RESEARCH OPPORTUNITIES FOR ROTORCRAFT

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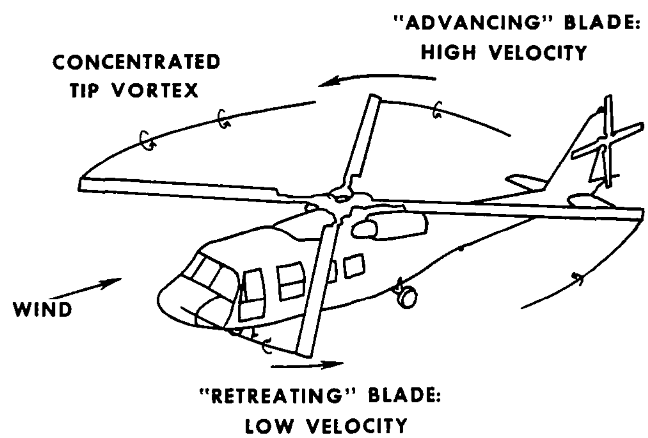
HELICOPTER ROTOR VIBRATORY LOADS

Helicopter vibration reduces crew performance, comfort, component life, and reliability. It originates primarily in unsteady aerodynamic loads on the rotor blades. Both lift and drag vary periodically because blade angle of attack and local velocity change as the blades rotate relative to the direction of flight and travel above and through the vortex wake, as depicted in this figure. Some harmonic components of the periodic blade loads are transmitted to the fuselage, where they produce airframe vibration. The absorbers and isolation systems currently used to reduce this vibration have undesirable weight penalties and often do not achieve vibration levels that are fully satisfactory.

A concept known as higher harmonic control is capable of suppressing vibration through active control of blade pitch at frequencies above the normal once-per-revolution pitch changes.

Successful results have been obtained in wind tunnel tests conducted at Boeing Vertol and by other researchers as well as in flight tests at Hughes Helicopter.



PRIMARY SOURCES	***SECONDARY SOURCES***
ROTOR BLADE SPEED DIFFERENTIAL	ARTICULATED BLADE MOTIONS
VELOCITIES INDUCED BY VORTEX WAKE	ELASTIC BLADE DEFLECTIONS

ACTIVE CONTROL

To achieve near-term results, most current R&D efforts have chosen to obtain the required pitch harmonics using the conventional swashplate control configuration rather than individual blade actuators in the rotating system. The swashplate is already used by both the pilot and the automatic flight control system to provide thrust control by setting the average blade pitch, called collective, and to provide trim and flight path control by creating a one-per-rev variation in blade pitch, called cyclic. The new control will superimpose higher frequency oscillations on the standard swashplate motions to control blade pitch and aerodynamic loads at the vibration harmonics and the adjacent harmonic frequencies. The harmonic hub loads are not to be eliminated completely, but reduced and rephased until their effects in the airframe cancel the effects of other vibration sources, particularly the unsteady aerodynamic loads on the fuselage itself. Higher harmonic control requires an automatic controller because the harmonic blade pitch which achieves optimal results varies greatly with flight condition. The automatic system must analyze vibration measurements in real time to determine the optimum harmonic control, in terms of amplitude and phase of several frequencies.

OPPORTUNITIES

- **FUSELAGE VIBRATION REDUCTION** ← CURRENT R&D EMPHASIS
- **POWER REDUCTION**
- **FLIGHT ENVELOPE EXPANSION (RETREATING BLADE STALL ALLEVIATION)**
- **FATIGUE LOAD REDUCTION BLADES CONTROL SYSTEM**
  - **BLADES**
  - **CONTROL SYSTEM**
- **IMPROVED HANDLING QUALITIES BY REDUCING APPARENT CONTROL LAG**

