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AIRCREW/GROUNDCREW LIFE SUPPORT SYSTEMS RESEARCH
VOLUME 1: CLIN 0001 RESEARCH REQUIREMENTS

ARMSTRONG LABORATORY

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The voluntary, fully informed consent of the subjects used in this research was obtained as required by AFR 169-3.

The animals involved in this study were procured, maintained, and used in accordance with the Animal Welfare Act and the "Guide for the Care and Use of Laboratory Animals" prepared by the Institute of Laboratory Animal Resources - National Research Council.

The Office of Public Affairs has reviewed this report, and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This report has been reviewed and is approved for publication.

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13. ABSTRACT *(Maximum 200 words)*

USAF Contract #F33615-89-C-0603 (SOW Section 3.2; CLIN 0001) with KRUG Life Sciences, Incorporated, San Antonio Division, supported the Armstrong Laboratory by providing for research in the following areas: human research subjects, experimental life support equipment development laboratory, anti-G suit research, development, test, and evaluation (RDT&E), research databases, subatmospheric research, molecular sieve technology, centrifuge testing of life support equipment, centrifuge support, cockpit integration and crew performance, and spatial disorientation research. This final report provides summaries of objectives and accomplishments including citations and abstracts for the publications documenting the work. AL-TR-1993-0012-VOL-2 is the final report for the CLIN 0002 portion of this contract.

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TABLE OF CONTENTS

PREFACE

KRUG Life Sciences, Incorporated, has provided technical support to accomplish the specific research, development, test, and evaluation (RDT&E) requirements for the Armstrong Laboratory at Brooks AFB, Texas. The KRUG Life Sciences, Incorporated, research team designed and performed experiments to support on-going RDT&E efforts in response to the requirements designated in Section C, Description/Specifications (CLIN 0001) of USAF Contract #F33615-89-C-0603. This final report provides summaries of objectives and accomplishments including citations and abstracts for the publications documenting the work. Reports which were not published in the open literature or as USAF Technical Reports or Technical Papers have been presented to the Armstrong Laboratory Technical Monitor for inclusion in the contract file or as attachments to equipment manuals where appropriate.

The following authors contributed substantially to the contractual effort by publishing the results of their efforts: Ms. Jemett L. Desmond, Mr. William R. Ercoline, Ms. Michele D. Fischer, Mr. John R. Garza, Dr. Robert W. Krutz, Jr., Mr. Danny L. Matthews, Dr. Thomas E. Nesthus, Mr. John H. Ohlhausen, Dr. Robert M. Olson, Mr. E. Payson Ripley, Ms. Grady L. Ripley, Mr. Aaron M. Shakocius, Dr. Barbara J. Stegmann, Dr. James T. Webb, and Ms. Janet F. Wiegman. The author cross-reference in Part D allows the reader to find the task report contributions of each author.

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LIST OF SYMBOLS, ABBREVIATIONS, AND ACRONYMS

AGSM	Anti-G Straining Maneuver
AL	Armstrong Laboratory (formerly USAFSAM)
ATAGS	Advanced Technology Anti-G Suit
DCS	Decompression Sickness
G-LOC	G-Induced Loss of Consciousness
GOR	Gradual Onset Run
HUD	Head-Up Display
MSOGS	Molecular Sieve Oxygen Generating Systems
NASP	National Aerospace Plane
PBG	Positive Pressure Breathing for G
RDT&E	Research, Development, Test, and Evaluation
SAC	Small Animal Centrifuge
SOAR	Space Operations and Applications Research
USAF	United States Air Force
USAFSAM	United States Air Force School of Aerospace Medicine
VGE	Venous Gas Emboli
WAT	Wingate Anaerobic Test

AIRCREW/GROUNDCREW LIFE SUPPORT SYSTEMS RESEARCH

VOLUME 1: CLIN 0001 RESEARCH REQUIREMENTS

PART A:

INTRODUCTION

Robert W. Krutz, Jr., and James T. Webb

USAF Contract #F33615-89-C-0603 (Statement of Work Section 3.2; CLIN 0001) with KRUG Life Sciences, Incorporated, supported the Crew Technology Division, Armstrong Laboratory, by providing a core cadre of contractor personnel working on-site at Brooks Air Force Base, TX, to perform research and research support in the following areas: human research subjects, experimental life support equipment development laboratory, anti-G suit research, development, test, and evaluation (RDT&E), research databases, subatmospheric research, molecular sieve technology, centrifuge testing of life support equipment, centrifuge support, cockpit integration and crew performance, and spatial disorientation research. This final report is a summary of the contract CLIN 0001 objectives and accomplishments.

The final report for the previous three-year research effort (USAF Contract #F33615-85-C-4503) summarized work which, in many instances, continued under the current contract. It was published as the following Technical Report.

Krutz RW Jr, Nesthus TE, Scott WR, Webb JT, Noles CJ, Wiegman JF, Chavez RA, Eshaghian B. Aircrew life support systems enhancement. USAFSAM-TR-89-26. 1990.

<u>Abstract</u>: "USAF Contract F33615-85-C-4503 with KRUG International, Technology Services Division, supported the Crew Technology Division, USAF School of Aerospace Medicine, in the areas of: human subject acquisition, decompression hazards research, decompression sickness and acceleration database development and refinement, anti-G suit fabrication and testing, chemical defense research, centrifuge support, centrifuge testing of life support equipment, cockpit integration research, oxygen systems research, and human factors research. This final report is a summary of the contract objectives and accomplishments; it includes a complete bibliography of reports generated for the Crew Technology Division. The scientific, engineering, and technical team from KRUG International provided support in accordance with task assignments developed from the statement of work as summarized in each of all the 11 areas discussed in this report. Each summary is followed by a review of the accomplishments with reference, where appropriate, to the appendix which lists publications documenting the work completed in that area. Reports which were not published in the open literature or in USAF Technical Reports or Technical Papers have been presented to the Crew Technology Division Contract Monitor for inclusion in the contract file."

PART B:

SUMMARY OF OBJECTIVES AND ACCOMPLISHMENTS

Note: The objective (or a summary of the objective and description of work) and accomplishments for each area are presented here in the same sequence as in the statement of work (SOW 3.2).

B.1 Human Research Subjects

B.1.1 Objective

In supporting research efforts conducted by the Crew Technology Division, human subjects were to be acquired as needed. The human subjects were to be 18-50 years of age, meet military height and weight standards, and be high school graduates. All subjects had to satisfactorily meet all requirements of the USAFSAM Test Subjects Physical and any other physical or medical examinations or requirements specified by the approved protocol in which they intended to participate. KRUG Life Sciences, Incorporated, was to ensure that the human research subjects met these medical requirements and were properly trained as required by each approved research protocol. All medical examinations required for contractor-furnished research subjects were to be accomplished at the USAF CLINIC BROOKS (AFSC) at no cost to the contractor. Additionally, the contractor was to provide personal liability insurance for the human research subjects as required by current Air Force directives from the Air Force Surgeon General. Minimum personal liability required was to be one million dollars for each research subject for each incident.

B.1.2 Accomplishments

Civilian subject recruitment, scheduling of civilian subject medical examinations, subject protocol training, and scheduling of civilian subject exposures are representative activities accomplished in accordance with protocol requirements. Prior to exposure, voluntary, fully informed, written consent was obtained in compliance with AFR 169-3, as well as with division and branch operating instructions. All civilian subjects were compensated for services performed at the contract-specified rates. Adequate insurance coverage was maintained as stipulated in the contract in the event any injuries were incurred by human subjects during research studies.

