The +$G_z$ette

Submissions from the International Acceleration Research Workshop Community

Volume 4, Issue 1 **May 2004**

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Where and When

This is the 17th anniversary of the International Acceleration Research Workshop conceived by Dr. Russell R. Burton. This year's workshop will be held again during the Aerospace Medical Association Annual Scientific Meeting in Anchorage, Alaska.

The workshop will take place at:

Chart Room, Hilton Hotel
Thursday, 6 May 2004
12:15 – 14:00

Editor's Note:

It is an exciting time for many in the acceleration community, with the introduction of new or updated high performance centrifuge facilities in Sweden, Germany, Malaysia and China being complete or underway. This may herald not only advances in pilot training, but also new avenues of research into the effects of high acceleration onset rate. Meanwhile, the debate continues on the need for chest counter-pressure during pressure breathing for G, and the significance of A-LOC in aviation. Hopefully you will find the information in this year's +Gzette useful and as a new feature this issue I have included a list of centrifuge facilities around the world. I look forward to a lively debate (as ever) at the workshop.

Wing Commander Nic Green
2004 Chairman and Editor, +Gzette

International Acceleration Workshop Website:
http://www.flightmed.au/workshop.html

2004 International Acceleration Research Workshop

Workshop Agenda

- **Welcome**
- **Introductions**
- **Special Announcements**
  (safety related events, requests for information)
- **Discussion of newsletter articles and/or Laboratory/National Reports**
- **Definition of A-LOC (discussion)**
- **Other presentations or discussions of acceleration research related topics**
- **Chair selection 2005**

The new Swedish Dynamic Flight Simulator in operation – initial experience

Britta Levin
Swedish Defence Research Agency

P-A Klingström
SAF Aeromedical Center

After being accepted in September 2003, the Dynamic Flight Simulator (DFS) is operating and being used for pilot training and various research projects. The Swedish Air force transferred their pilot training from the centrifuge at Karolinska Institutet to the DFS in the fall of 2003. Since then, appr.105 pilots have been successfully trained in the DFS using the standardized training curriculum. They have begun experiencing the advantages of the flight simulation capabilities, which are much appreciated. The DFS is operated and maintained by the Defence Materiel Administration (FMV) while the Aeromedical Centre (FMC) conducts the pilot training and the medical supervision. The DFS is intended to be used for pilot training and qualification, flight physiological and cognitive research, equipment testing, tactical evaluation and as a player in networked simulation.

The DFS is a versatile high performance pilot training and research device. Technically it is a man-rated centrifuge combined with fully controlled and motor operated pitch and roll gimbals (2-axis) and a flight simulation system based on JAS 39 aircraft models and controls. A unique perception algorithm, modeling the expected sensations, provides a "realistic" flight experience and increased comfort since undesired sensations are minimized. One interesting feature is the "target-chasing task", a prerecorded free flight that is played back through the DFS out-the-window display system providing the pilot with a target to chase.

Sweden has a very well developed acceleration training program that includes initial pilot selection, introductory G training, advanced G training, defined G qualifications, as well as refresher training at various points in the tactical fighter's career. The process of incorporating the DFS capabilities into these various components of the training program has begun. Training pilots are allowed to fly the DFS with a variety of targeting tasks for evaluation.

The DFS offers a whole new range of opportunities for cognitive and acceleration research as well as advanced pilot training. The Swedish Defence Research Agency has been assigned to explore and validate the unique DFS capabilities with respect of Air force and research needs.
The first test series, currently under preparation, includes the use of the target chase mode as a means to simulate an ACM. The goal is to develop a new training curriculum that takes advantage of the flight simulation capabilities, i.e. makes the pilots train the way they fly.
The DFS has also received a lot of attention from around the world and a number of countries have already shown an interest in bringing their own pilots for training.

