**Contract # N00014-14-C-0004**

# Autonomous Control Modes and Optimized Path Guidance for Shipboard Landing in High Sea States

**Progress Report (CDRL A001)**

**Progress Report for Period: July 9, 2014 to October 9, 2014**


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## Section I:  Project Summary

### 1. Overview of Project

This project is performed under the Office of Naval Research program on Basic and Applied Research in Sea-Based Aviation (ONR BAA12-SN-0028).  This project addresses the Sea Based Aviation (SBA) initiative in Advanced Handling Qualities for Rotorcraft.

Landing a rotorcraft on a moving ship deck and under the influence of the unsteady ship airwake is extremely challenging. In high sea states, gusty conditions, and a degraded visual environment, workload during the landing task begins to approach the limits of a human pilot's capability. It is a similarly demanding task for shipboard launch and recovery of a VTOL UAV. There is a clear need for additional levels of stability and control augmentation and, ultimately, fully autonomous landing (possibly with manual pilot control as a back-up mode for piloted flight). There is also a clear need for advanced flight controls to expand the operational conditions in which safe landings for both manned and unmanned rotorcraft can be performed. For piloted rotorcraft, the current piloting strategies do not even make use of the available couplers and autopilot systems during landing operations. One of the reasons is that, as the deck pitches and rolls in high sea states, the pilot must maneuver aggressively to perform a station-keeping task over the landing spot. The required maneuvering can easily saturate an autopilot that uses a rate limited trim system. For fly-by-wire aircraft, there is evidence that the pilot would simply over-compensate and negate the effectiveness of a translation rate command/position hold control mode. In addition, the pilots can easily over-torque the rotorcraft, especially if they attempt to match the vertical motion of the deck.

This project seeks to develop advanced control law frameworks and design methodologies to provide autonomous landing (or, alternatively, a high level of control augmentation for pilot-in-the-loop landings). The design framework will focus on some of the most critical components of autonomous landing control laws with the objective of improving safety and expanding the operational capability of manned and unmanned rotorcraft. The key components include approach path planning that allows for a maneuvering ship, high performance station-keeping and gust rejection over a landing deck in high winds/sea states, and deck motion feedback algorithms to allow for improved tracking of the desired landing position and timing of final descent.

### 2. Activities this period

*Task 1 - Plant and Disturbance Model*

High fidelity dynamic models of the rotorcraft and accurate models of the shipboard environment are critical aspects of this project.  The project will make use of the FLIGHTLAB modeling and simulation software, which includes accurate models of the coupled non-linear fuselage and rotor blade dynamics, unsteady rotor aerodynamics and inflow models, non-linear landing gear models, engine / rotor RPM dynamics, and the capability to simulate ship airwake and ship motion effects.  The project will investigate three different classes of rotorcraft: 1) A small UAV rotorcraft (FireScout class), 2) A utility helicopter (H-60 class), 3) A large transport rotorcraft (H-53 class).  The flexibility of the FLIGHTLAB modeling and simulation tool will be required to readily model this diverse set of rotorcraft.

During this reporting period, the H-60 class model was distributed by ART to NAVAIR and Penn State team members. The model consists of a 4-bladed blade element main rotor using unsteady airloads and high order Peters-He's finite state dynamic wake model. It simulates fully articulated rotor dynamics with geometrically exact multi-body dynamics modeling that includes flap and lead-lag degrees of freedom. Each blade is modeled using 10 aerodynamic segments and aerodynamic forces/moments are computed for each segment with respect to the segment local angle of attack, Mach number, and dynamic pressure. The unsteady airloads allows for the effects of blade yawed-flow, pitch rate, and stall delay due to the blade rotation. The airframe model consists of a fuselage, empennage, sensors, and landing gear. The fuselage is modeled using nonlinear 6-DOF dynamics and the fuselage airloads are computed using empirical table look-up as a function of fuselage angle of attack and angle of sideslip. The empennage consists of both left and right horizontal stabilator as well as a vertical fin. The sensor model outputs aircraft body attitude and rate information for use by the flight control SAS and FPS. The landing gear system model consists of left and right main as well as a tail landing gear. Both main and tail landing gear are modeled using a full nonlinear spring/damper formulation. The landing gear model also considers ground friction and tire deformation effects to support shipboard landing simulation.

In addition, a full set of linear models of the H-60 class rotorcraft (required for control synthesis) were provided. Note that in this phase of work, PSU and NAVAIR used the Penn State GENHEL-PSU simulation model (H-60 simulation) to generate preliminary simulation results, as the PSU dynamic inversion control laws were already fully integrated with that simulation software. However, in the next quarter we will transition to use of the FLIGHTLAB software.

*Task 2 – Overall Control Architecture*

The overall control architecture uses a modular design, with the idea that key CLAW sub-system technologies can stand on their own, and the individual modules could readily be adapted in future prototype and production CLAW software. A block diagram is shown in Figure 1, with the key “novel” design concepts highlighted in blue (these are described in more detail in the proposal).

In this study, the core of the CLAW is non-linear dynamic inversion (NLDI). This is a well-known control law methodology, but it has not seen widespread use on rotorcraft. Most rotorcraft Fly-by-wire CLAW design efforts have used explicit model following (EMF). We believe that the NLDI architecture itself might be of interest to the rotorcraft controls community, as our preliminary studies have shown some potential advantages over EMF (discussed below), but it is important to note that the research does not rely on this specific CLAW design methodology. Many of the modules shown in Figure 1 could be implemented with EMF.

