to an overall life cycle MRS/FDS
- Concept of keeping the highest damage potential



Step 2: Synthesize FDS & MRS



Step 2: Synthesize FDS & MRS
Comparison between old and new console



Step 2: Synthesize FDS & MRS
Comparison between old and new console

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Comparison

- Old console has overall higher FDS than new console, except at **33 Hz**, the 5th harmonic (blade passing frequency)
  33 Hz is resonance in old & new console, but more distinct in new console.
- **65 Hz and 98 Hz** are highly damped in new console, clearer peaks in old console.
- **130 Hz** is mode in old & new console, shows up as a peak.

Conclusion

- Higher damage for new console at 33 Hz due to resonance and blade excitation
- New console not guaranteed to survive 30.000 hours based on this comparison

Step 3: Statistics
Test & Uncertainty factors

Uncertainty factor: Limited number of measurements performed
Take into account material and environment variability

$$k = \exp\left[\text{aerf}\sqrt{(1+V_E^2)(1+V_R^2)} - \ln\sqrt{\frac{1+V_E^2}{1+V_R^2}} \right] \qquad \text{aerf} = \text{erf}^{-1}\left(F - \frac{1}{2}\right)$$

ln

With V_E = Environmental coeff of variation
V_R = Material coeff of variation
F = reliability = 1 – P(failure)

Test factor: Limited number of shaker tests planned

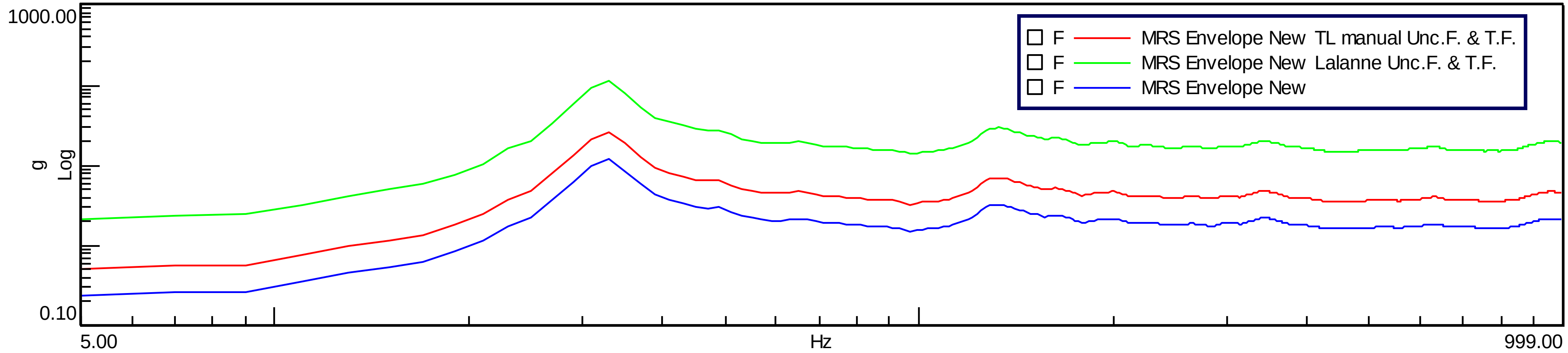
$$T_F = \exp\left(a'\sqrt{\frac{\ln(1+V_R^2)}{n}}\right)$$

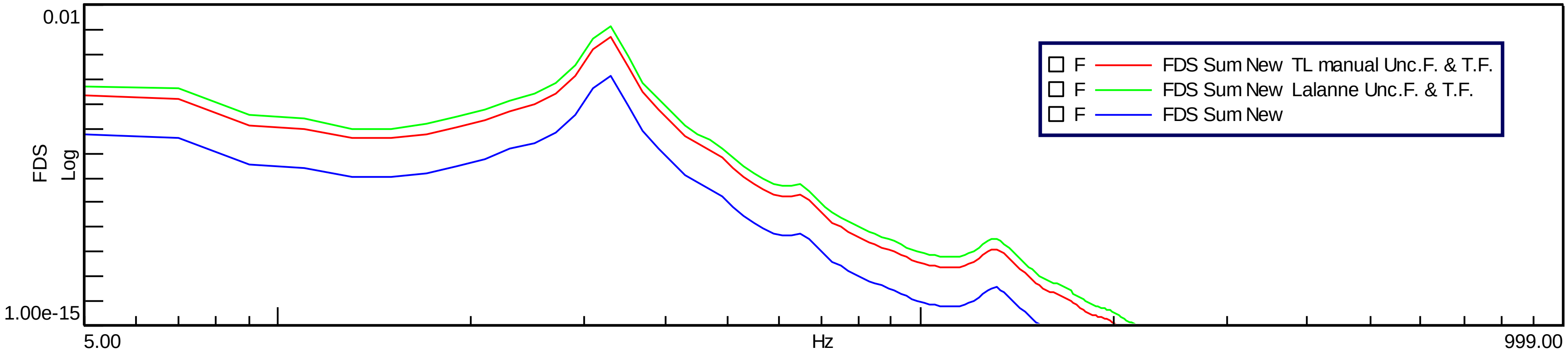
With n = number of tests
a' = probability factor for a given confidence level π_0