Acceleration Research Report from the Swedish Defence Research Agency

Ola Eiken
Swedish Defence Research Agency
Stockholm March 20, 2004

The new Dynamic Flight Simulator (DFS) is now operational (see page3) and acceleration research projects are presently being undertaken both at the DFS and at the centrifuge at the Karolinska Institute. Projects/problems that have been dealt with during the past year are:

• G-tolerance and G-comfort
  - Effects of the counter-pressure jerkin during pressure breathing at high G-loads.
  - Interaction between different G-protective measures i.e. AGSM, extended coverage anti-G suit and PBG.
  - Effects of a new heavier flight jacket for JAS 39-Gripen pilots on pulmonary function at increased G-load.
  - Pulmonary gas distribution at increased G-load as influenced by the different components of the anti-G-suit.
  - Autonomic responsiveness in individuals with high vs low relaxed G-tolerance.
  - G-tolerance as influenced by the distensibility of the blood vessels in the legs.
  - Release of vasoactive substances at high G-loads.

• Spatial disorientation and motion illness
  - Vestibular mechanisms involved in the development of ”the leans”
  - Effects of motion sickness on autonomic functions

• Man Systems Interaction
  - Memory function at increased G-load

18 Years Human Centrifuge in Königsbrück – An Era Ends

Dr. Heiko Welsch
Flugmedizinisches Institut der Luftwaffe
Königsbrück, Germany

As you know, in 2004 the announced upgrade of the GAF human centrifuge will be carried out. We started this upgrade 1st of March 2004 and will be on duty again 1st of December 2004.

Some information of the history:

26. Feb 2004: LTC Robert „Robs" Hierl, Projectpilot Eurofighter, OTC 61, Manching, performed the last run of 14,392 overall manned runs in the cabin of the human centrifuge, evaluating the latest version of the "Libelle"- Anti-G-suit (see Fig 1).

There were totally 18,819 runs (technical runs, safety and inspection runs, test runs and the 14,392 runs with subjects) without major disturbances since the human centrifuge, manufactured by AMST, Austria, was put into operation in 27th of March 1986 – that time in the former German Democratic Republic.

The human centrifuge technical team – together with the head of the Div. Aviation Physiology of the German Air Force Institute of Aviation Medicine (GAFIAM), Colonel Dr. Heiko Welsch, who is in charge with the acceleration device since 1st of April 1993 in Koenigsbrueck – is shown in Fig. 2. During his leadership more than 14,000 runs (inclusive nearly 12,000 manned runs) were performed, helping the new generation of fighter pilots to learn to survive and to act within the full range of the acceleration envelope of future fighter aircraft and to avoid G-LOC events. In this time new equipment for fighter pilots were evaluated, some research in the field of ophthalmology was done, and last not least recommendations were given for the selection of pilot candidates and for decision making, who get a waiver for fit to fly in a high performance fighter aircraft.

Fig. 1: Robs Hierl, the last subject in the old gondola of the Koenigsbrueck human centrifuge

Fig. 2: The head of GAFIAM Div. Aviation Physiology, Col. Dr. Heiko Welsch together with the engineer-team with the chief engineer of the human centrifuge, Steffen Zoellner (4th from left) with the human centrifuge.

The upgrade of the human centrifuge includes a new “light weight” gondola, a new digital steering regime and the full capability to cover the performance data and geometric cockpit dimensions of the Eurofighter “Typhoon”. For the training of fighter pilots the DFS-mode (dynamic flight simulation), close to reality, is obvious.

Update from NAWCAD Patuxent River

Barry S. Shender, Ph.D
barry.shender@navy.mil

The Aircrew Integrated Life Support System (AILSS) program began in 1995 at the Naval Air Warfare Center Aircraft Division Warminster, PA, and has evolved from proof of concept to integrated ensembles. The AILSS approach addresses some of the perceived deficiencies of current systems by integrating multiple modes of protection into ensembles, while preserving aircrew mobility, flexibility, and function. AILSS is a DoD Human Systems Defense Technology Objective (HS.56).

AILSS provides integrated protection for rotary wing aircrew with the Helicopter AILSS (HAILSS), a modular system that provides protection against thermal stress, immersion, and fire, which can be donned as a single ensemble. HAILSS has been tested in the thermal chamber in Nov '03 to Jan '04 optimize its internal ventilation distribution system. As part of the AILSS program, new initiatives in materials engineering are in progress, including development of a stretch Nomex and an automatically closing neck seal (based on hydrogel impregnated neoprene), which is activated upon contact with fresh or seawater. The gel in the neck seal can be tailored for reaction time, degree of expansion, and reactivity to chemicals (e.g. sweat).

