PROPOSAL ABSTRACT

STOVL UAV Design Using Low Acoustic Signature Propulsors

A White Paper Submitted to

Sam Wilson
Smart Collection Program Manager
Intelligence Advanced Research Projects Activity
samuel.b.wilson@ugov.gov

by

Dr. Jonathan Rogers
Assistant Professor
Department of Aerospace Engineering
Texas A&M University
jrogers@aero.tamu.edu
(979) 862-3413

Overview and Motivation

This white paper describes a short take-off, vertical landing (STOVL) UAV concept designed for tactical intelligence collection operations. The vehicle will be designed to operate from a pick-up truck, from which it can be launched, controlled, landed, and refueled, and will leverage low-acoustic signature propulsive technology being developed under IARPA's Great Horned Owl (GHO) Program. Several technological innovations will separate the proposed design from current UAV systems, including a horizontal-to-vertical flight transition capability, in-flight foldable wings, precision IR-based landing system, and differential thrust control system providing a precise landing capability. It is envisioned that this seedling project will be pursued alongside the GHO Program in order to harness GHO's propulsive technology while providing game-changing improvements in UAV flight performance.

The inspiration for a STOVL UAV stems from several sources. First, there is a clear need to combine low acoustic signature flight with a vertical landing capability. Intelligence operations typically involve a handful of personnel operating from remote areas where terrain or infrastructure may prohibit even short takeoff or landing patterns. Landing is particularly problematic since the aircraft must dissipate nearly all energy on its own without encountering an obstacle. While rotorcraft UAV's have been explored extensively and are in use today, their noise signatures, thrust to weight ratios, and vulnerability to obstacles during takeoff and landing make them impractical for tactical intelligence missions. New UAV designs must be created that combine the efficiency of flight using high-aspect-ratio wings with vertical landing capability.

Only a handful of STOVL UAV's have been designed to date, although none of them provide a reasonable platform for intelligence collection. The FanWing UAV (www.fanwing.com) uses a long rotor turning about the aircraft's lateral axis for both lift and thrust, and has demonstrated takeoff and landing distances on the order of 5 ft. However, the aircraft has a maximum speed of 40 kts and cannot be easily controlled during slow flight. On a more massive scale, Urban Aeronautics' AirMule (www.urbanaero.com) is a ducted-fan UAV capable of STOVL operations, but has a takeoff weight of 2,400 lbs and a payload capacity of more than 800 lbs. While its ducted fan vertical lift technology is suitable for its size, the design would present gust rejection issues if applied to smaller vehicles (which are far more vulnerable to gusts).

Figure 1. Two Current STOVL UAV Designs: the FanWing (left) and AirMule (right).

Proposed Design

The proposed vehicle is envisioned as a flying wing equipped with three propulsive devices, providing on the order of 9-12 lbs of thrust each. One thruster will be placed along the vehicle centerline, while the others will be placed along each wing. Vehicle flight is initiated from a rail-type device (of length 6 ft or less) equipped with a spring-launching mechanism. Thrust from the vehicle propulsors combined with the impulse provided from the launch mechanism will allow the vehicle to achieve flight speed without a ground roll, and thus takeoff could potentially be performed from the bed of a pick-up truck. In flight, the vehicle will resemble a flying wing, and will be capable of flight speeds between approximately 35 kts and 100 kts during cruise.

After operations in cruise flight conclude, the vehicle flies overhead of the landing site and initiates a vertical descent. This is performed through a rapid climb maneuver in which the vehicle transitions quickly from horizontal to vertical flight. The vehicle rapidly loses speed and establishes hover at altitude. Then, the wings are folded about a hinge placed at roughly half-span along each wing. The wing hingelines are misaligned from the vehicle centerline so that as the wings fold, thrust from the engines take place along three non-colinear axes. Once the wings are folded into place, the vehicle is in a triangular configuration. This configuration is attractive during landing for several reasons:

- The vehicle cross-section exposed to the wind is significantly less, and thus gust-rejection can be performed more effectively.
- Vehicle control during descent and landing can be accomplished via differential thrust from the three propulsors.
- The vehicle can fold about the payload, and thus physically protect any sensitive electronic equipment during landing.
- The vehicle can land in a much smaller space (such as the bed of a pickup truck) since its largest length is now roughly 1/3 of the wingspan.
- Vehicle thrust-to-weight ratio can be less than 1 throughout the entire flight until landing, when any remaining excess fuel can be jettisoned if needed to make the ratio less than 1.

