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European Aviation Safety Agency

# Helicopter anti resonance and vibration ground & flight testing

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## Objective

- To provide an overview on helicopter regulation regarding vibrations
- To provide an approach to vibration testing to design organizations not dealing daily with external loads

# A PRACTICAL CASE

**Once upon a time…**

**South Europe, ca 1998**

# installing an external load

- Aspects to consider when installing an external load:
  - performances (rate of climb, hover, etc)
  - handing qualities (VFR/IFR), AFCS
  - Vibrations (initial resonance, in flight)
  - Anemobarometric impact (Altitude, airpeeed)
  - Aeroelasticity
  - Trajectory analysis in case of loss of the item

  *(list not exhaustive…)*

  - We will focus on vibration testing

# Helicopter vibrations: A bit of regulatory background

**CS 27&29.251** Vibration

Each part of the rotorcraft must be free from excessive vibration under each appropriate speed and power condition.

**CS 27&29.771** Pilot compartment

For each pilot compartment:

(a) The compartment and its equipment must allow each pilot to perform his duties without unreasonable concentration or fatigue;

(c) The vibration and noise characteristics of cockpit appurtenances may not interfere with safe operation.

# Helicopter vibrations: A bit of regulatory background

## **CS 27&29.1141** Powerplant controls: general

(c) Each control must be able to maintain any set position without:

(1) Constant attention; or

(2) Tendency to creep due to control loads or vibration.

## **CS 27&29.1321** Arrangement and visibility

(c) Instrument panel vibration may not damage, or impair the readability or accuracy of, any instrument.

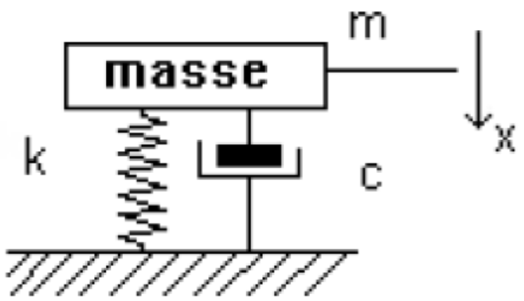
## **CS 27&29.1327** Magnetic direction indicator

(a) Except as provided in sub-paragraph (b):

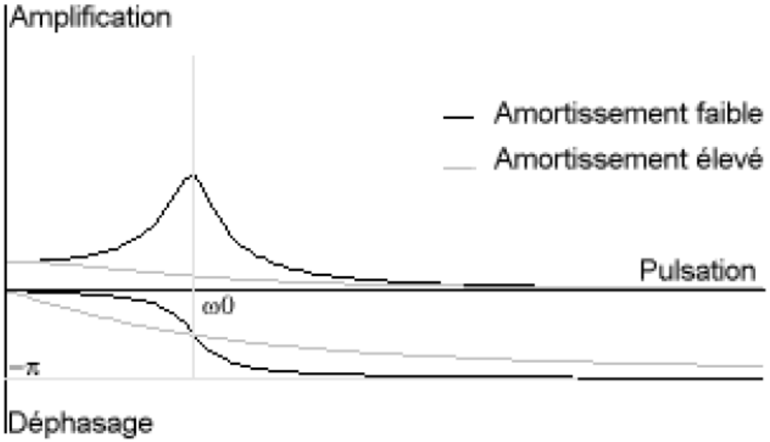
(1) Each magnetic direction indicator must be installed so that its accuracy is not excessively affected by the rotorcraft's vibration or magnetic fields;

# Some theory recall

- Linear system spring/damping at one degree of freedom:

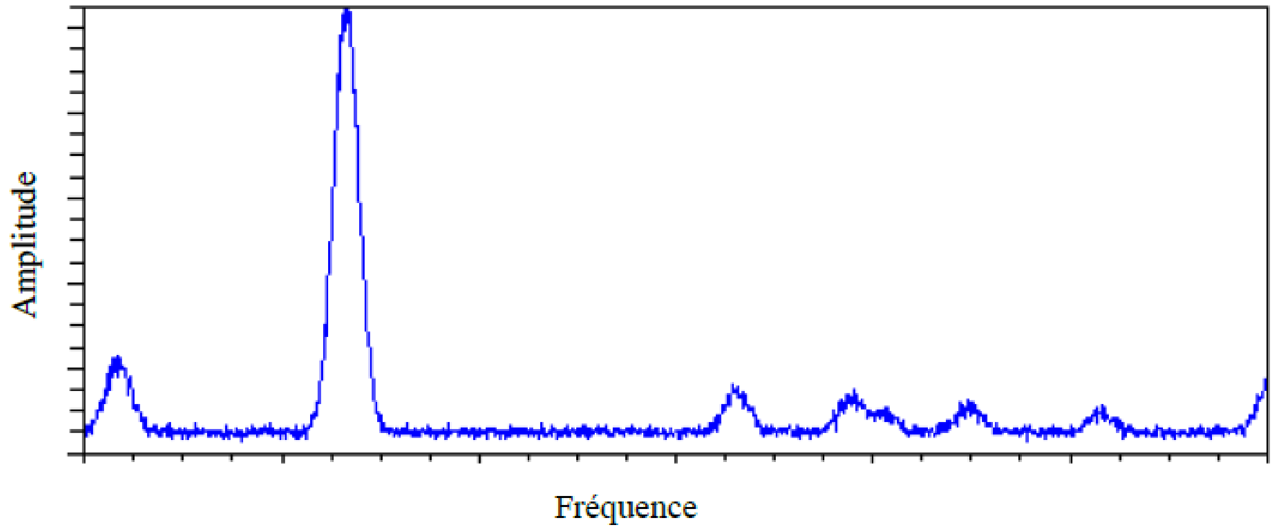



- This will lead to the following:



# Some theory recall

- During the flight the result is something as below:



# Standards talking about vibration testing

- **Standards talking about vibration testing** :
  - MIL-STD 810 (USA),
  - DEF- STAN 0035 P3(UK),
  - IEC 60068 (international)
  - STANAG 4370 (NATO),
  - GAM EG 13/AIR 7306 (France)
  - EUROCAE ED-14G (Europe) (equivalent to the US DO160 G)

# Source of vibrations induced by the helicopter

| Source | Frequency Range (Hz) |
|---|---|
| Ride motions, effects of turbulence | 0-3 |
| Main Rotor R | 3-7 |
| Fuselage bending modes | 5-8 |
| Rigid body modes of external stores on their carriers | 6-20 |
| Main Rotor blade passing nR | 11-26 |
| Tail rotor T, multiples of nR, tail drive shaft, pumps, gearboxes | 8-80 |
| Tail rotor blade passing nT, Pumps, engines and gearbox, output shafts | 100-140 |
| Main gearbox tooth meshing | 450-700 |
| Further gearbox tooth meshing frequencies | 1000-5000 |
| Engine turbine blades passing | 10000-plus |