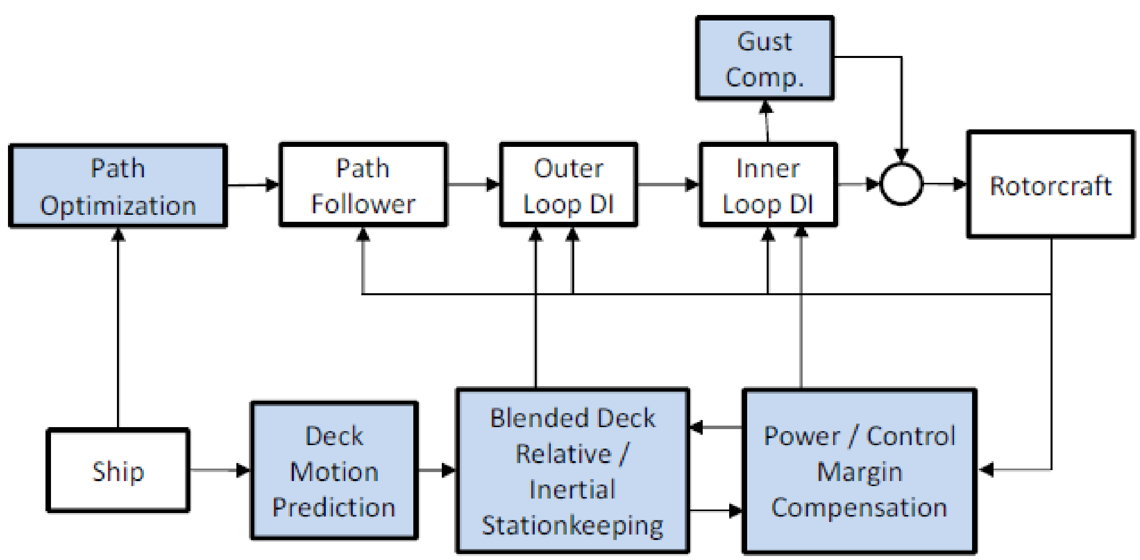



Figure 1: Overall Control Architecture

A schematic of the NLDI control law is shown in Figure 2. The design method is described in detail in a recent AHS Forum paper, [Soneson and Horn, 2014], and will not be described in detail here.

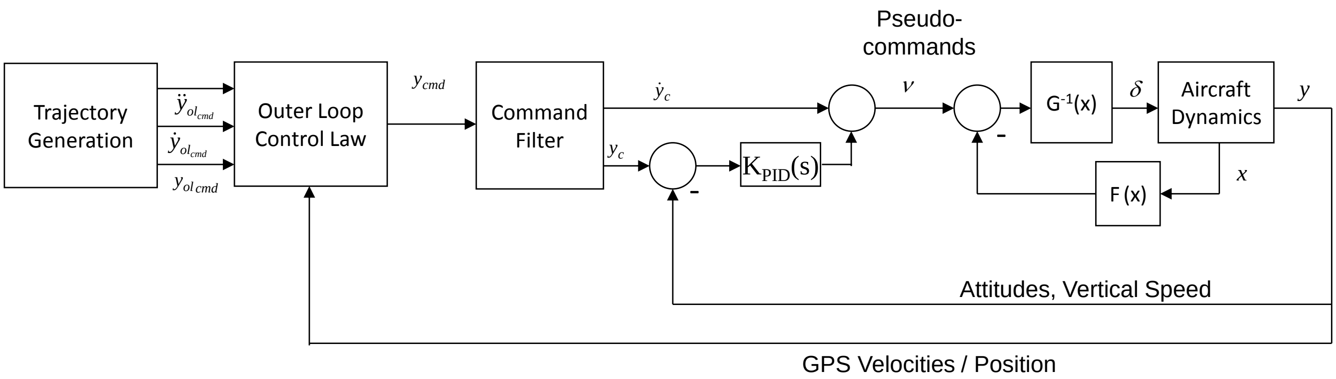



Figure 2: Dynamic Inversion Control Law

*Task 3 –Design Criteria*

Design criteria are defined to guide the CLAW design and to assess the performance. We have set up preliminary threshold and objective requirements as described below (Table 1 and 2). Sink rates were based on H-60 guidelines for slope landings (the numbers below are based on 90% and 80% of the maximum sink rate in slope landings). We are still looking into acceptable horizontal velocities at touchdown. These numbers are preliminary and we will continue to revise in early part of year 1. For control requirements we will attempt to meet MIL-F-9490 stability margin requirements if possible (it is not uncommon for rotorcraft to violate these guidelines for more highly augmented control systems).

| Parameter | Threshold | Objective |
|---|---|---|
| Position/tracking error (ft)<br>- En-route<br>- On approach<br>- Terminal phase of approach<br>- Touchdown | <br>50<br>10<br>5<br>3 | <br>25<br>5<br>3<br>1 |
| Relative Velocities at Touchdown (ft/sec)<br>- Sink Rate<br>- Horizontal Velocity | <br>2.7 ft/sec<br>TBD | <br>2.4 ft/sec<br>TBD |
| Control margins | 10% margin from full throw | 20% margin from full throw |
| Engine Torque Margins | 5% margin from aircraft limits | 10% margin from aircraft limits |
| Uncommanded attitude transients (deg) | ≤10 | ≤5 |

Table 1: Proposed Performance Design Criteria

| Parameter | Threshold | Objective |
|---|---|---|
| Stability Margins | 30° PM<br>4 dB GM | 45° PM<br>6 dB GM |
| Engage / Dis-engage Transients (transitions to and from manual pilot mode) | Meet threshold requirements in control margin and attitude transients | Meet objective requirements in control margin and attitude transients |
| Sensors | Realistic sensor models with: noise, bias, sampling delay | |
| Actuators | Authority limits representative of baseline aircraft, 100% / sec rate limits, 5 Hz Bandwidth | |

Table 2: Proposed Control System Design Requirements

*Task 4 – Dynamic Inversion Control Design*

The NLDI control laws have been fully implemented in the GENHEL-PSU simulation using SIMULINK, and we are currently porting them to FLIGHTLAB using the Control System Graphical Editor (CSGE) tool. Two major efforts were performed during this reporting period. First, we conducted a gain tuning study to evaluate and set the stability margins. Secondly we implemented an outer-loop path following control law to autonomously track a time parameterized trajectory.