$a' = \sqrt{2}\, E_1^{-1}(\pi_0)$ With E_1 = error function

Step 3: Test & Unc. factor

LMS Test.Lab vs Lalanne:

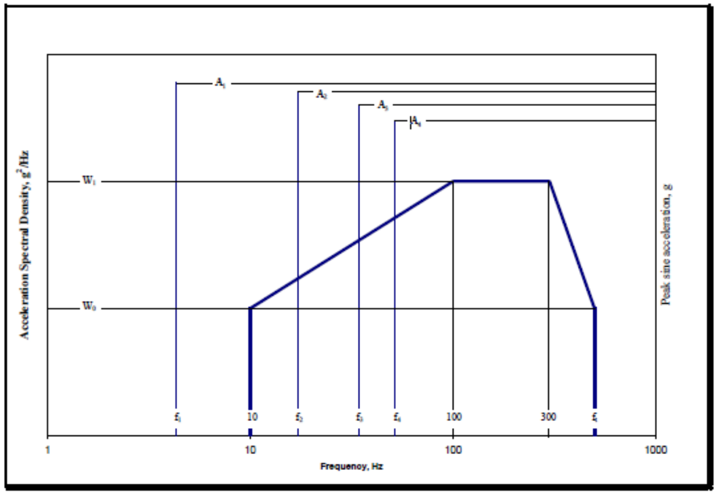




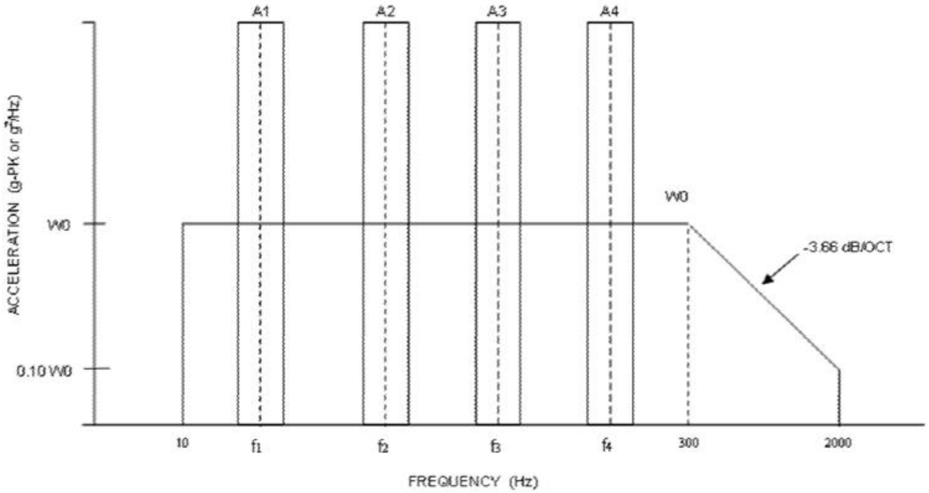
Step 4: Compare with standards

2 Standards (Sine-on-Random):

MIL 810 G
Military standard
random + 4 fixed sines

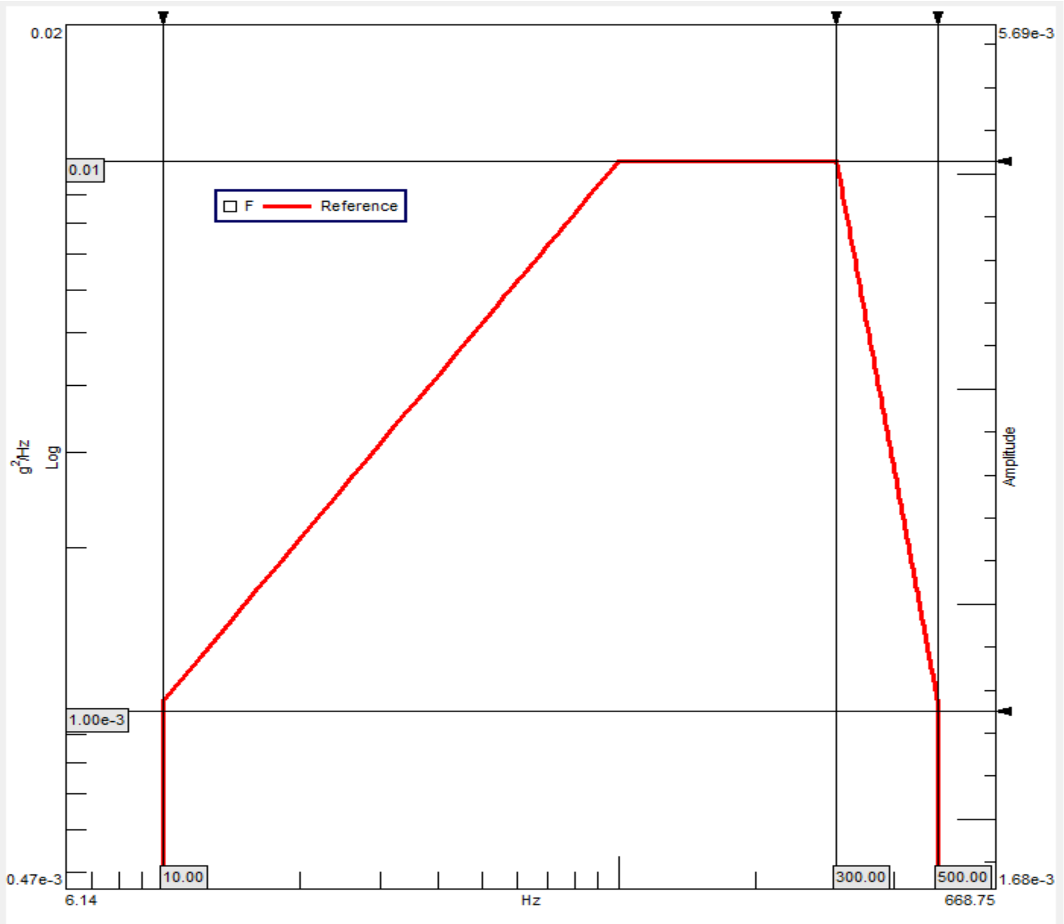


DO 160 F
Civil standard
random + 2 fixed sines



MIL 810 G: random + 4 fixed sines

Random:



Step 4: Compare with standard PSD

MIL 810 G: random + 4 fixed sines

Rotation speed main rotor: 392 rpm = 6,53 Hz

N = nr of blades = 5

f1 = 6,53 Hz	A1 = 0,168 g
f2 = 32,67 Hz	A2 = 1,75 g
f3 = 65,33 Hz	A3 = 1,05 g
f4 = 98 Hz	A4 = 1,05 g

Main or Tail Rotor Frequencies (Hz) Determine 1P and 1T from the Specific Helicopter or from the table (below).		
f_1 = 1P	f_1 = 1T	fundamental
f_2 = n x 1P	f_2 = m x 1T	blade passage
f_3 = 2 x n x 1P	f_3 = 2 x m x 1T	1st harmonic
f_4 = 3 x n x 1P	f_4 = 3 x m x 1T	2nd harmonic