*(values for reference only)*

# Source of vibrations vs helicopter area

*Beware of location of external load  and ist related main source of vibration*

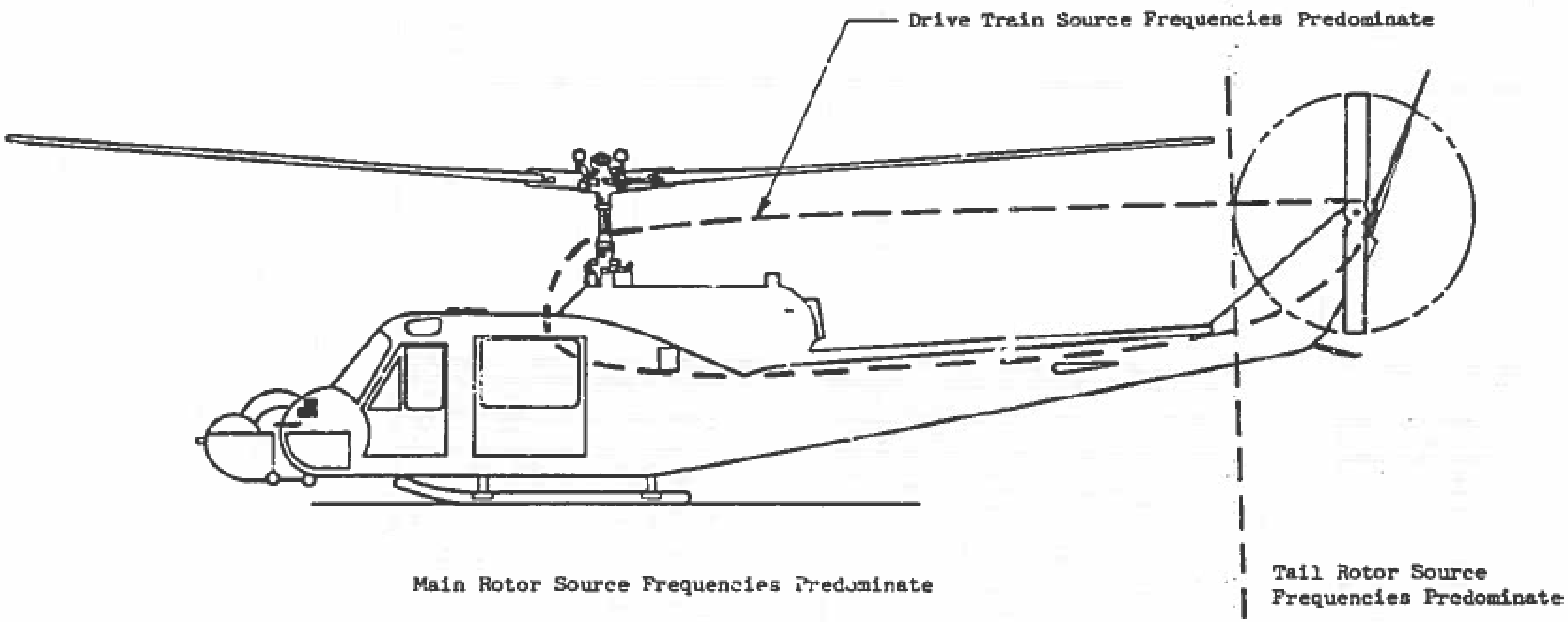



FIGURE 514.3-29. Zones for rotary wing aircraft.

# Nominal fundamental rotor frequency per type

**Identify the helicopter nominal frequencies**

- For both main and tail rotor
- Beware of variable rotor RPM!
- The standards usually report tables for helicopter
- To be checked again with the RFM

| Helicopter | MAIN ROTOR | | TAIL ROTOR | |
|---|---|---|---|---|
| | Rotation Speed 1P (Hz) | Number of Blades n | Rotation Speed 1T (Hz) | Number of Blades m |
| | 5.40 | 2 | 27.7 | 2 |
| | 7.80 | 5 | 47.5 | 2 |
| | 4.82 | 4 | 23.4 | 4 |
| | 4.86 | 4 | 23.6 | 4 |
| | 3.75 | 3 | 2 main rotors and no tail rotor | |
| | 7.80 | 5 | 47.5 | 2 |
| | 8.10 | 4 | 51.8 | 2 |
| | 5.90 | 2 | 43.8 | 2 |
| | 6.60 | 4 | 39.7 | 2 |
| | 5.40 | 2 | 27.7 | 2 |
| | 4.30 | 4 | 19.8 | 4 |

# Checking your helicopter allowed vibration exposure

## Calculate max values allowed

*(examples not updated)*

- The standards provide graphics reporting energy vs frequency divided for kind of external or internal stores
- To be used on specific tables

| MATERIEL LOCATION | RANDOM LEVELS | SOURCE FREQUENCY ($f_x$) RANGE (Hz) | PEAK ACCELERATION (A) at $f_x$ (GRAVITY UNITS (g)) |
|---|---|---|---|
| General | $W_0 = 0.0010\ g^2/Hz$ | 3 to 10 | $0.70/(10.70 - f_x)$ |
| | $W_1 = 0.010\ g^2/Hz$ | 10 to 25 | $0.10 \times f_x$ |
| | $f_t = 500$ Hz | 25 to 40 | 2.50 |
| | | 40 to 50 | $6.50 - 0.10 \times f_x$ |
| | | 50 to 500 | 1.50 |
| Instrument Panel | $W_0 = 0.0010\ g^2/Hz$ | 3 to 10 | $0.70/(10.70 - f_x)$ |
| | $W_1 = 0.010\ g^2/Hz$ | 10 to 25 | $0.070 \times f_x$ |
| | $f_t = 500$ Hz | 25 to 40 | 1.750 |
| | | 40 to 50 | $4.550 - 0.070 \times f_x$ |
| | | 50 to 500 | 1.050 |
| External Stores | $W_0 = 0.0020\ g^2/Hz$ | 3 to 10 | $0.70/(10.70 - f_x)$ |
| | $W_1 = 0.020\ g^2/Hz$ | 10 to 25 | $0.150 \times f_x$ |
| | $f_t = 500$ Hz | 25 to 40 | 3.750 |
| | | 40 to 50 | $9.750 - 0.150 \times f_x$ |
| | | 50 to 500 | 2.250 |
| On/Near Drive System Elements | $W_0 = 0.0020\ g^2/Hz$ | 5 to 50 | $0.10 \times f_x$ |
| | $W_1 = 0.020\ g^2/Hz$ | 50 to 2000 | $5.0 + 0.010 \times f_x$ |
| | $f_t = 2000$ Hz | | |