THE EXTENT OF THE BENEFITS ATTAINABLE DEPENDS ON ROTOR AND FUSELAGE DYNAMICS AND WILL VARY AMONG HELICOPTER DESIGNS

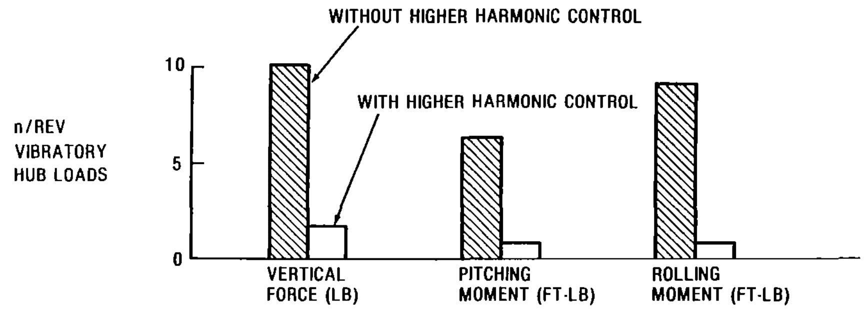
VIBRATION REDUCTION - WIND TUNNEL DEMONSTRATION

The benefits of active control in vibration treatment are shown in this figure. An experimental investigation involving a 10-foot diameter hingeless rotor was conducted at the Boeing Vertol V/STOL wind tunnel. This chart shows that the simultaneous application of three harmonic control inputs resulted in a dramatic reduction in the three vibratory hub loads presented here.

These results were achieved through closed-loop control using hub strain gage balance loads as feedback parameters. The demonstrated response time was 0.075 sec. Typically, higher harmonic control requires a frequency response that is 10 to 20 times greater than primary flight control to provide suppression of higher harmonic loads, particularly during maneuvers and in turbulence. Continued operation at these high frequencies requires improved bearing and seal designs to avoid rapid wear. Furthermore, precise control of the pitch actuation system at higher harmonic frequencies is required for effective vibration reduction.

WIND TUNNEL DEMONSTRATION

- 10-FOOT DIAMETER HINGELESS ROTOR
- THREE HARMONICS APPLIED SIMULTANEOUSLY
- INPUTS SELECTED BY ACTIVE (CLOSED-LOOP) CONTROLLER WITH 0.075 SEC. RESPONSE TIME



REFS. 1 AND 2

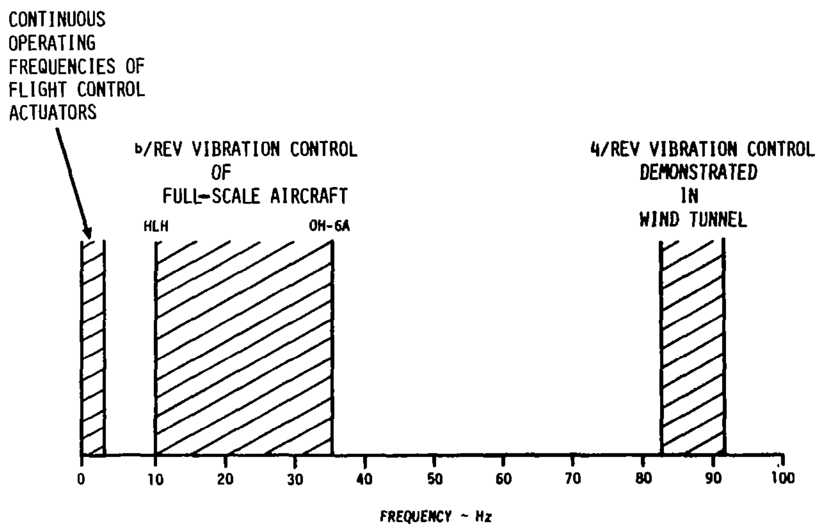
CONTROL ACTUATOR RESPONSE

Flight control power actuators used in all current helicopters have a response bandwidth sufficient for good handling qualities and automatic flight control system performance. Since rotor dynamics dictate a sharp cutoff at rotor rotational speed, there is no need for high system response. Vibration control through higher harmonic pitch demands that control system output be predictable and well defined in both gain and phase at frequencies up to 30 to 40 Hz for small aircraft.

Accurate control at 90 Hz has been experimentally demonstrated in the wind tunnel although at actuator amplitudes and service lives considerably below flight vehicle requirements.

FREQUENCY RANGE OF VIBRATION CONTROL

MUCH HIGHER THAN CURRENT FLIGHT CONTROL PRACTICE



REQUIRED IMPROVEMENTS

Required improvements include:

- Feedback measurements, algorithm design, and closed-loop response to keep pace with the rapidly changing blade pitch requirements needed during maneuvers. Large transient vibration levels are very objectionable to the pilot. It is necessary to understand the effect on aircraft performance and component loads.
- Substantially upgraded control system performance.
- Service life characteristics suitable for production aircraft.