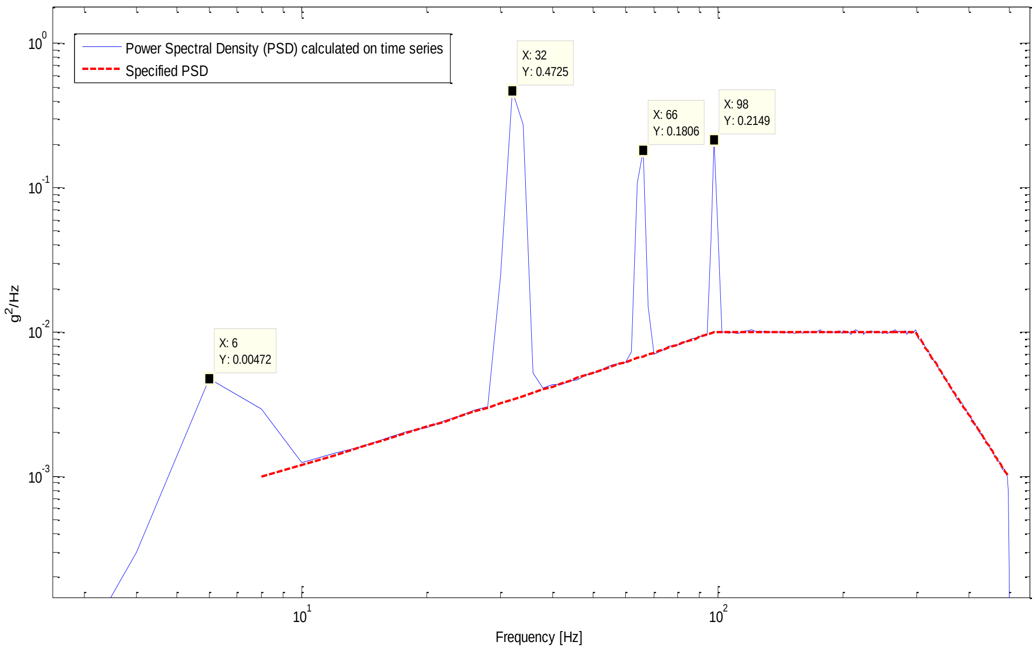
Instrument Panel	W_0 = 0.0010 g^2/Hz W_1 = 0.010 g^2/Hz f_t = 500 Hz	3 to ≤ 10 >10 to 25 25 to 40 40 to 50 50 to 500	0.70 /(10.70 - f_x) 0.070 x f_x 1.750 4.550 - 0.070 x f_x 1. 050

Step 4: Compare with standard PSD

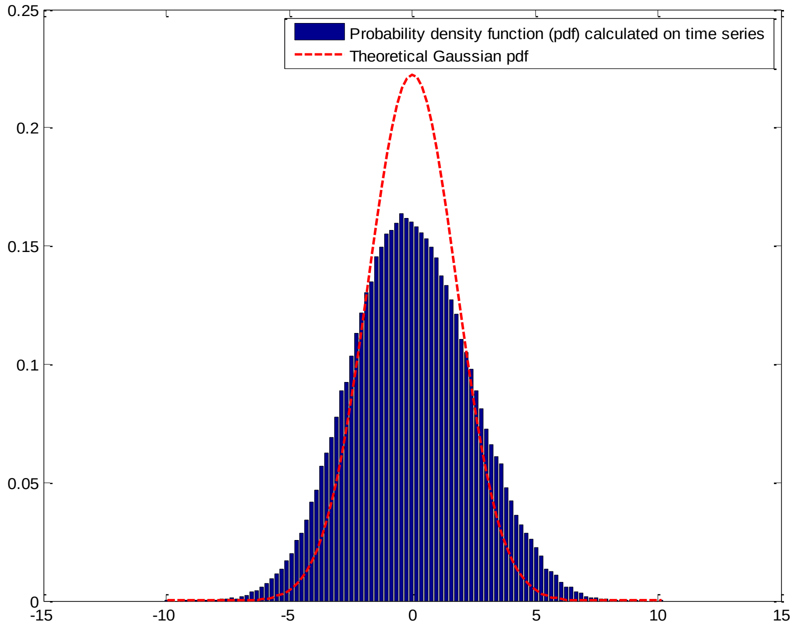
MIL 810 G: random + 4 fixed sines

- Timeseries Sine-on-Random: synthesised in Matlab
  - Timeseries of fixed sines + timeseries of random PSD profile
  - Simulated timerecord of 60s
  - MIL 810 G is for 4h testing, representing 2500h lifetime
  - Need 30 000h lifetime → 48h testing time needed → 2880 repetitions

MIL 810 G: Timeseries Sine-on-Random



Sine-on-Random profile calculated from timeseries plotted with the specified random PSD



PDF of the timeseries is not perfectly Gaussian anymore

Step 4: Compare with standard PSD

DO 160 F: random + 2 fixed sines

Rotation speed main rotor: 392 rpm = 6,53 Hz = FM

NM = nr of blades = 5

f1 = 32,67 Hz   A1 = 2,5 g

f2 = 65,33 Hz   A2 = 2,5 g

Helicopter Zone Vibration Test Frequencies						
Zone / Test Curve	1a / G	1b / G	2 / G	3 / H	4 / I	7 / J
(1) Test Frequencies f_n	Fuselage	Tail boom	Instrument Panel Console & Equipment Rack	Nacelle & Pylon	Engine & Gear Box	Empennage, & Fin Tip
f_1	NMxFM	NMxFM	NMxFM	NMxFM	NMxFM	NMxFM
f_2	2xNMxFM	2xNMxFM	2xNMxFM	2xNMxFM	2xNMxFM	2xNMxFM
f_3		NTxFT		FE	FE	NTxFT
f_4		2xNTxFT		FG	FG	2xNTxFT