The Tactical aircrew ensemble (Tactical AILSS, or TAILSS), based on lessons learned from the development of HAILSS, adds protection against acceleration and altitude stress for use by high performance fixed-winged aircrew. TAILSS features a system of physiologic sensors and control logic that provides real time closed loop biofeedback electronic control of life support equipment that adapts to the individual's changing requirements. TAILSS monitors ECG, abdominal EMG and temperature and humidity, by using dry contact electrodes incorporated into a ventilated vest. Integrated into the tactical aviator helmet are sensors for head level pulse, SpO2, and EEG. All of these sensors require no skin preparation. Respiration is monitored using a pressure transducer in the oronasal mask. (In a centrifuge evaluation in Feb '04, two new capacitively coupled electrode concepts were tested for ECG and EMG. A new fast (10-50 Hz sampling rate) near infrared spectroscopy device was incorporated into the helmet and tested as well.) Based on the values of these measures, the TAILSS risk predictor model compares actual physiologic responses to "nominal" responses, based on literature and previous centrifuge study data. Based on this comparison, TAILSS modifies the anti-G suit and positive pressure breathing inflation schedule to supply either a more (faster onset and higher level) or less (reduce the pressure when an individual demonstrates high tolerance) aggressive response. TAILSS garmentry has been designed to correct the perceived deficiencies of Navy Combat Edge and other extended coverage ensembles. The upper TAILSS garment is a vest that provides counter pressure for PBG, ventilation (via a combination of a blower fan and textile engineering that enables flow distribution across the torso and chest even when strapped into an aircraft seat), and serves as a sensor platform. It is more comfortable and cooler that the currently fielded vest. The lower garment represents a compromise between the desire for extended pressure bladder coverage and the need for mobility and reduced thermal load. TAILSS has been tested at the Brooks City-Base centrifuge in June '03 and Feb '04 and will undergo developmental flight-testing in the spring of 2004.

For 2004, TAILSS is also expanding the concept of integrated protection to include musculoskeletal protection, specifically of the neck. The approaches include a modified racecar Hands and Neck Support (HANS®) device that allows for increased range of motion and a series of passive and active inflatable concepts.

The Future of Sustained Acceleration Science & Technology

Bill Albery
AFRL, WP AFB

Country	Facility	Future S&T Research in Sustained Acceleration
Canada	DRDC	-Neck injury in rotor wing (now) and CF18/JSF pilots (long term) with the use of various helmet mounted displays such as NVGs, JHMCS, etc. -Developing models of cognitive capability decrement due to a multitude of environmental stress including thermal, G, fatigue, and helmet mass. -Using the centrifuge as a tool to investigate the interaction between G stress and disorientation (vice versa) especially during rapid G transition and rapid roll maneuvers
Germany	Institute for Flight Physiology	-Neck loading by the mass/weight of new helmets. -G-LOC detection or warning algorithms -Studying the changes of the intro-ocular pressure (push-pull), deflection of the cornea and the bulbous (LASIK-surgery and reaction under high G), and fitting of toric contact lenses under moderate and high G.
Germany	Autoflug/Libelle	-Develop countermeasures to reduce pilot fatigue and thermal burden -Research methods to raise sustained G protection level -Enable voice activated commands, even at G -Provide integrated flight equipment (include NBC & immersion protection & ensure compatibility) -Provide one system capable of covering all jets -Provide emergency altitude protection without operational disadvantages -Reduce total operating costs
Poland	Polish Air Force Institute of Aviation Medicine	-Layoff and G-tolerance research. -G-tolerance and "push-pull" (dedicated to "push" restricted to 0-(+1) Gz range) research. -G-LOC prediction methods
Sweden	DFS	-Performance recovery time following G-LOC using a 'real' flight scenario rather than simple math and tracking tasks -Practical research concerning PBG, CSAR equipment, and G tolerance -Vestibular mechanism research -Pilot consciousness monitoring system research for ground collision avoidance system -Research to optimize suit/breathing pressures for pneumatic G-Protection systems – perhaps provide more 'zones' for the bladders and pressure schedule to match physiologic need -General development to make all pilot equipment lighter and more ventilated to reduce heat stress -Development of immersion and NBC-protection in conjunction with G-load. -G-tolerance, G-protection, and SD research.
United States	NASA Ames Research Center	-Test the efficacy of short radius centrifugation as a countermeasure to spaceflight deconditioning -Methods to effectively generate artificial gravity so that it can be used to prevent or eliminate the physiologically deconditioning effects of long-term exposure to weightlessness. -Research to maximize the beneficial effects of centrifugation.
United States	ETC-Orange Flag	-Continuing research on use of the high performance centrifuge platform as a flight simulator. -Determining what capabilities high performance human centrifuges need to support training pilots of super-maneuverable aircraft (Gx, Gy, Gz). -Flight simulation that features sustained acceleration.