| Main or Tail Rotor Frequencies (Hz) Determine 1P and 1T from Specific Helicopter or from Table (below). | | | Drive Train Component Rotation Frequency (Hz) Determine 1S from Specific Helicopter and Component. | |
|---|---|---|---|---|
| $f_1 = 1P$ | $f = 1T$ | fundamental | $f = 1S$ | fundamental |
| $f = n \times 1P$ | $f = m \times 1T$ | blade passage | $f = 2 \times 1S$ | 1st harmonic |
| $f = 2 \times n \times 1P$ | $f = 2 \times m \times 1T$ | 1st harmonic | $f = 3 \times 1S$ | 2nd harmonic |
| $f = 3 \times n \times 1P$ | $f = 3 \times m \times 1T$ | 2nd harmonic | $f = 4 \times 1S$ | 3rd harmonic |

# Checking your helicopter allowed vibration range (ctd)

## Check your reference tables
*(examples not updated)*

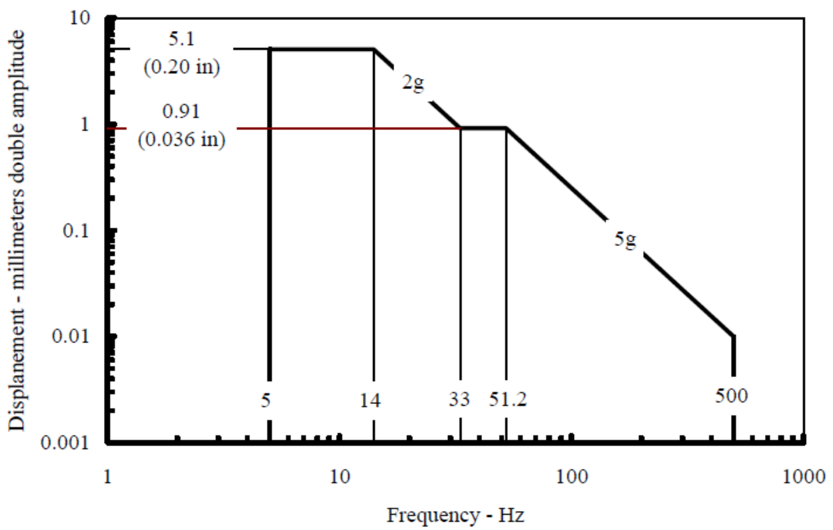



FIGURE 514.5C-18. Helicopter minimum integrity exposure.

