Project Title:	**REACT-LE: Robust Encounter Avoidance and Conflict Resolution for Long-Endurance Aircraft**
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1 Executive Summary

Robust Encounter Avoidance and Conflict Resolution for Long Endurance Platforms (REACT-LE) is designed to provide a low C-SWaP detect and avoid (DAA) system for unmanned aircraft systems (UAS). REACT-LE will focus on performance-limited Group V UAS and includes maneuver optimization for strategic and tactical avoidance maneuvers. SSCI's DAA software leverages a decade of development in threat state estimation, threat declaration and reporting, maneuver prediction, and avoidance maneuver generation. This work is funded under a Phase II SBIR through AFRL, with the DZYNE Ultra UAS as the test vehicle.

REACT is SSCI's DAA approach to *track* all vehicles in proximity to the UAS, *assess* the risk of collision or loss of well clear (LOWC) for vehicles within a specified spatio-temporal radius, and *avoid* collisions through real-time response (tactical collision avoidance) or longer-term planning and guidance (strategic separation). REACT-LE uses a maneuver prediction model for each threat to probabilistically represent the evolving risk. SSCI's sensor fusion combines ADS-B with target tracks from two lightweight, low-cost radars (FORTEM R-30) to satisfy the due regard expectations described by RTCA DO-366.

The outputs of REACT will be contained in "threat reports" containing information about risk posed by nearby vehicles, and maneuver recommendations to resolve the potential threat. This data will be available for rendering in a ground-based Graphical User Interface (GUI) to increase the situational awareness of the remote operator. Autonomous avoidance maneuvers can resolve the high threat encounters in closed-loop systems, or can be presented to the operator for approval and implementation.

Prior to this contract, our research and development of DAA has been model-based environment testing, which includes digital representations of sensors for detection, ownship state estimation, onboard computation and processing, and interaction with the pilot and/or autopilot. The purpose of this proposed effort is to demonstrate the software in and a real-time system aboard a Long Endurance UAS. REACT-LE applies its previously developed technology to the flight envelope, mission objectives, and constraints associated with the DZYNE Ultra UAV. For the purposes of this research contract, the test plans are meant to increase the TRL, provide a basis of confidence in the REACT system, and provide additional data supporting a safety justification using real flight experience as we mature the system.

2 System Overview

Robust Encounter Avoidance and Conflict Resolution for Long Endurance Platforms (REACT-LE), shown in Figure 1, is designed to provide a low C-SWaP detect and avoid (DAA) system for unmanned aircraft systems (UAS). REACT-LE will focus on performance-limited Group V UAS and includes maneuver optimization for strategic and tactical avoidance maneuvers. SSCI's DAA software leverages a decade of development in threat state estimation, threat declaration and reporting, maneuver prediction, and avoidance maneuver generation. Under a current Navy Phase II SBIR, SSCI is applying REACT to Unmanned Carrier Aviation (using MQ-25 refueling tanker missions) for DAA in dense carrier-controlled airspace.