B.2 Experimental Life Support Equipment Development Laboratory

B.2.1 Objective

KRUG Life Sciences, Incorporated, was to provide professional and technical personnel and support to further develop and conduct identified research, and operate and maintain the Life Support Equipment Development Laboratory (LSEDL). RDT&E was to include but not be limited to designing, developing, manufacturing, and evaluating the following experimental life support equipment:

a. Anti-G suits (G = Acceleration force in multiples of the earth's gravitation force.);
b. State-of-the-art pressure suits;
c. Combination G/Chest counter-pressure garment;
d. Chemical defense (CD) respirator;

e. CD respirator-compatible protective hood;
f. CD casualty coveralls and transit equipment;
g. CD impervious/inflatable protective garments;
h. Inflatable chemical warfare field shelter and airlocks; and
i. Liquid- and air-conditioned garments for protection against thermal stress.

B.2.2 Accomplishments
The LSEDL and KRUG Life Sciences, Incorporated, personnel designed, developed, manufactured, and evaluated the experimental life support equipment listed above. This effort partly supported task order research detailed in Volume 2 under Task Orders 1, 26, 34, and 37. Other results of this effort are described in the following report.

Ripley GL, Matthews DL, Burns JW. G protective equipment for human analogs. Proceedings of the 29th Annual SAFE Symposium. 1992:274-7.

Abstract: "Animal models are sometimes used as analogs for human subjects in acceleration studies. Miniature swine and baboons are the most commonly used animals in these studies. To more closely represent advanced human acceleration protective equipment, full coverage anti-G suits for swine and baboons were recently designed and fabricated in the Armstrong Laboratory's Life Support Equipment Development Laboratory (LSEDL). Prior to this time, anti-G protection using only the abdominal bladder of the anti-G suit was available for animal research. The design and fabrication of animal anti-G suits was complicated, requiring numerous iterations to acquire a proper fit. Many factors must be considered for optimal fit and comfort and to ensure that when the anti-G garment is worn, physiologic responses to acceleration in animals is similar to human responses during G. Some of these factors include body shape and size of the animal, the position in which they ride the centrifuge, and the restraint apparatus employed. This paper describes the unique aspects of the design, development, and fabrication of animal anti-G garments."

B.3 Anti-G Suit RDT&E

B.3.1 Objective
KRUG Life Sciences, Incorporated, was to determine, in accordance with the appropriate Air Force specification, and further develop the most promising uniform pressure anti-G suit concept. This was to include modifying the abdominal bladder to provide support to the diaphragm during rapid G-onset, then provide a comfortable and stable platform for performance of straining maneuvers after peak sustained G-level is reached.

Experimental anti-G suits were to be developed and manufactured in the contractor-maintained LSEDL (see B.2).

B.3.2 Accomplishments
The following publications describe the results of technical and scientific research support of anti-G suit RDT&E.

Besch EL, Wiegman JF. Metabolic bases of +Gz-duration tolerance. 13th Annual Meeting of the IUPS Commission on Gravitational Physiology, Sept 1991, San Antonio, TX. Physiol. 1991;35:S135-8.

Abstract: "While available information suggests that the metabolic basis for tolerance to HSG is primarily anaerobic capacity and the ability of the body to use that capacity, little is known about the role of aerobic capacity and its influence on +Gz duration time. Defining the role of aerobic metabolism on human +Gz-duration tolerance is necessary to determine the importance of supplemental oxygen for operational use. Utilizing the Armstrong Laboratory (Brooks AFB) Centrifuge, 6 human subjects were exposed to the simulated aerial combat maneuver (SACM) until fatigued or until light loss criteria were reached. The centrifuge runs were repeated, in series, with the subjects breathing gas mixtures containing different concentrations of oxygen ranging between 12% to 60%. Preliminary data reveal that the SACM duration times for subjects breathing 20% oxygen were similar to previous reports; a positive relationship between +Gz-duration times and inspired oxygen was detected. No differences in blood lactates were detected between the 20% and 60% oxygen groups but a positive relationship appeared to exist between blood lactates and percent inspired oxygen. We could not detect any enhancement of +Gz-duration due to hyperoxia. Further data collection and analysis are needed before a more detailed assessment of the aerobic effects on +Gz-duration can be made."

Besch EL, Wiegman JF, Nesthus TE, Shahed AR, Werchan PM. Effect of hypoxia and hyperoxia on +Gz-duration tolerance. (Abstract) Aviat. Space Environ. Med. 1992;63:398.

Abstract: "**INTRODUCTION.** While available information suggests the metabolic basis for tolerance to high sustained G (HSG) is primarily anaerobic capacity and the ability of the body to use that capacity, little is known about the role of aerobic metabolism and its influence on +Gz-duration time. Understanding that role is necessary to determine the importance of supplemental oxygen for operational use. **METHODS.** Utilizing the Armstrong Laboratory (Brooks AFB) Centrifuge, 8 human subjects were exposed to the +4.5 to 7.0 Gz simulated aerial combat maneuver (SACM) until fatigued, light loss criteria were reached, or protocol/medical reasons terminated the centrifuge run. These runs were repeated, on 6 different days, with the subjects breathing gas mixtures containing different concentrations of oxygen ranging between 12% to 60%. Blood oxygen saturation (S_aO_2) and heart rate were monitored continuously and blood lactates sampled periodically during all centrifuge exposures. **RESULTS.** A positive relationship between +Gz-duration times and inspired oxygen (F_IO_2) was detected in subjects breathing 12% to 20% O_2 gas mixtures; no change in duration time was detected between the 20% and 60% F_IO_2 groups. Although fatigue and light loss were the end points of interest, only about 50% of the centrifuge runs were terminated for those reasons, Heart rate was negatively related and S_aO_2 positively related to F_IO_2. SACM resulted in increased heart rates but decreased S_aO_2; these SACM effects were additive to effects of F_IO_2. A positive relationship was detected between peak blood lactates and SACM duration time. **CONCLUSION.** Whereas +Gz-duration is limited by reduced S_aO_2, it may not be enhanced by hyperoxia."

Burns JW, Fanton JW, Desmond JL. Hemodynamic responses to pressure breathing during +Gz (PBG) in swine. In: "High Altitude and High Acceleration Protection for Military Aircrew." Proceedings of the NATO AGARD Symposium 71st Aerospace Medical Panel. October, 1991. Pensacola, FL. AGARD-CP-516. 1991:5pp (10-1 to 10-5).
Summary: "Twelve chronically instrumented, unanesthetized, miniature swine were used to investigate the hemodynamic interrelationships of PBG, the AGSM, and the G-suit, during GOR and SACM +Gz profiles. Maximum LVP and AP of over 300 mmHg, and LVEDP and RVEDP of over 160 mmHg and 100 mmHg, respectively, were common during the GOR and SACM exposures at 9 +Gz using an ECGS. A concurrent, substantial increase in intrathoracic pressure attenuated transmural vascular pressures within the thorax. The performance of the ECGS was significantly better than the ABGS, with or without PBG. A PBG effect could not be demonstrated while using the ECGS, during either the GOR or SACM profiles."

