CENTRIFUGE TESTING OF A G COMPENSATED/PRESSURE DEMAND OXYGEN REGULATOR

Philip E. Whitley, Ph.D. and Leonid Hrebiien, Ph.D.
NAVAL AIR DEVELOPMENT CENTER
Warminster, PA 18974-5000

April 1986

INTERIM REPORT
Program Element No. 62758N

APPROVED FOR PUBLIC RELEASE, DISTRIBUTION IS UNLIMITED

Prepared for
OFFICE OF NAVAL TECHNOLOGY
Department of the Navy
Washington, DC 20361
NOTICES

REPORT NUMBERING SYSTEM - The numbering of technical project reports issued by the Naval Air Development Center is arranged for specific identification purposes. Each number consists of the Center acronym, the calendar year in which the number was assigned, the sequence number of the report within the specific calendar year, and the official 2-digit correspondence code of the Command Office or the Functional Directorate responsible for the report. For example, Report No. NADC-86015-20 indicates the fifteenth Center report for the year 1986, and prepared by the Systems Directorate. The numerical codes are as follows:

<table>
<thead>
<tr>
<th>CODE</th>
<th>OFFICE OR DIRECTORATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>Commander, Naval Air Development Center</td>
</tr>
<tr>
<td>01</td>
<td>Technical Director, Naval Air Development Center</td>
</tr>
<tr>
<td>02</td>
<td>Comptroller</td>
</tr>
<tr>
<td>10</td>
<td>Directorate Command Projects</td>
</tr>
<tr>
<td>20</td>
<td>Systems Directorate</td>
</tr>
<tr>
<td>30</td>
<td>Sensors &amp; Avionics Technology Directorate</td>
</tr>
<tr>
<td>40</td>
<td>Communications and Navigation Technology Directorate</td>
</tr>
<tr>
<td>50</td>
<td>Software Computer Directorate</td>
</tr>
<tr>
<td>60</td>
<td>Aircraft &amp; Crew Systems Technology Directorate</td>
</tr>
<tr>
<td>70</td>
<td>Planning Assessment Resources</td>
</tr>
<tr>
<td>80</td>
<td>Engineering Support Group</td>
</tr>
</tbody>
</table>

PRODUCT ENDORSEMENT - The discussion or instructions concerning commercial products herein do not constitute an endorsement by the Government nor do they convey or imply the license or right to use such products.

APPROVED BY: [Signature]   DATE: 10 November 1986
### CENTRIFUGE TESTING OF A G COMPENSATED/PRESSURE DEMAND OXYGEN REGULATOR

**Author(s):** Phillip E. Whitley, Ph.D. and Leon Hrebien, Ph.D.

**Type of Report:** Interim

**Date of Report:** April 1986

**Page Count:** 11

#### Abstract

Six subjects were exposed to unassisted positive pressure breathing at levels not exceeding 30 mmHg breathing pressure while riding on a centrifuge. Acceleration in the +Gz direction was applied as either a ramp or a plateau and conditions ranged from relaxed to unassisted positive pressure breathing with an anti-G suit. The purpose of this study was to evaluate the performance of a G compensated positive pressure breathing regulator with respect to stated output pressure versus +Gz level, the pressure control concept/schedule employed, and subject acceleration tolerance. The regulator was found to perform as stated given the pressure range of interest and the experimental conditions. The pressure control concept/schedule and acceleration tolerance were related factors. It was found that the subjects who rode to higher +Gz levels received higher levels of breathing pressure and in turn an increase in acceleration tolerance.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>List of Figures</td>
<td>ii</td>
</tr>
<tr>
<td>Abstract</td>
<td>1</td>
</tr>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Methods</td>
<td>1</td>
</tr>
<tr>
<td>Results</td>
<td>2</td>
</tr>
<tr>
<td>Discussion and Conclusions</td>
<td>5</td>
</tr>
<tr>
<td>References</td>
<td>6</td>
</tr>
<tr>
<td>Biography</td>
<td>6</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>Description</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Experimental Configuration</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Upright Gradual Onset Run</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Upright Rapid Onset Run</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Supine Gradual Onset Run</td>
<td>3</td>
</tr>
<tr>
<td>5</td>
<td>Supine Rapid Onset Run</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>Upright In-line Pressure versus (+G_z) Plateau</td>
<td>4</td>
</tr>
<tr>
<td>7</td>
<td>Supine In-line Pressure versus (+G_z) Plateau</td>
<td>4</td>
</tr>
<tr>
<td>8</td>
<td>Comparison of Grand Means by Condition</td>
<td>5</td>
</tr>
<tr>
<td>9</td>
<td>Increased G-Tolerance versus In-line Pressure</td>
<td>5</td>
</tr>
</tbody>
</table>
Centrifuge Testing of a G Compensated/Pressure Demand Oxygen Regulator.