Country	Facility	Future S&T Research in Sustained Acceleration
United States	Patuxent River (NAVAIR)	-TTCP effort to study the use of head mounted displays under +Gz-stress -Development of a series of neck injury mitigation concepts for maneuvering flight and during ejection. -AILSS -G-simulation device as part of a flight simulator that will provide the same amount of head/neck loading experienced in flight in a closed loop system to study the effects of work/rest cycle on the ability to fly and move the head under G without the risk of nausea seen in the human centrifuge.
United States	CHI Systems- Use WPAFB or Brooks Centrifuge	-Research concerning the A-LOC phenomenon.
United States	Air Combat Command	-Eliminate "compartmentalization" mentality of life support equipment (unify efforts). - Devise innovative ways to protect against G, heat, cold, altitude, survival, escape, and evasion -Develop a G-suit that is less bulky and imposes far less thermal burden on aircrew

Summary of Acceleration Models

Title	Author	Year	Variables	Capabilities	Limitations
Percent Cerebral Oxygen Saturation Model (%rSO2)	Andy McKinley	2003	Percent Cerebral Oxygen Saturation (%rSO2)	PC model of %rSO2 for an average human performing any Gz acceleration profile	Verified but not fully validated
G Effective (Ge)	Dr Dana Rogers	2002	Effective Value of Gz in the Human Body based on Cardiovascular Physiology	PC-based mathematical model utilizing 2nd order transfer functions to predict the effective value of Gz (Ge) for single peak Gz profiles	Not Validated – currently can not be used for multiple peak or long duration profiles
Mechanical model of Cerebral Circulation	Cirovic S., Walsh C., Fraser W.D.	2001	Blood circulation to the brain	Mechanical model using ascending & descending tubes to represent arteries and veins respectively, and a rigid container for the skull.	The change in G vector was accomplished by tilting the model; however flow drops with increasing tilt
PilAccel	Dr. Rafik D. Grygoryan	1999	Cardiovascular System (CV); Blood Volume; External Pressure	PC-based mathematical model with GUI interface that models the CV system and the respective blood pressures, volumes and external pressures at many locations on the body	Not Validated – model is extremely complex, thus it is difficult to asses the accuracy of all its elements
Eye Level Blood Pressure Model (Peye)	Dr Dana Rogers	1998	Eye Level Blood Pressure	PC-based mathematical model utilizing a 2nd order transfer function to predict eye-level blood pressure variations due to Gz loading	Currently not valid for multiple peak or long duration profiles.
Cardiovascular Dynamics Model	Jing Bai	1997	Cardiovascular Dynamics	Mathematical model of human cardiovascular dynamics that is capable of incorporating various G protective techniques, such as the G suit, M-1 and L-1 Maneuver, and positive pressure breathing.	Not yet validated
Cardiovascular Model for Studying Impairment of Cerebral Function	Dr. Dov Jaron, Dr. Thomas Moore, Chia-Lin Chu	1984	Cardiovascular system	Predicts CLL and peripheral light loss (PLL). Can model G-suits.	Verified using real data although not validated
Arterial Blood Oxygen Saturation Model	Kent Gillingham, R. Burton	1975	Arterial Blood Oxygen Saturation	Mathematical model that uses transfer functions to model arterial blood oxygen saturation levels using +Gz as the input. Reasonable capability up to 6G.	Not valid for Gz profiles above 6G. Prediction of responses to variable G stress was unsuccessful