HELICOPTER VIBRATION TEST CURVE TEST LEVELS (ENDURANCE)				
Test [(1)] Frequency Range, Hz	Sinusoidal Test Levels, An, (g-PK) [(2)]			
	G	H	I	J
$3 < f_n < 10$	$0.05 \times f_n$	$0.07 \times f_n$	$0.1 \times f_n$	$0.2 \times f_n$
$10 < f_n < 20$	$(0.2 \times f_n)-1.5$	$(0.28 \times f_n) - 2.1$	$(0.3 \times f_n) - 2$	$(0.3 x f_n) - 1$
$20 < f_n < 40$	2.5	3.5	4.00	5.00
$40 < f_n < 200$	2.5	3.5	$(0.1 \times f_n)$	5.00
$200 < f_n < 2000$			20.00	
PSD	Random curve level (g^2/Hz (Grms))			
W_0	0.02 (3.89)	0.02 (3.89)	0.02 (3.89)	0.02 (3.89)

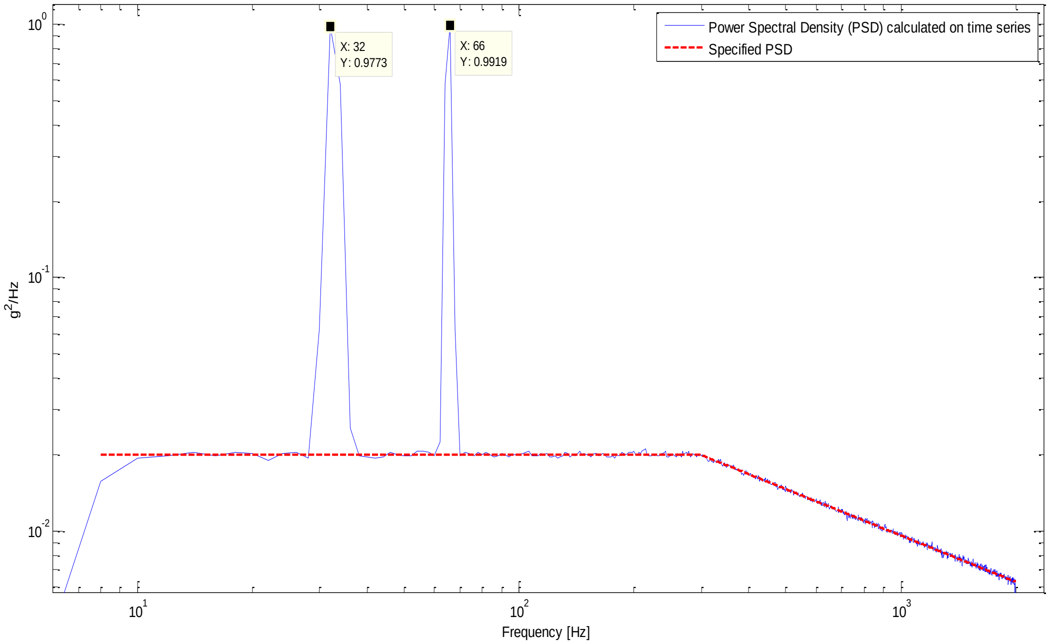
Step 4: Compare with standard PSD

DO 160 F: random + 2 fixed sines

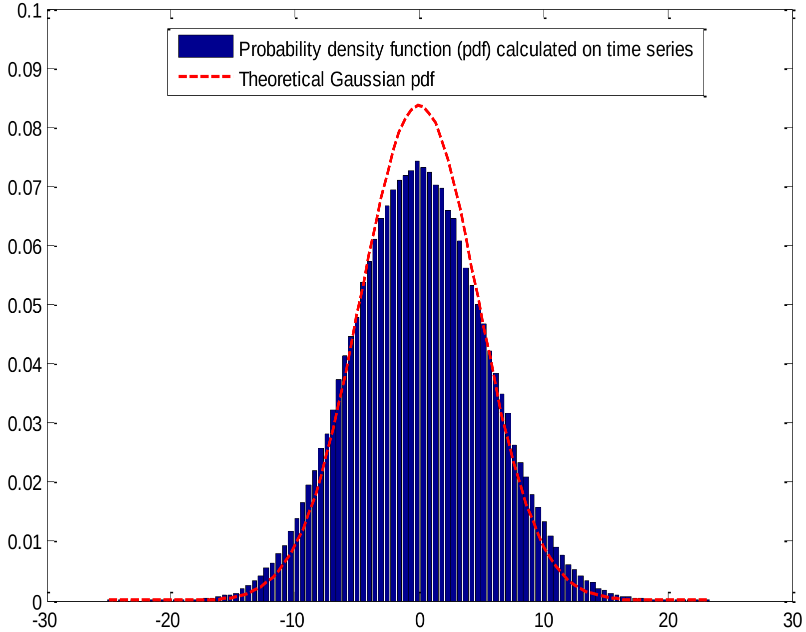
- Timeseries Sine-on-Random: synthesised in Matlab
  - Timeseries of fixed sines + timeseries of random PSD profile
  - Simulated timerecord of 60s
  - DO 160 F is for 2h testing, representing total lifetime (= 30 000h)
  - 2h testing→ 120 repetitions needed
  - good FSD & MRS (peaks at right frequencies)