During vertical landing, the UAV resembles a tailsitter aircraft and will accordingly be susceptible to perturbations from wind gusts. A critical element of the proposed design will be an infrared-based landing positioning system which provides differential thrust commands to the propulsors. Details of this vertical landing subsystem are described below. Annotated drawings of the conceptual design are presented in Figures 2 and 3, while basic vehicle parameters are outlined in Table 1. The following subsections describe in more detail each of the vehicle design elements.

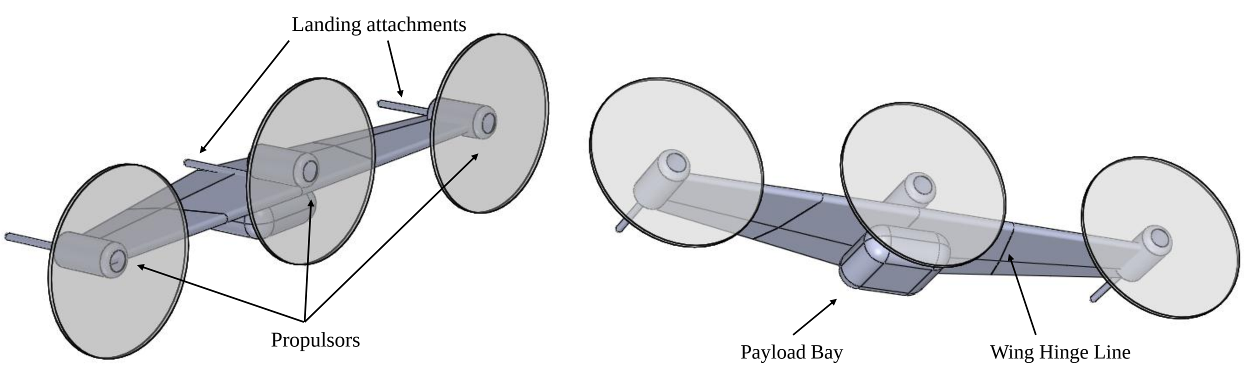

Figure 2. STOVL UAV Concept – Wings Extended in Forward Flight Configuration.

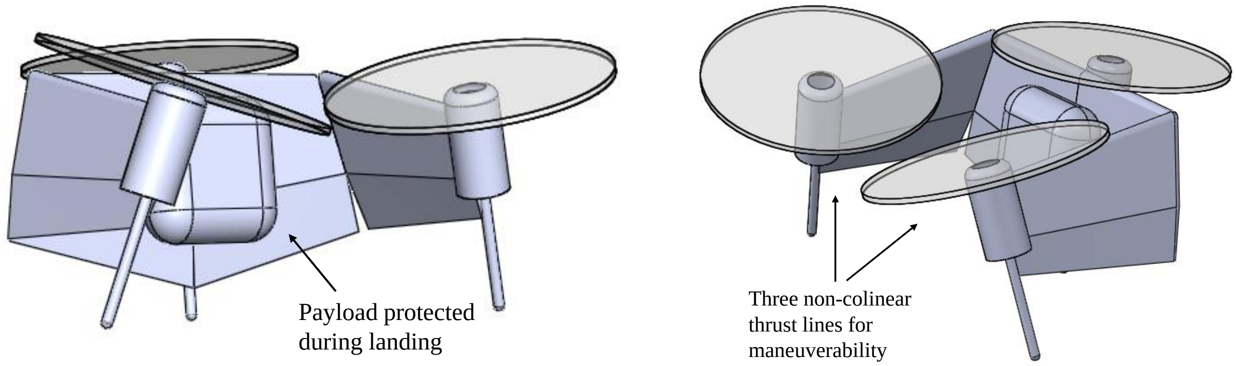

Figure 3. STOVL UAV Concept – Wings Folded in Vertical Flight Configuration.

Table 1. Basic Vehicle Parameters (Approximate).