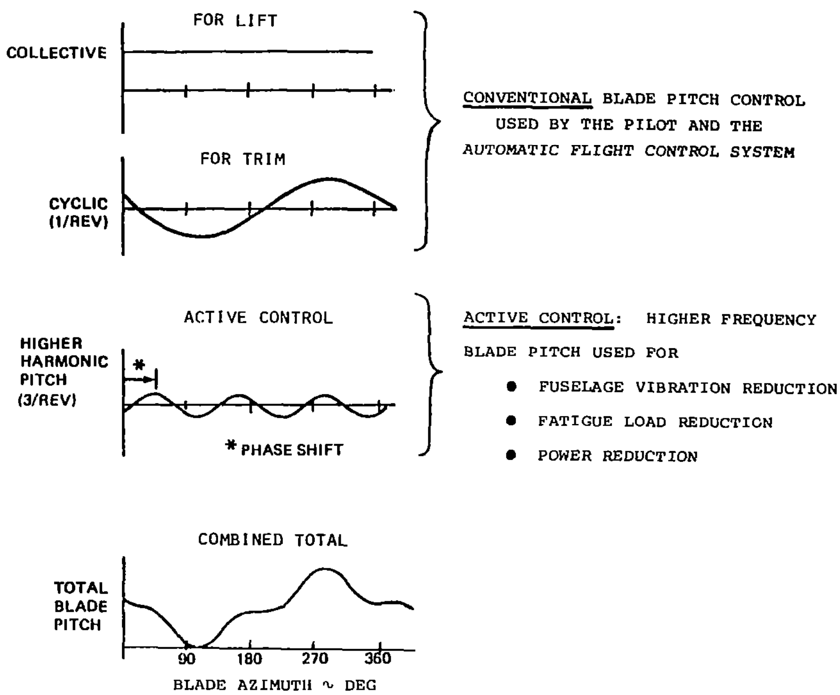
- **REAL-TIME COMPUTATION OF HIGHER HARMONIC INPUTS TO KEEP UP WITH RAPID CHANGE OF FLIGHT CONDITIONS**
- **LARGE INCREASE IN PITCH ACTUATION POWER AND RATE CAPABILITIES**
- **DESIGN FOR GOOD RELIABILITY AND MAINTAINABILITY**
- **PRECISE CONTROL OF PITCH ACTUATION SYSTEM AT HIGHER HARMONIC FREQUENCIES**

SYSTEM BENEFITS

Since vibration has always been a generic problem with helicopters, all research efforts to date have concentrated on reducing aircraft vibration. Unlike other vibration control devices such as isolators and absorbers which add weight and therefore reduce payload, higher harmonic control offers the unique opportunity of more than paying its own way. Redistribution of blade section lift and drag over the rotor disc can significantly reduce power required and increase the usable flight envelope.

It may also be possible to reduce fatigue loads and improve handling qualities. It may not be possible to achieve all these simultaneously. However, the potential benefits to helicopter users are so large that this additional tool now available to helicopter designers must be explored to its fullest.

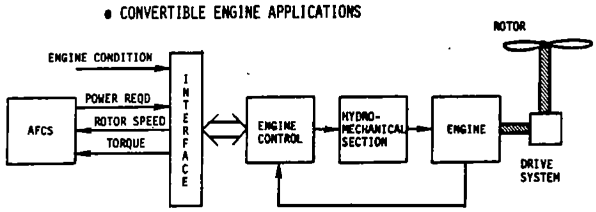
ACTIVE CONTROL USES ROTOR BLADE PITCH TO CONTROL THE UNSTEADY AERODYNAMIC LOADS



ENGINE/FLIGHT CONTROL INTEGRATION

For advanced rotorcraft applications, especially those with more than one mode of operation, improved integration between systems results from including thrust/power management in the AFCS. Generally, functions related to blade pitch control are performed within the aircraft system. By uniting thrust and power management, simpler, more flexible mode transition and selection are possible. The engine control may then act solely as a power control with required limitations, resulting in a more adaptable engine.