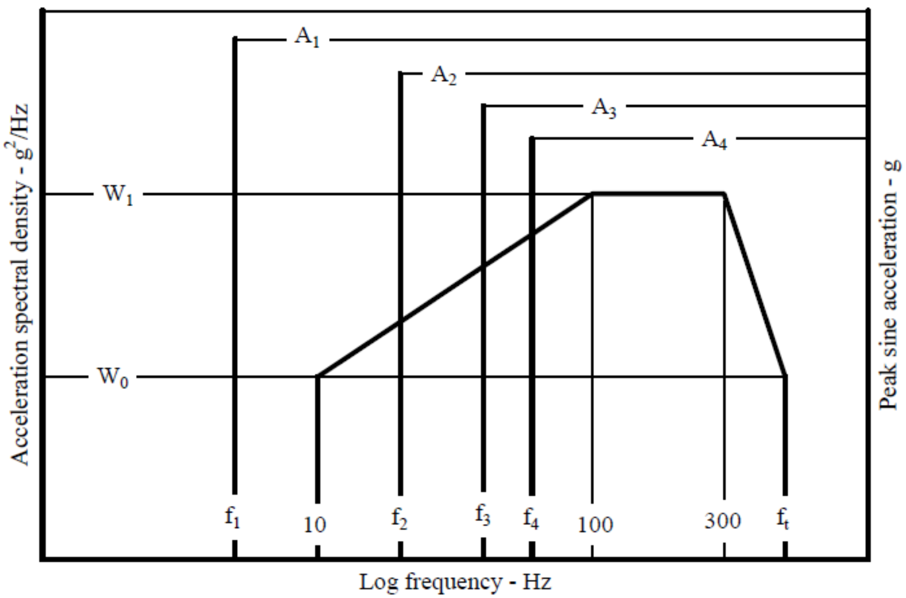
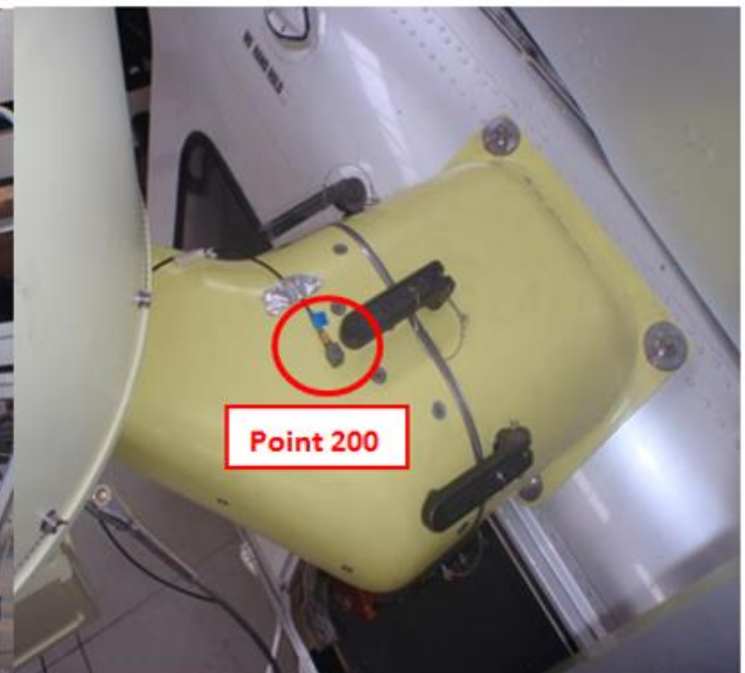



FIGURE 514.5C-10. Helicopter vibration exposure.

# GROUND TESTING: natural frequency determination

- Install your external load
- Place accelerometer(s) on the external load /attachment means