Burns JW, Fanton JW, Desmond JL. Hemodynamic responses of the swine to G-suit inflation, the AGSM and pressure breathing during +Gz (PBG). (Abstract) Aviat. Space Environ. Med. 1992;63:419.
Abstract: "INTRODUCTION The G-protective benefits of PBG have been well demonstrated. A swine model has been developed to investigate the physiologic bases for these benefits. METHODS A mask and a chest counterpressure garment have been fabricated for application of PBG to the swine. G-suit protection was supplied by an extended coverage suit which provided nearly complete body coverage caudal to the rib cage. Left and right ventricular pressure, left and right ventricular stroke volume (SV) and cardiac output (CO), aortic pressure, eye-level blood pressure (ELBP), heart rate (HR), central venous pressure, esophageal pressure, mask pressure, and G-suit pressure were measured during +Gz with and without PB and during PB without +Gz. RESULTS During a 130 sec exposure to a 5-9 +Gz SACM mean ELBP was maintained above 55 mmHg without PBG and above 70 mmHg with PBG by an increase in total peripheral resistance, even though SV, CO and HR decreased by 57%, 63% and 5%, respectively, without PBG and by 45%, 60% and 2%, respectively, with PBG. The combination of G-suit inflation, the AGSM and PB during +Gz resulted in significantly increased intravascular pressures. However, a similar increase in intrathoracic pressure resulted in minimal transmural vascular pressure changes. CONCLUSIONS Elevated ELBP with PBG compared to without PBG supports the finding in man of extended time at +Gz and a reduction in the physical effort to maintain vision during sustained +Gz."

Burns JW, Morgan TR, Krutz RW Jr. Recent developments in acceleration protection (Abstract) Aviat. Space Environ. Med. 1990;61:495.
Abstract: "Before the era of high performance fighter aircraft acceleration protection was adequately provided by the conventional G-suit and G-valve, and a moderate contribution from the anti-G straining maneuver (AGSM). However, current aircraft G-protection requires significantly greater, near-maximal, effort from the AGSM, to the point of fatigue and possible loss of consciousness (LOC). Over the near horizon are several pieces of new G-protective equipment and techniques that will significantly reduce fatigue and extend

the pilot's capabilities for more optimum performance of the aircraft. The addition of assisted positive pressure breathing (APPB) has provided fatigue reduction and extended time at G by over 100% compared to the combination of G-suit and AGSM. The ambitious Combat Edge program is developing G protective equipment around APPB with projected inclusion into current aircraft in FY 90. Another significant improvement in G-protection which is planned for inclusion into Combat Edge, when available, is an advanced technology anti-G suit (ATAGS) which provides uniform pressure to the lower extremities through bladders which completely encircle the legs, including the feet and ankles. Improved comfort as well as a 60% improvement in G-endurance have been demonstrated with ATAGS compared to the standard G-suit. Near-term regulator and G-valve improvements will also be integrated into Combat Edge for planned continued improvement in G-protection."

Fischer MD, Wiegman JF, Bauer DH. Female tolerance to sustained acceleration. A retrospective study. SAFE J. 1992:22(2):31-35 and 29th Annual SAFE Symposium Proceedings. 1992:283-7.

Abstract: "In 1986, Gillingham et al. concluded that there were no differences in the relaxed or straining G-tolerance levels of men and women. He also reported no difference in their tolerance to +7 Gz sustained for 15 s. Since women may play an equal role in serving as aircrew on high-performance combat aircraft, their tolerance to high, sustained acceleration (>15 s and/or > +7 Gz) must be examined. The purpose of this study was to compare the +8 and +9 Gz tolerance of females and males. Data on 102 females and 200 males (flight surgeons, aerospace physiologists, and medical residents at Brooks AFB, between the years 1986 and 1991) were obtained from the Armstrong Laboratory Centrifuge data repository. Results showed that a proportionate number of females and males attempted +8 Gz for 15 s (55.9% and 56.5%, respectively) but, of those attempting the run, 63.2% of the females, compared to 80.9% of the males, completed the run. Fewer females and males attempted +9 Gz for 15 s (31.4% and 42.0%, respectively), with 59.4% of the females and 72.6% of the males completing the run. Chi Square analyses indicated a significant difference in the completion rates (p<.05) at the +8 Gz level, but no difference was detected at the +9 Gz level. We suggest that the differences found may be attributed to poor-fitting anti-G suits for the female subjects. Controlled centrifuge studies should be conducted to further investigate women's tolerance to high sustained +Gz."

Krock LP, Garza JR, Wiegman J. Thermal evaluation of two prototype aircrew chemical defense ensembles, USAFSAM-TP-89-10. 1989:19pp.

Abstract: "Individual aircrew members are protected against chemical warfare environments by the Aircrew Chemical Defense Ensemble (ACDE). The current regulation ACDE (flight suit coverall worn over an activated charcoal undergarment) inhibits dissipation of body heat, resulting in severe physiological limitations on task performance. Several second-generation ACDE prototype designs are undergoing review by the U.S. Air Force Life Support System Program Office. Two of these candidate ACDEs were compared to the current ACDE with respect to thermal stress associated with task performance. The two ACDEs evaluated

were: the Gentex Intimate Blend Coverall, and the Winfield Monopack Saratoga Coverall. Human subjects were instrumented; they then dressed in the experimental ACDE plus flight safety equipment, and performed scheduled tasks in a climate-controlled chamber at the U.S. Air Force School of Aerospace Medicine, Brooks AFB, Texas. To initiate the experiment, subjects pedaled on an ergometer (50 W) for 10 min, after which they sat in a high-performance aircraft ejection seat and performed minimal physical activities for 1 hr; following this seated phase, the subjects again pedaled the ergometer (50 W) for 30 min. Heart rates, core (rectal) temperatures, and 5 skin temperatures (chest, back, upper arm, upper leg, and calf) were measured at 30-s intervals throughout the experiment. To measure sweat production and sweat evaporation, the subjects were weighed, both nude and fully dressed, immediately before and after the experiment. Temperature and heart rate data, averaged over the last 5 min of each phase, were subjected to a three-way, mixed-model analysis of variance with repeated measures. Under the conditions of these experiments, the candidate second-generation aircrew chemical defense ensembles (Gentex and Winfield) did not differ significantly from the current ACDE."

Krutz RW Jr. Advanced concepts in acceleration protection. Ibero-American Assoc. Aerosp. Med. Bull. 1990;1:4-5.

<ins>Abstract</ins>: "Before the advent of the F-15 and F-16 fighter aircraft the standard anti-G suit combined with a reasonably effective anti-G straining maneuver (AGSM) provided adequate G-protection. However, these and other newer aircraft with low wing loading and high thrust-to-weight ratios generate high sustained G levels which have caused a renewed interest in protective techniques to prevent G-induced loss of consciousness (G-LOC). Although there are many potential solutions to the G-LOC problem including tilt-back seats and flying in the prone position, there are many engineering problems inherent in these solutions which make them impractical at the present time. The new G- protective measures which appear to be most feasible for alleviating the G-LOC problem include:

(1) advanced training in the AGSM,
(2) improved anti-G suits,
(3) assisted positive pressure breathing and
(4) a combination of (2) and (3).