Summary of Performance Models

Model Name	Developer/Author	Year	System/Skill Modeled	Capablities	Limitations
G-TOP	Bob O'Donnell	2003	Overall Pilot Performance	Uses 10 distinct skills to predict performance decrements at G. Utilizes the G effective (Ge) model to produce an effective Gz profile.	Not validated. Look-up tables built on acceleration performance data below 5G.
Pursuit Tracking Task Model	Andy McKinley	2003	Pursuit Tracking	Models average root mean square (RMS) error for a 2-D pursuit tracking task during G exposure.	Model is only verified for G levels up to 7.0G.
Performance G-LOC Model	Dr Dan Repperger	2003	Recovery from G-LOC based on Tracking Performance	The mathematical model incorporates a first-order exponential function to model the return of tracking performance.	Not yet validated. Does not consider height, gender, or weight factors that may predispose someone to G-LOC.
Mathematical models for predicting G-level tolerances	R.R. Burton	2000	G-Level Tolerance for the Average Human	Mathematical models of human G-level tolerances: 1) rapid onset relaxed (ROR); 2) gradual onset relaxed (GOR); and, 3) straining-rapid onset.	Only capable of predicting G-level tolerances
Mathematical models for predicting G-Duration tolerances	R.R. Burton	2000	G-Duration Tolerance for the Average Human Body	Mathematical model that can predict fatigue-based G-duration tolerances for relaxed and straining subjects.	Defines tolerance levels for G-levels between 5 and 9, however, it does not model specific physiological data.

Worldwide Human Centrifuge Status - 1

	Canada DRDC Toronto, ON	USA (USN) (NAWC), PA	USA (USN) NAS Lemoore, CA	USA (NAMRL) Pensacola FL	USA (USAF) AFRL Brooks CB San Antonio	USA (USAF) Holloman AFB, NM	USA (USAF) WP AFB, Dayton, OH
Commissioned	**?**	**1952 (1964)**	**1996**	**?**	**1962 (1984)**	**1988**	**1969**
Operational Status	**Under refit**	**Mothballed**	**Full**	**Full ?**	**Full**	**Full**	**Full**
Training/ Research	**Research, Training**	**Research, Training**	**Training**	**Research**	**Research, Training**	**Training**	**Research**
Arm length	**6.1m (20ft)**	**15.2m (50ft)**	**7.62 metre**	**Max 6.1m (40ft diameter)**	**6.1 metres**	**6.1 metres**	**5.8 metres**
Maximum G	**+15G**	**+40G**	**+15G**	**+7.45G**	**+30G**	**+15G**	**+20G**
Peak G Onset Rate	**3G/sec**	**10G/sec**	**8.5G/sec**	**15 deg/sec/sec**	**6G/sec**	**6G/sec**	**1G/sec**
<1G Capability	**Under development**	**Yes**	**No**	**Yes, -3G**	**No**	**No**	**Yes**
Builder	**EMRO, DRDC, ETC**	**McKiernan-Terry**	**ETC**	**KPT Mfg Company**	**Rucker**	**ETC**	**Franklin Inst.**
Availability	**Open**	**Pending**	**Training**	**Open**	**Open**	**Limited**	**Open**
Gondola control	**?**	**Active**	**Active**	**?**	**Passive**	**Passive**	**Active**
Remarks	**-Gz in hand**			**Variable arm**		**Replacement under consideration at Luke AFB**	**Dynamic Environment Simulation**

