Innovative Rotorcraft Flight Control Systems Options to Enhance Shipboard Operations

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PROBLEM STATEMENT

Advanced control design and evaluation for disturbance rejection is needed to improve rotorcraft handling qualities in turbulent environments throughout both military and commercial aviation activities. Applications include shipboard operations, urban operations, firefighting, and other natural disaster (e.g. hurricanes) rescue and relief. There are hundreds of rotorcraft operating in such turbulent environments. Both commercial companies and the military are increasingly relying more on computer aided analysis and simulation to maintain cutting edge technology while reducing operating costs. Therefore, the market need for advanced control options to effectively reduce pilot workload and enhance flight safety is significant. Tilt rotor aircraft are particularly susceptible to disturbances due to the large moment arm of each rotor from the vehicle center of mass. The target platform for this investigation is the XV-15, since it is the prototype of the V-22 and is representative of tilt rotor aircraft. The XV-15 was also chosen because of the availability of data.

WHO CAN BENEFIT?

Additional platforms in the Defense Community that can benefit from this technology include; Navy shipboard operations with the V-22, SH-60, and CH-53K; Army urban operations and NOE operations; unmanned aerial vehicles (UAV) shipboard and urban operations; Emergency medical evacuation; Firefighting, Logging, and Construction.

BASELINE TECHNOLOGY

Current helicopter flight control systems do not address disturbance rejection. Consequently pilots must manage disturbances due to gusts by relying on flying skills. This "Baseline Technology" draws attention away from combat operations and requires a higher level of training and experience on the part of the pilot.

An extension of Aeronautical Design Standard 33 (ADS-33) to handling qualities requirements for shipboard operations is currently being developed. Current control designs do not take these requirements into account and consequently cannot provide adequate handling qualities for shipboard operations.

TECHNOLOGY DESCRIPTION

There are two commercial products that can be developed from this research. One is the control design tool for the disturbance rejection and the other is the designed control products, such as turbulence rejection and mission task autopilot modules.

Control Design Tool

A control /design Tool is being developed in the FLIGHTLAB environment to take advantage of the high fidelity flight dynamics and turbulence modeling available in this environment and the extensive interactive engineering analysis capability. FLIGHTLAB is a physics-based dynamic modeling tool with an interpretive command language, similar to Matlab, that is uniquely geared for nonlinear system modeling and analysis. FLIGHTLAB includes the ability to linearize the full nonlinear simulation to obtain reduced order linear models that are suitable for control design applications. The control design tool includes the ADS-33 handling qualities criteria in the objective function to insure that the aircraft will achieve acceptable handling qualities. Once the design has been completed it can be tested in the FLIGHTLAB environment with the full nonlinear model to evaluate its performance across the flight envelope. This robust testing environment can significantly reduce the cost and risk of the flight test programs required for final certification of the flight control system. The following Features, Advantages and Benefits Table addresses the Control Design tool.

Features	**Advantages**	**Benefits**
Physics-based modeling of flight dynamics	Accurate modeling across flight envelope	Improved control design from improved plant model accuracy
Extraction of accurate linearized models	Full nonlinear model reduced to tractable low order linear system for design application	Model simplicity and accuracy promote simpler and more robust controller design
Control Design based on ADS-33 Handling Qualities criteria	Army handing qualities requirements are imbedded in controller design	Disturbance rejection is performed without degrading handling qualities
Control System Testing with full nonlinear aircraft model and accurate turbulence representation	Supports testing across flight envelope with accurate model	Reduces actual flight test time and reduces flight test risk

Disturbance Rejection Control System

The control design output from the new control design tool will be structured to operate with existing control laws. This provides a modular upgrade of current control systems to address disturbance rejection without requiring modification of existing control systems. The controller will provide automated disturbance alleviation thereby relieving the pilot of the intense workload currently required to accomplish this manually. Since the control design included the ADS-33 handling qualities criteria as a constraint, the controller will also provide the augmentation to existing controllers necessary to satisfy ADS-33 criteria. The following Features, Advantages and Benefits Table addresses the Disturbance Rejection Control System.

Features	Advantages	Benefits
Supplements existing control system to reduce disturbance response	Can be added to existing controller	Provides modular upgrade
Provides automated rejection of disturbance	Pilot workload reduced	Flight safety improved
Incorporates ADS-33 handling qualities criteria	Handling qualities improved in a manner consistent with new criteria	Flight safety and maneuver accuracy improved

CURRENT STATE OF DEVELOPMENT

The following tasks were completed under the Phase I effort and the associated Technology Readiness Levels (TRL) were achieved.

1) Developed algorithm to represent CFD data in compact form (TRL 6)
2) Enhanced vortex wake model (TRL 6)
3) Developed Proportional/Integral (PI) control structure (TRL 6)
4) Extracted 9 state linearized model of XV-15 tilt rotor (TRL 6)
5) Tuned control parameters of PI controller to satisfy gust rejection criteria (TRL 6)
6) Tested controller with closed loop nonlinear simulation model using airwake disturbance (TRL 6)

The following tasks will be completed under the Phase II effort and the associated Technology Readiness Levels (TRL) will be achieved.

1) Improved accuracy of linearized model (TRL 6)
2) Incorporate ADS-33 criteria (TRL 6)
3) Use direct optimization methods with linearized model to tune PI controller parameters to satisfy ADS-33 criteria (TRL 7)

4) Test controller with closed loop nonlinear simulation model using airwake disturbance (TRL 7)
5) Develop Graphical User Interface (GUI) (TRL 7)
6) Develop Matlab Interface (TRL 7)

Under the Proposed Phase II+ Program the following tasks will be completed and the associated Technology Readiness Levels (TRL) will be achieved.

1) Enhance existing FLIGHTLAB V-22 model with assistance of data provided by Navy (TRL 7)
2) Repeat Phase I control design for V-22 model (TRL 8)
3) Use direct optimization methods with nonlinear V-22 model to tune controller parameters to satisfy ADS-33 criteria while satisfying performance and loads constraints. (TRL 8)

The final task is to flight-test the controller on the V-22 to certify the controller. This will take the cooperation of Bell/Boeing and should be performed under a Phase III activity.

1) Test disturbance rejection control system with V-22 flight test in shipboard operations (TRL 9)

REFERENCES

The following third parties can be contacted with regard to ART's technology.

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ABOUT THE COMPANY

Advanced Rotorcraft Technology, Inc. (ART), located in Mountain View California, has led the industry in the development of high fidelity simulation models of rotorcraft dynamics since 1982. We have used our flight dynamics modeling and analysis tool, FLIGHTLAB, to support Government, Industry and Academia in performing engineering

analysis of rotorcraft. We have integrated our dynamics models into a wide array of third party real-time simulators for engineering and training applications, and have combined our simulation software with the most cost-effective commercial off-the-shelf simulator hardware available. ART has utilized our software tools and rotorcraft expertise to support the Navy in the development of new ADS-33 criteria for handling qualities in shipboard operations. Our experience in rotorcraft technology, mathematical modeling, control design, and handling qualities evaluation uniquely qualify ART for developing the control design tool and the gust rejection controller.

ART was founded by Dr. Ronald Du Val who serves as the President of the company. The majority of our Engineers hold Ph.D.s in Aerospace engineering, and can provide consulting and engineering services for many different disciplines including Computational Fluid Dynamics (CFD), Computational Structural Dynamics (CSD), Stability and Control Modeling and Analysis, and Engine/Drivetrain Modeling and Analysis.