**REPORT DOCUMENTATION PAGE**

<table>
<thead>
<tr>
<th>1. REPORT DATE</th>
<th>2. REPORT TYPE</th>
<th>3. DATES COVERED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Viewgraphs</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4. TITLE AND SUBTITLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMCA Flight Test of the C-2A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5a. CONTRACT NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5b. GRANT NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5c. PROGRAM ELEMENT NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5d. PROJECT NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5e. TASK NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5f. WORK UNIT NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>6. AUTHOR(S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michael Wagner; Chuck Webb</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naval Air Warfare Center Aircraft Division</td>
</tr>
<tr>
<td>22347 Cedar Point Road, Unit #6</td>
</tr>
<tr>
<td>Patuxent River, Maryland 20700-1161</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>8. PERFORMING ORGANIZATION REPORT NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>10. SPONSOR/MONITOR'S ACRONYM(S)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>11. SPONSOR/MONITOR'S REPORT NUMBER(S)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

**12. DISTRIBUTION/AVAILABILITY STATEMENT**

Approved for public release; distribution is unlimited.

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**

**15. SUBJECT TERMS**

**16. SECURITY CLASSIFICATION OF:**

<table>
<thead>
<tr>
<th>a. REPORT</th>
<th>b. ABSTRACT</th>
<th>c. THIS PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**17. LIMITATION OF ABSTRACT**

**18. NUMBER OF PAGES**

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>19a. NAME OF RESPONSIBLE PERSON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Michael Wagner / Chuck Webb</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>19b. TELEPHONE NUMBER (include area code)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(301) 757-3881 / (301) 757-2900</td>
</tr>
</tbody>
</table>

20010406 104
$V_{MCA}$ Flight Test of the C-2A

Michael J. Wagner
Charles E. Webb
Naval Air Warfare Center-Aircraft Division
Patuxent River, MD

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION IS UNLIMITED.

30 Mar 2001
C-2A Greyhound - The Basics

- Aircraft Carrier-based cargo aircraft built by Grumman. Original design/construction early-mid 60’s.
- Twin-engine turboprop producing 4,600 SHP per engine.
- Range - 1200 NM, Basic weight - 38,000 lbs., Max T/O weight - 60,000 lbs.
- Cargo - 10,000 lbs., Pax - 26
- Wingspan - 81 feet, Length - 57 feet
$V_{MCA}$ - Background

- Original pitot-static system upgraded to L-shaped pitot-static probes
- L-Probe test results showed approach speeds below some historical approach speeds and those published in Aircraft Recovery Bulletin.
- Approach speeds also below then-published $V_{MCA}$ for nearly all landing weights.
Configuration PA(20)
Approach Speeds

NATOPS Maximum Arrested Landing Weight
Reported $V_{MCA}$

Historical Approach Speed
• Acft Recovery Bulletin
- BuNo 162141
- BuNo 162142

CALIBRATED AIRSPEED - KCAS

GROSS WEIGHT - lb

Force Aircraft Test Squadron
\( V_{MCA} \) - Background (2)

- Then-current Flight Manual (NATOPS)
  \( V_{MCA} \)
  - 100 KCAS came from C-2A Increased Gross Weight testing of 1988
  - 100 KCAS transposed to 100 KIAS
  - Report data showed at 100 KCAS additional rudder control power was still available
$V_{MCA}$ - Scope of Tests

- Conditions
  - WO(20) - gear down, flaps 20 deg
  - WO(30) - gear down, flaps 30 deg
  - Power - defined by test technique
  - Altitude - 4000 ft

- 10 flights, 23 hours, $V_{MCA}$ Static and Dynamic

- Test techniques used
  - Classic (method used to obtain previous $V_{MCA}$)
  - Waveoff (method used in E-2C PLUS tests, considered more mission representative, yielded results herein)
Classic Technique

- Stabilize in climb at target airspeed with max power (4600 ISHP/engine)
- At target altitude copilot fails desired engine by rapidly pulling Condition Lever to FX (simulated - power lever to Flight Idle)
- No inputs for 1 second (except longitudinal inputs to control airspeed loss if desired)
- Apply recovery inputs as required
Classic Technique: Pros and Cons