Worldwide Human Centrifuge Status - 2

	UK (RAF CAM) Henlow	UK (Qinetiq) Farnborough	France, Bretigny	Holland, Soesterberg	Germany, Konigsbruck	Poland, Inst Av Med	Sweden, Linkoping
Commissioned	**-**	**1955**	**1999**	**1983**	**1988**	**?**	**2003**
Operational Status	**TBD**	**Full**	**Full**	**Full**	**Closed, under refit**	**Full**	**Full**
Training/ Research	**Research, Training**	**Research, Training**	**Research, Training**	**Research, Training**	**Research, Training**	**Research, Trg**	**Research, Training**
Arm length	**TBD**	**9.14m (30ft)**	**8 metre**	**4 metres**	**10 metres**	**9.0 metres**	**9.14 metres**
Maximum G	**+15G**	**+20G**	**+30G**	**+23.5G**	**+12G**	**+16G/-2.5G**	**+15G**
Peak G Onset Rate	**10G/sec**	**1G/sec**	**10G/sec**	**3.5G/sec**	**5G/sec**	**4G/sec**	**10/sec**
<1G Capability	**Yes**	**No**	**Yes, -10G**	**No**	**Yes**	**Yes**	**No**
Builder	**TBA**	**ML Aviation**	**Latecoere**	**HOLEC Co**	**AMST**	**Polskie ZL Co**	**Wyle**
Availability	**Open**	**Open**	**Open**	**Open**	**Limited**	**Open**	**Open**
Gondola control	**Active**	**Passive**	**Active**	**Passive**	**Active**	**Active**	**Active**
Remarks	**Under review for cancellation**	**Scheduled to close 2006**			**Being upgraded**		**Dynamic Flight Simulator**

Worldwide Human Centrifuge Status – 3

	Sweden, Karolinska	Japan	Singapore	Turkey	Taiwan	Russia, Zhukovsky	NASA AMES Moffett Field, CA
Commissioned	**?**	**1999**	**1994**	**1990**	**?**	**2002**	**1966**
Operational Status	**Full**	**Full**	**Full**	**Full**	**?**	**Full**	**Full**
Training/ Research	**Research, Training**	**Research, Training**	**Training**	**Training**	**Training**	**Research**	**Research**
Arm length	**7.25 metres**	**7.6 metres**	**7.62 metres**	**6.1 metres**	**8 metres**	**8 metres**	**8.84 metres**
Maximum G	**+15G**	**+12G**	**+15G**	**+15G**	**?**	**+15G**	**+20G**
Peak G Onset Rate	**5G/sec**	**6G/sec**	**8G/sec**	**6G/sec**	**?**	**9G/sec**	**1G/sec**
<1G Capability	**Yes, U/S at present**	**No**	**No**	**No**	**?**	**Yes**	**No**
Builder	**ASEA Sweden**	**ETC**	**ETC**	**ETC**	**Latecoere**	**AMST**	**In house**
Availability	**Open**	**No, unless approved**	**Open**	**Open**	**Open**	**Open**	**Open**
Gondola control	**Passive**	**Active**	**Active**	**Passive**	**?**	**Active**	**Passive**
Remarks	**Upgraded in 97**					**A monster!**	

Worldwide Human Centrifuge Status – 4

	USA (SUNY), Buffalo, NY	India, IAF IAM Bangalore	South Korea	Malaysia	China, Beijing		
Commissioned	**?**	**?**	**1990**	**-**	**-**		
Operational Status	**Full**	**Full**	**Full**	**Being installed**	**Being installed**		
Training/ Research	**Research**	**Research, Training**	**Research, Training**	**Training**	**Research, Training**		
Arm length	**?**	**5.0 metres**	**6.1 metres**	**7.62 metres**	**7.62 metres**		
Maximum G	**?**	**+10G**	**+15G**	**+15G**	**+15G**		
Peak G Onset Rate	**1G/sec**	**2G/sec**	**10G/sec ?**	**10G/sec (13G/sec max instantaneous)**	**10G/sec**		
<1G Capability	**No**	**No**	**No**	**Yes**	**?**		
Builder	**?**	**Siemens**	**ETC**	**ETC**	**AMST**		
Availability	**Open**	**Indian military aircrew only**	**?**	**?**	**?**		
Gondola control	**Passive**	**Passive**	**Passive**	**Active**	**Active**		
Remarks		**Possibly to be upgraded**		**Expected commissioning in 2004**	**Expected commissioning in 2005**		

The above centrifuge list has been compiled from the Air Standards Co-ordinating Committee Working Party 61 Information Publication 61/103/23, and from information provided by Dr Bill Albery. We wish to keep this list up to date, and so please point out any corrections, additions or deletions to the Editor of the +Gzette for the next edition.

Proposed Description of A-LOC

Bhupi Singh
Air Standards Co-ordinating Committee (ASCC) Working Party 61

The following text is being considered for publication by ASCC WP61 as a description of the phenomenon of Almost Loss of consciousness (A-LOC). The views of the international acceleration community are welcomed in the consideration of this definition.

