UNITED STATES AIR FORCE
RESEARCH LABORATORY

MAXPAC Test Program Final
Presentation

Joseph Morris

Aerojet
Propulsion Division
P.O. Box 13222
Sacramento CA 95813-6000

December 1996

Final Report for the Period July 1996 to December 1996

20011002 057

Approved for public release; distribution is unlimited.

Human Effectiveness Directorate
Biodynamics and Protection Division
Biodynamics and Acceleration Branch
2800 Q Street BLDG 824 RM 206
Wright-Patterson AFB OH 45433-7947
NOTICES

When US Government drawings, specifications of other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications or other data, is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Please do not request copies of this report from the Air Force Research Laboratory. Additional copies may be purchased from:

National Technical Information Services
5285 Port Royal Road
Springfield, Virginia 22161

Federal Government agencies registered with the Defense Technical Information Center should direct requests for copies of this report to:

Defense Technical Information Center
8725 John J. Kingman Rd STE 0944
Ft. Belvoir, VA 22060-6218

TECHNICAL REVIEW AND APPROVAL

AFRL-HE-WP-SR-2001-0006

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE DIRECTOR

F. WESLEY BAUMGARDNER
Acting Chief, Biodynamics and Protection Division
Human Effectiveness Directorate
Air Force Research Laboratory
**Title:** MAXPAC Test Program Final Presentation

**Author:** Joseph Morris

**Performing Organization:**
- **Veridian Engineering, Inc.:** Aerojet
- **Human Effectiveness Group:** P.O. Box 13222
- **Dayton OH 45431-1285:** Sacramento CA 95813-6000

**Sponsoring/Monitoring Agency:**
- **Human Effectiveness Directorate:** Wright-Patterson AFB OH 45433-7947

**Funding Numbers:**
- **Contract:** F41624-95-C-6014
- **PE:** 63231F
- **PR:** 2830
- **TA:** 283068
- **WU:** 28306820

**DISTRIBUTION/AVAILABILITY STATEMENT:**
Approved for public release; distribution is unlimited.

**Abstract:**
This report summarizes the results of a United States Air Force funded effort to demonstrate the Multi-Axis Pintle Attitude Control (MAXPAC) system. The MAXPAC system is a spin-off of the Fourth Generation Escape Systems Technology Demonstration Program. MAXPAC uses four discrete, pintle-controlled rocket nozzles to provide variable thrust in three axes. The intent is to provide an under-seat retrofit for the Advanced Concept Ejection Seat (ACES) II replacing the current pitch stabilization rocket with the three-axis stabilization MAXPAC.

**Subject Terms:**
- Escape system, pintle-control, stabilization

**Security Classification:**
- **Report:** Unclassified
- **This Page:** Unclassified
- **Abstract:** Unclassified

**Number of Pages:** 57

**Price Code:** UNLIMITED

**Source Document Information:**
- **NSN:** 7540-01-280-5500
- **Computer Generated:** 1996
- **Standard Form 298 (Rev. 2-89):** Prescribed by ANSI Std. 239-18
  - 298-102
This page intentionally left blank.
PREFACE

This report was prepared under contract F41624-95-C-6014, Task 62, Engineering Support of Biodynamics Research – Crew Escape Technologies (CREST) Demonstration Support. The Prime Contractor for this effort was Veridian Engineering, Inc., Dayton, OH and the major subcontractor was Aerojet – Propulsion Division of Sacramento CA.

This Final Report summarizes the results of a United States Air Force funded effort during the period July through December 1996 to demonstrate the Multi-Axis Pintle Attitude Control (MAXPAC) system. The MAXPAC system is a spin-off of the Fourth Generation Escape System Technology Demonstration program. The intent of the program was to provide an under-seat retrofit for the Advanced Concept Ejection Seat (ACES) II replacing the current pitch stabilization rocket with the three-axis stabilization MAXPAC.
Table of Contents

AGENDA.................................................................................................................. 1
MAXPAC OVERVIEW................................................................................................. 2
MAXPAC TEST ARTICLE DESIGN REVIEW..................................................... 4
MAXPAC TEST DATA REVIEW AND GROUND TEST GROUNDING ISSUES... 21
CONCLUSIONS AND RECOMMENDATIONS..................................................... 53
This page intentionally left blank.
AGENDA

