Degraded Visual Environment Mitigation (DVE-M) Program,
Yuma 2016 Flight Trial

Zoltan Szoboszlay
Brian Fujizawa
Major Joe Minor
Major Zachariah Morford
Major Michael Osmon
U.S. Army Aviation Development Directorate, AMRDEC

Bradley Davis
U.S. Army Research Laboratory

Approved for Public Release AMRDEC 2615
April 4, 2017 Oslo Norway; April 6, 2017 Braunschweig Germany;
April 24, 2017 Ft. Rucker Alabama USA
Outline

• Introduction
• Research Systems Description
• Methods
• Yuma Videos
• Results
• Conclusions
• European Trials Videos
Introduction
The purpose of the Degraded Visual Environment Mitigation (DVE-M) program is to generate knowledge about technical solutions and procedures that enable operations in degraded visual environments.

- Decrease the number of accidents.
- Enable intentional operations in DVE when the adversary cannot operate – a disruptive capability.
NATO Sponsorship

- NATO Joint Capability Group-Vertical Lift (JCG-VL) is the NATO Flight Trials Sponsor for the 2016 Yuma Flight Trials and the 2017 Europe Flight Trials.

- A DVE Informal Working Group (IWG) was established by NATO JCG-VL in September 2014 to lead the planning of the flight trials.

- DVE IWG Mission:
  - Primary: To plan and conduct the Europe Rotorcraft DVE Flight Trials to take place in Germany and Switzerland in FEB 2017.
  - Secondary: To assist the US RDECOM DVE Mitigation Program in the planning of the Rotorcraft DVE Flight Trials to take place in Yuma, Arizona in SEP 2016.
# NATO Participation at Yuma

<table>
<thead>
<tr>
<th>System Participant</th>
<th>Platform Type</th>
<th>Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>US Army RDECOM DVE-M</td>
<td>EH-60L #657 (ADD-AFDD, Moffett Field, CA based)</td>
<td>• Modernized Control Laws (MCLAWS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Integrated Cueing Environment (ICE)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Two Sensor Lines of Effort (LOE)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- LOE 1: SNC Radar, LIDAR &amp; FLIR, DTED</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- LOE 2: Areté, LIDAR &amp; FLIR, DTED</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Modernized Control Laws (MCLAWS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Integrated Cueing Environment (ICE)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Two Sensor Lines of Effort (LOE)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- LOE 1: SNC Radar, LIDAR &amp; FLIR, DTED</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- LOE 2: Areté, LIDAR &amp; FLIR, DTED</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Modernized Control Laws (MCLAWS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Integrated Cueing Environment (ICE)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Two Sensor Lines of Effort (LOE)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- LOE 1: SNC Radar, LIDAR &amp; FLIR, DTED</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- LOE 2: Areté, LIDAR &amp; FLIR, DTED</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Modernized Control Laws (MCLAWS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Integrated Cueing Environment (ICE)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Two Sensor Lines of Effort (LOE)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- LOE 1: SNC Radar, LIDAR &amp; FLIR, DTED</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- LOE 2: Areté, LIDAR &amp; FLIR, DTED</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Modernized Control Laws (MCLAWS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Integrated Cueing Environment (ICE)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Two Sensor Lines of Effort (LOE)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- LOE 1: SNC Radar, LIDAR &amp; FLIR, DTED</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- LOE 2: Areté, LIDAR &amp; FLIR, DTED</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Modernized Control Laws (MCLAWS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Integrated Cueing Environment (ICE)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Two Sensor Lines of Effort (LOE)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- LOE 1: SNC Radar, LIDAR &amp; FLIR, DTED</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- LOE 2: Areté, LIDAR &amp; FLIR, DTED</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Modernized Control Laws (MCLAWS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Integrated Cueing Environment (ICE)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Two Sensor Lines of Effort (LOE)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- LOE 1: SNC Radar, LIDAR &amp; FLIR, DTED</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- LOE 2: Areté, LIDAR &amp; FLIR, DTED</td>
</tr>
</tbody>
</table>

