Rotor Noise Sources

- Rotor harmonic noise sources usually dominate external noise:
  - Thickness
  - Loading
- Engine noise is not a major contributor
- Fluctuations in airloads can cause loading noise at higher frequency harmonics:
  - Blade-Vortex Interaction (BVI)
  - Rotor-Wing Interactions
  - Rotor-Stator Interactions
  - Rotor-Rotor Interactions
- These sources are much less sensitive to tip speed reduction
Nondimensional Governing Parameters for Isolated Rotor Harmonic Noise

Ex: Theory & Experiment show harmonic noise to be a function of:

- **Advance Ratio** sets section Mach number and horizontal wake geometry
  \[ \mu = \frac{V_{TAS}}{\Omega R} \]

- **Hover Tip Mach Number** sets section Mach numbers and horizontal wake geometry
  \[ M_H = \frac{\Omega R}{a_0} \]

- **Thrust Coefficient** proportional to section lift coefficients and vortex circulation strength
  \[ C_T = \frac{T}{\rho_0 A (\Omega R)^2} = \frac{v_z}{v_x} \]

- **Wake Skew Ratio** proportional to vertical separation between vortex wake and blade

Additional parameters may be required for configurations where the rotor is not well “isolated”
Low Noise Operations Today

1. Measure noise for one vehicle, at one site, and in steady flight
2. Build noise database
3. Tell operators to avoid the “noisy” flight states

But, what about:
• Unsteady flight?
• Configuration changes?
• Varied ambient conditions?
Fundamental Rotorcraft Acoustic Modeling from Experiments (FRAME)
Three conditions measured:
- Loiter
- Cruise
- Descent

FRAME model calibrated

500 conditions generated:
\[
\chi : \quad -0.03 \text{ to } 0.21 \\
\mu : \quad 0.08 \text{ to } 0.25 \\
C_T : \quad 0.0033 \text{ to } 0.0088
\]
Real Time Noise Awareness

65 dBA
“Annoyance Threshold”

Source Noise Intensity

Climb / Accel
BVI Avoidance Guidance
Descend / Decel

Moving Map

Constant Torque Descending Turn

“Near Time” Low Noise Guidance

- Large reductions in ground noise levels possible through tailored operations that control the rotor state through:
  - Airspeed
  - Flight path angle
  - Acceleration/Deceleration
  - Bank angle

- Flight profiles must be developed at the time-of-use due to changing:
  - Atmospheric conditions
  - Air traffic
  - Mission plans
  - Vehicle configuration

- Fast noise modeling (~500 x real-time) and “greedy” optimization allow “near time” generation of low noise trajectories

Vehicle Configuration Control

- Most rotorcraft have nonunique trim
  - Blade pitch (collective, cyclic, higher-harmonic)
  - RPM
  - Rotor tilt
  - Control surfaces
  - Drag devices
  - On-blade controls (e.g., flaps, jets)
- These nonunique trim states can be exploited for noise reduction
- Some methods of noise reduction may be directional and may harm performance
- “Acoustically-aware” flight controls should optimize vehicle configuration for best balance between noise exposure and performance
Concluding Remarks

• Accurate real time rotor noise estimates are now possible, given some empirical data

• Modeling can be used to provide the operator with “awareness” of the acoustic impact in flight

• Potential for significant noise reductions through tailoring the trajectory and configuration of the vehicle

• “Acoustically-aware” semi- or fully-autonomous systems could be developed to realize acoustic benefits without adding to the pilot workload