Phillip E. Whitley, Ph.D. and Leonid Hrebeni, Ph.D.
Naval Air Development Center, Warminster, Pennsylvania 18974-5000

ABSTRACT: Six subjects were exposed to unassisted positive pressure breathing at levels not exceeding 30 mmHg breathing pressure while riding on a centrifuge. Acceleration in the +Gz direction was applied as either a ramp or a plateau and conditions ranged from relaxed to unassisted positive pressure breathing with an anti-G suit. The purpose of this study was to evaluate the performance of a G compensated positive pressure breathing regulator with respect to stated output pressure versus +Gz level, the pressure control concept/schedule employed, and subject acceleration tolerance. The regulator was found to perform as stated given the pressure range of interest and the experimental conditions. The pressure control concept/schedule and acceleration tolerance were related factors. It was found that the subjects who rode to higher +Gz levels received higher levels of breathing pressure and in turn an increase in acceleration tolerance.

INTRODUCTION: The Navy is currently evaluating positive pressure breathing as an acceleration tolerance enhancement technique. Many factors must be considered with this technique such as unassisted versus assisted pressure breathing, pressurization schedule and its dependencies, and the applicability to the high G onset and endurance situations. The first phase of this effort was to evaluate a commercially available G-compensated positive pressure breathing regulator. Past studies using unassisted positive pressure breathing (25-35 mmHg) have indicated increases in tolerance level and time (5)(4) but an insignificant difference in tolerance between this method and the H-I maneuver(2). The study to be described marks the completion of the first phase of the evaluation effort.

METHOD: Six experienced subjects, trained in the use of the NADC lightbar and familiarized with unassisted positive pressure breathing, were exposed to +Gz accelerations on the NADC Dynamic Flight Simulator (DFS). Greyout thresholds were determined using the PALE seat, the NADC curved light bar and the NADC servo-controlled anti-G valve (SCAG). All combinations of the following independent variables were systematically varied for each subject: two seat back angles (15 degrees upright and 60 degrees supine), two G onset profiles (GOR at 1G/15 sec. and ROR at haversine onset/offset durations of 3 seconds with a 15 second plateau), two anti-G pressurizations (no pressure or normal pressure), and two breathing techniques (with and without positive pressure breathing). During a daily exposure, there was one GOR profile to 5G upright or 7.5G supine and then three greyout thresholds at the ROR profile were determined for each of the remaining independent variables. All runs were made with the subjects relaxed and greyout thresholds were determined by incrementing the G plateau levels in 0.5G steps. Greyout thresholds and calculations for G tolerance have been described in a previous publication (3). Subjects were instrumented for electrocardiogram, ultrasound Doppler velocimetry, and blood pressure (inflated cuff). The breathing pressure supplied to the subject was monitored by a pressure transducer connected in the line to the oxygen mask. The subjects were dressed in standard NAVY flight gear. The HGU-33/P helmet assembly was used for these experiments and consisted of the PRK-37/P helmet, PRU-39A/P form-fit liner, and MBU-12/P oxygen mask.

A G compensated/pressure demand oxygen regulator was obtained from Clifton Precision, Instruments and Life Support Division (Davenport, Iowa). This regulator provided positive pressure as a function of +Gz. The actual control signal was pneumatic and derived from the anti-G suit line. The regulator outlet pressure was 1.8±3.6 mmHg until 3.5 PSIG anti-G valve pressure (3.3G) and then followed as a linear function of the anti-G valve pressure until 11 PSIG at which point the regulator outlet pressure was 60 mmHg. To use this regulator for unassisted positive pressure breathing, it was necessary to place three relief valves in line with the regulator output. These relief valves were set to vent pressures over 30 mmHg at a 95 lpm flow rate. The complete gondola configuration is shown in Figure 1. A combination of three-way valve position and selective application of power to the solenoid allowed for variation of the related independent variables.
During the supine exposures, the anti-G suit pressure was corrected for the seatback angle which resulted in lower suit and therefore lower regulator pressures (3). Figure 4 shows the results from a supine gradual onset exposure. The break-in point for positive pressure was at +5.0Gz to 8.0 mmHg and rose to 24.8 mmHg at +7.5Gz. These values are within specifications given the supine anti-G suit inflation schedule. Figure 5 shows the results from a supine rapid onset run to a lightbar endpoint. After reaching the +7.5Gz plateau, the in-line pressure rose to an initial 18 mmHg within 1.8 seconds. The average peak pressure during this run was 22.5 mmHg.

