Active Aeroelastic Wing Shape Tailoring for Aircraft Performance and Control

Modern aircraft are increasingly designed with lightweight, flexible airframe structures. By employing distributed flight control surfaces, a modern wing structure (which implies aircraft wing, horizontal stabilizer, and vertical stabilizer) can be strategically tailored in-flight by actively controlling the wing shape so as to bring about certain desired vehicle characteristics. For example, active aeroelastic wing shape tailoring can be employed to control the wash-out distribution and wing deflection in such a manner that could result in improved aerodynamic performance such as reduced drag during cruise or increased lift during take-off. Another novel use of active aeroelastic wing shape tailoring is for flight control. By actively controlling flexible aerodynamic surfaces differentially or collectively, the motion of an aircraft can be controlled in all three stability axes. In high speed supersonic or hypersonic vehicles, effects of airframe-propulsion-structure interactions can be significant. Thus, propulsion control can play an integral role with active aeroelastic wing shape tailoring control in high speed flight regimes.

This technology area involves the development of various technical elements including:

- Innovative aircraft concepts that can significantly improve aerodynamic performance and control by leveraging active aeroelastic wing shape tailoring.
- Sensor technology that will enable in-flight wing twist and deflection static and dynamic measurements for control development.
- Actuation methods that examine novel modes of actuation for actively controlling wing shape in-flight, and effective placements of distributed control effectors on a wing structure.
- Vehicle dynamic modeling capability for aero-propulsive-servo-elasticity that will provide a knowledge foundation upon which vehicle control and dynamics can be developed.
- Integrated approaches for active aeroelastic wing shape tailoring control with distributed control surfaces that will provide effective advanced control strategies to achieve aerodynamic performance and flight control objectives, taken into account airframe-propulsion-structure interactions that can exist in all three flight regimes.
**Gust Load Alleviation Control**

In a future NextGen operational concept, close separation between aircraft in super density operations could lead to more frequent wake vortex encounters. The increasing use of flexible airframe design in modern aircraft will inherently lead to a potential increase in vehicle dynamic response to turbulence and wake vortices. Gust load alleviation control technology can improve ride qualities and reduce undesired structural dynamic loading on flexible airframes that could shorten aircraft service life. Gust load alleviation control technology can be either reactive or predictive. In a traditional reactive control framework, flight control systems can be designed to provide sufficient aerodynamic damping characteristics that suppress vehicle dynamic response as rapidly as possible upon a turbulence encounter. There is a trade off, however, between increased damping for mode suppression and command-following objectives of a flight control system. Large damping ratios, while desirable for mode suppression, may result in poor flight control performance.

Predictive control can provide a novel gust load alleviation strategy for future aircraft design with lightweight flexible structures. Novel look-ahead sensor technology can measure or estimate turbulent intensity to provide such information to a predictive gust load alleviation control system which in turn would dynamically reconfigure flight control surfaces as an aircraft enters a turbulent atmospheric region. Technology development of predictive gust load alleviation control may include the following:

- Novel sensor technology for Optical Air Data Systems based on LIDAR or other novel detection methods that can measure near-field air turbulent velocity components directly in front of an aircraft in the order of one-body length scale to provide nearly instantaneous predictive capability to significantly improve the effectiveness of a gust load alleviation control system.

- Predictive gust load alleviation control technology that can reliably reconfigure flight control surfaces dynamically based on the sensor information of the near-field turbulence to mitigate the vehicle structural dynamic response upon a turbulence encounter. The predictive control strategies should be cognizant of potential adverse effects due to potential latency issues that can counteract the objective of gust load alleviation, or potential structural mode interactions due to control input signals that may contain frequencies close to the natural frequencies of the airframe.

**Modular and Distributed Control for Propulsion Systems**

Modular and flexible control architecture for propulsion systems is an essential technology, which will enable the full realization of turbine engine system performance. Distributed technology can alleviate the thermal constraints on engine control electronics by improving tolerance to elevated temperature and creating opportunities for relocating electronics to a more compatible environment. It will enable the implementation of more complex control law, paving the way for further integration of performance-enhancing control for reduced fuel burn, lower emissions, and operability. Directly, distributed control will reduce engine system weight. This is a multi-disciplinary research area involving high temperature electronics, sensing and actuation, control system integration, and engine system stability.