Advanced AGSM training is provided at both the United States Air Force School of Aerospace Medicine (USAFSAM), Brooks AFB, Texas, and Holloman AFB, New Mexico. Classroom instruction is provided before critiqued performances of the AGSM on a human-use centrifuge. This high G training has been unanimously endorsed by participating aircrew. The Advanced Technology Anti-G Suit (ATAGS) was designed to enhance G-tolerance and endurance by lessening the physical effort required by pilots performing the AGSM. ATAGS covers the entire lower body, thereby more effectively reducing blood pooling and increasing the pilot's ability to tolerate high sustained G. ATAGS has been tested on the USAFSAM human-use centrifuge and at the USAF Test Pilot School in both the RF-4C and F-16B. Pilots unanimously agreed that ATAGS reduced fatigue and improved performance at high sustained G when compared to the standard anti-G suit. Assisted positive pressure breathing for G (PBG) has been under development at USAFSAM since the early 1970s. This G-protective technique reduces the level of fatigue caused by performance of the AGSM. Because fairly high breathing pressures are used, a counterpressure vest is worn to balance pressures across the chest wall thus preventing breathing difficulty and possible pulmonary damage. The addition of PBG to ATAGS shows great promise of providing an optimal anti-G protective ensemble. The high accelerative forces generated by today's fighter aircraft have pushed aircrew beyond their G-tolerance/endurance limits. The most promising current and developmental methods to counteract the physiologic effects of these high G forces without major engineering design changes in the cockpit have been described."

Krutz RW Jr. Acceleration physiology and countermeasures in the 21st century (Abstract) Aviat. Space Environ. Med. 1992;63:438.

Abstract: "Methods to enhance man's survivability in the sustained high or low G environments continue to be at the forefront of aeromedical research. Several acceleration protection research efforts are being actively pursued in programs with high visibility. A new reentry G-suit for NASA which employs uniform pressure (UP) to the lower extremities promises to increase G-protection during shuttle reentry without the discomfort of an abdominal bladder (AB). This suit concept should also be adaptable for the National Aerospace Plane's (NASP) reentry G-protection requirements. It is hypothesized that the low G levels encountered in these environments do not significantly increase heart-to-eye distance and thus the requirement for an AB is negated but the need to prevent blood pooling in hypovolemic crewmembers is critical. The same G-protection principle used in these suits, i.e., lower body uniform pressure, is also the basis for a new advanced technology anti-G suit (ATAGS) soon to be flight-tested by the USAF. The AB is an absolute necessity in ATAGS since it is to be worn in fighter-type aircraft with high G onset rates which cause a rapid increase in heart-to-eye distance, decreased eye-level blood pressure and subsequent G-induced loss of consciousness (G-LOC). The USAF is now in the process of fielding COMBAT EDGE, an ensemble which uses positive pressure for G-protection (PBG) in combination with the current anti-G suit. PBG offers relief to tactical aircrews from the fatiguing effects of acceleration in air-to-air combat. Preliminary studies have demonstrated that PBG is even more effective when used with ATAGS."

Krutz RW Jr, Bagian J, Burton RR, Meeker LJ. Heart rate and pulmonary function while wearing the launch-entry crew escape suit (LES) during $+G_x$ acceleration and simulated shuttle launch. SAE Technical Paper #901358. 1990:8pp.

Abstract: "Space shuttle crewmembers have been equipped with a launch-entry crew escape system (LES) since the Challenger accident in 1986. Some crewmembers, wearing the new pressure suit, have reported breathing difficulties and increased effort to achieve the desired range of motion. This study was conducted to quantify the reported increased physical workloads and breathing difficulty associated with wearing the LES. Both veteran astronauts and centrifuge panel members were exposed to various $+G_x$ profiles (including simulated shuttle launch) on the USAF School of Aerospace Medicine (USAFSAM) human-use centrifuge. Maximum

heart rate data showed no increased workload associated with arm and head movement in the LES when compared to the flight suit/helmet ensemble (LEH). However, the LES did impose a significant increase in breathing difficulty beginning at +2.5 G_x which was demonstrated by a decrease in forced vital capacity and subjective questionnaires."

Krutz RW Jr, Burton RR, Forster EM. Physiologic correlates of protection afforded by anti-G suits. Aviat. Space Environ. Med. 1990;61:106-11.

Abstract: "A new uniform-pressure pneumatic anti-G suit (UPS) was compared with the standard CSU-13B/P anti-G suit, using measurements of: blood lactate, heart rate changes, and segmented lower-body blood pooling (by impedance plethysmography). Subjects were exposed to a series of gradual-onset-rate (GOR) runs (0.1 G s^{-1}), rapid-onset-rate (ROR) runs (6 G s^{-1}), and simulated aerial combat maneuvers (SACM) on the USAF School of Aerospace Medicine human-use centrifuge. All measured parameters and subjective reports indicated that increased protection was afforded by the UPS. The impedance plethysmography measurements indicated that prevention of blood pooling in all lower-body segments is the predominant mechanism whereby uniform pressure permits significantly longer times-to-fatigue during SACMs."

Meeker LJ, Ohlhausen JH. System parameters of the advanced technology anti-G suit (ATAGS). A progress report. 30th Annual SAFE Symposium Proceedings. 1993:345-350.

Abstract: "Previous centrifuge and flight testing have shown that the advanced technology anti-G suit (ATAGS) offers superior G endurance protection even when operated at lower pressures than the standard anti-G suit. All of the previous ATAGS testing was done, however, using human test subjects for the purpose of evaluating G protection. The purpose of the parametric tests was to provide basic system data such as volumes, fill rates and pressure differentials for the ATAGS. In order to allow direct comparison with data taken previously on the AF standard anti-G suit (CSU-13A/P), these tests were based on procedures detailed in SAM-TR-78-12, Engineering Test and Evaluation During High G, VOL III: Anti-G Suits. ATAGS volumes were measured using pressure change during expansion from a known volume. The volumes of several suit sizes were taken, both with the suit unmounted and mounted on a mannequin to a proper fit. Total flow was measured with a flowmeter in the main fill hose. Differential pressure in various parts of the suit during rapid fill was measured at test points located on both sides of the abdominal bladder, on each thigh, and at the bottom of each leg. Preliminary data from these tests are presented."

Wiegman JF, Besch EL, Nesthus TE, Shahed AR, Werchan PA. Comparison of the hypoxic and hyperoxic response to maximal anaerobic exercise and sustained +Gz exposure. (Abstract) Aviat. Space Environ. Med. 1992;63:398.

Abstract: "**INTRODUCTION.** While it is generally accepted that +Gz-duration tolerance is primarily an anaerobic activity, the degree of aerobic involvement has not been successfully quantified. On the other hand, the Wingate Anaerobic Test (WAT), an exercise task directly related to a simulated aerial combat maneuver (SACM) centrifuge profile, has been shown to use approximately 85% anaerobic and 15% aerobic

resources. The purpose of this study was to compare the physiologic response to WAT with that of the SACM during hyperoxia, normoxia, and hypoxia. **METHODS.** Following WAT and SACM training, subjects (N=7) performed either WAT or SACM while exposed, in random order and with 48h between tests, to either hyperoxia (60% inspired oxygen (F_IO_2)), normoxia (20% O_2) or hypoxia (18,16,14,12% O_2). Heart rate and blood oxygen saturation (S_aO_2) were recorded continuously. Blood was sampled via fingerprick for lactate determination pre- and post-gas (i.e., controls), post warm-up, and at 3 intervals following WAT and SACM. **RESULTS.** The level of inspired oxygen was directly related to maximum heart rate during SACM, but showed no relationship with maximum heart rate during WAT. While blood lactate level at 3-min post-SACM was related to F_IO_2, post-WAT blood lactate level did not appear to be influenced by inspired oxygen. SACM duration was significantly affected by F_IO_2. A significant F_IO_2 effect ($p<.05$) was also indicated for WAT power values; however, post-hoc comparison of means revealed that the effect on mean power was due to the 14% O_2 exposure (14<16,18,20,60%). Five of 7 subjects were unable to initiate the WAT at 12% O_2 due to an $S_aO_2 \leq 60$ during warm-up (limitation of protocol). Blood oxygen saturation was significantly altered ($p<.05$) as a result of F_IO_2 during both WAT and SACM. **CONCLUSION.** Exposure to SACM may present a stressor which includes an aerobic component that may be greater than that previously reported for the WAT."

