Surf Zone Technology Standoff Delivery

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LONG-TERM GOAL

The long-term goals are to define, analyze, and develop technologies associated with the accuracy of delivery and verticality at impact for long, standoff delivery of bombs or other ordnance for clearing obstacles in the surf zone, beach zone, and craft landing zone. Additionally, these breaching systems need to be cost effective, delivered from over the horizon, and be utilized in-stride with a Marine Expeditionary Force amphibious assault.

OBJECTIVES

This fiscal year, one of the objectives is to determine the ingress accuracy of a glide bomb under ideal and various weather and electronic jamming conditions. This information will help define the “basket” for a terminal guidance seeker. This “basket” represents an area in the sky where a glide bomb must fly to, in order for the seeker to be within parameters to guide to the target. There are two candidate systems, Leigh Aerosystems’ LongShot™ wing kit and the Joint Direct Attack Munition (JDAM). LongShot™ will be used as the baseline representative because JDAM currently does not have the desired range; however, JDAM is capable of achieving a vertical impact. A second objective is to identify and describe various stations keeping methods to control a swarm of bombs, using LongShot™. Finally, the third objective is to determine the feasibility of using biomimetic algorithms for multispectral imaging seekers.

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APPROACH

The approach was to have Leigh Aerosystems conduct Hardware in Loop Simulations (HILS) of their LongShot™ wing kit. Leon Vaizer, Coastal Systems Station (CSS), was to perform a covariance analysis of LongShot™ 's navigation sensors. John Webster (CSS) was to build an aerodynamic model of LongShot™ mated to a Mk-84 bomb. Rafael Rodrígez (CSS) was to determine if it is feasible to control the LongShot™ model to hit a target accurately and vertically. Eric Tuovila (CSS) was to perform a “first look” study of possible stations keeping methods to control a swarm of bombs gliding, in formation, from a distance of ~25 nautical miles. Finally, Dr. Geoffrey Brooks of the Air Force Research Laboratory (AFRL) was to apply biomimetic algorithms to multispectral data, supplied by CSS, to determine the feasibility of using them on a multispectral seeker.

WORK COMPLETED

CSS supplied Leigh Aerosystems with a copy of NASA Contractor Report 3309 as a reference to use for the wind model in the HILS. Leigh Aerosystems is currently running the HILS and has supplied documentation on LongShot™ 's navigation and control systems, the Global Positioning System (GPS) jamming model, and the run matrix using varying levels of GPS jamming and quartering wind speeds. Three levels of jammer Effective Radiated Power (ERP) were used. The run data and final report are still pending completion.

The covariance analysis, controls simulation, and stations keeping study have been completed. The covariance analysis program contains an 18-state IMU model as well as GPS, altitude, and about a dozen other sensor models. The sensors are integrated using an algorithm or Kalman filter. The controls simulation is based on a six-degree-of-freedom Mk-84 (with fixed CBU tail fins) aerodynamic model mated to a LongShot™ wing kit with 30-inch lug spacing. The model and simulation were developed by CSS using HYDAT and *MATLAB® Simulink* toolbox.

Also, CSS supplied AFRL/MNGI with two sets of multispectral data; each set contained six distinct spectral bands. During April, I attended the SPIE AeroSense conference in Orlando to increase my knowledge of imaging systems/algorithms. During June, a vision processing working group was hosted at AFRL/MNG centering on a coarse-coding academic topic. The biomimetic algorithm work was done, over the summer, by two Air Force-sponsored interns, using *MATLAB®*. The work is finished and the results are promising.

RESULTS

The results of the covariance analysis are surprising. LongShot™ 's navigation suite, simulated under ideal conditions, has a 10 meter Circular Error Probable (CEP). However, when the suite was simulated against a GPS jammer, located at the target, the results degraded significantly. These results stress the importance of using high anti-jam GPS receivers and nulling or beamforming antennae.

It should be noted that the following results are based on a CSS developed control system without detailed information from Leigh Aerosystems. These results may change when more information is received. The results of the control study indicate that it is not possible to hit the target accurately and achieve a vertical impact for a weapon of this configuration. Some improvement in the radial position error may be possible by designing a better vertical control autopilot to reduce the overshoot and to speed up the response in the terminal phase. However, such an improvement would most likely be offset by the negative effect of other factors ignored in this study such as wind gust, sensor noise, and actuator dynamics. Since this is a feasibility study, the control algorithms are very simple and do not account for all the effects that must normally be considered in aircraft control.

The wing kit provides two degrees of control freedom: vertical (pitch) control by moving the wing control surfaces in unison (elevator), and roll control by moving the control surfaces differentially (aileron). As suspected, an extra degree of freedom, e.g., controllable tail fins or nose fins, is needed in the terminal phase.