Tables 3 and 4 show the resulting gain margins, phase margins, and the disturbance rejection properties as measured by disturbance rejection bandwidth (DRB) for two different gain sets. Table 3 shows properties that meet the standard MIL-F-9490 45° / 6 dB margins, while Table 4 shows those that meet relaxed margins (30° / 4 dB) with higher disturbance rejection. The differences represent the well-known trade off in stability margins with disturbance rejection. We found that for equivalent stability margins, the NLDI controller gave better disturbance rejection compared to EMF control laws used for UH-60 control as published in an AHS paper published by the U.S. Army Aero Flight Dynamics Directorate [Mansur et al, 2009]. We believe this is because of the cross-channel feedback paths that more effectively de-couple the rotorcraft dynamics.

| Control Axes | GM (dB) | ωgm (rad/s) | PM (deg) | ωpm (rad/s) | DRB (rad/s) |
|---|---|---|---|---|---|
| ACAH | | | | | |
| Lateral Cyclic | 7.8 | 7.9 | 45 | 4.3 | 1.5 |
| Longitudinal Cyclic | 15.1 | 9.4 | 45 | 2.8 | 0.35 |
| Pedals | 11.8 | 16.7 | 45 | 6.2 | 3.7 |
| TRC | | | | | |
| Lateral Cyclic | 8.3 | 7.8 | 41* | 3.6 | 0.7 |
| Longitudinal Cyclic | 15.7 | 10.35 | 45 | 2.7 | 0.4 |

Table 3 Standard Stability Margins

| Control Axes | GM (dB) | ωgm (rad/s) | PM (deg) | ωpm (rad/s) | DRB (rad/s) |
|---|---|---|---|---|---|
| ACAH | | | | | |
| Lateral Cyclic | 5.7 | 8.3 | 30 | 5.6 | 1.8 |
| Longitudinal Cyclic | 10.9 | 9.3 | 30 | 4.1 | 1 |
| Pedals | 7.8 | 16.1 | 30 | 8.7 | 5 |
| TRC | | | | | |
| Lateral Cyclic | 5.6 | 8.4 | 30 | 5.5 | 0.8 |
| Longitudinal Cyclic | 10.8 | 10 | 30 | 4.3 | 0.5 |

Table 4 Relaxed Stability Margins

Figure 1 shows a schematic of an outer-loop path following controller for the longitudinal axis. The controller is designed to track a smooth, continuous trajectory defined by a kinematically consistent set of position, velocity, and acceleration commands parameterized by time. The simple control law uses a dynamic inversion scheme to produce command roll and pitch attitudes, yaw rate commands, and vertical speed command that are then fed to the inner loop control system.

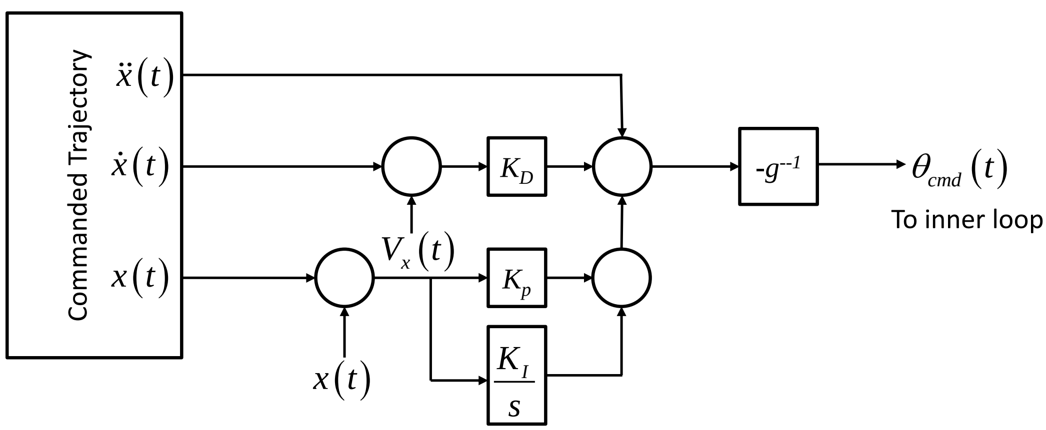



Figure 1: Outer Loop Path Following Control Law (longitudinal axis)

Figures 2 and 3 show sample simulation results from GENHEL-PSU for a trajectory used in the path optimization study (described below for Task 6). These simulations were performed for approaches of the H-60 to a frigate moving at 20 knots in a 5 kts head wind (25 kts, 0° relative wind). A CFD airwake database from the SFS2 generic frigate shape was used to simulate airwake. The aircraft and controller are therefore subject to airwake disturbances near the ship, as well as sensor noise perturbations. The results in Figure 4 and 5 are for the most aggressive approach trajectory used in the path optimization study (we see a 25° nose up attitude in the final deceleration). However, tracking of the trajectory is quite good, especially at the final hover point. There is some notable overshoot of the forward position and the altitude in the deceleration phase of the maneuver, which could be improved (or perhaps justify a less aggressive approach as studied in Task 6).