Wiegman JF, Besch EL, Werchan PM, Nesthus TE, Shahed AR, Fischer MD. Effect of hypoxia and hyperoxia on the physiologic response to anaerobic work. (Abstract) Med. Sci. Sports Exer. 1992;24(Suppl):S152.

Abstract: "While effects of hypoxia and hyperoxia on aerobic capacity are well documented, relatively few data are available to describe their effects on anaerobic performance. This study compared physiologic responses to the Wingate Anaerobic Test (WAT) during hyperoxia, normoxia, and hypoxia. Seven male subjects performed WAT while exposed to either hyperoxia (60% inspired oxygen (F_IO_2)), normoxia,(20% O_2), or hypoxia (18,16,14,12% O_2) in random order and with a minimum 48 h between tests. Heart rate and blood oxygen saturation (S_aO_2) were recorded continuously. Power outputs (peak 5-s, mean 30-s, and % decrease) were calculated for each 2-m pedaled. Blood was sampled via fingerprick for lactate determination pre and post gas (i.e., controls), post warm up, and at 3, 6, and 12 min post WAT. Analysis of variance indicated the F_IO_2 did not influence maximum heart rate during WAT or peak lactate levels post WAT. A direct F_IO_2 effect ($p<.05$), indicated for WAT power values, was largely due to 14% O_2 (14<16,18,20,60% O_2). There was no detectable F_IO_2 effect on %power decrease. S_aO_2 at 5-min post gas (prior to exercise) was significantly reduced ($p<.05$) as a result of decreases in F_IO_2. Analysis of variance revealed a significant difference between all gas mixtures for the lowest S_aO_2 during exercise. Means for lowest S_aO_2 ranged from 97.4 to 63.9 for the 60 to 12% O_2 levels, respectively. Five of seven subjects were not allowed to initiate the WAT at 12% O_2 exposure due to an $S_aO_2 \leq 60\%$ during the warm up. Results suggest that ability to produce anaerobic power and capacity is affected by exposure to 14% O_2, but unaffected by hyperoxia. Hypoxia, hyperoxia, and maximal anaerobic work influence S_aO_2."

Wiegman JF, Burton RR, Greene JR. Anaerobic capacity in Tactical Air Command pilots and USAFSAM acceleration test subjects. (Abstract) Aviat. Space Environ. Med. 1990;61:466.

Abstract: "INTRODUCTION. Using USAFSAM acceleration test subjects, a positive correlation has previously been demonstrated between +Gz endurance and anaerobic capacity (AC). Current research seeks to determine if the Wingate Anaerobic Test (WAT) can, likewise, be used as an indicator of the fighter-pilot's ability to endure high G. The objective of this study was to compare anaerobic capacity in centrifuge subjects and fighter-pilots. METHODS. Lower body WATs were conducted on 35 Tactical Air Command pilots (P) and 11 USAFSAM acceleration test subjects (S). The results of the maximal-effort, cycle ergometer test is 30-sec mean power (MP, an index of AC), as well as highest power for a 5-sec period (HP) and power decrease (PD). RESULTS. Means and SD for selected variables are shown below.

GROUP	AGE	MP(AC)	HP	PD
P	31.4	576.3 ± 90.9	758.9 ± 127.3	45.2 ± 5.4
S	25.6	607.9 ± 128.5	831.7 ± 172.5	49.2 ± 5.0

ANOVA testing for group effects (P vs S) revealed no significant differences for MP or HP; while PD values were significantly different. CONCLUSIONS. Although results suggest that S fatigue more rapidly during high-intensity work, this is due, in part, to their higher HP and does not effect MP, our measure of anaerobic capacity. Since AC has been correlated to +Gz endurance in S and no AC differences between S and P were found, the implications for future AC correlations to fighter-pilot high-G endurance is strong."

Wiegman J, Hart S, Fischer J, Peel G. Physical conditioning for G-tolerance in Tactical Air Command pilots. (Abstract) Aviat. Space Environ. Med. 1991;62:476.

Abstract: "INTRODUCTION. Current recommendations for physical training to enhance G-tolerance are described in USAFSAM-SR-88-1/NAMRL-1334. The degree to which USAF fighter-pilots are adhering to these programs is unknown. This paper describes the current exercise status of F-16 pilots based on age, flying experience, and previous exercise habits. Exercise status as it relates to gradual-onset relaxed (GORR) and straining (GORS) G-tolerance level is also discussed. METHODS. A questionnaire detailing demographics and exercise history was administered to F-16 pilots stationed at both an operational and training base. For analysis the pilots were stratified into groups which included age (20-29, 30-39, 40+) and prior exercise group (runners, weight lifters, both or neither). The frequency distribution data were examined using techniques of categorical analysis to identify the populations who are or are not able to adhere to present recommendations for G-fitness. Analysis of variance was used to test the null hypothesis that there was no significant difference in the mean G-tolerances of the four exercise groups. RESULTS. Preliminary results indicate that pilots who regularly run

average 10.2 miles per week, while pilots who lift weights average 2.6 workouts per week with the average duration of a workout being 1.0 hr. The frequency distribution data suggest that adherence to current recommendations is inversely related to age and unrelated to prior exercise group. Although not statistically significant, preliminary means are highest for GORS and GORR in the group of pilots that both run and weight train, while the lowest GORS and GORR are in the run-only group. CONCLUSIONS. Current recommendations for physical conditioning to enhance G-tolerance are successfully impacting the new generation of F-16 fighter-pilots."

B.4 Research Databases

B.4.1 Objective

KRUG Life Sciences, Incorporated, was to maintain and modify, as required, the existing databases for collection and retrieval of research data, concerned with decompression sickness (DCS) and acceleration research. This included writing necessary procedures and programs for transferring the databases from the Sperry UNIVAC system to VAX. Additionally, the contract required development of procedures for obtaining statistical information in the form of graphs, charts, tables, and other computer documents.

B.4.2 Accomplishments

The AL Hypobaric Decompression Sickness Research Database was transferred to the VAX from the Sperry UNIVAC and has been further converted to a relational database system from the earlier hierarchical system. Considerable correction of earlier, 1983-1991 datasheets and entries have resulted in a more accurate and usable database. Revised symptom codes and datasheet simplification have reduced the risk of errors in recording data. As of 10 November 1992, 1096 man-flights were recorded on the database. Procedures have been developed for computer-generated tables and other documents which have been used in support of many of the publications cited in section B.5.

The AL Hypobaric Decompression Sickness Literature Database was converted from an ENABLE format to a DBase format (PC File 5.01). In the process, keyword standardization and revision, report format revision, and a database backup in condensed format were accomplished. At the beginning of the current contract, the database contained approximately 385 entries. At the end of the contract, the DCS Literature Database contained 1068 entries. Numerous printouts based on keyword or author searches have been produced in support of hypobaric decompression research.

