Resolving the conflict between Ship design and UAV Launch & Recovery deck limits; the development of enhanced DI Study tests

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Presentation Outline

- Typical Ship Motion Forecasting on ship design
  - SMP/SHIPMO Predicted Ship Transfer Functions
  - Traditional Simulated Ship Motion
  - Predicted deck limits of UAV example

- When the constructed ship displays unpredicted motion/airwake characteristics
  - Example of the LCS classes

- Solution: fully define in real-time environmental ship’s characteristics
  - Quiescent Period Prediction Project
  - LiDAR based technologies
  - Active Operator Guidance

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Defining the Environment’s effects on helicopter

The Environment over the deck is Complex; then consider the effects by the ship on the environment.

To ensure an acceptable response by the air vehicle, all force contributors from the flight deck must be defined.

\[
\begin{align*}
F_x &= k \cdot A X_{cg} \\
F_y &= k \cdot A Y_{cg} \\
F_z &= k \cdot A Z_{cg}
\end{align*}
\]

\[
\begin{align*}
(X, Y, Z) &= \begin{bmatrix} T_{11} & T_{12} & T_{13} \\
T_{21} & T_{22} & T_{23} \\
T_{31} & T_{32} & T_{33} \end{bmatrix} \begin{bmatrix} F_x \\
F_y \\
F_z + W \end{bmatrix} \\
\text{FRMG}_{\text{WIND}} &= \left(F_W \right) \frac{(W_{\text{LCP}} - W_{\text{LG}})}{(L_{\text{BL}} - R_{\text{BL}})} \\
\text{ship motion}
\end{align*}
\]

Fi = encountered inertial forces due to ship motion: given as \( S_r = S_w \cdot X \cdot [\text{RAO}]_{H_s, T_0} \)
Ship Motion Computational Summary (Legacy type ships)

Sea Spectrum (Ship’s Speed and Wave Heading)

- Spectrum for given Significant Wave Height and Given Encountered Conditions
- $S_w$ to Each DOF for Given Encountered Conditions and for Each of “n” Frequency

RAO’s

- $O_x$, $O_y$, $O_z$
- Heave, Roll, Pitch, Yaw, Sway, Surge

Response Spectra

- $S_2$, $S_3$, $S_4$, $S_5$, $S_6$, $S_7$
- Heave, Roll, Pitch, Yaw, Sway, Surge

Harmonic Components

- $A_{z1}$, $\omega_1$, $\xi_{z1}$
- $A_{z2}$, $\omega_2$, $\xi_{z2}$
- $A_{x1}$, $\omega_1$, $\xi_{x1}$
- $A_{x2}$, $\omega_2$, $\xi_{x2}$
- $A_{y1}$, $\omega_1$, $\xi_{y1}$
- $A_{y2}$, $\omega_2$, $\xi_{y2}$
- $A_{n1}$, $\omega_1$, $\xi_{n1}$
- $A_{n2}$, $\omega_2$, $\xi_{n2}$

$S_R = S_w \times RAO$
- At Each of “n” Freq.
- Phase Lag at each Freq. Not Shown

Harmonic Analysis Into “n” Components

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Predicted Event sets limits preliminary NATOPS (SHOL)

Encountered Force HH65 x LPD-4 10601511 with Slide

SLIDE INDICATED

kg of force

RFX
RFY
RFZ
FORCE

time(seconds)

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Sum of Simulated Events = Forecasted Deck Limit

Relative Wave Heading
Probable Aircraft Incident zone
Significant Wave Height
In Limit (no probable aircraft incident zone)

Ship Speed
- 5 knots
- 10 knots
- 15 knots

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Solution: Fully Define in real-time the environmental ship characteristics

1. Why is it important for UAVs?
2. Quiescent Period Prediction Project
   - LiDAR based technologies
   - Active Operator Guidance (AOG)
Background: Why we are here?

**Ship Design and UAV Operations**

- Objective: explain, define and characterise ship environment; to program LCS specific launch and recovery solutions.

- In the course of MQ-8B/C envelope expansion (DI) trials on both classes of LCS vessel, *unexpected ship motions* have been observed and recorded.

- These unexpected motions are mainly observed to be large roll events.

- Coincidentally axial degrees-of-freedom observed to be largely in-phase, normally a rare event.

- Whilst there were much fewer events of unexpected ship motion during flight operations; they still occurred.

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Why are we here, suite?

Based on LCS – 1 to LCS – 8 testing experience

- Lateral motions were observed (and recorded) composed of rapid peak cycles. Hypothesis relates jet nozzle motions & autopilot commands creating these cycles.

- Coincidently a stern “shimmy” has been observed and thought to be related to the ship’s “autopilot”.

- Shedding vortices as seen on LCS-4 (”dust devils”) may be related to oblique recoveries coupled by unexpected ship motions.

- Some of the ship motion observations may have a baring on the formation of unusual burble shapes coupled with the presence deck structures “winglets”.