Step 4: Compare with standard PSD

DO 180 F: Timeseries Sine-on-Random

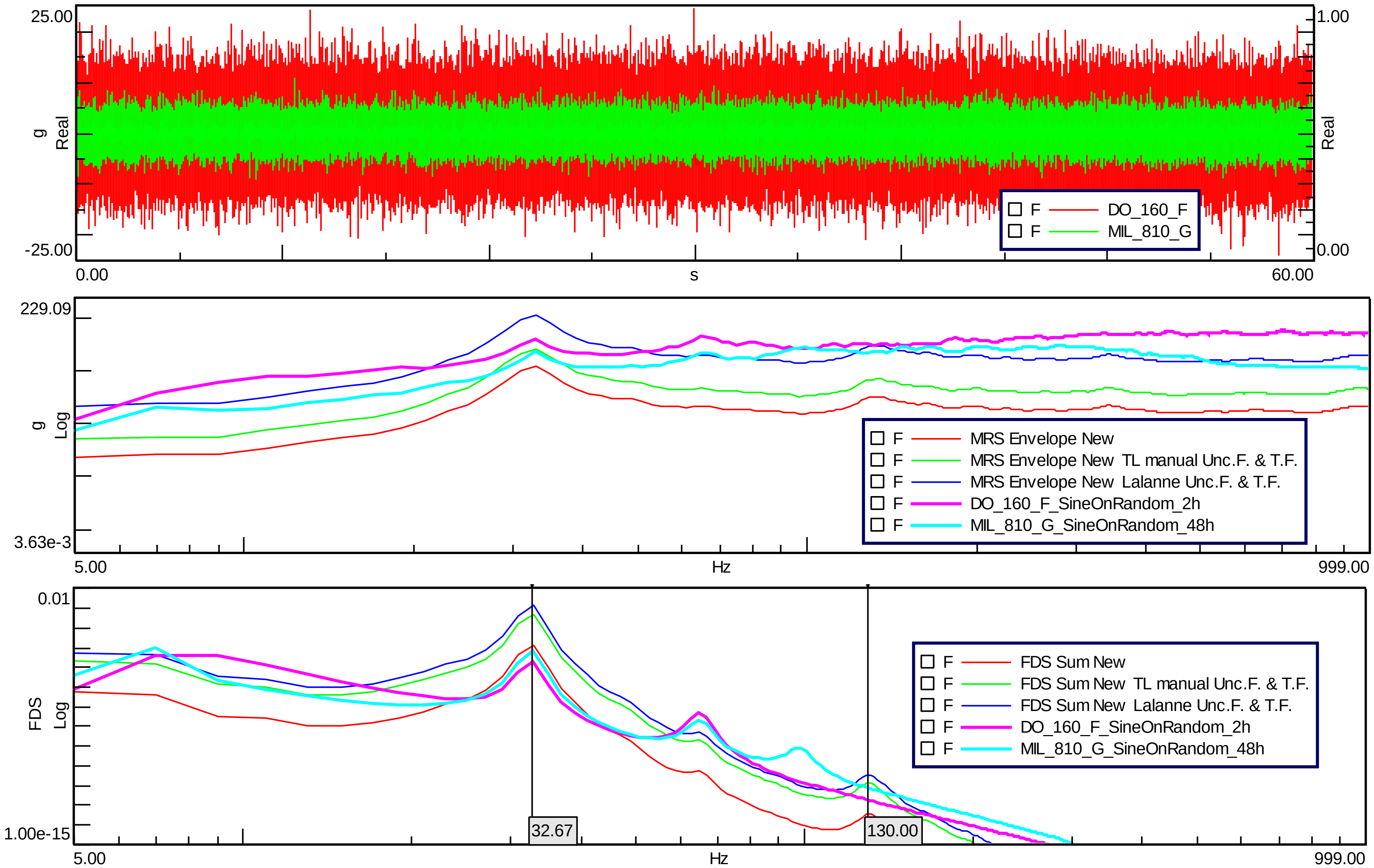


Sine-on-Random profile calculated from timeseries plotted with the specified random PSD