The AL Acceleration Research Database has been converted to a relational database system on the VAX from the earlier hierarchical system. Extensive modification of data entry procedures was accomplished to streamline the process and eliminate many sources of error. As of 10 November 1992, 6,797 exposure records were on the database which consist of 28,571 acceleration exposure runs.

The Tactical Air Command (TAC) High-G Training Database was used to provide information about G-tolerance for the following reports.

Oakley CJ, Webb JT. Can fighter pilot G tolerance be predicted by using anthropometric and physiologic parameters? (Abstract) Aviat. Space Environ. Med. 1990;61:466.

__Abstract__: "__INTRODUCTION.__ There is a high level of interest in predicting G tolerance that could lead to low cost screening tools for selection of fighter pilot trainees. __METHODS.__ The rapid onset runs (ROR, +9 Gz for 15 s with an inflated anti-G suit) of over 1400 fighter pilots during High-G Training (HGT) on the USAF School of Aerospace Medicine centrifuge were studied. Discriminant analyses were performed to determine which of these anthropometric and physiologic parameters (age, weight, height, blood pressure, and blood lipids) would be useful to identify the pilots that accomplished the training goal of +9 Gz for 15 s. __RESULTS.__ The analyses selected height and weight as significant parameters for the prediction equation. This prediction equation agreed with the actual observed results for 55% of the pilots studied. Analysis of a subgroup of pilots in the age group eligible for entry in pilot training (21-27.5 yrs) yielded a comparable 53% success rate. __CONCLUSIONS.__ Since a 50% success rate occurs by chance alone, predication of fighter pilot G tolerance is not feasible using these anthropometric and physiologic parameters."

Webb JT, Oakley CJ, Meeker LJ. Unpredictability of fighter *pilot G tolerance using anthropometric and physiologic* variables. Aviat. Space Environ. Med. 1991;62:128-35.

__Abstract__: "Correlation and regression analyses were used to study relationships between centrifuge G tolerances of 1,434 fighter pilots during High-G Training (HGT) and anthropometric and physiologic variables. Multiple regression analyses yielded a four-variable model in which gradual onset run (GOR) relaxed-G tolerance was inversely correlated with height and directly correlated with age, weight, and diastolic blood pressure. Although the four-variable model was able to predict more of the variation in G tolerance than any single variable, neither method showed a correlation (r) of greater than 0.35 with GOR relaxed or straining G tolerance. No subject variable was significantly different between the pilot groups that did and did not experience G-induced loss of consciousness. Prediction of G tolerance during centrifuge HGT is concluded to be unreliable using anthropometric and physiologic variables. The anti-G straining maneuver remains the major determinant of an individual's G tolerance."

B.5 Subatmospheric Research

B.5.1 Objective

KRUG Life Sciences, Incorporated, was to conduct the following research tasks:

a. Investigate the role of different types of exercise, i.e., isotonic and isometric, in the etiology of DCS;

b. Determine the effect of different breathing gas mixtures in enhancing the efficacy of denitrogenation for DCS prevention;

c. Determine hematologic correlates of DCS;
d. Measure headward fluidshifts using impedance plethysmography during onset of space adaptation syndrome;
e. Design, develop, and manufacture a state-of-the-art experimental pressure suit for Strategic Air Command (SAC) aircrew members;
f. Operate and maintain a Hewlett-Packard Series 60 echo-imaging systems for intravenous bubble detection, overseeing the conduct of experiments, provide an Air Force approved Physiological Training Officer (PTO) for research chamber flights, provide a physician medical monitor, and document the written results of the research studies.

B.5.2 Accomplishments

Items c. and d. above were completed and results published prior to initiation of the current contract. Refer to the following reports for further information.

Webb JT, Smead KW, Jauchem JR, Barnicott PT. Blood factors and venous gas emboli: surface to 429 mmHg (8.3 psi). Undersea Biomed. Res. 1988;15:107-21.

Webb JT, Smead KW, Inderbitzen RS. An altered control position for simulating fluid shifts during shuttle launch. 25th Annual SAFE Symposium Proceedings. 1988:41-4.

Item e became the Personal Transatmospheric Protection System (PTAPS) program and KRUG Life Sciences, Incorporated, provided engineering and technical support for the design of advanced pressure suit gloves. Scientific research, engineering, medical monitoring, exercise physiologist, and technical support activities were provided for accomplishment of hypobaric decompression sickness protocols and reported in the following publications and presentations:

Fischer MD, Wiegman JF, McLean SA, Olson RM, Pilmanis AA. Evaluation of four different exercise types for use in altitude decompression sickness studies. 30th Annual SAFE Symposium Proceedings. 1993:102-5.

<u>Abstract</u>: "A study is ongoing at the Armstrong Laboratory, Brooks AFB, to determine the effects of four types of exercise on altitude decompression sickness. The four types of exercise (isometric arm or leg, isotonic arm or leg) simulate events that may occur during high altitude reconnaissance flight or extravehicular activity in space. For the study, it is imperative that subjects perform equivalent work, while exercising, during exposure to altitude. The purpose of this paper is to describe a procedure to equate work, as measured by VO_2 (ml/min), for the four exercise types. In four separate sessions, subjects (N=13) performed exercise, at varying percentages of their maximal isometric strengths, while oxygen consumption data were recorded. From these data, exercise intensities, for each exercise type, were selected that would elicit a similar VO_2. In four additional sessions, the selected work loads were verified during repeated 12-min exercise bouts. An analysis of variance (ANOVA) was performed to compare the 12-min average VO_2 for the four exercise types. Mean VO_2 of 388, 388, 385, and 392 ml/min for isometric arm and leg and for isotonic arm and leg, respectively, were not significantly different. Results

show that the described procedures are a valid method that can be used to equate four uniquely different types of exercise."

Garber MA, Stegmann BJ, Pilmanis AA. The role of pulmonary surfactant in extreme altitude exposures. (Abstract) Aviat. Space Environ. Med. 1992;63:422.

Abstract: "**INTRODUCTION.** A guinea pig model is being used at the HAPF [Armstrong Laboratory High Altitude Protection Function] to test the efficacy of various treatment modalities for the unprotected exposure to near vacuum. The incidence of respiratory arrest and the difficulty of pulmonary resuscitation have led to the hypothesis that normal lung surfactant function is disrupted in extreme altitude exposure. **METHODS.** Scanning and transmission electron microscopy (with special stains for surfactant) have been used to compare the lung ultrastructure between altitude-exposed and control animals. Low pressure vascular perfusion fixation has been utilized to minimize disruption of the alveolar surface lining layer. **RESULTS.** Preliminary analysis indicates that, in comparison to controls, the lungs of exposed animals demonstrate a reduced thickness of surfactant lining alveolar spaces. Animals which survive the exposure demonstrate a marked increase in surfactant production 48 hours later. Otherwise, no significant ultrastructural disruption of normal morphology is noted. **CONCLUSIONS.** Pulmonary surfactant is reduced by altitude exposure in this model. Artificial surfactant may have a role in the clinical treatment of ebullism."

Kemper GB, Stegmann BJ, Pilmanis AA. Inconsistent classification and treatment of Type I/Type II decompression sickness. (Abstract) Aviat. Space Environ. Med. 1992;63:410.

