Nonlinear Dynamics of Helicopter Rotors

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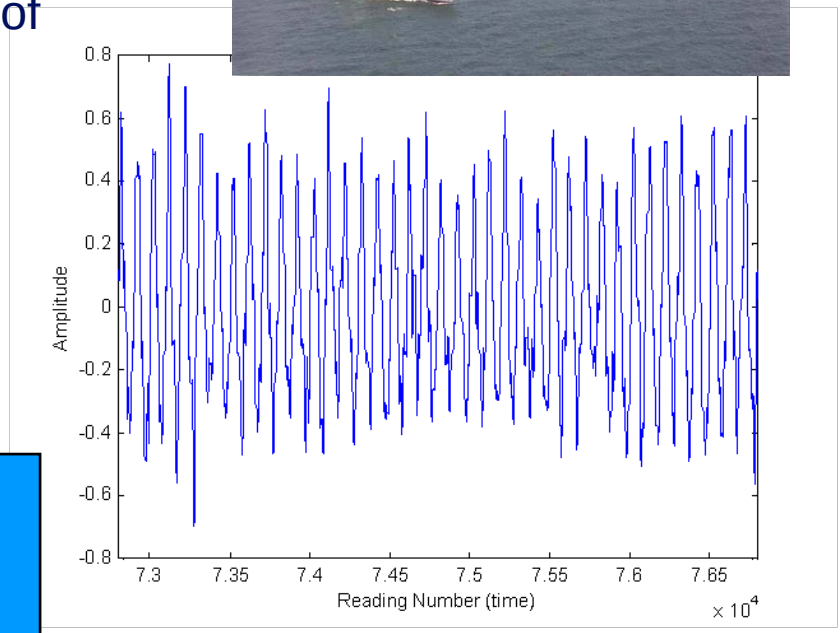
Findings from Previous R&D

- Rotor vibrations occur primarily at the blade passing frequency, plus harmonics.
- Amplitude varies irregularly by up to a factor of two from cycle-to-cycle.
- Dynamics are chaotic, i.e., deterministic but predictable only for short periods of time.
- The source of the instability is likely to be nonlinear cross-coupling among flap-wise, lead-lag, and twisting modes of blade deflection.

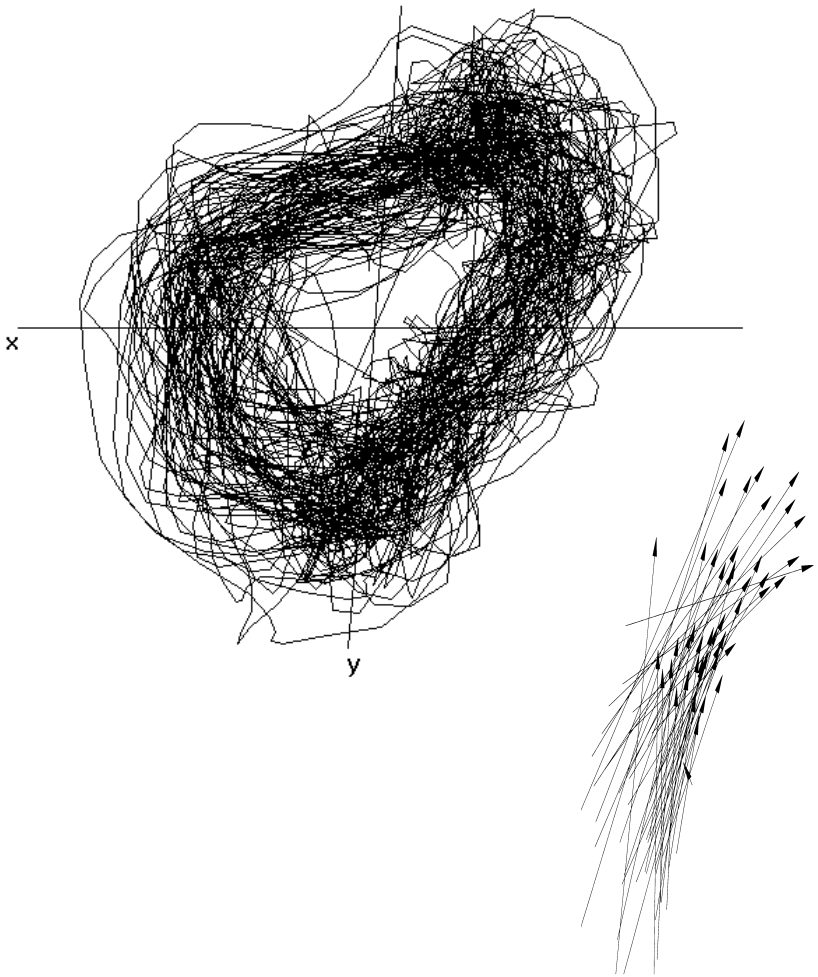
- **Simulations that do not account for these dynamics cannot predict performance approaching DARPA's objectives.**
- **Reduced scale physical tests do not produce the same chaotic dynamics as full scale aircraft.**