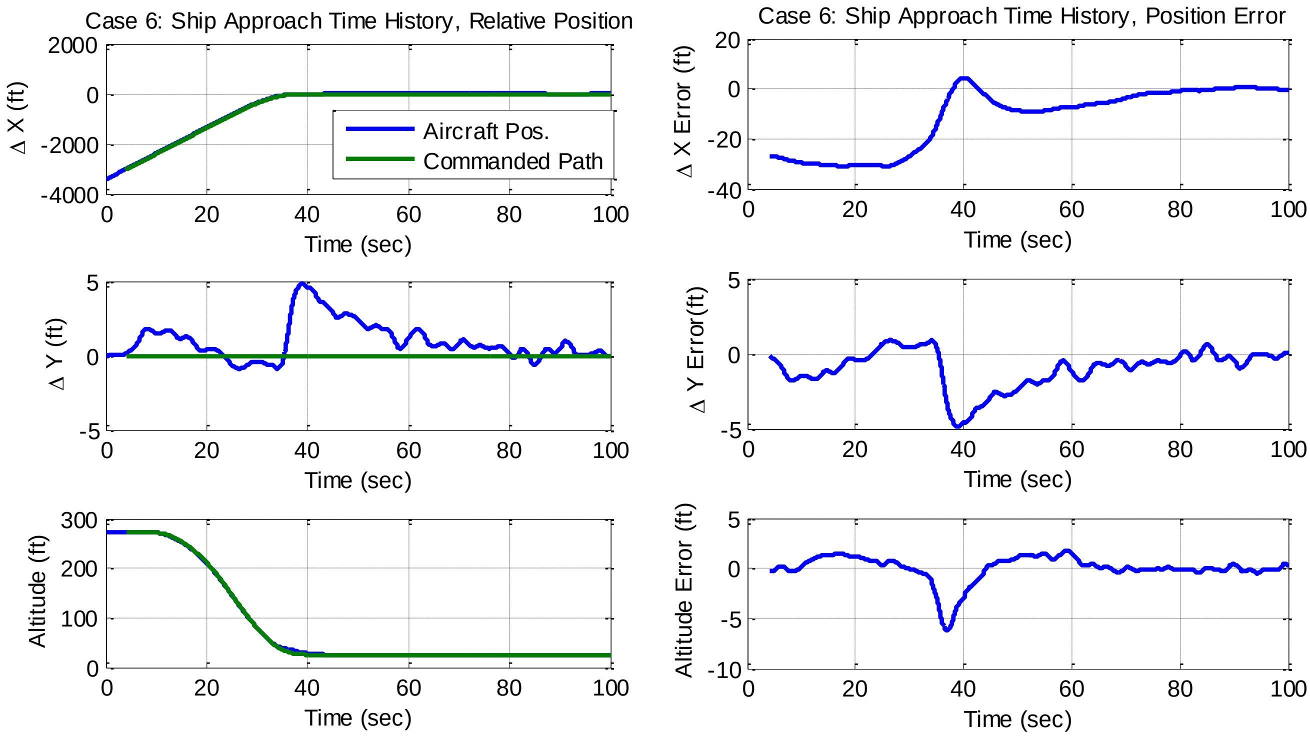



Figure 2: Sample Approach Trajectory

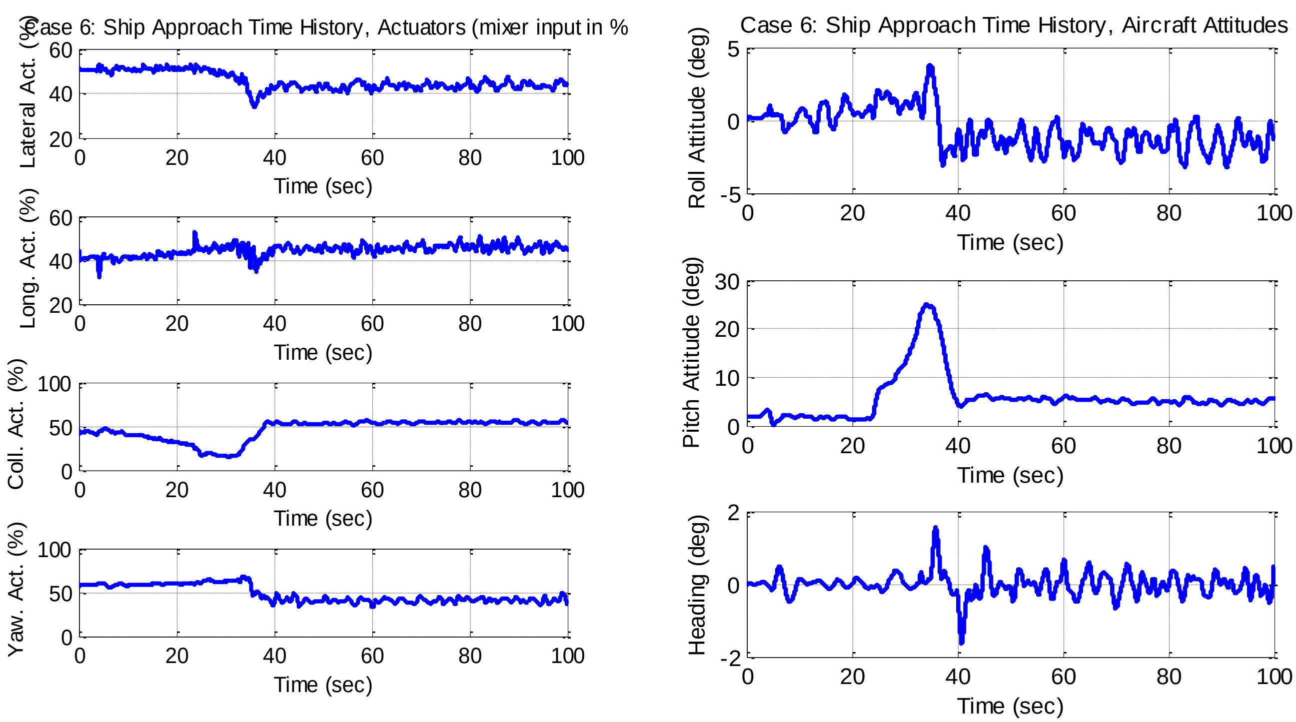



Figure 3: Actuators and Attitude during Sample Trajectory

*Task 5 – Deck Motion Prediction Algorithm*

Ship deck motion forecast provides a good opportunity for shipboard rotorcraft controller to take advantage of using advanced control laws (such as a robust feed-forward control) for a safe shipboard landing under high sea states. Efforts were made in this reporting period in investigating dynamic forecasting methods and formulating a ship deck motion forecast framework to support the development. The ship deck motion forecasting framework under development includes 1) forecasting algorithm formulation and implementation; 2) test condition formulation for ship motion time history data generation; 3) evaluation criteria for the prediction confidence measurement.