- *Airbus Mi-2 from U. of Iowa Operator Perf. Lab (OPL)*
  - Airbus DS SFERION system
  - • HMD and PMD
  - • LADAR and DTED

- *CDRDC (Defence Research & Development Canada)*
  - Ground Only (tower)
  - Ladar characterization

- *United Kingdom Defence Science and Technology Laboratory*
  - Ground Only (tower)
  - IR characterization
Number of U.S. Combat, Non-Hostile, Rotorcraft Losses for OEF/OIF (Oct 2001 – Sep 2009)

- Controlled Flight Into Terrain (CFIT), 15
- Wire Strike, 9
- Inadvertent IMC, 7
- Midair Collision, 10
- Object Strike (Cruise), 5
- Object Strike (Landing, Hover, Taxi), 11
- DVE, 38
- Flat Hatting, 2
- Power Train Failure, 4
- Fire, 7
- Other Mechanical Failures, 2
- Improperly Forecast Weather, 2
- Loss of Control (Mechanical), 6
- Engine Failure (Mechanical), 12
- Flight Related, 7
- Other Human Factors, 2
- Hard Landing/Dynamic Rollover, 3
- Loss of Control (Pilot Error), 6
- Pr>Pa, 9

157 Total. Hostile Action Losses = 70.
Graph from Couch and Lindell, 2010.
OEF = Operation Enduring Freedom
OIF = Operation Iraqi Freedom

Yellow: Low speed / hover, human factors
Red: High speed, human factors
Blue: Mechanical, non-human factors
Violet: Weather forecast and Undetermined
Degraded Visual Environments at Yuma

Aircraft Induced DVE

- Brownout
- Whiteout

Aircraft Independent Degraded Visual Environments

- Smoke
- Sand / Dust
- Fog
- Rain
- Clouds
- Snow
- Smog
- Night
- Flat Light

Yuma Trials

Use weather to your military advantage
Research Systems Description
Research Systems Overview

Integrated DVE Systems
- Multi-Spectral Terrain/Obstacle Sensors
- Programmable Research Flight Control System
- Programmable Integrated Cueing Environment (ICE) System

Instrumentation
- EGI, GPS
- Video Combiners and Recorders
- Data Acquisition Sensors and Recorders
Multi-Spectral Terrain / Obstacle Sensors

Sierra Nevada Corp
- RADAR (3D)
- LADAR (3D)
- Infrared (2D)
- Pre-Stored Terrain (3D)

Areté Associates
- LADAR (3D)
- Infrared (2D)
- Pre-Stored Terrain (3D)
Fused Sensor and DTED Imagery

Sierra Nevada Corp

Areté Associates

Sensors provide data to the fusion processor for a 3D, persistent database of elevations

- Used by the guidance algorithms for symbology and coll. coupling
- Used by the graphics generator to render the pilot’s displays
Guidance for the Approach to Landing Maneuver

Mode A:
Guidance can use 3D sensor database of terrain and obstacle elevations.

Or

Mode B:
Guidance can use pre-loaded obstacle location and height data and radar altimeter.

### Landing Criteria

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Desired</th>
<th>Adequate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical Speed</td>
<td>&lt; 150 ft/min</td>
<td>&lt; 300 ft/min</td>
</tr>
<tr>
<td>Forward Speed</td>
<td>&lt; 2 kts</td>
<td>&lt; 5 kts</td>
</tr>
<tr>
<td>Aft Speed</td>
<td>= 0 kts</td>
<td>&lt; 0.5 kts</td>
</tr>
<tr>
<td>Lateral Speed</td>
<td>&lt; 0.5 kts</td>
<td>&lt; 1.0 kts</td>
</tr>
<tr>
<td>Long. Position</td>
<td>± 10 ft</td>
<td>± 20 ft</td>
</tr>
<tr>
<td>Lateral Position</td>
<td>± 6 ft</td>
<td>± 10 ft</td>
</tr>
<tr>
<td>Heading</td>
<td>± 5 deg</td>
<td>± 10 deg</td>
</tr>
</tbody>
</table>