EH-101 Flight Data
(ACSR turned off)
140 kias

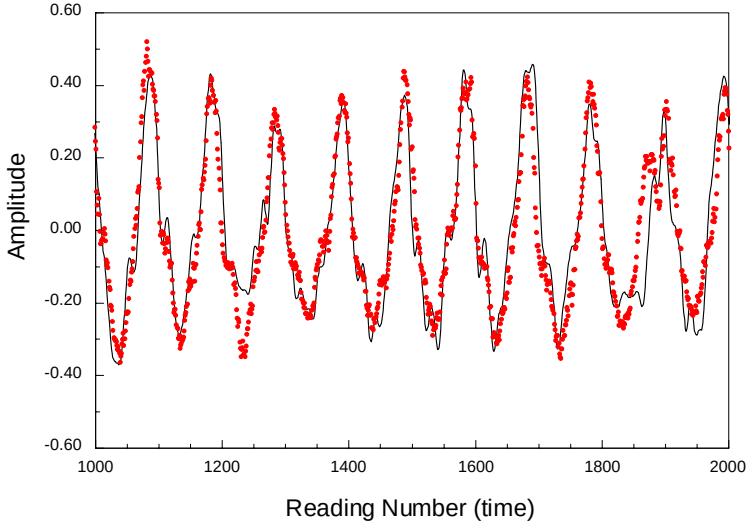
From Raw Data to Reconstructed Dynamics

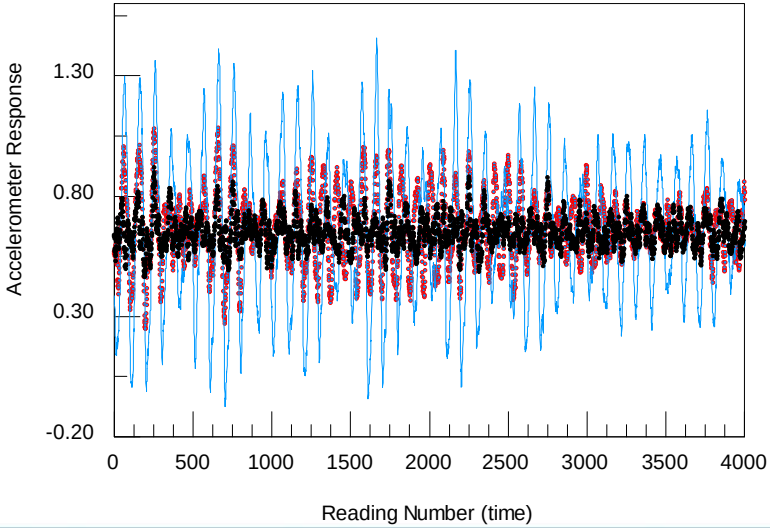
- Rotor dynamics can be reconstructed in real time from experimental data.
- This representation appears somewhat rough, but is actually highly structured: flow in any neighborhood of the attractor is well behaved.
- This means the behavior can be predicted, albeit for short periods of time.
- Where there is prediction, there is control.



Applying Prediction to Vibration Isolation

- Lab testing used reconstructed state space prediction as the basis for an enhancement to ACSR vibration isolation.
- Reduction in vibration response was far greater than with unmodified ACSR, approaching limit of airframe controllability.
- Accompanying detailed knowledge of dynamics provides a basis for sensitive diagnostics.
- The resulting control system is being considered for use in VH-71.





Extension to Mission Adaptive Rotor

- Applying control to a MAR addresses dynamics at their source, calling for a different controls approach.
- Here, the blades themselves would be actuated in response to the flight dynamics (e.g., measured by deflections).
- This may require greater control authority than is currently achievable.
- If successful, the low-dimensional chaos of uncontrolled vibration would be replaced by low-amplitude normal vibration.
- The detailed knowledge of the rotor dynamics would permit sensitive (i.e., prognostic) health monitoring.
- Without accounting for chaotic rotor dynamics, DARPA's vibration reduction objectives probably cannot be met.