MAXPAC OVERVIEW
PROGRAM OBJECTIVES AND STATUS
REVIEW OF TEST ARTICLE DESIGN
KISTLER LOAD TABLE DESCRIPTION
PROOF TEST RESULTS
TEST DATA REVIEW AND GROUND TEST GROUNDING ISSUES
CONCLUSIONS & RECOMMENDATIONS
<table>
<thead>
<tr>
<th>OBJECTIVE</th>
<th>STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>DESIGN &amp; ANALYSIS</td>
<td>CMPLT</td>
</tr>
<tr>
<td>MOTOR ASSEMBLY AND BENCH TESTING</td>
<td>CMPLT</td>
</tr>
<tr>
<td>TEST PLANS</td>
<td>CMPLT</td>
</tr>
<tr>
<td>GROUND STATIC MOTOR TESTS</td>
<td>CMPLT</td>
</tr>
<tr>
<td>REPORTING: MONTHLY TECHNICAL &amp; BUDGET, MOTOR TEST QUICKLOOK</td>
<td>CMPLT</td>
</tr>
<tr>
<td>MEETINGS: KICK-OFF, TRR, AND FINAL PRESENTATION</td>
<td>66% CMPT</td>
</tr>
</tbody>
</table>
2 - Thruster Housing

1 - Motor Case w/ 4.3 lbs of 1.3 Reduced Smoke Propellant

4 - EM Actuators
MAXPAC IGNITER

- 64 BKN03-2A Pellets (10 grams)
- Quantic, dual bridgewire squib
- Located in Thruster Housing 1-2

Igniter
Squib
Thruster Housing
Joint Bolt Holes
O-ring Groove
- 4.3 Pounds of Modified ANB-3679, Developed on the ARS Program
- Reduced Smoke, Hazards Class 1.3
- 7-Fin Grain Design, Full Length
- Elastomer Liner for Propellant to Case Bonding
- ~9.0 inches Long, ~3.8" OD, ~0.8" ID, ~0.3" Fin Gap
MAJOR COMPONENTS

- 4- Electro-Mechanical Actuators
  - 150 VDC, 40 Amp
  - Stall Load >300 Lbf
  - Stroke > 0.22", > 120 Hz
- 1- Quad Actuator Controller
- 2- 5K Flightweight Paine Pressure Transducers, PN 177398
- 2- 5K Taber Pressure Transducers, Facility Equipment
- Kistler Load Measuring Table
- Motor Hold Down Brackets
• Control Logic in "C"
• EDACS (Engineering Data Acquisition and Control)
  » Pentium 90MHz
  » National Instruments Data Acquisition Boards
  » Electro Strain Gage Amplifiers
  » Validyne Amplifiers
  » Ordnance Firing Circuit
• Sample Rate of 400 Samples / Second
• Backup Data on Separate PC486/50
CONTROL LOGIC

- MAXPAC Control Logic Identical to 4TH GEN Initial Testing Logic
- Two Paine Amplified Pressure Transducers for Control
- Transducer Logic Checks for Bad Transducer
- Thrust Commands Limited to Available System Thrust
- Initial Pintle Positions at Spring 0-Load Point
- Versatron Actuators
  - 120 Hz Bandwidth
  - 15 Inches / Second
  - 360 lbf
  - 140 VDC @ 40 amps
CONTROL LOGIC

- MAXPAC Control Logic Identical to 4TH GEN Initial Testing Logic
- Two Paine Amplified Pressure Transducers for Control
- Transducer Logic Checks for Bad Transducer
- Thrust Commands Limited to Available System Thrust
- Initial Pintle Positions at Spring 0-Load Point
- Versatron Actuators
  » 120 Hz Bandwidth
  » 15 Inches / Second
  » 360 lbf
  » 140 VDC @ 40 amps
**MAXPAC INSTRUMENTATION LIST**