Figures 6 and 7 summarize the results for upright and supine rapid onset exposures respectively. These graphs represent subject in-line pressure data and regulator specifications versus +Gz levels. In Figure 6 the break-in point is shown to be +Gz and there is good agreement between the maximum pressure points and the regulator specification line (solid) up to 21 mmHg where there was divergence due to the in-line pressure values. There was also a constant difference between maximum and minimum pressure of 2.5 mmHg. Results for the upright position are shown in Figure 7. Here the break-in point was +5.0Gz. The maximum pressure points were consistently below the regulator specification line but were still

**UPRIGHT**

**EKG**

**DOPPLER**

30.0-

22.5-

16.0-

7.0-

**PPB**

**GGR**

-8.0Gz

**Figure 2 Upright Gradual Onset Run.**
Figure 3  Upright Rapid Onset Run.

Figure 5  Supine Rapid Onset Run.

Figure 4  Supine Gradual Onset Run.
within the regulator error limits up to 20 mmHg. Divergence from the specification line is again due to the relief valves and a constant pressure difference is maintained up to 20 mmHg.

The in-line relief valves were essential to limit the regulator output pressure to 30 mmHg (unassisted positive pressure breathing), but the relief valves also caused some artifactual results. Below the point where the relief valves open, an inspiration is indicated by a positive slope on the pressure curve and an expiration by a negative slope. After the relief valves open, a different mechanism occurs in which the mask pressurizes to the relief valve opening...
pressure. When an inspiration occurs the line pressure decreases (negative slope) and on expiration the pressure rises to the original value. The maximum pressure in either case is still accurate, but the characteristics have reversed.

Mean acceleration tolerance is shown in the bar graph of Figure 8. While upright versus supine and anti-G suit versus relaxed conditions were statistically different (p<0.005) there were no statistically significant differences between any conditions that employed unassisted positive pressure breathing and its respective control (positive pressure alone versus relaxed and combined anti-G suit/positive pressure versus anti-G suit alone). However a plot of subject increased G tolerance versus in-line pressure, Figure 9, indicates that upright pressures greater than 27 mmHg and supine pressures greater than 20 mmHg gave individual increases in G tolerance greater than 0.5G.

DISCUSSION AND CONCLUSIONS: The G compensated/pressure demand oxygen regulator performed within specifications across the range of pressures investigated. When used with the NADC SCAG valve, the onset of the regulator pressure did not lag the anti-G suit pressure by more than the two seconds specified and typical values were less than one second. Divergence from the regulator output curve were due solely to the experimental requirement of pressure relief valves. Incorporation of relief valves into the regulator output line introduces undesirable changes in pressure waveform character but has no effect on any maximum pressure measurements.

Subject response to unassisted positive pressure breathing was that it was much easier to breath in the supine position but not difficult in the upright position. There was also the unanimous response from subjects who experienced high G with high positive
pressure that the regulator was not functioning on G offset. This response has been recorded before and is more related to the effects of breathing high positive pressure than any lack of regulator function (1).

The acceleration tolerance data obtained from this study indicate that unassisted positive pressure supplied with this schedule gives no increase in rapid onset acceleration tolerance. It is apparent from Figure 4 that the subjects who rode to higher +Gz levels received higher breathing pressures and that these higher pressures were more beneficial. With this pressure schedule, a subject's acceleration tolerance directly limited the maximum pressure that was supplied and some subjects reached their tolerance before the regulator supplied positive pressure. It is also apparent from Figure 9 that 20 mmHg supine and 25-30 mmHg upright were beneficial pressure levels. Future pressurization schedules for the rapid onset regime should take into consideration these minimum pressure values. In the unassisted mode of positive pressure breathing this may cause excessive fatigue but when coupled with counter-pressure assistance should be tolerated for much longer periods of time. The complete benefit of positive pressure breathing in the rapid onset regime has yet to be determined. Acceleration tolerance improvements beyond decreased breathing effort while supinated will be the subject of future research.

REFERENCES
2. Balldin, Ulf I. Positive pressure breathing and a faster filling ready pressure anti-G suit: effects on +Gz tolerance. AAM Annual Scientific Meeting, 1982.

BIOGRAPHY
Dr. Whitley is a member of the Acceleration Physiology Research Team at the Aircraft and Crew Systems Technology Directorate. Dr. Hrebien is head of that same team. Both received their training in Biomedical Engineering and are faculty members at Drexel University in Philadelphia, Pa.
END
3-87
Dtic