'The term "Almost Loss of Consciousness" (A-LOC) was coined by the US Navy in the late 1980's. A-LOC is a syndrome that includes a wide variety of cognitive, physical, emotional, and physiological signs and symptoms, including sensory abnormalities, amnesia, confusion, euphoria, difficulty in forming words, transient paralysis, and reduced auditory acuity resulting from exposure to acceleration stress. Often it is manifested by the apparent disconnection between the desire and the ability to perform an action. These deficits may persist after the +Gz exposure ceases. These signs and symptoms have been demonstrated both in the human centrifuge and in-flight.'

Pressure Breathing During G Without a Counter-Pressure Vest

Rob O'Connor
AFRL
Brooks City Base, San Antonio

Purpose: This study was to determine whether safe and adequate G-protection could be maintained if the COMBAT EDGE counter-pressure vest were eliminated.

Method: Eleven subjects, including five F-15 aircrew, completed centrifuge exposures up to +9 Gz using pressure breathing for G (PBG) at 60 mm Hg pressure with and without the counter-pressure vest. Additional G-exposures using pressures of 0, 30, and 45 mm Hg were performed without the vest.

Results/Discussion: Elimination of the COMBAT EDGE counter-pressure vest did not significantly reduce G-tolerance. The use of PPG, with or without the vest, was preferred by all test subjects. PBG at 60 mm Hg produced the highest G-protection and was preferred by the test subjects over lesser pressures. Subjects reported no adverse effects from use of PPG without chest counter-pressure. Whether PBG without counter-pressure will increase fatigue during multiple sorties was not determined.

Background

The Combined Advanced Technology Enhanced Design G Ensemble (COMBAT EDGE) evolved from the advanced development program known as the Tactical Life Support System (TLSS). Along with other protective features, TLSS utilized positive pressure breathing (PPB), a chest counter-pressure vest, and a full-coverage anti-G suit to provide altitude protection to 60,000 feet and sustained acceleration protection to +9 Gz. The COMBAT EDGE (CE) program was initiated to allow for rapid fielding of the G-protective aspects of TLSS. As part of the rapid fielding process, the developmental full-coverage G-suit of TLSS was replaced with the legacy CSU-13B/P G-suit. The vest was retained for G-protection because studies had shown that G-endurance increased when PPB was used with chest counter-pressure.

The purpose of the CE system was to reduce the physical workload of aircrew performing the anti-G straining maneuver (AGSM). When done correctly, the AGSM is a total body effort, combining a strong contraction of the muscles of the limbs, stomach and chest with a breathing pattern that requires a rapid and forceful exhalation and inhalation every three seconds. While a proper AGSM can effectively increase G-tolerance, the muscular strain component is extremely fatiguing and the breathing component is hindered at high +Gz by the increased downward force on the chest wall. CE uses positive pressure breathing for G (PBG) to increase intra-thoracic pressure and facilitate inspiration during +Gz exposure. The increase in intra-thoracic pressure elevates blood pressure and results in a reduced muscular straining requirement during the AGSM. The enhanced inspiration from PBG supports air exchange at high-G.

The PBG delivery schedule of CE begins at +4 Gz and increases by 12 millimeters of mercury (mm Hg) of pressure per G to a maximum of 60 mm Hg at +9 Gz. The CE components worn by aircrew consist of the following:

- Modified HGU-55/P Helmet
- MBU-20/P Oxygen Mask
- CRU-94/P Integrated Terminal Block (ITB)
- CSU-13B/P Anti-G Suit
- CSU-17/P Counter-pressure Vest.