A group of auto-regression and moving average algorithms for dynamic forecasting based on past time history data was studied. A Holt-Winters (H-W) algorithm (Markridakis 1998) was selected for initial testing. The H-W algorithm predicts the future variation based on an on-line adaptive update of the mean, the trend, and the cyclic characteristic from past time history. The algorithm adopts a smoothing technique with weight decaying exponentially with older observations and therefore, places a much heavier weight on using the most recent information for forecast. In implementation, a multi-block method was used where the data are organized in multiple sampling blocks with offset from each. The H-W algorithm is then applied to each data block with adaptation to generate the forecasting for that block. The outputs from each block are then combined from the multi-block prediction to result in the forecasting. Figure 4 illustrates the H-W based multi-block method.

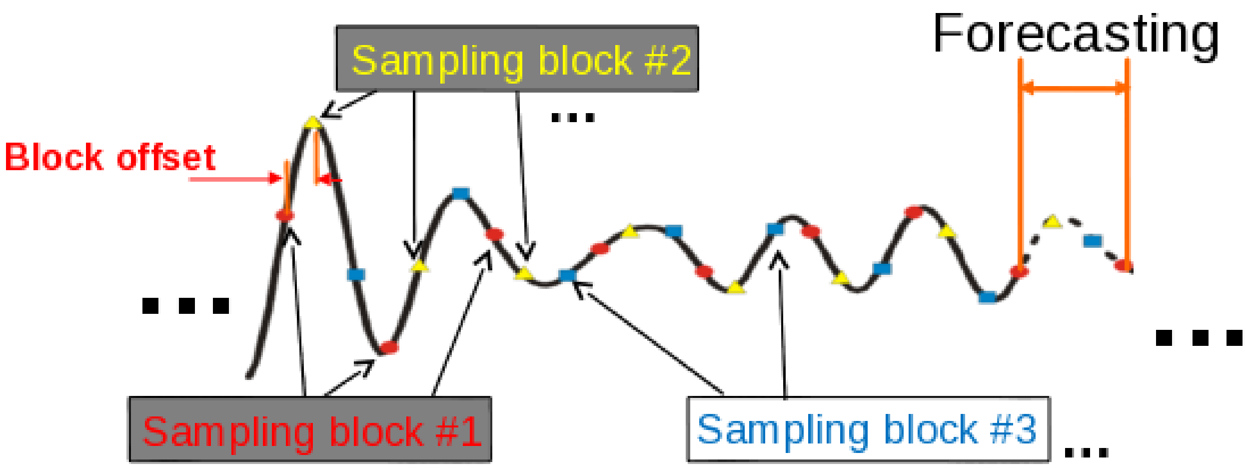



Figure 4: H-W based multi-block forecasting method

It is best to use measured ship deck motion data (if available) for the algorithm test and evaluation. Due to lack of the measured data, the ship motion outputs from USN SMP and STH are used for this research. The 6-DOF ship deck motion to consider includes surge, sway, heave, roll, pitch, and yaw. The full 6-DOF motion is in response to the variation of sea state wave conditions, wave angle with respect to the ship course, and ship speed. The sea state conditions are statistically defined in terms of sea state number and large sets of sample data for deck motion are required in order to be statistically meaningful for the forecast method evaluation. Given a ship speed and wave angle, the data can be collected by sweeping the significant wave height and wave modal period for the range as defined by a sea state table. Moreover, for each test case, the wave angle may also be varied in the course of the deck motion data generation to maximize the seaway conditions that a ship may encounter.

The establishment of the ship deck motion forecast accuracy criteria is another important part of the methodology framework development. The forecast capability requirements involve both forecasting time (i.e., how far into the future the algorithm can predict) and how reliable the prediction is. The forecasting time for this development is targeted in 5 to 10 seconds in order to be useful for shipboard landing control support. The initial testing showed that a 5 second in advance forecasting is possible. But, notice that this is just the very initial finding and more tests remain to be performed before a solid conclusion can be attained. The prediction confidence is quantified by a measured value which is the sum of “Best Estimate” and “Uncertainty”. From the initial testing, it was observed that the forecast error variations in terms of standard deviation are very close to a normal distribution. The observation will be further verified through more extended testing in next period that follows. Based on normal distribution, a successful forecast probability will be computed by standard deviation in sigma value. For example, a 2.0 sigma gives a 95.5% of prediction probability that the forecasted ship deck motion will be within the prediction criteria as set.

*Task 6 - Path optimization of shipboard helicopter:*

Under this task, the shipboard path optimization problem will be rigorously formulated and corresponding algorithms will be developed and tested. This formulation involves: (i) the mathematical description of a spatially and temporally-varying approach profile using a design vector, $\mathbf{X}$, (ii) the development of a novel objective function, $F(\mathbf{X})$, that serves as a quantitative assessment of the approach performance, and (iii) mathematical constraints, $g_j(\mathbf{X})$, which are imposed to ensure that the optimization results are operationally feasible and safe.