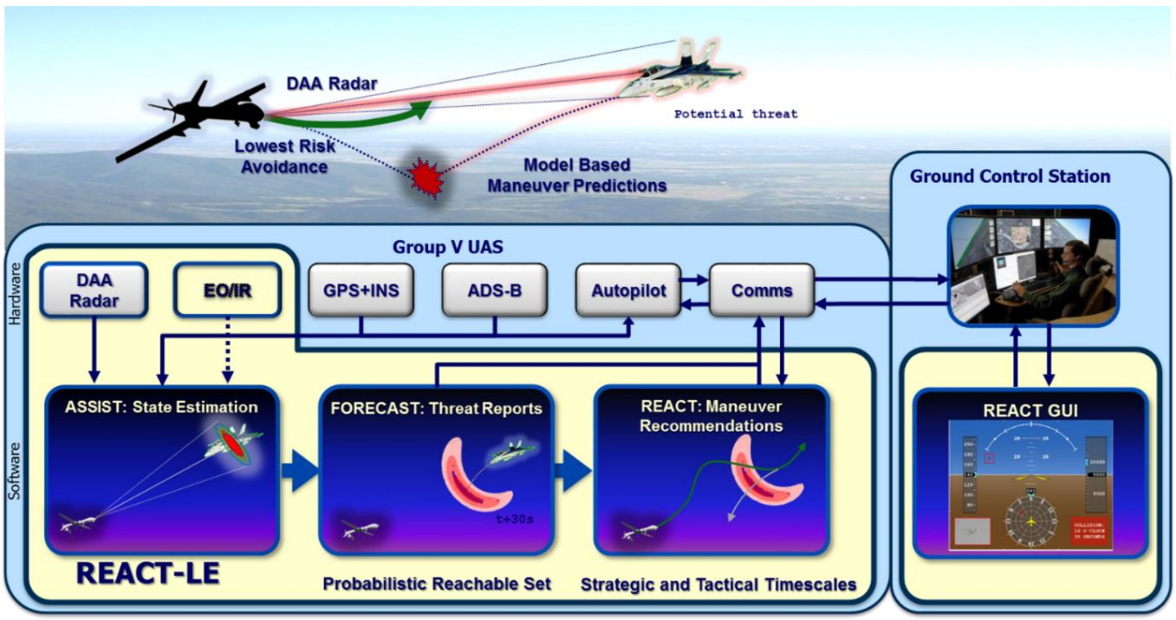

Figure 1. REACT-LE System Diagram. REACT-LE brings a hardware-agnostic approach to DAA. SSCI sensor fusion for track estimation incorporates all available sensing modalities. SSCI has experience developing and testing vision-only SAA systems and propose to integrate a radar system with EO/IR sensors under follow-on studies. Time-parameterized Probabilistic Reachable Sets are the basis for computing maneuver recommendations to prevent loss of well clear when detections are at strategic avoidance time-scales (longer), and to avoid near mid-air collisions (NMAC) when at tactical avoidance time scales (shorter). Prior studies avoided LOWC 93.4% of the time, and prevented NMAC 100% of the time.

Risk assessment utilizes our novel approach to building a Probabilistic Reachable Set, which is formulated to encapsulate the set of points that could evolve from the current state through a series of dynamic transitions, according to the Uncorrelated Encounter Model (UEM) developed by MIT Lincoln Laboratory. This model incorporates two weeks of VFR traffic data collected and distilled into a Bayesian network, which was then queried and sampled, then reduced to a parametric model that matches the maneuver uncertainty characteristics over a 30-60 second time window, consistent with the data from which the model was derived. An example for non-zero turn rate is shown in Figure 2.

For declaration thresholds, we adopt the definitions of "well clear" and "loss of well clear" from the Minimum Operational Performance Standards for DAA systems, published in RTCA DO-365. These constrain the geometry relative to the moving hazard zone, and the criteria for the safe separation metrics and the overall system success criteria.

The REACT DAA system is platform and sensor agnostic and enables seamlessly adaptation for REACT-LE to apply to the DZYNE Ultra long-endurance Group V UAS, even under significant performance limitations. The maneuver recommendations from REACT are produced by model-based predictions of ownship and threat trajectories. Candidate maneuvers are scored based on risk, and down-selected based on rules of the road and disruption to the mission. Those with unacceptable risk are rejected, and candidates receive higher scores for more effectively meeting the mixed criteria. The sufficient, but less-effective alternatives are also presented, though indicated as nearer the threshold.

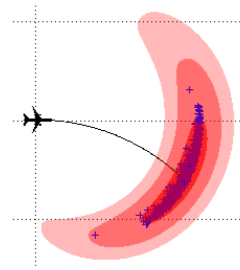

Figure 2. 15 second PRS snapshot, given initial conditions for non-zero right turn rate

REACT-LE will use a low C-SWaP radar system developed by Fortem Technologies onboard the customer's Group V UAS platform. This radar was selected as the best balance of cost, weight, and effective range for the purposes of this project. The REACT sensor fusion and tracking subsystem is capable of integrating measurements from any radar system and so for follow-on or transition efforts the radar itself could be replaced or upgraded as new developments come from Fortem Technologies. Additionally, REACT can incorporate EO/IR measurements, such as from SSCI's SAFESEE Optical Collision Threat Detection technology. This opens the opportunity to extend functionality to EMCON under follow-on efforts or to augment the radar system by providing more reliable detections for fast-moving, head-on threats.

The REACT-LE software receives live data feeds from DAA sensors to produce threat reports and maneuver recommendations. To display alerts, metrics, and maneuver recommendations to the remote operator we will adapt notional heads-up display designs. SSCI uses the cross-platform software to produce graphical user interfaces. After converting all REACT components to C++, we will install REACT-LE on an NVIDIA Jetson embedded computer platform which will be installed on the Group V UAS and interface with the DAA radar and the GCS through the onboard communications link.