- CONTROL CONFIGURATION FOR ADVANCED APPLICATIONS
  - ADVANCED HELICOPTER
  - TILT ROTOR
  - X-WING
  - CONVERTIBLE ENGINE APPLICATIONS



- POWER MANAGEMENT ACCOMPLISHED IN AFCS
  - RESPONSIBILITY FOR ROTOR CONTROL (SPEED & PITCH) IS ENTIRELY WITHIN AFCS - NOT SPLIT AS WITH CONVENTIONAL SYSTEM
  - MULTI-MODE INTERACTIONS AND INCREASED INTEGRATION REQUIREMENTS ARE BEST HANDLED WITHIN AFCS

- ENGINE CONTROL PROVIDES GAS GENERATOR GOVERNING & LIMITING
  - SIMPLER ENGINE CONTROL FUNCTIONING AS POWER CONTROLLER
  - EACH APPLICATION DOES NOT NEED A TAILORED ENGINE CONTROL

- FEWER ENGINE AIRFRAME INTERCONNECTIONS

- PROVIDES HIGH LEVEL OF REDUNDANCY

OVERALL INTEGRATION GOALS

Primary goals for integrating engines and flight controls are to improve handling qualities and system performance. Aircraft control response characteristics may be enhanced through selective inputs to the engine control. Reducing pilot workload by providing simpler engine cockpit controls and eliminating manual backup are important considerations. Automatically optimizing engine performance and establishing diagnostic requirements aimed at improving mission reliability and safety are also engine-related goals of an integration program.

- **IMPROVED HANDLING QUALITIES**

  IMPROVE AIRCRAFT CONTROL RESPONSE CAPABILITY

  SIMPLIFY PILOT CONTROL
  - **ELIMINATE MANUAL BACKUP**

- **OPTIMIZE SYSTEM PERFORMANCE**

  OPTIMIZE ENGINE PERFORMANCE

  IMPROVE MISSION RELIABILITY/SAFETY

  DEVELOP DIAGNOSTIC REQUIREMENTS

INTEGRATION OBJECTIVES

Program objectives should be to optimize response of the integrated system and to upgrade overall engine performance. Specifically, the program should be aimed at improving torsional stability of the engine-rotor/drive when considering multi-mode configurations and engine-out conditions; emphasis should be placed on increasing rotor thrust response to decrease rotor speed droop during rapid maneuvers, gust rejection, and precision hover conditions. Engine and control diagnostics and trend monitoring represent important considerations toward improving engine/aircraft availability. Methods for displaying power margin in conjunction with power assurance and techniques for continuously optimizing system performance should be addressed. An additional objective of a program should be engine failure recognition and indication with subsequent corrective action by the flight guidance system.

OPPORTUNITIES

- OPTIMIZE RESPONSE

  INCREASED TORSIONAL STABILITY
  OF ROTOR/DRIVE SYSTEM

  IMPROVED ROTOR THRUST RESPONSE TO CONTROL
  - RAPID MANEUVERS
  - GUST REJECTION
  - PRECISION HOVER

- UPGRADE ENGINE PERFORMANCE

  ENGINE AND CONTROL DIAGNOSTICS

  TREND MONITORING

  POWER MARGIN/POWER ASSURANCE

  PERFORMANCE OPTIMIZATION

  FAILURE RECOGNITION

ADDITIONAL RESEARCH TOPICS

- DEVELOP LOW-ALTITUDE ATMOSPHERIC TURBULENCE MODEL

  AERODYNAMIC ENVIRONMENT BELOW 100 ft. NEAR OBSTRUCTIONS IS NOT WELL QUANTIFIED

- HUMAN FACTORS

  FLIGHT SIMULATION VISUAL AND MOTION CUE REQUIREMENTS

  METHOD(S) FOR MEASURING PILOT WORKLOAD

- SENSOR TECHNOLOGY

  APPROACHES TO USE OF MULTISPECTRAL IMAGING

  ANALYTICAL REDUNDANCY

  WIRE FINDERS

- PARAMETER IDENTIFICATION

  COMPLEXITY OF REQUIRED MODELS HAS RETARDED PROGRESS RELATIVE TO FIXED-WING AIRCRAFT

REFERENCES

1. Shaw, John and Albion, Nicholas: Active Control of Rotor Blade Pitch for Vibration Reduction: A Wind Tunnel Demonstration. Vertica, vol. 4, no. 1, 1980, pp. 3-11.

2. Shaw, John and Albion, Nicholas: Active Control of the Helicopter Rotor for Vibration Reduction. J. Amer. Helicopter Society, vol. 26, no. 3, July 1981, pp. 32-39.