The major focus thus far in this task has been the initial formulation of the approach profile and the development of an objective function. It is anticipated that both of these elements of the optimization will evolve over the life

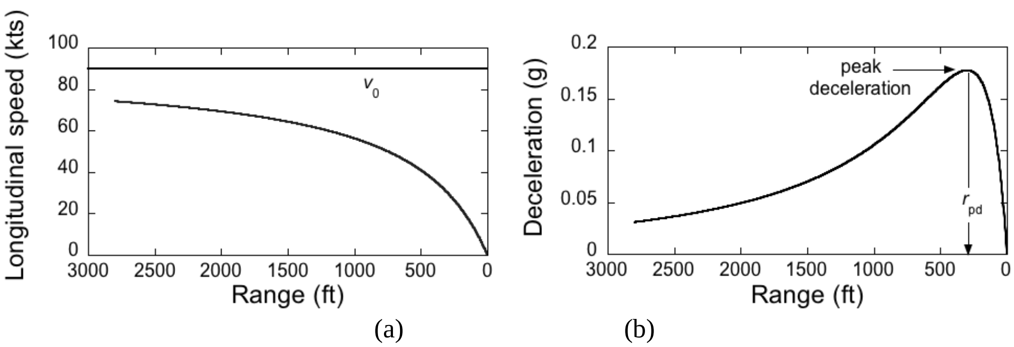



**Figure 5: Heffley’s formulation of longitudinal deceleration and velocity profiles for a visual approach (Tritschler, 2014).**

of the research project, and the present examples are purposefully simple to facilitate initial investigations.

The approach profile utilized in the present study is an extended version of Heffley’s mathematical formulation of longitudinal deceleration and velocity profiles for a visual helicopter approach (Heffley, 1979). Heffley’s formulation (see Fig. 5) is based on only two parameters (an asymptotic velocity, $v_0$, and the range from the landing spot at which peak deceleration occurs, $r_{pd}$), and this simplicity makes it ideal for preliminary investigations. This formulation was previously extended to allow for the prescription of the

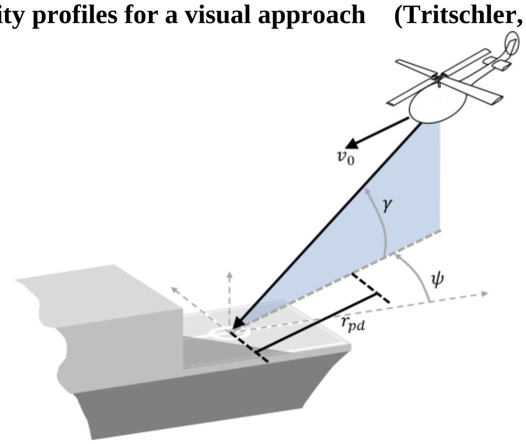



**Figure 6: Schematic diagram showing the four approach profile design variables.**

approach path through an approach angle, $\gamma$, in a brownout-related trajectory optimization (Tritschler, 2014). It is being extended further in the present work to include a ship-relative azimuth angle, $\psi$. The resulting approach profile design vector consists of four variables, i.e., $\mathbf{X} = [v_0\ r_{pd}\ \gamma\ \psi]^T$. A schematic is shown in Fig. 6.

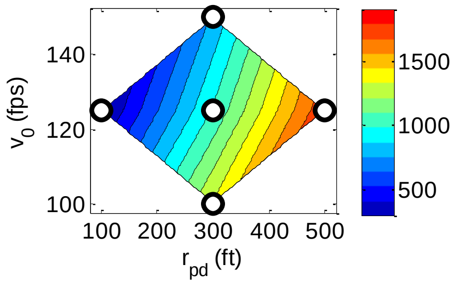
Notice that the first two variables describe the temporal approach profile, i.e., $\mathbf{X_{temp}} = [v_0\ r_{pd}]^T$, and the second two variables describe the spatial approach profile, i.e., $\mathbf{X_{spatial}} = [\gamma\ \psi]^T$. In other words, $\mathbf{X_{temp}}$ describes the way in which the aircraft traverses the path defined by $\mathbf{X_{spatial}}$. It is important to notice that there are many other factors that could be included in the approach profile design vector, such as: (i) yaw/sideslip angle (the present formulation assumes that the nose of the helicopter is pointed in the direction of flight), (ii) aircraft gross weight, (iii) wind over deck (i.e., the magnitude and azimuth), and (iv) ship motion (where the proper mathematical description of ship motion remains an open research question). The inclusion of such factors will be addressed as the project progresses.

Work on the development of an objective function has focused on determining the most important factors that ought to be considered in assessing the overall approach performance—and how those factors can be mathematically defined. Three candidate performance factors were identified for preliminary investigation: (i) the approach "work", which combines transit time and power requirements, (ii) position error, and (iii) airwake effects. Selecting the right combination of performance factors to be included in the objective function is of primary importance, and the three factors in the present study are not meant to be comprehensive. Rather, the present work has focused on the ways in which multiple factors may be combined in a single objective function.

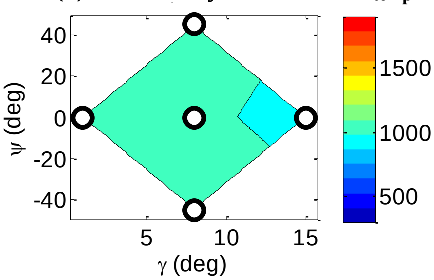
A sensitivity study was conducted to explore the relationship between these performance factors and the approach profile design variables. The work performed for each approach profile was computed by integrating the power required over the duration of the maneuver. The sensitivity of the approach work to $\mathbf{X_{temp}}$ and $\mathbf{X_{spatial}}$ is shown in Fig. 7 (a) and (b), respectively. Note that these contour maps include only the test cases in which the other two approach design variables are held at their nominal values. For example, the sensitivity of approach work to $\mathbf{X_{temp}}$ shown in Fig. 7 (a) only considers cases in which $\mathbf{X_{spatial}}$ was held to nominal values. Therefore, the contour maps do not show any interdependencies between $\mathbf{X_{temp}}$ and $\mathbf{X_{spatial}}$. Notice that Fig. 7 clearly shows a stronger sensitivity to $\mathbf{X_{temp}}$ than $\mathbf{X_{spatial}}$. This result is consistent with what would be intuitively expected—the work performed is more strongly impacted by the aircraft velocities and accelerations than by which approach path is taken.