  *(beware 1 to 3 axes, location! )*

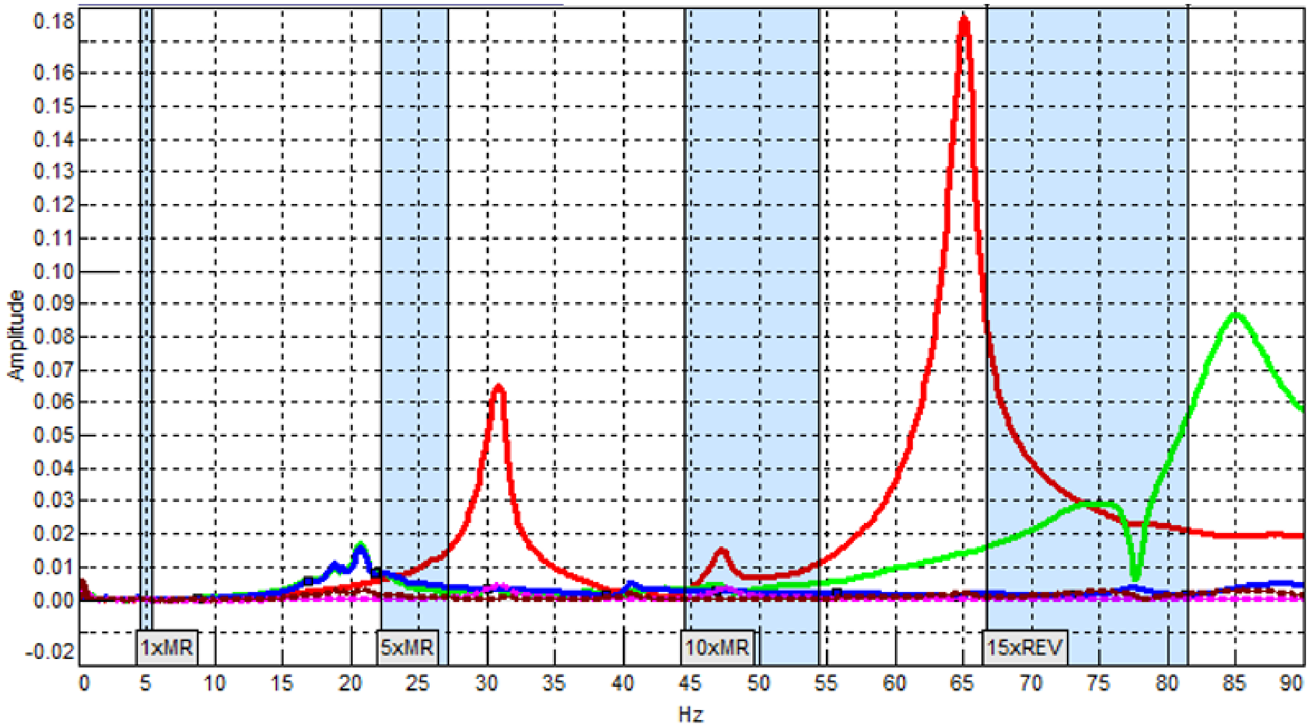


# GROUND TESTING: natural frequency determination *(ctd)*

- **Perform a Bong or Rap test**

# GROUND TESTING: natural frequency determination *(ctd)*

- **Identify natural frequency of the external load**
- **Make comparison with helicopter nominal frequencies:**



# GROUND TESTING: natural frequency determination *(ctd)*

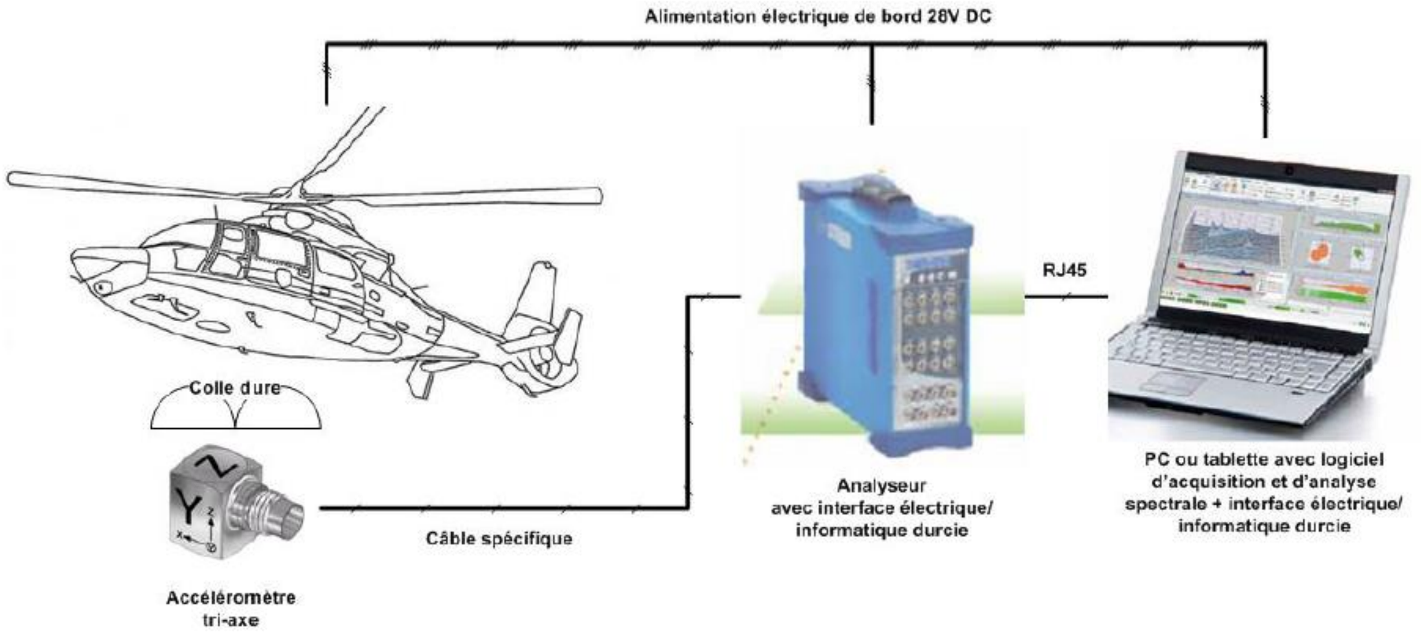
- **If conflict exists, then modify parameters affecting the natural frequency**

  ***(usually change of inertia like weight of geometry change)***

  ***TIP: NEVER START UP THE ROTOR BEFORE DOING THE ABOVE CHECKS!!!***

# FLIGHT TESTING: (1) preparation

- **Install your vibration collecting device**




- ***TIP: accelerometers on the load/attachment and on a reference maintenance location***