Wingspan (wings extended)	12-15 ft
Vehicle Width (wings folded)	4-5 ft
Cruise Speed Range	35-100 kts
Max Takeoff Weight	40-50 lbs
Max Landing Weight (Vert. Descent)	~33 lbs
Thrust Available	~36 lbs

Vehicle Guidance and Control

In its forward flight condition, the vehicle will be controlled using a standard GPS-based autopilot that can be tasked remotely. During transition to vertical flight, the vehicle first performs a pull-up maneuver so that it is flying almost vertically (assuming thrust-to-weight is less than 1). Once it establishes vertical flight, it decelerates to hover and the wings are folded into place with the propulsors still running. A terminal descent is then initiated. A transitional flight controller will be built to handle this phase of flight.

Control is performed during vertical descent using differential thrust from the three propulsors. Note that although the three thrust axes are offset by less than 10 deg from each other, little differential thrust is required to provide precise wind corrections. Furthermore, gust response of the vehicle will be mitigated due to its triangular shape during descent. Terminal descent guidance will be performed using a downward-looking IR camera system and a set of three IR beacons positioned at the landing site. The IR camera system will provide precise guidance corrections to the UAV during terminal descent, and will enable much higher landing accuracy than is currently achievable with GPS-based systems.

An in-house TAMU flight simulation of the notional design was used to generate an example trajectory (Figure 4) showing a transition to vertical flight and terminal descent.

Vehicle Propulsion

Propulsion will be provided by the advanced electric propulsors being developed under IARPA's Great Horned Owl (GHO) Program. Power is provided to these motors via a quiet fuel-to-electricity subsystem. Three electric propulsors and the fuel-to-electricity subsystem will be incorporated in the vehicle designs, and have been accounted for in preliminary weight calculations.

Technology development of the STOVL UAV will proceed alongside the GHO program, and it is envisioned that the TAMU team will work with IARPA and GHO contractors to continually incorporate the latest propulsor designs and specifications. The TAMU team will, where possible, attend Technical Interchange Meetings for the GHO program. Simulation models of the STOVL UAV will include high-fidelity models of the propulsor systems based on GHO contractor-provided specifications.

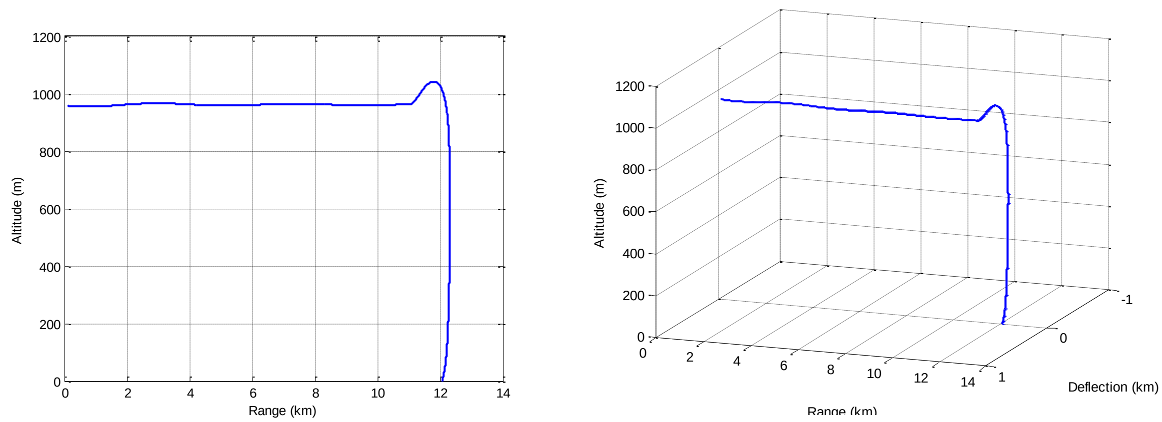

Figure 4. Notional Cruise Flight, Vertical Flight Transition, and Final Descent.

<u>Vehicle Launch and Recovery System</u>

Part of the development process will include design of the UAV launch and recovery system. The launcher will consist of a spring-loaded rail which can be fixed to a vehicle such as a pickup truck. A landing fixture will also be designed incorporating IR beacons for terminal guidance and latches that can be attached to the UAV once it has landed for storage and transportation.

