**STATEMENT OF WORK**

**Analysis of Separation Assurance in the Presence of Communication Failures**

Proposal to be submitted to NASA

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The objective of the proposed research is to develop an analytical framework for assessing the impact of low-connectivity conditions on the automated separation assurance of multiple cooperative airplanes sharing the same airspace. The framework explicitly takes into account the switching topology and possibly degrading connectivity of communication networks and performance characteristics of heterogeneous airplanes to assess the separation guarantees.

The proposed solution is based on transforming the key results of the recently developed framework of “Coordinated Path Following (CPF) of Multiple UAVs.” The CPF concept is based on the 4D notion of trajectory representation that consists of the 3-dimensional analytical definition of path and the 1-dimensional velocity profile associated with the path. Multiple airplanes can be safely assigned to follow the same paths that intersect in space but are still separated in time. The CPF concept naturally fits the NextGen 4D notion of the airspace utilization; its fundamental results are a perfect match for the key objectives of the nation-wide program.

We propose to apply the developed distributed coordination solution to the separation assurance task by addressing the following challenge. Consider multiple airplanes entering an airspace sector where they are assigned to follow a given set of paths with assigned nominal speed profiles. Assess the separation assurance bounds of these airplanes under modeled degraded communication conditions. Find the worst case communication scenario that would result in violating the predefined set of separation constraints; the separation constraints are different for different classes of airplanes. Develop methods that will improve separation assurance guarantees even in the case of degraded communication conditions that are limited by the current level of communication technologies.

The solution to assess the separation assurance problem naturally follows from the results of the CPF project. Besides the guaranteed performance bounds of path following, the key result relevant to the separation assurance objective of this NRA is a novel distributed coordination control law. The developed control law enforces the temporal constraints that guarantee tight coordination of the fleet of multiple airplanes in the same airspace by adjusting the speed profile of each vehicle. This adjustment is done onboard of each airplane in distributed fashion and is based on coordination states exchanged among the vehicles over a supporting communications network; for example ADS-B. Theoretical simplicity, proven stability and the distributed nature is what makes this novel solution especially suitable for the task at hand. Furthermore, the control law is proven robust to the intermittent nature and loss of QoS in communication networks; the analytical bounds of coordination performance are explicitly given as functions of the Persistency of Excitation (PE)-like condition of network connectivity. The control law is computationally inexpensive and thus is readily feasible for onboard implementation.

The nature of this research conforms to the NRA-AFCS-1.5 goals and objectives for utilization of distributed heterogeneous communication resources which are either given by existing technologies (ADS-B, GPS, TIS-B, CPDLC) or will be developed in the near future. The proposed research provides solutions for the analysis and assessment of the adverse impact of communication disruptions on separation assurance.

The proposal team is uniquely suited to accomplish this task. The team possesses a mixture of experience in multi-aircraft control law design, control theory development, and in-flight validation and verification. Prof. Hovakimyan have developed The Theory of Fast and Robust Adaptation. Dr. Xargay significantly extended the fundamental results of the Time-Critical Cooperative Path-Following Control of Multiple UAVs. The NPS team comprised of Prof. Kaminer, Prof. Dobrokhodov, and Prof. Jones have collaborated with them towards extension of the theoretical results to specific flight control problems, design of the representative case studies and their flight validation. This collaboration has resulted in successful integration of coordinated path following algorithms in several multi-UAV missions that were successfully flight tested over the period of 2006-2013 in joint USSOCOM-NPS exercises, in Camp Roberts, CA.

The specific tasks that the research team will address are the following. During the first year of research the analytical framework for the analysis of the individual and integrated failure space of communication technologies will be developed to facilitate a better understanding of the single fault (separation failure) detection and its probable spread across the network of airplanes. In particular, the NPS team will focus on the analysis of existing communication links available onboard of airplanes and the analytical description of their performance limitations in the form suitable for the formal analytical analysis of separation assurance. This step builds an interface between the CPF theoretical framework and the technology solutions available today. During the second year of research the NPS team will specify a set of communication failures based on the performance characteristics of existing ground and airborne ATC solutions: ADS-B, GPS, TIS-B, and CPDLC. The realistic setups representing nominal and worst case communication scenarios will be built in coordination with partners at UIUC and assessed in software simulations, thus providing numerical illustrations of achievable separation assurance bounds. During the last year of research at NPS, a set of representative scenarios will be developed that can be tested using high-fidelity hardware-in-the-loop simulations and flight tests utilizing advanced capabilities which are available at NPS and NASA facilities. The separation assurance bounds will be investigated during comprehensive flight-testing by using different autopilots and UAVs instrumented with advanced Real-Time (RT) control capability. To achieve verifiable flight test results we propose to utilize the capabilities of the Rapid Flight Control Prototyping System (RFCPS) developed at NPS that allows for onboard integration and RT execution of advanced algorithms.