Abstract: "**INTRODUCTION.** In military aviation, decompression sickness (DCS) has historically been symptomatically classified as either Type I or Type II. Type I DCS is generally considered "minor" or synonymous with simple bends; a Type II DCS diagnosis can lead to permanent disqualification of an aircrew member. Despite the potential consequences of a Type II diagnosis, the criteria for differentiating Type I and Type II are unclear and subject to provider bias. We examined individual interpretation in diagnosing and treating patients with suspected DCS. **METHODS.** Experts in both the diving and flying communities were presented with 10 case descriptions of aircrews with specific DCS manifestations and asked to classify them as either Type I or Type II. The experts were also asked to comment on the course of treatment and future flight status in each of the cases. **RESULTS.** Case #1 was the only case diagnosed as Type I by 100% of the experts. All other cases received mixed diagnoses. Cases #5 and #7 were the only cases not considered Type I. However, only 78% felt these cases were of the Type II classification. Six cases were diagnosed as neither Type I nor Type II. All cases diagnosed as Type II were recommended for waiver and return to flying status. **CONCLUSIONS.** The results indicate that significant variations exist in the definition of DCS types, treatment, and flying status disposition. Recommend using clinical descriptions for classifying DCS instead of Type I or Type II."

Krutz RW Jr, Webb JT, Dixon GA. Determining a bends-preventing pressure for a space suit. SAFE J. 1989;19:20-4.

<u>Abstract</u>: "It is desirable that a pressure suit used for extravehicular activity (EVA) (1) eliminate the threat of decompression sickness (bends) and (2) require no preoxygenation prior to EVA. This paper chronicles the definition of a pressure to prevent bends during EVA without preoxygenation and subsequent studies to test and evaluate this pressure using both male and female subjects with different breathing gas mixtures. Initially, a study using simulated EVA workloads was conducted at 7.8 psia using 50% O_2:50% N_2 breathing gas mixture without prebreathing 100% O_2. Since this pressure did not totally eliminate bends, a subsequent study was conducted using step-wise increases in pressure to determine a suit pressure at which both significant intravascular bubbles and bends were eliminated without preoxygenation. The results indicated that 9.5 psia met the aforementioned criteria in male subjects. To validate 9.5 psia, subsequent studies were conducted using both males and females and 40% O_2:50% N_2 and 100% O_2 breathing gases. No cases of significant bubbling, bends, or any other detrimental physiologic effects were noted during any exposure. It appears then, from a physiological viewpoint, that a minimum pressure of 9.5 psia should be considered as the standard for EVA [when decompressing] from 14.7 psia space station."

Nesthus TE, Schiflett SG. Monitoring Cognitive Function and Mood with the Automated Neuropsychological Assessment Metrics (ANAM) in decompression sickness (DCS) Research. (Abstract) Sixth Annual Workshop on Space Operations, *Applications, and* Research Symposium (SOAR '92). NASA Conference Publication 3187. 1993;II:498.

<u>Abstract</u>: "Hypobaric decompression sickness (DCS) research presents the medical monitor with the difficult task of assessing the onset and progression of DCS largely on the basis of subjective symptoms. Even with the introduction of precordial Doppler ultrasound techniques for the detection of venous gas emboli (VGE), correct prediction of DCS can be made only about 65% of the time according to data from the Armstrong Laboratory's (AL) hypobaric DCS database. An AL research protocol concerned with exercise and its effects on denitrogenation efficiency includes implementation of a performance assessment test battery to evaluate cognitive functioning during a 4 h, simulated 30,000 ft (9144 m) exposure. Information gained from such a test battery may assist the medical monitor in identifying early signs of DCS and subtle neurologic dysfunction related to cases of asymptomatic, but advanced DCS. This presentation concerns the selection and integration of a test battery and the timely graphic display of subject test results for the principal investigator and medical monitor. A subset of the Automated Neuropsychological Assessment Metrics (ANAM) developed through the *Office of Military Performance* Assessment Technology (OMPAT) was selected. The ANAM software provides a library of simple tests designed for precise measurement of processing efficiency in a variety of cognitive domains. For our application and time constraints, two tests requiring high levels of cognitive processing and memory were chosen along with one requiring fine psychomotor performance. Accuracy, speed, and processing throughput variables as well as RMS error are

collected. An automated mood survey provides "state" information on 6 scales including anger, happiness, fear, depression, activity, and fatigue. An integrated and interactive LOTUS 1-2-3 macro was developed to import and display past and present task performance and mood-change information."

Olson RM, Dixon GA. Significance of delayed symptom onset in altitude DCS. (Abstract) Aviat. Space Environ. Med. 1990;60:482.

Abstract: "INTRODUCTION. It is well known that bubbles and bends often occur long after a subject reaches altitude. A very surprising and significant finding recently reported by Dixon et al. is that subjects exposed to altitudes so low that bends is precluded still frequently develop large numbers of circulating bubbles. The following *in vitro* experiments help explain these theoretically important observations. METHODS. Preformed 50-100 μM bubbles were taken to various altitudes in a model chamber with transparent walls and an indwelling ultrasonic probe. Bubble size initially measured ultrasonically was thereafter followed visually. RESULTS. It was found that the rate and duration of bubble growth was strongly altitude dependent, with bubbles at low altitudes reaching their maximum but small size in minutes and bubbles at high altitudes reaching their relatively large size in hours. CONCLUSIONS. It was concluded that bubbles must reach a minimum size or threshold before they cause symptoms. At low altitude such as used by Dixon et al., bubbles ceased to grow before they reached symptomatic threshold size. Likewise, at high altitudes the delay time noted above is the time it takes bubbles to reach symptomatic threshold size."

Olson RM, Krutz RW Jr. Significance of delayed symptom onset and bubble growth in altitude decompression sickness. Aviat. Space Environ. Med. 1991;62:296-9.

Abstract: "Three characteristics of altitude induced decompression sickness (DCS) are: 1) symptoms occur some time after arrival at altitude; 2) symptoms seldom occur below 18,000 ft, even though bubbles are frequently detected at that low altitude; 3) symptoms seldom occur after 4 h at altitude. These observations could be explained if it were postulated that bubbles must reach a threshold size before symptoms of DCS occur. In vitro techniques were used in this study to measure bubble growth at various altitudes. The results indicate that although the growth rate of bubbles depends strongly on the altitude where they form, bubble growth requires time. This helps explain the first observation above. We found that bubbles stop growing early at a small size below 18,000 ft. This helps explain the second observation above. Finally, we found that bubbles stop growing when the fluid immediately surrounding the bubble is cleared of supersaturated gas regardless of the fluid composition a few centimeters from the bubble. This helps explain the last observation above."

Olson RM, Krutz RW Jr. Latent period of symptoms in decompression sickness. (Abstract) Aviat. Space Environ. Med. 1991;62:452.