Similar results to those in Fig. 7 for approach work are shown in Fig. 8 for position error and Fig. 9 for airwake effects. The error shown in Fig. 8 is the mean position error from the prescribed path over the course of the maneuver. This may need to be updated to reflect the fact that the true path accuracy requirements should depend on the phase of flight (e.g., the aircraft position must be much closer to its prescribed path in the later stages of the approach than in the initial stages). Note also that Fig. 9 illustrates the effects of the airwake as a maximum thrust fluctuation from a mean thrust value. While thrust fluctuation is a major consideration for helicopter flight in turbulent airwakes, other performance factors may need to be considered.

The three performance factors can be combined into a single objective function, i.e., $F(\mathbf{X})$, by normalizing the constituent values and averaging across the performance factors; see Fig. 10. Although this objective function is only preliminary, it demonstrates the methodology that will be employed to define candidate objective functions over the course of the project. Aside from the addition of other performance factors (e.g., actuator margins) and adjustments to the way in which some of the existing performance factors are included (e.g., alternative metrics for capturing the airwake effects), future objective functions will investigate the effect of weighting the various performance factors.

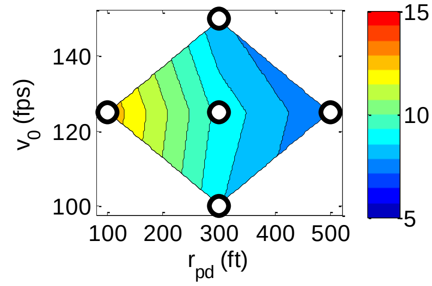



**(a) Sensitivity of work to $X_{temp}$**

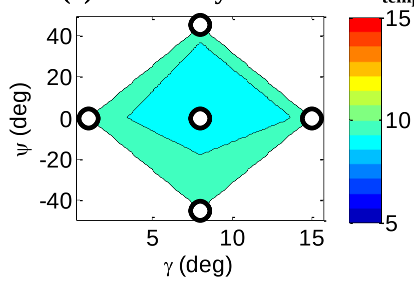



**(b) Sensitivity of work to $X_{spatial}$**

**Figure 7: Sensitivity of work (hp-min) to the approach profile design.**

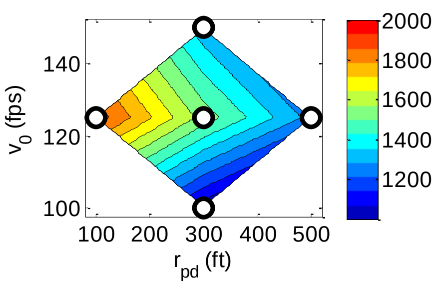



**(a) Sensitivity of error to $X_{temp}$**

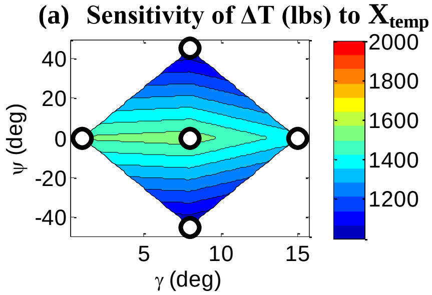



**(b) Sensitivity of error to $X_{spatial}$**

**Figure 8: Sensitivity of mean position error (ft) to the approach profile**

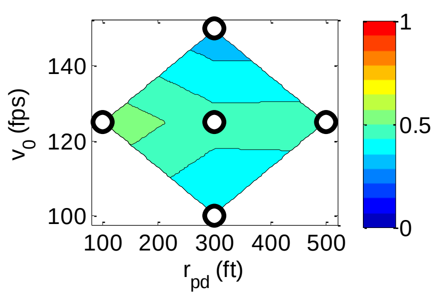



**(a) Sensitivity of ΔT (lbs) to $X_{temp}$**

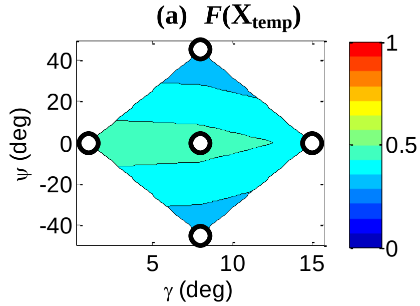



**(b) Sensitivity of ΔT (lbs) to $X_{spatial}$**

**Figure 9: Sensitivity of airwake effects to the approach profile design.**




**(a) $F(X_{temp})$**




**(b) $F(X_{spatial})$**

**Figure 10: Preliminary objective function.**

## 3. Significance of Results

During the first quarter of effort, the team has made significant progress in establishing the basic tool sets for each of the team members. The FLIGHTLAB software and H-60 class model has been distributed to NAVAIR and PSU. PSU has generated preliminary results with a fully autonomous DI controller, and NAVAIR has conducted an initial path optimization studies. While these capabilities were largely in place in previous work, the algorithms and methodologies required "dusting off" and tuning for the specific application in this project. The control architecture is currently well-defined and design criteria have been established. Preliminary analyses of the DI controller have indicated it is an effective control architecture for this study.

The deck motion forecast methodology framework was established, including forecast algorithm, test condition setup for the deck motion data generation, and forecasting confidence measurement criteria. The significance of the methodology framework is in its modular formulation, which laid the foundation for a very straightforward upgrade and enhancement of any of the modules. The initial deck motion prediction results were encouraging in that it can provide a 5 second in advance forecasting with reasonable accuracy. The establishment of forecast confidence measurement in terms of probability percentage offers a statistically meaningful criterion for evaluating the forecasting method on ship deck motion that is random in nature.