<table>
<thead>
<tr>
<th>Function</th>
<th>Name</th>
<th>Range</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chamber Pressure</td>
<td>PC - 1 &amp; 2</td>
<td>0 - 5,000 psia</td>
<td>2Paines-2Tbrs</td>
</tr>
<tr>
<td>Igniter Circuit Current</td>
<td>II - 1</td>
<td>TBD amps</td>
<td></td>
</tr>
<tr>
<td>Pintle Actuators (1-4) Current</td>
<td>IAP-1 thru IAP-4</td>
<td>0 -40 amps</td>
<td></td>
</tr>
<tr>
<td>Pintle Actuators (1-4) Voltage</td>
<td>EAP-1 thru EAP-4</td>
<td>0 - 1400 volts</td>
<td></td>
</tr>
<tr>
<td>Pintle #1 Actuator Command</td>
<td>CAP-1 thru CAP-4</td>
<td>0 - 10 volts</td>
<td></td>
</tr>
<tr>
<td>Pintle Position</td>
<td>PP-1 thru PP-4</td>
<td>0 - 0.25 inch</td>
<td></td>
</tr>
<tr>
<td>Forces along X, Y Axes</td>
<td>FX, FY</td>
<td>± 4496 lbf</td>
<td>Tests 2 &amp; 3</td>
</tr>
<tr>
<td>Forces along Z Axis</td>
<td>FZ</td>
<td>-4496 to 8993 lbf</td>
<td>Tests 2 &amp; 3</td>
</tr>
<tr>
<td>Moments about X, Y Axes</td>
<td>MX, MY</td>
<td>± 369 ft-lbs</td>
<td>Tests 2 &amp; 3</td>
</tr>
<tr>
<td>Moments about Z Axis</td>
<td>MZ</td>
<td>± 738 ft-lbs</td>
<td>Tests 2 &amp; 3</td>
</tr>
</tbody>
</table>
- Multi-component Force Plate Provides 3 Orthogonal Components Of Force, Fx, Fy, & Fz
- $Fx \& y = \pm 4496 \text{lbf}; Fz=-4496$ to $8993 \text{lbf}$
- High Frequency due to Stiffness
- 4 - 3 axis Quartz Type Load Cells
- Micro-Processor/ Amplifier, Determines Moments and Resultant Forces
• Hydro-Proof Test
  ✫ Motor Assembled as Planned with Nozzle Plugs
  ✫ Max Pressure 4600 psi

• Motor Held Target Pressure for 60 Seconds

• Joint Failed- Bolts Pulled from Bolt Hole: Bolt L/D was too Small, < 0.7 Critical Ratio

20- 1/4" x 28 screws
1/8 Long

Posttest Bolt Centerline
Pretest Centerline
• Brainstorming Session Lead to Near Term Fix
  ✴ Salvage Existing Hardware
  ✴ Must Use Larger Bolts
  ✴ Drill Through Thruster Housing To Acquire More Length
  ✴ Bond in Stainless Steel Shim
  ✴ Coat Shim Joint with vulcanized rubber
  ✴ Consequently Increased L/D

• Long Term Fix, Redesigned Joint, Probably Lockwire
MAXPAC TEST DATA REVIEW
AND
GROUND TEST GROUNDING ISSUES

KEVIN PETERSON
- Pressure Rise
  Normal on Number 1 Side
- Pressure Port Blocked on Number 2 Side
- Pressure Dropped Due to Abort
- Pressure Rise at End When Pintles Moved to No Load Point
MAXPAC TEST 100 RESULTS

- Control Pressure
  - 2 Thrown Out Due to Delta PC > 200 psi for 6 Continuous Samples

- Control Pressure
  - 1 Thrown Out Due to 3 Continuous Samples of PC < -150 or PC > 5000 psi

- Both Transducers Bad, Test Aborted
- Pressure Transducer Failure Caused by Noise
- Noise Occurred When Actuator Current Increased
MAXPAC NOISE ISSUES

- Noise on Pressure Transducer Feedback Signals
  - Both The Facility Tabers And The Paine Flight Transducers
- Noise Appeared When Actuators Energized
- Noise Increased With Increased Actuator Current Draw
- Noise Caused Abort on Test 100
Noise Elimination Solutions

- Versatron Suggested Batteries for Actuator Power
  - Noise Significantly Reduced, But Not Eliminated
- Next Step, Grounding
  - Common Ground Between Actuator Controller and D/A Card
  - Common Ground Between Signal Conditioners
  - Tied Actuator Controller Case to Earth Ground
  - Tied All Shields to Instrumentation Ground
- Noise Reduced to Acceptable Level on Taber Transducers
  (± 10 psi)
- Noise Effectively Eliminated
- Paine Flightweight Transducers Matched Facility Tabers
- Pressure Variations of 500 psi
- Burn Time Approximately 0.1 sec < Predicted
  - Possibly Burn Rate Variation
- Pintles Followed Commands
- Springs Appear to Work as Designed
- Cause of Spikes in Data Unknown
  - Noise
  - Spring Effects
- Pintle 2 Sticks After 0.3 seconds
  - Evidence of Igniter Welding
MAXPAC TEST 200 RESULTS