Guidance profile is close to a clear day approach to landing.
Guidance for the Approach to Hover Maneuver

### Hover Criteria

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Desired</th>
<th>Adequate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude Error</td>
<td>± 3 ft</td>
<td>± 6 ft</td>
</tr>
<tr>
<td>Long. Position Error</td>
<td>± 3 ft</td>
<td>± 6 ft</td>
</tr>
<tr>
<td>Lat. Position Error</td>
<td>± 3 ft</td>
<td>± 6 ft</td>
</tr>
<tr>
<td>Heading</td>
<td>± 3 deg</td>
<td>± 6 deg</td>
</tr>
</tbody>
</table>

Start Guidance
0.8 NM

Hover Pt

30 ft

5° Typical

Ground
## Flight Control Systems Available

### Mode 1

**Standard EH-60L**
- **Cyclic (pitch and roll)**
  - SAS (10% authority)
  - Angular rate cmd.
  - No pos. hold modes
- **Pedals**
  - SAS
  - Heading hold
- **Collective**
  - No coupling
  - No hold modes

### Mode 2

**Research Flight Control System**
- **Cyclic (pitch and roll)**
  - MCLAWS (10% authority)
  - Attitude cmd / attitude hold
  - Position hold modes
- **Pedals**
  - MCLAWS
  - Heading hold
- **Collective**
  - Coupled to guidance
  - Altitude hold mode
Flight Control Systems Available

Mode 3

**Standard EH-60L**
- Cyclic (pitch and roll)
  - SAS (10% authority)
  - Angular rate cmd.
  - No hold modes

- Pedals
  - SAS
  - Heading hold

**Research Flight Control System**
- Collective
  - Coupled to guidance
  - Altitude hold mode
Pilot Displays

Safety Pilot HMD
- Monochrome
- Non-Head Tracked
- 18x18 deg FOV
- VGA (640x480)

Safety Pilot PMD
- Color
- 8 inch diagonal
- 800x600 pixels

Evaluation Pilot Primary Flight Display
- Color
- 10 inch diagonal
- 1024x768 pixels

Top down view of sensor data
Two ICE Symbology Pages

**Enroute Page**
- Above 60 knots

**Hover / Approach / Take-off (HAT) Page**
- Below 60 knots
- Any speed when approach guidance is ON
Additional aural cues were implemented for flight control mode changes, and cautions and warnings for excessive torque and excessive vertical speed near the ground.
Tactile (Vibration) System

Modes:
- Approach to hover/landing
- Hover position keeping

Pilot should always move away from vibration

Categories:
- Advisory: 200ms of vibration repeated at 1 Hz
- Caution: 100ms of vibration repeated at 2 Hz
- Warning: 50ms of vibration repeated at 4 Hz
Methods
Independent Variables

- For cyclic and pedals, MCLAWS vs. standard UH-60A/L (attitude command / attitude hold vs. rate command)
- Collective Coupling OFF vs. ON
- Aural Cueing OFF vs. ON
- Tactile Cueing OFF vs. ON

ICE visual cueing used for all maneuvers due to airworthiness requirements.
Independent Variables

- For cyclic and pedals, MCLAWS vs. standard UH-60A/L (attitude command / attitude hold vs. rate command)

- Collective Coupling OFF vs. ON

- Aural Cueing OFF vs. ON

- Tactile Cueing OFF vs. ON

ICE visual cueing used for all maneuvers due to airworthiness requirements.
Results
Video of Landing in Yuma
Video of Landing in Yuma
Video of Hover in Yuma
Overall Test Statistics

• **14 Evaluation flights (29.3 flight hours)** conducted using four evaluation pilots
  – 6 Sorties (13.5 flight hours) with LOE 1 (engine replacement required)
  – 8 Sorties (15.8 flight hours) with LOE 2