We will coordinate with Fortem Technologies to design DAA radar mounting and connecting hardware. The two radar panels will be mounted underwing with fairings to provide aerodynamic efficiency in a composite lay-up approximately 18 inches tall tapering to a point over 4 feet. The scanning of each radar will overlap a central cone and extend to a total of ±110° azimuth required by the DAA MOPS.

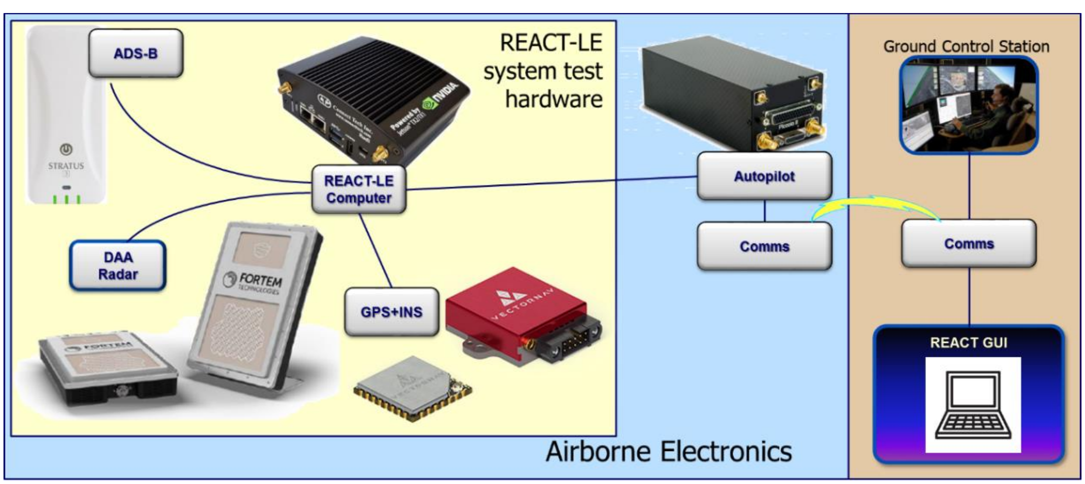

Figure 3. Conceptual Makeup of REACT-LE System Electronics

3 Experimental Process

To mitigate risk for the final flight test on the customer's vehicle, we propose a staged test plan, detailed below in the work plan.

Bench Test: The bench test and software unit testing will be performed in Laboratory space within the SSCI offices at **Woburn, MA**. The bench test is to ensure all components are running properly and communicating without error.

Ground Test: The ground test will be functionally similar to the bench test, but it will be performed out of the office at Boire Field in **Nashua, NH**. Under previous SAFESEE programs, sensing equipment has been tested on the ground with sensors aiming at aircraft in the local airspace of the runway. We have in the past been granted access to the runway via or facility usage arrangement with CR Helicopters. As an optional ground test site, **Pepperell, NH**,has a private airfield that may also be used for data collection.

Flight Test on Surrogate Platform: Flight testing on a surrogate platform will be facilitated by CR Helicopters in **Nashua, NH**, a partnership that SSCI has developed under the SAFESEE program. A rotorcraft or fixed wing aircraft will be fitted with the radar system, REACT-LE computer, and accompanying systems and will be flown against a fixed wing aircraft to represent the intruder.

Table 1. Flight Test Plan on Surrogate Vehicles.

Event	Host	Intruder	Location
Ground-based Testing 1			Nashua Airport (CR Helicopters)
Ground-based Testing 2			Nashua Airport (northwest field)
Instrumented Ground Test (1-hour flight)		Helicopter (R-44)	Nashua Airport (northwest field)
Flight Demonstration 1 (2-hour AM flight, 2-hour PM flight)	Helicopter (R-44)	Helicopter (R-44)	Nashua Airport
Flight Demonstration 2 (2-hour AM flight)	Helicopter (R-44)	Fixed-wing (Caravan)	Nashua Airport / Pepperell Airport

Flight Test on Customer's Platform: Details on the timing and location of the flight tests on the customer's platform will be developed under the performance period of this contract. Notional time window for flight demonstrations at **Eglin Air Force Base, FL** will be for June or July 2024. As part of preparation for this flight test, the hardware will be installed on the ULTRA vehicle at the DZYNE Technologies facilities in **Irvine, CA** in the spring of 2024, prior to the aircraft being shipped to Eglin Air Force Base. SSCI will work with the customer to coordinate the flight test.