National Aeronautics and
Space Administration

TECHNOLOGY SOLUTION

Mechanical and Fluid Systems

Improving VTOL Proprotor Stability

Adaptive control methodology provides tiltrotor aircraft improved operational boundary and vibration reduction

Vertical take-off and landing (VTOL) aircraft such as tiltrotors hold the promise to provide the next generation of air transport but are limited in their forward airspeeds due to complex, coupled rotor and wing dynamic instabilities. NASA Langley's Advanced Generalized Predictive Control (AGPC) technology provides swashplate actuators with high-frequency control signals to stabilize dynamic instabilities allowing envelope expansion and to reduce vibration anywhere in the envelope. Compared to existing Generalized Predictive Control (GPC) systems, AGPC is self-adaptive and compares actual system behavior with that predicted by experimentally-derived system identification parameters. This methodology is unique in that modeling parameters are updated by observation of the operational controller and requires no or negligible excitation of the system in order for the adaptation to be successful.

BENEFITS

- Active Ride Control: Self-adaptive control response optimizes damping performance even as flight conditions change.
- Faster Forward Flight Speeds: AGPC eliminates vibrations that would otherwise destabilize proprotors at high airspeeds.
- Ease of Implementation: No additional manual inputs are required to trigger control system corrections to match new flight conditions.
- Expanded Operational Boundaries: May provide faster gust attenuation and flutter suppression response times, improving craft airworthiness.

APPLICATIONS

The technology has several potential applications:

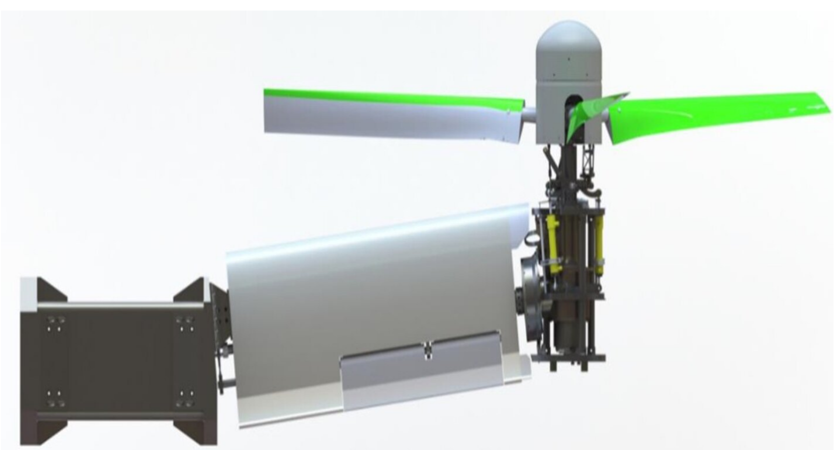
- Urban Air Mobility: Active Ride Control for Passenger Comfort and possible extension as flight controller for changing conditions
- Aerospace: Controllers for surface actuators or hydraulic systems
- Military: Rotorcraft & Payload Stabilization
- Other dynamic systems that employ active controls

THE TECHNOLOGY

Proprotors on tiltrotor aircraft have complex aeroelastic properties, experiencing torsion, bending, and chord movement vibrational modes, in addition to whirl flutter dynamic instabilities. These dynamics can be stabilized by high-frequency swashplate adjustments to alter the incidence angle between the swashplate and the rotor shaft (cyclic control) and blade pitch (collective control). To make these high-speed adjustments while minimizing control inputs, generalized predictive control (GPC) algorithms predict future outputs based on previous system behavior. However, these algorithms are limited by the fact that tiltrotor systems can substantially change in orientation and airspeed during a normal flight regime, breaking system continuity for predictive modeling.

NASA’s Advanced GPC (AGPC) is a self-adaptive algorithm that overcomes these limitations by identifying system changes and adapting its predictive behavior as flight conditions change. If system vibration conditions deteriorate below a set threshold for a set time interval, the AGPC will incrementally update its model parameters to improve damping response. AGPC has shown significant performance enhancements over conventional GPC algorithms in comparative simulations based on an analytical model of NASA’s TiltRotor Aeroelastic Stability Testbed (TRAST). Research for Hardware-In-the-Loop testing and flight vehicle deployment is ongoing, and hover data show improved vibration reduction and stability performance using AGPC over other methods.

The example presented here is an application to tiltrotor aircraft for envelope expansion and vibration reduction. However, AGPC can be employed on many dynamic systems.



Tilt-Rotor Aeroelastic Stability Testbed (TRAST) for investigating aeroelastic stability augmentations for tiltrotor aircraft while in cruise

Research is ongoing to develop Advanced Generalized Predictive Control (AGPC) for wind tunnel tiltrotor testing and flight vehicles.

PUBLICATIONS

Patent Pending

“Generalized Predictive Control for Active Stability Augmentation and Vibration Reduction on an Aeroelastic Tiltrotor Model.” AIAA SciTech 2022 Forum Conference Paper, January 3, 2022.

"Advanced Generalized Predictive Control and its Application to Tiltrotor Aircraft for Stability Augmentation and Vibration Reduction." Dissertation, Old Dominion University, December 2022.

"Experimental Testing of Advanced Generalized Predictive Control for Stability Augmentation and Vibration Reduction of Tiltrotor Aircraft." Vertical Flight Society International, Forum Conference Paper, May 2023.

More Information

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