While it seems unlikely that the weapon, in this configuration, can be flown to an accurate vertical impact, the question of what is the largest impact angle that can be achieved remains open. The model shows that the weapon is not capable of climbing to correct for the initial loss of altitude that occurs during release from the aircraft. Larger impact angles can be achieved if the weapon is capable of climbing. Therefore, the Mk-84 (CBU) model should be examined carefully to determine if indeed the weapon is unable to climb, or if this effect is due to a modeling error.

Figure 1 shows a typical flight profile. Figure 2 shows LongShot™ mated to a Mk-84 bomb. Figure 3 shows the flight profile from one simulation scenario. The weapon was released from an initial altitude of 35,000 feet, at 200 knots, and 25 nautical miles away from the target. The red dashed-line denotes the flight path angle that the vehicle should follow in the initial part of the flight (glide phase). Upon reaching an altitude of 10,000 feet the vehicle enters the terminal phase and switches to a steeper flight path of 85° to the target. The blue arrows indicate vehicle position at various points during the flight. Due to the initial altitude loss, the weapon reached the terminal phase altitude sooner than planned. Therefore, the terminal flight path angle was less than 85°. The radial error in the terminal position was 94 feet, and the final pitch angle was only 47° nose down.

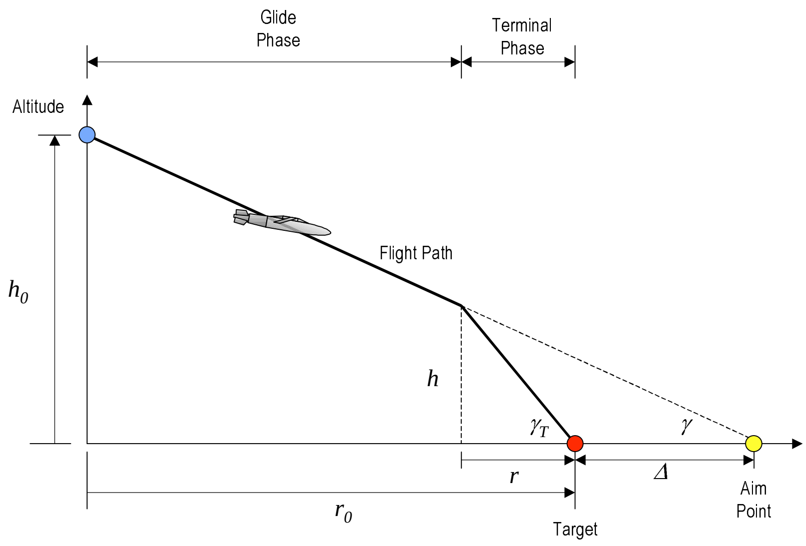

Figure 1. Typical Flight Profile for Controls Simulations

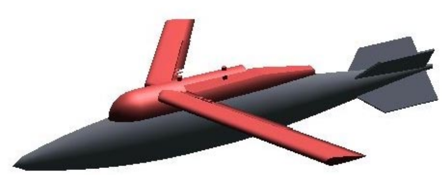

Figure 2. LongShot™ with Mk-84

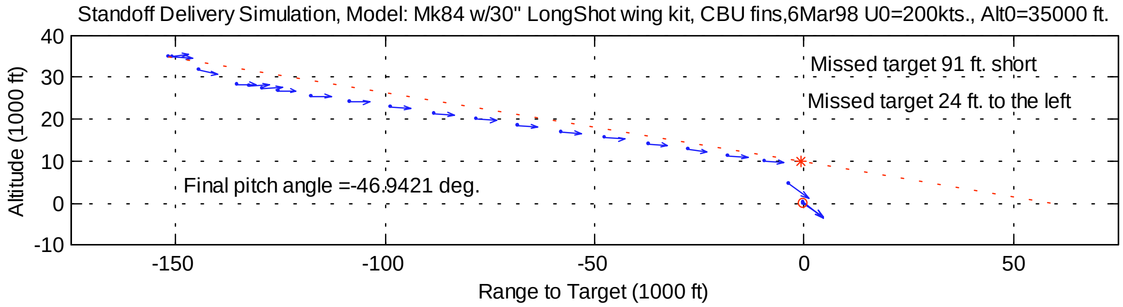

Figure 3. Flight Profile of the Mk-84 (CBU)/LongShot™ In Close Loop Flight (Initial Altitude: 35,000 ft., Terminal Phase Altitude: 10,000 ft., Terminal Flight Path Angle: 85°)