PDF of the timeseries is not perfectly Gaussian anymore

Step 4: Compare with standard PSD



Step 4: Compare with Standards

Comparison with standards

- Both DO 160 F and MIL 810 G undertest at 33 Hz (at the blade pass frequency)
- Both undertest at 130 Hz (20th harmonic of rotor frequency)

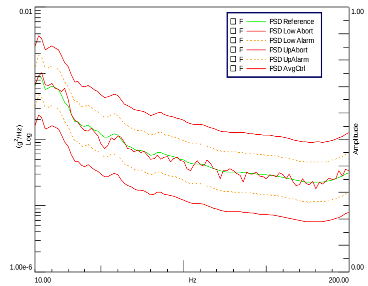
Conclusion

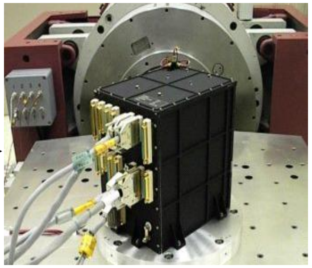
- Succesfull shaker tests based on standards will not guarantee lifetime of 30.000 hours of VHF radios when mounted on new console
- Design of new console is not sufficient -> Redesign necessary
- Repeat measurements and calculations after redesign

Step 5 : Test Profile Synthesis

Test Profile Synthesis

Final MRS and FDS



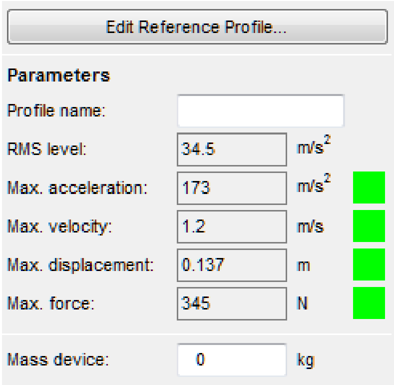


Test Profile Synthesis:

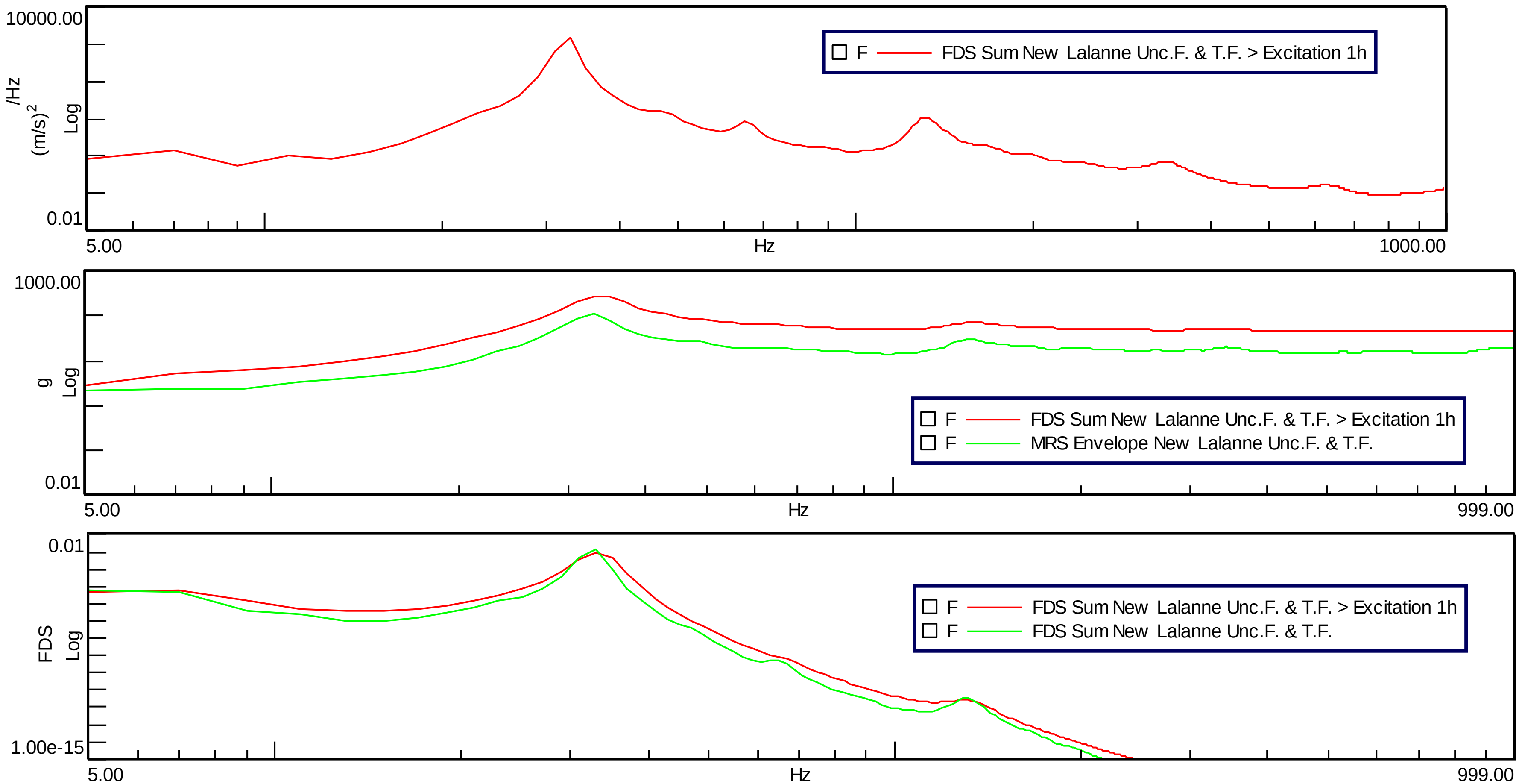
- Choose desired test (Random Control test or Sine Control Test)
- Create shaker profile based on FDS result
- Choose Total testing time using MRS result