Heilmeier Questions

1. What are you trying to do?

The goal of this project is to design, and eventually build, a short-takeoff vertical-landing (STOVL) UAV. The design, using quiet propulsion technology developed under the IARPA GHO Program, would be easily portable, and could be launched and recovered by a pickup truck. The UAV would be an intelligence collection platform for tactical missions, and would provide a low-signature, highly covert, and versatile collection capability.

2. How is it done at present? Who does it? What are the limitations of present approaches?

Currently, the IC operates a range of UAV’s, most requiring improved or at least cleared areas for takeoff and landing. Oftentimes it is desirable to operate in forested areas or urban areas where numerous obstacles may exist. While rotorcraft have provided a solution, they have a high acoustic signature and must maintain high thrust-to-weight ratios throughout flight. A few STOVL UAV designs have been developed (outlined above), but none are attractive to the tactical intelligence mission.

3. What is new about your approach? Why do you think it can be successful at this time?

Our approach uses a folding flying-wing design to combine high lift-to-drag ratios in cruise flight with vertical landing capability. Its ability to takeoff using a launcher (rather than strict vertical thrust) is attractive in that the aircraft can have a thrust-to-weight ratio of less than 1 during takeoff, which is not true for a helicopter. The wing folds along an axis offset from the aircraft centerline, enabling both a lower cross section exposed to gusts and three non-colinear thrust axes for precise control. Because of the use of differential thrust control during terminal maneuvers, the aircraft is expected to significantly outperform standard tailsitter aircraft which rely on control surface deflections. The design is likely to be successful since all the required technology components and guidance algorithms have either already been developed or have a high likelihood of successful development over a short time frame.

4. If you succeed, what difference will it make?

Successful development and deployment of the STOVL UAV design will provide unprecedented tactical intelligence collection capabilities to the IC. The vehicle will be extremely quiet given its low-noise propulsors, and may be transported and operated from a standard vehicle with highly-reduced terrain or obstacle avoidance restrictions. The vehicle has a flexible payload capacity and thus can support a variety of missions. Finally, the vehicle will be extremely robust due to its folding configuration, which protects the aircraft during landing or potential collision with obstacles.

5. How long will it take? How much will it cost? How will you evaluate progress during and at the conclusion of the effort?

The proposed program will be a 2 year effort, and will be comprised of two consecutive 12 month phases.

> Phase 1 (12 Months) – Vehicle design, Simulation, and Trade Studies. Preliminary design of the aircraft will be performed in CAD, and a detailed 6DOF simulation model of the aircraft will be constructed. The transitional and vertical flight controller will be designed and tested in simulation to demonstrate performance and robustness. Vehicle design parameters will be optimized through trade studies. **Cost of Phase 1: $80,000.**
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> Phase 2 (12 Months) – Vehicle Prototype Construction and Testing. The optimized design created during Phase 1 will be fabricated at TAMU facilities. Flight control laws will be further refined and implemented using in-house TAMU autopilots. Flight testing will take place at TAMU's Riverside flight facility, and/or at an alternative location at IARPA's discretion. **Cost of Phase 2: $120,000.**

Progress will be evaluated during Phase 1 and Phase 2 through final reports (each phase) and regular meetings and teleconferences with IARPA and IC personnel. Deliverables for Phase 1 include a detailed and optimized STOVL UAV design incorporating models for the low-noise propulsors and flight control algorithms. Deliverables for Phase 2 are a prototype vehicle and flight test data demonstrating the performance of the STOVL UAV.

Principle Investigator Biography

Dr. Jonathan Rogers is an Assistant Professor in the Department of Aerospace Engineering at Texas A&M University, and is the director of the Helicopter and Unmanned Systems Laboratory (HUSL). Dr. Rogers has published over 20 academic papers in the fields of autonomous systems, flight dynamics, and control, and has extensive experience in development of low-cost and nontraditional unmanned vehicles and control systems. Dr. Rogers earned his PhD and MS degrees in Aerospace Engineering from Georgia Tech, and his BS degree in Physics from Georgetown. He was a CIA employee from 2004-2011 with experience working in both the DS&T and NCS. **Dr. Rogers holds a current Top Secret Clearance.**