The stations keeping report gives eight possible methods of controlling a swarm of bombs (bomb swarm). All the options have some common requirements: a) A spread spectrum modem to send data from the lead bomb to the follower bombs; b) An inertial system; c) A flux gate compass to get the heading of each bomb; and d) controllable tail/nose fins. Options 1, 2, and 3 require GPS coverage during the glide phase; Options 4, 5, 7, and 8 may be used in both the glide and terminal phases, without GPS. Option 6 was considered not viable. The three most promising options are:

Option 1. This option incorporates a 2-axis low frequency (10-100KHz) magnetic transmitter on the lead bomb and a 3-axis receiver (magnetometer) on the follower bombs. The spreading loss will give the distance to the lead bomb and the 3-axis measurement of the magnetic field will give the relative angular orientation from the lead bomb. The attitude of the lead bomb will be measured and transmitted to the follower bombs.

Potential Problems. The bomb casings are made of steel and will bend the magnetic fields we are trying to measure. Therefore, the transmitter coils and receiver coils need to be mounted away from the body. Some experimentation will be required to determine the exact effect. However, since controllable tail fins will be installed on each bomb, it may be possible to integrate the transmitter and receiver coils into nonmetallic tail fins. In addition, because fluxgate compasses use an AC magnetic field in the 10-100 kHz range, the frequencies for the 3-axis magnetometers, operating in the same range, need to be chosen such that they don't interfere with each other. Finally, since GPS is required for the glide phase, if the GPS signal is lost, this option may not work.

Option 2. The lead bomb will transmit its control fin movements or its inertial measurements, and the follower bombs will duplicate them or a combination of the two may be used. Since the bombs will fall for only a short time (approximately 10 seconds), an open loop control system like this might be accurate enough. This option is an excellent choice for a simulation. If this option works it will be the first choice because it requires the least amount of hardware.

Potential Problem. This system relies on GPS for the bombs to maintain formation position during the glide phase. If GPS is lost, there is no way for the bombs to stay in formation – any error in the initial X, Y, Z position at the start of the terminal phase will only add to the final error.

Option 8. This option uses a phased array antenna of five elements. During level flight, an array of antennae on top of the lead bomb will be used. During vertical flight, an antenna array on the tail fins will be used. The array generates a cartiod beam pattern and rotates the notch, electronically, in a circle. The telemetry link will transmit the attitude of the lead bomb and the direction of the notch.

When the follower bomb receives a low amplitude signal from the lead bomb, it will be able to get its bearing to the lead bomb. A transponder system, operating above 100 MHz, will be used to measure distance to the lead bomb. The lead bomb will send a pulse and follower bombs will retransmit it; the lead bomb then measures the time delay. Each bomb can have a different frequency or a digital code.

Potential Problem. The bearing information may become erroneous due to unwanted reflections off the bombs.

To reiterate, Options 1, 2, and 3 require GPS coverage all the way to the terminal phase; Options 4, 5, 7, and 8 may be used in both the glide and terminal phases, without GPS. Option 2 is the most cost effective, while Option 1 has the highest probability of success. However, if GPS is likely to be lost then Option 8 is the best way to proceed.

The results of the vision research indicate a potential for object discrimination capability from varying distributions of energy across the visible spectrum. Near term plans include using the Infrared Modeling and Analysis (IRMA) simulation tool for demonstrating multispectral object discrimination using color vision models. IRMA, developed by Nichols Research Corporation, is used extensively by the Air Force for modeling and simulation.

IMPACT/APPLICATION

The results from the LongShot™ ingress study will help define requirements for a terminal guidance seeker. This seeker may use multispectral image algorithms. Novel vision and signal algorithms can possibly allow a weapon to see targets that may be masked in some spectra. The bomb swarm study may lead to formations of bombs that will glide to a target and detonate simultaneously – potentially giving greater damage results.

TRANSITIONS

None for FY98.

RELATED PROJECTS

DAMASK is an infrared imaging seeker being developed by the NAWC/WPNS branch at China Lake. Howard McCauley is the point of contact. This project is of interest because some of the algorithms and hardware may be interchangeable, for example, the correlation algorithm, and the optical fiber link. The difference is that DAMASK is looking in the infrared spectrum while this Multispectral Imaging Seeker (MSIS) will be looking in two or more spectra.

REFERENCES

Show-Tien Wang and Walter Frost, 1980: “Atmospheric Turbulence Simulation Techniques with Application to Flight Analysis,” NASA Contractor Report 3309.

Naval Coastal Systems Center, 1983: “HYDAT - Hydrodynamic Analysis Techniques Users Manual,” Panama City, FL, March.

A. Jones, 1997: “Surf Zone Technology Standoff Delivery,” FY97 ONR321OE Year-End Report.