Result:

- Profile with same damage potential as in real life
- Check if profile can be used on shaker (shaker limitations)



Step 5: Synthesise excitation PSD



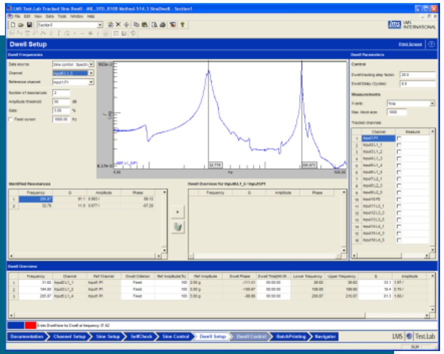
LMS Test.Lab Vibration Control

Random

- ✓ Random Control
- ✓ Response limiting
- ✓ Online Random & Acoustic Reduction

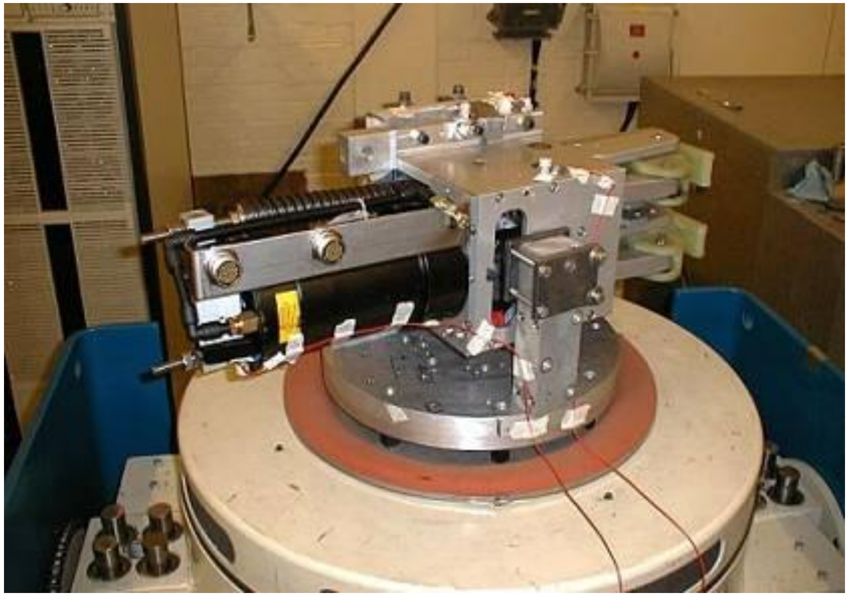
Sine

- ✓ Sine control
- ✓ Sine Notching
- ✓ Throughput recording
- ✓ Online Sine Reduction



Setup

- ✓ Take profile from Mission Synthesis
- ✓ Take corresponding testing time



Thank you

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