Repeat:
Objective: explain, define and characterise ship environment; to program LCS specific launch and recovery solutions.
MQ-8B x LCS-3, recorded stats
What happened here?

- Total hours recorded at sea: 240
  - **Sea State: 0 – 3** Ship Speeds: 2 – 15 knots (only NOAA seaway data tracked)
  - Max motions: roll – 9.9° pitch – 2.5° Z’ – 0.7 m/s Z” – 1.0 m/s²
    Y’ – 0.6 m/s Y” – 0.6 m/s² X’- .28 m/s X” - .29 m/s²
  - MQ-8 deck limits: roll – 5°, pitch – 3°, Z’– 2.2 m/s(7.2’/s), Y’ – 0.86m/s(2.8’/s)

- The number of rise time events: 252 (non slam)
  - Average minimum rise time recorded: 10 seconds
  - Computational minimum rise time: 6.3 seconds
  - No of Slam events: 0 (non aviation);
  - **Excessive ship motion axis causing risetime:**
    - **Roll:** 100.0%
    - Y, Z’: 0.0%
    - Pitch 0.0%

- The number of launch and recovery events recorded = 177 (86 launch; 86 recovery; 5 wave-off): 64 piloted serials; 22 autonomous serials;
  - Launch: 55 green, 20 gr-amber, 25 amber, 0 red events
  - Recovery: 60 green, 15 gr-amber, 25 amber, 0 red events

- **Other: ship’s power failure events (some occurring during flight ops). System robustness is a requirement for the success of this test.**

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Sample LCS-3 Analysis with FltOps

RECALL:
- Excessive motions seem to favour roll
- Motion axes are all in phase.
- It "feels" as though the ship enters a form of resonance.
- Need to establish the encountered seaway and ship's speed favouring the ship's response.

Ship did not appear to be in roll cycles during this stage of envelope expansion

Not normal

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Objective

- Conduct flowfield measurements aboard LCS Freedom class ship to assess the impact of ship airwake on the Fire Scout launch and recovery envelope
  - Quantify flow characteristics in the plane of the rotor for the MQ-8 at low hover
  - Provide validation data set for CFD computations of LCS Freedom class ships
  - Provide experimental data set for development of ship airwake disturbance model within Fire Scout flight simulation
Solution: Fully Define in real-time the environmental ship characteristics

1. Why is it important for UAVs?
2. Quiescent Period Prediction Project
   - LiDAR based technologies
   - Active Operator Guidance (AOG)
Rating criteria: lacking a human, UAS cannot provide qualitative assessments or ratings.

Variability: Humans have varying experience, skill and technique. UAS robots have flight law definitions contained in their guidance, navigation and control (GNC) system. The robot will execute its recovery in the same manner over and over again.

Visual cues: Humans apply visual cues to interpret the dynamic conditions of the physical world manipulating helicopter controls, accordingly. For this reason it is a significant contributor to pilot workload. Robots replace human empirical cueing assessment with instrumented measures to achieve programmed launch and recovery objectives.
Human Unscripted Decision Making Process

Where should I eat? (Fast Food Edition)

1. Are you in Canada?
   - Yes
   - No

2. Is it after 10:00 PM?
   - Yes
   - No

3. Is it before 10:30 AM?
   - Yes
   - No

4. Are you a police officer?
   - Yes
   - No

5. Do you live on the west coast?
   - Yes
   - No

6. Is your name Jared?
   - Yes
   - No

7. Do you have more than $3?
   - Yes
   - No

8. Are you drunk?
   - Yes
   - No

Options:
- Tim Hortons
- Dunkin' Donuts
- McDonald's
- Subway
- In-N-Out Burger
- Jack in the Box
- Taco Bell

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To Program Designers
the System equates

Every action a human takes in conducting launch or recover, must be contained in a program

Non fuzzy logic
Robotic decision
Is asymptotic w human axis
The Next Generation of Air/Ship Interface Issues

Wave Profiling RADAR

Analysis Shows wave Direction, Height and Wave Velocity

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The Next Generation of Air/Ship Interface Issues

- Mass approximately 85 Kg
- Enclosure dimensions: 630 x 530 x 400 mm
- Power requirement: 24 V DC, 150W
- Extra 340 W for enhanced active cooling option for 50°C ambient temperatures

Doppler LIDAR
QPP – Active Operator Guidance (AOG)

Sum (lay-over) of all Maps for the best course to steer

Individual Parametric Mapping

Measured Deck Attitude in real-time is transmitted to the UAV launch and recovery computer

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From Dynamic Interface computations:

- UAS is by its nature a simulation of piloted flight. For non-fuzzy logic robots, every human action must be encoded. The UAV will repeat the same error unless corrected in the code.

- Defining aircraft’s deck motion will permit increased NATOPS/SHOL deck limits leading to better aircraft availability and deck definitions.

- Improved definition of the ship platform environmental characteristics will increase confidence in robotic flight will reduce need for extensive experimentation.
Typical QPP Trial Interface event
Short term prediction horizon

QUESTIONS?

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