• **152 record test points** (approaches to landing or hover) were attempted
  – **76 Successful brownout landings** (including demonstration points)
  – **69 Successful extended (30 sec) brownout hovers** (including demonstration points)
  – **7 Approaches resulted in go-arounds** due to pilot performance (not meeting established maneuver standards for safety; due primarily to adverse winds and/or swirling dust effects)
  – These numbers do not include approaches abandoned due to system anomalies or sensor failures

• **Hover maneuvers totaled more than 34 cumulative minutes of brownout** at 30 ft AGL.
Landing Performance

64 Landings (not including demonstration points)

- All touchdowns within 22 ft of intended landing point (mean 6 ft)
- All forward speeds within 4 knots (mean 1.5 knots)
- All lateral speeds ≤ 1.5 knots (mean 0.3 knots)
- All vertical speeds ≤ 180 ft/min (mean 97 ft/min)

6 Go-Arounds

(Distances as measured by the Embedded GPS/INS (EGI) inertial sensor)
All 64 landings were within a main rotor diameter.

53% of landings met all 6 desired criteria.

92% of landings met at least the 6 adequate criteria.

8% of landings had at least one parameter outside of adequate:
- 1 short
- 2 wide
- 4 had lateral speed 1.0 - 1.5 knots
Performance

Touchdown Position Error (Radial)
64 Landings

Hover Position RMS Error
55 Hovers

Landing Radial Error: $p = 0.03$
Hover Radial Error: $p = 0.06$
Vertical RMS Error: Not significant

Collective coupling enables more consistent hover performance.
Bedford Workload Rating for Unobstructed Landings

Unobstructed, SAS/FPS

- △ uncoupled
- ○ coupled
- ◆ mean

Better

Collective coupling reduces workload for landing

Coupling refers to collective axis only
Summary Usability Ratings of ICE Components

- **2D Symbology (24)**: 42% Excellent, 50% Good, 8% Poor
- **Guidance Symbology (34)**: 24% Excellent, 59% Good, 15% Poor, 3% Unsatisfactory
- **3D Conformal Symbology (17)**: 6% Excellent, 71% Good, 24% Poor
- **Aural Cueing (15)**: 87% Excellent, 7% Poor
- **Tactile Cueing (12)**: 33% Excellent, 50% Good, 17% Poor

Tactile was the only component mostly poorly rated:
- Vib. in more than axis at a time.
- Thresholds too Sensitive.
- Need to turn off with acknowledge button or when converging to desired performance.

This chart includes landing and hovers.
Conclusions from Yuma

Integrated system of terrain/obstacle imaging sensors, flight control, and pilot cueing was successfully demonstrated.

- Sensors provided a stable image of terrain/obstacles in the dust. However, workload was too high for the pilot on the controls to interpret the image. Small obstacles lost in clutter.

- Collective coupling improves performance and reduce workload. However, workload still too high to interpret sensor image. Need to investigate benefits of coupled cyclic.

- Test could not have been done without landing guidance and symbology cueing. Aural cueing complemented symbology.
Video of NATO Trial in Germany

- NATO sponsored flight trials in DVE conditions using LOE #1 Sensor
  - Rain/fog/clouds at WTD-61, Manching, Germany
  - Whiteout at Ällgialp from Militärflugplatz Alpnach, Switzerland

- 25 Total flights (30.5 flight hours) conducted from 1-27 February in Germany and Switzerland

- US system received feedback from 12 foreign XPs (6 Swiss, 4 German, 2 UK)
Use weather to your military advantage.
Video of NATO Trial in Germany
Video of NATO Trial in Switzerland
Questions?
Bedford Workload Rating for Obstructed Landings

For Obstructed, SAS/FPS:
- Uncoupled
- Coupled
- Mean

For Obstructed, MCLAWS:
- Uncoupled
- Coupled
- Mean

Better Bedford Workload Rating for Obstructed Landings