CALCULATED PINTLE LOAD #1

- Theoretical Pintle Loads Kept Below 200 lbs

TIME, sec

PINTLE LOAD, lb

- TOTAL PRESSURE SPRING
### Kistler Load Table

- A Multicomponent Force Plate
  - Consists of Four Tri-Axis Load Cells
- Separate Multichannel Charge Amplifier
- Outputs the Following Measurements
  - $F_x1+2$  X-Axis Load Cell 1 & 2
  - $F_x3+4$  X-Axis Load Cell 3 & 4
  - $F_y1+4$  Y-Axis Load Cell 1 & 4
  - $F_y2+3$  Y-Axis Load Cell 2 & 3
  - $F_z1$    Z-Axis Load Cell 1
  - $F_z2$    Z-Axis Load Cell 2
  - $F_z3$    Z-Axis Load Cell 3
  - $F_z4$    Z-Axis Load Cell 4
  - $1/2 F_x$ 1/2 X-Axis Thrust
  - $1/2 F_y$ 1/2 Y-Axis Thrust
  - $1/4 F_z$ 1/2 Z-Axis Thrust
  - $1/4 M_x$ 1/4 Moment About X-Axis
  - $1/4 M_y$ 1/4 Moment About Y-Axis
  - $1/4 M_z$ 1/4 Moment About Z-Axis
MAXPAC TEST 200 RESULTS

Y-AXIS MOMENT

MOMENT, ft-lb

TIME, sec

My
Mycmd
MAXPAC TEST 200 RESULTS

Z-AXIS MOMENT

MOMENT, ft-lb

TIME, sec

-700 -600 -500 -400 -300 -200 -100 0 100 200 300 400 500

- Mz
- Mzcmd
MAXPAC TEST 200 RESULTS

Nozzle 3 Thrust

F3
FCMD3

THRUSt, lb

TIME, sec
MAXPAC TEST 200 RESULTS

Nozzle 4 Thrust

THRUXT, lb

TIME, sec
MAXPAC TEST 300 RESULTS

THRUST COMMANDS

TIME, sec

THRUST, lb

FCMD1
FCMD2
FCMD3
FCMD4
- Paine Flightweight Transducers Matched Facility Tabers
- Pressure Variations of 300 psi
- Burn Time
  - Approximately 0.1 sec < Predicted
  - Possibly Burn Rate Variation

![Graph showing pressure over time for Taber and Paine Transducers](image-url)
- Pintles Followed Commands
- Springs Appear to Work as Designed
- Same Type of Spikes Occurred
  - Noise
  - Spring Effects
- Pintle 2 Sticks Again
  - Evidence of Igniter Welding

**PINTLE POSITIONS**

```
POS  | POS1 | POS2 | POS3 | POS4
-----|------|------|------|------
POS1 | 0.08 | 0.07 | 0.06 | 0.05
POS2 | 0.06 | 0.05 | 0.04 | 0.03
POS3 | 0.04 | 0.03 | 0.02 | 0.01
POS4 | 0.02 | 0.01 | 0.00 | -0.01

TIME, sec
```

- Position, in
MAXPAC TEST 300 RESULTS

Z-AXIS MOMENT

MOMENT, ft-lb

TIME, sec
MAXPAC TEST 300 RESULTS

Nozzle 3 Thrust

3D2H

THRUSt, lb

TIME, sec
Nozzle 4 Thrust

THRUSS, lb

TIME, sec

F4

FCMD4

MAXPAC TEST 300 RESULTS
CONCLUSIONS & RECOMMENDATIONS

● CONCLUSIONS

❖ ALL PROGRAM OBJECTIVES WERE ACHIEVED
❖ SOME HARDWARE MODIFICATIONS WERE NECESSARY TO ACCOMPLISH MOTOR TESTING
❖ NEAR TERM CASE JOINT FIX WORKED AS PLANNED
❖ KISTLER FORCE MEASURING TABLE PERFORMED AS DESIRED
❖ TEST 2 & 3 PROVIDED CRITICAL DATA ILLUSTRATING THAT THE MAXPAC ROCKET MOTOR DOES PROVIDE THE THRUST LEVELS AND RESPONSE TIMES NECESSARY

● RECOMMENDATIONS

❖ REDESIGN CASE JOINT AND HYDROTEST
❖ CONDUCT COMPONENT MATERIAL SWAPOUT TESTS RE: WEIGHT REDUCTION
❖ CONDUCT 4 OR 5 GROUND TESTS DEMONSTRATING SYSTEM INTEGRATION, (ROCKET MOTOR, EPAC AND SEAT)
❖ PREPARE FOR SLED TESTING IN SUMMER OF '97