# FLIGHT TESTING: (2) reference flight- clean-

- **Do a reference flight WITHOUT external load installed**

  *TIP: Do before a main and tail rotor track and balance*

- **Test the maneuvers as hover, low speed quartering flights, cruise, climb, descent**

# FLIGHT TESTING: reference flight- *(ctd)*-

**An example of flight profile is given in ADS 27**

*(data not updated)*

- **INCREAMENTAL APPROACH!**

*NOTE: Normally 1.11 VNE should be flown to comply with CS/FAR 27/29. 251*

ADS-27A-SP

TABLE II. Flight Vibration Survey Test Conditions

| CONDITION | VELOCITY | DENSITY ALTITUDE |
|---|---|---|
| Hover IGE | 0 | Runway |
| Hover OGE | 0 | 50 ft. above runway |
| Hover, Petal Turns L&R | 0 | 50 ft. above runway |
| Forward Flight | (.1, .2, .25, .3, .35, .4) $V_H$ | Runway |
| Rearward | (.33, .67, 1) $V_{Rear\ Limit}$ | Runway |
| Left Sideward | (.33, .67, 1) $V_{Left\ Limit}$ | Runway |
| Right Sideward | (.33, .67, 1) $V_{Right\ Limit}$ | Runway |
| RPM Sweep .9$V_H$, .4$V_H$ | (.96, .98, 1.0, 1.02) % $N_R$ (or to the "beep" limits | Safe Altitude |
| Forward Flight | (.5, .6, .7, .8, .9, 1.0) $V_H$ | Safe Altitude |
| Descent & $V_H$ | (1.1, 1.2) $V_H$, $V_{NE}$ | Safe Altitude |
| Left and Right Turns | .9 $V_H$ (1.5, 1.75, 2.0, 2.25g) | 5000 ft. |
| Left and Right 40° Bank | .3$V_H$ | Runway |
| Autorotations | Max Entry Speed | Safe Altitude |
| Climbs | | Safe Altitude |
| Descents | | Safe Altitude |

# FLIGHT TESTING: reference flight- *(ctd)*-

- **Check for each maneuver the vibratory level on the reference location used for maintenance flights**
  - *This will serve as reference value for the next flight*
- **Use the vibration rating scale to qualitatively assess each flight phase**

**VIBRATION RATING SCALE**

| Degree of Vibration | Description | Pilot Rating |
|---|---|---|
| No Vibration | | 0 |
| Slight | Not apparent to experienced aircrew fully occupied by their tasks, but noticeable if their attention is directed to it or if not otherwise occupied. | 1<br>2<br>3 |
| Moderate | Experienced aircrew are aware of the vibration but it does not affect their work, at least over a short period. | 4<br>5<br>6 |
| Severe | Vibration is immediately apparent to experienced aircrew even when fully occupied. Performance of primary task is affected or tasks can be done only with difficulty. | 7<br>8<br>9 |
| Intolerable | Sole preoccupation of aircrew is to reduce vibration. | 10 |

# FLIGHT TESTING: (3) Vibration test flight

- **BEFORE THE FLIGHT: safety inspection (or survey) of the helicopter Flight Test Installation and of the attachment and external load**

  *TIP: Same Team to reassess qualitatively the vibrations inside the helicopter*

- **ESTABLISH A PASS FAIL CRITERIA qualitative and numeric**

- **Repeat maneuvers of reference flight**

- **INCREMENTAL APPROACH + REAL TIME MONITORING**
- *TIP: consider observers/camera to monitor the load visually*

# FLIGHT TESTING: Vibration test flight *(ctd)*

- **AFTER FLIGHT:**
  - **Safety inspection of the external load and the attachment**

- **DATA ANALYSIS**
  - **data will allow to say if the helicopter external load is within the accpetable range of vibrations dictated by the standards**
  - **The job however is not ended, further structural analysis will then confirm the fatigue life, interval for inspections**

# NEXT STEPS… and special thanks

**NEXT FUTURE STEP:**

- **Create dedicated Guidance Material**

**SPECIAL THANKS to**

- **Reparto Sperimentale Volo**
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  - *INE Patrick Sarda, PEH Patrick Lanteri*
- **EASA**
  - *FTE Raffaele Di Caprio*

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# Thank you for your attention

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