A significant accomplishment was the development of an outer loop path follower for the DI control law, integration of preliminary approach trajectories, and a preliminary path optimization study. Results to date on path optimization have been interim in nature. The development of compact mathematical formulations for the approach profile and the definition of a suitable objective function are essential for the overall success of this task. For the approach profile formulation, a key consideration is in striking the right balance between approach profile flexibility and the computational cost. The number of performance factors to be included in the objective function must strike a similar balance. There must be enough factors considered to adequately characterize the performance of a given approach profile, but the inclusion of many performance factors will likely result in an objective function with challenging mathematical properties for optimization (e.g., nonlinearity, non-convexity, etc.). Given the progress on Task 6 thus far, the team is now ready to investigate these effects in greater detail.

## 4. Plans and upcoming events for next reporting period

*Task 1 – Plant Model and Disturbance Models*: The FireScout and H-53 class FLIGHTLAB models will be developed and distributed to team members.

*Task 3 – Design Criteria:* We will continue to research U.S. Navy requirements for ship landing and the design criteria will be refined and more formally established.

*Task 4 – Dynamic Inversion Control Design*: The DI control scheme will be fully ported to the FLIGHTLAB simulation environment.

*Task 5 – Ship Motion Prediction*: Next focus will be on the forecasting algorithm enhancement for a significant improvement in both accuracy and prediction horizon length. Extensive tests will then be performed to collect sufficient amount of deck motion data for the algorithm evaluation. A DDG-81 class ship will be used for the testing.

In addition, we will begin working on preliminary vertical axis and station-keeping control laws that make use of an assumed deck motion prediction capability. The objective will be to understand the requirements for deck motion prediction in terms of accuracy and prediction horizon for auto-landing capability. In this phase, we will focus on a control strategy that commands the aircraft to hold a fixed relative position to the landing spot. Performance will be evaluated in terms of tracking error, and the phase lag between commanded and actual vehicle response will be critical. This is where deck motion prediction algorithms will improve performance of the control law.   Later studies will look at other strategies, i.e. timing the landing rather than trying to track deck motion.

*Task 6 - Path optimization of shipboard helicopter:* Next steps involve the continued formulation of the optimization problem and algorithm development.  In the near term, the present approach profile formulation will be utilized and the focus will be on objective function development.  This will involve detailed investigation into which performance factors ought to be considered and how they ought to be weighted.  Work will transition from the current PSU-GENHEL simulations to FLIGHTLAB simulations.

## 5. References


Heffley, R. K., "A Model for Manual Decelerating Approaches to Hover," 15th Annual Conference on Manual Control Proceedings, Air Force Flight Dynamics Laboratory, Dayton, OH, November 1979, pp. 545–554.

Tritschler, J. K., Celi, R., and Leishman, J. G., "Methodology for Rotorcraft Brownout Mitigation Through Flight Path Optimization," Journal of Guidance, Control, and Dynamics, Vol. 37, No. 5, September–October 2014, pp. 1524–1538.

Soneson, G.L., and Horn, J.F., "Simulation Testing of Advanced Response Types for Ship-Based Rotorcraft," Proceedings of the American Helicopter Society 70th Annual Forum, Montreal, Canada, May 2014.

Mansur, M.H., Lusardi, J.A., Tischler, M.B., and Berger, T., "Achieving the Best Compromise between Stability Margins and Disturbance Rejection Performance, American Helicopter Society 65th Annual Forum Proceedings, Grapevine, TX, May, 2009.

Markridakis, W. and Hyndman, R.J., `` Forecasting:  Methods and Applications," Wiley, 1998.


## 6. Transitions/Impact

Results were presented at the SBA program 2014 year-end review at Carderock.

## 7. Collaborations

Penn State and ART have collaborated directly with John Tritschler at NAVAIR.  In addition, we are communicating with other Navy researchers pursuing similar projects: Al Schwarz at NSWCCD who is investigating ship motion prediction and AutoLand, and Dave Findlay at NAVAIR who is investigating advanced control laws for shipboard landing.  We have informally discussed transferring the DI control laws (in FLIGHTLAB CSGE format) to Al Schwarz.

## 8. Personnel supported

Principal investigator:   Joseph F. Horn

Graduate Students:   None (new graduate student being recruited for January 2015 start).

## 9. Publications

No publications to date. We are currently preparing a draft manuscript for submission to the 2015 AIAA AFM Conference on the path optimization work.

## 10. Point of Contact in Navy

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## 11. Acknowledgement/Disclaimer

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**Section II: Project Metrics**

**Contract # N00014-14-C-0004**

**Autonomous Control Modes and Optimized Path Guidance for Shipboard Landing in High Sea States**

**Progress Report (CDRL A001)**

**Progress Report for Period: July 9, 2014 to October 9, 2014**


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**October 31, 2014**

## 1. Metrics

Number of faculty supported under this project during this reporting period: 1

Number of post-doctoral researchers supported under this project during this period: 0

Number of graduate students supported under this project during this reporting period: 0

Number of undergraduate students supported under this project during this period: 0

Number of refereed publications during this reporting period for which at least 1/3 of the work was done under this effort: 0

Number of publications (all) during this reporting period: 0

Number of patents during this reporting period: 0

Number of M.S. students graduated during this reporting period: 0

Number of Ph.D. students graduated during this reporting period: 0

Awards received during this reporting period: 0

Invited talks given: 0

Conferences at which presentations were given (not including invited talks above): 0

2. **Financial information**

| FY 2014 | Total Budget | Obligated This Period | Obligated Cumulative | Expended This Period | Expended Cumulative | Grant/ Contract Period of Performance |
|---|---|---|---|---|---|---|
| **6.2 (Applied Research Funding)** | **$245,000** | **$160,004** | **$160,004** | **$15,059** | **$15,059** | **July 9 ,2104 to July 8, 2015** |

3. **Administrative notes and other items of interest**

Note that PSU has recruited a new PhD student, who will begin work on the project starting in January 2015. A current MS student will likely assist on the project (temporarily) in November / December 2014.