The counter-pressure vest is worn to balance the intra-thoracic pressure during PBG and to reduce the respiratory fatigue and discomfort associated with active exhalation against the high breathing pressures. While CE helps to reduce the risk of high-G exposure, a number of aircrew have stated a concern that the vest adds to their heat stress during flight, and may create a burden that is greater than the benefit provided by PBG. At the request of Air Combat Command (ACC), the Air Force Research Laboratory's (AFRL) Biosciences and Protection Division (HEP) conducted a study of the heat stress associated with wear of the vest (Balldin et. al., 2002). It was determined there were no significant differences in core or skin temperatures, or levels of dehydration, with or without wear of the vest. Nevertheless, to ensure aircrew do not unnecessarily endure a possible in-flight discomfort or distraction, ACC requested that AFRL/HEP determine if PBG can be successfully utilized without wear of a counter-pressure vest (ACC/DRS letter dated 27 Mar 03). Specifically, the Commander of ACC requested that the following be addressed:

"Review the requirement for positive pressure breathing (PPB) and an upper counter pressure vest. Evaluate different levels of PPB without the chest counter pressure garment. Determine the optimal level of PPB and G protection without the upper counter pressure vest. Report the marginal G benefit with and without the upper counter pressure vest."

Several studies have shown that PBG increases G-tolerance and endurance (e.g. Burns and Balldin, 1988; Morgan et, al. 1992; and Tong et, al. 1998). As mentioned above, one of the benefits of PBG is the reduced requirement for muscular strain during the AGSM. In a recent study by Fernandes et. al. (2003), high muscle activity was observed far less during PBG than without PBG. However, it is not known if use of PBG without chest counter-pressure, referred to as unassisted PBG, will increase the work of respiratory muscles to the point of discomfort or decreased G-tolerance. In an abstract by Gronkvist et. al. (2003), it was shown that use of a counter-pressure vest during PBG reduces the breathing effort, suggesting removal of the vest increases work during expiration even at high-G.

In order to successfully use unassisted PBG, the elimination of the vest must not decrease G-tolerance or endurance, increase aircrew discomfort or fatigue, or produce a medical risk for aircrew. The primary medical concern related to unassisted PBG is the potential for over-distension of the chest and lungs, with the possible result of a tearing of the lungs. Earlier studies using high levels of unassisted pressure breathing at 1 G did not show such effects. Meehan (1966) had five subjects exposed to 30 minutes of 60 mm Hg pressure breathing in the supine position four times a day for 28 days in a bed-rest study without a counter-pressure vest or anti-G suit. Balldin and Wranne (1980) exposed subjects to unassisted pressure breathing at 50 mm Hg for 4 minutes with an anti-G suit and with catheters in the right atrium and in the pulmonary artery for hemodynamic measurements. Neither study showed any adverse effects other than breathing fatigue. In a report by Krebs and Pilmanis (1996), evidence is presented suggesting the unsupported chest wall of the human population can safely support 80 mm Hg static and dynamic over-pressure of the lungs. This would be similar to unassisted PBG during a G-induced loss of consciousness (G-LOC), when there is no counter-pressure support to the thorax since the breathing muscles are relaxed. Krebs and Pilmanis also state that safe static pressure in the human population, wearing chest and abdomen support devices, is at least 190 mm Hg. That pressure is similar to what can occur during the respiratory straining portion of the AGSM, during weight lifting, and during the playing of musical instruments (such as the trumpet), when the breathing muscles restrict over-expansion of the lungs. Fortunately, the highest PBG pressures are provided at the highest G-levels. During high-G exposure, the increased weight of both the thorax wall and the aircrew's flight equipment will create some counter-pressure to the thorax, and thus may permit use of unassisted PBG up to 60 mm Hg.

Centrifuge studies of unassisted PBG to date have used a maximum of 52 mm Hg of breathing pressure, and have used a maximum G-onset rate of +1 Gz per second. One study reported increased respiratory fatigue with use of breathing pressure above 30 mm Hg (Shaffstall and Burton, 1979). However, the extended duration of the G-profile used in that study may not be operationally relevant. Most recently the Swedish Defence Research Agency reported on a centrifuge study (0.5 G/sec onset rate) comparing use of inflated and non-inflated counter-pressure vests with 40 mm Hg PBG (Gronkvist et al. 2003). They demonstrated no change in G-tolerance to +8 Gz between the vest/no vest (non-inflated) conditions, but confirmed the earlier finding of increased expiratory work of breathing without wearing of a vest. The purpose of this study was to determine whether unassisted PBG, with up to 60 mm Hg of breathing pressure, is acceptable for use during 6G per second onset exposures up to +9 Gz.