• Pros
  – Repeatable
  – Stable conditions at maximum power

• Cons
  – Nose high attitude
  – Not mission representative
  – Airspeed control following engine failure
    • Large airspeed loss
    • Large longitudinal push-over required to minimize airspeed loss
Waveoff Technique

- Establish 500 FPM ROD (simulated approach)
- At target airspeed and altitude, rapidly advance power levers to max
- On power addition, copilot immediately fails desired engine by pulling Condition Lever to FX (simulated - power lever to Flight Idle)
- No inputs for 1 second (except small longitudinal inputs to control airspeed gain)
- Apply recovery inputs as required
Waveoff Technique: Pros and Cons

- **Pros**
  - Very mission representative (engine failure on waveoff)
  - Better airspeed control than Classic following engine failure

- **Cons**
  - Airspeed control following engine failure
    - Acceleration during power addition
  - Dynamic engine response with power addition
  - There can be non-repeatable control inputs on waveoff and recovery
### Waveoff Technique Adjustments

<table>
<thead>
<tr>
<th>Method</th>
<th>Waveoff</th>
<th>FX/Power Lever Chop</th>
<th>Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Some</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rudder</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Rudder Pos)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rudder</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Rudder Pos)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loop</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Rudder Pos)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loop</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Rudder Pos)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

--- 1 sec delay ---->

---

**Time**

---

*Force Aircraft Test Squadron*
Waveoff Technique: Built-In Conservatism

- Very rapid power addition
  - Power for Glide Slope to max power in ~0.2 seconds
  - Mechanical Power Lever Stop - adjustable for test day conditions. Allowed rapid power addition while preventing engine over-torque or over-temp

- Minimized airspeed acceleration
  - Simultaneously failed target engine while adding power on other
  - Permitted nose to rise slightly on power addition
Waveoff Technique: Built-In Conservatism (2)

- Aft CG
- 1 second delay from engine failure to initial recovery inputs
- Different test pilot used for end points
Waveoff Technique: Another Possible Approach

- Stabilize on target airspeed with 1/2 max power on each engine
- Concurrently -
  - FX target engine
  - Add Max power on other engine
- Recovery inputs after 1-2 second delay
- Technique may minimize airspeed change on engine failure
  - Net change of 0 thrust
- Not tested here
$V_{MCA}$ Criteria:

- Angular acceleration fails to reverse immediately at control input
- Time from initiation of rudder input to 0 yaw rate is greater than 2 sec
- $23 \frac{1}{2}$ units AOA (artificial stall warning)
- $> 15$ deg sideslip
$V_{MCA}$ Criteria (2):

- > 20 deg bank angle
- > 20 deg heading change
- Static single engine control airspeed
- Recovery is unsafe or required excessive workload for the average pilot
Results

- Left engine was determined to be critical from previous testing and $V_{MC}$ Static
- Results indicate a lower $V_{MCA}$ than previously reported
  - $V_{MCA}$ flaps 20 - 95 KIAS (excessive workload)
  - $V_{MCA}$ flaps 30 - 96 KIAS ($V_{MC}$ Static)
- Although controllable above $V_{MCA}$, adequate SERC performance is not assured
Engine Response

RT Power Lever Angle

Transient SHP Limit (4800 SHP)
Military SHP Limit (4600 SHP)

LT & RT HORSEPOWER - SHP

RT Horsepower
LT Horsepower

TIME - sec

RT POWER LEVER ANGLE - deg

5000
4000
3000
2000
1000
0

1000
2000
3000
4000
5000

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

0
10
20
30
40
50
60
70
80
90
100
110
120

Force Aircraft Test Squadron

Slide 21
Recommendations

- C-2A NATOPS changes
  - New VMCA
  - "Engine Failure During Waveoff" - descriptive paragraph not previously incorporated
Lessons Learned

- Test Planning:
  - Consider normal dual-engine waveoff control input profiles and assess their impact on control inputs during VMA tests
  - Consider different methods of securing engine/prop (Auto FX, Condition Lever, T-handle)
Lessons Learned (2)

- Testing:
  - Minimize airspeed change from engine failure to recovery inputs.
  - Consider impact of airspeed changes in data reduction.
  - Waveoff technique - Operating engine may not be at maximum power when making recovery inputs (depends on engine response).
Lessons Learned (3)

- $V_{MCA}$ Ramification
  - Adequate single engine performance may not be assured at $V_{MCA}$
- Example: Rate of climb
Questions