Abstract: "**INTRODUCTION**. The time between arrival at altitude and the onset of decompression sickness (DCS) is a matter of a few minutes to a few hours. In a previous paper, in vitro

studies were presented which suggested that this delay is the time it takes bubbles to grow to a size where they are capable of producing symptoms. Since it was also shown that bubbles grow faster at higher altitudes, it follows that for any given subject, DCS should occur sooner at higher altitudes. **METHODS**. To examine this theory, fourteen healthy male subjects were exposed after breathing 100% oxygen for one hour to 25,000 ft simulated altitude on one occasion and 30,000 ft on another. At altitude they did light exercise for one out of every 16 minutes, and they were ultrasonically monitored for circulating bubbles at 16 minute intervals. When DCS occurred they were returned to ground level in a lock where the exact pressure and time when symptoms disappeared could be monitored. **RESULTS**. In most cases, bends occurred sooner at 30,000 ft. In all cases, symptoms disappeared suddenly as the ambient pressure in the lock was increasing, suggesting that bubbles were squeezed to subthreshold size. **CONCLUSIONS**. This experiment suggests that bubble size is a critical factor in the development of DCS."

Olson RM, Pilmanis AA, Scoggins TE. Echo imaging in decompression sickness research. SAFE J. 1992;22(2):26-29 and 29th Annual SAFE Symposium Proceedings. 1992:278-82.
Abstract: "For two decades a noninvasive, ultrasonic Doppler device has been available to detect the bubbles associated with decompression sickness (DCS) in humans. Although it is of undisputed value in DCS research, this device has some limitations. First, the signals from the bubbles produce sounds rather than visual images. Second, the bubbles have to be in motion and thus in the vascular system to be detected. Finally, no estimate of bubble size is easily available. A new type of ultrasonic device which overcomes these limitations has recently become available. This device was used to examine four decompressed subjects and it was found that this new device produces visual images of bubbles. These bubbles can be seen even if they are outside the vascular system and thus stationery. A preliminary attempt at estimating bubble size with this device is presented."

Olson RM, Pilmanis AA, Scoggins TE. Use of echo imaging in decompression sickness model development. (Abstract) Aviat. Space Environ. Med. 1992;63:386.
Abstract: "**INTRODUCTION.** A model which assesses the risk of decompression sickness (DCS) associated with altitude exposures of various profiles is needed. This paper describes how echo imaging techniques can provide critical measurements, such as bubble size, to support the development of a decompression model. **METHODS.** Three healthy male subjects were exposed to a simulated altitude of 29,500 ft. They were monitored with the Hewlett Packard SONOS 1000 echo imaging system at two monitoring sites, the heart and the inferior vena cava (IVC) as viewed through the liver. Consequently, the hepatic veins and bile duct system were also observed. **RESULTS.** Bubble size was found to be between 5 and 100 micra both in the IVC and in the hepatic veins. The upper size limit was established by IVC microbubble flotation rates. Size confirmation was provided by observation of pressure-induced right ventricular bubble resolution. Microbubbles were visualized in the gall bladder and hepatic veins but not in the liver itself.

Therefore, hepatic tissue bubbles, if they exist, are smaller than intravascular bubbles. This size range was incorporated into the ongoing development of a decompression model. CONCLUSIONS. Echo imaging is a powerful tool for DCS research and model development."

Olson RM, Pilmanis AA. Use of ultrasound in altitude decompression modeling. (Abstract) Sixth Annual Workshop on Space Operations, Applications, and Research Symposium (SOAR '92). NASA Conference Publication 3187. 1993;II:543.

Abstract: "A model that predicts the probability of developing decompression sickness (DCS) with various denitrogenation schedules is being developed by the Armstrong Laboratory, using human data from previous altitude exposures. The voluntary, fully informed consent of the subjects used in this research was obtained as required by AFR 169.3. It was noted that refinements are needed to improve the accuracy and scope of the model. A commercially developed ultrasonic echo imaging system is being used in this model development. Using this technique, bubble images from a subject at altitude can be seen in the gall bladder, hepatic veins, vena cava, and chambers of the heart. As judged by their motion and appearance in the vena cava, venous bubbles near the heart range in size 30-300 M. The larger bubbles skim along the top whereas the smaller ones appear as faint images near the bottom of the vessel. Images from growing bubbles in a model altitude chamber indicate that they grow rapidly, going from 20 to 100 M in 3 sec near 30,000-ft altitude. Information such as this is valuable in verifying those aspects of the DCS model dealing with bubble size, their growth rate and site of origin."

Pilmanis AA, Melkonian AD. Altitude decompression computer development: A progress report. In: Proceedings of the 1990 hypobaric decompression sickness workshop. (Pilmanis AA, ed.). AL-SR-1992-0005. 1992:261-72.

Summary: The ongoing development of an altitude decompression model for the USAF is expected to take several years. This descriptive overview describes the progress to date and defines the future direction of the project. The initial stages have been directed at defining the theoretical algorithms. Existing decompression modeling approaches have been reviewed. The first generation of the model is compartmental and was used to test various approaches from several of the exiting algorithms. As a test bed for this model development process, a set of 15 altitude exposure scenarios was compiled and represents a spectrum of operational exposures to be used as computer simulations. Future validation of the model will involve exposing human volunteers to selected altitude profiles in altitude chambers.

Pilmanis AA, Olson RM. The effect of inflight denitrogenation on altitude decompression sickness. (Abstract) Aviat. Space Environ. Med. 1991;62:452.

Abstract: "INTRODUCTION. The risk of altitude decompression sickness is routinely reduced by the technique of breathing 100% oxygen (prebreathing) at ground level prior to ascent to altitude. Prebreathing at altitude may be as effective as at ground level. This capability of inflight denitrogenation would have important application in high altitude aircraft operations. METHODS. Fifteen male subjects were subjected to 8 flights each in an altitude chamber to 29,500 ft after either one or two hours of breathing 100% O_2 at (1) ground level, (2) 8,000 ft, (3) 12,000 ft, or (4) 16,000 ft of altitude. The subjects performed periodic minimal arm exercises. At 15 min. intervals, the subjects were monitored for venous gas emboli (VGE) audio/visually with an HP Sonos 500 Doppler Echocardiograph. The Spencer scale for bubble grading was used. Flights were terminated at 4 hours, or when a subject reported mild to moderate constant bends pain. **RESULTS.** Flights with 1 hour ground level O_2 prebreathing resulted in 80% detectable VGE and 80% bends. Two hours of O_2 prebreathing at ground level resulted in 56% VGE and 39% bends. Preliminary results indicate that there were no significant differences in either VGE or bends between ground level prebreathing and prebreathing at 8,000, 12,000, or 16,000 ft for either one or two hrs. **CONCLUSIONS.** The VGE and bends rates for these altitude exposures conformed well to previous USAFSAM data. Increasing O_2 prebreathing from one to two hours significantly reduces both VGE and bends. Prebreathing to prevent DCS appears to be as effective at altitudes up to 16,000 ft as at ground level."

Pilmanis AA, Olson RM. Arterial gas emboli in altitude-induced decompression sickness. (Abstract) Sixth Annual Workshop on Space Operations, Applications, and Research Symposium (SOAR '92). NASA Conference Publication 3187. 1993;II:547.

Abstract: "Exposure to high altitudes can result in the evolved-gas condition referred to as decompression sickness (DCS). Ultrasonic monitoring techniques have clearly demonstrated the presence of venous gas emboli (VGE) during decompression. Although important in DCS research and our understanding of the physiological mechanisms of this condition, VGE per se have not been considered clinically hazardous, unless in extreme numbers. Arterial gas emboli (AGE), on the other hand, are generally viewed with great concern. AGE can enter the cerebral arterial circulation and arrest blood flow, resulting in potentially serious injury. Left ventricular gas emboli were observed with echo imaging in five volunteer subjects during exposure to simulated altitude. These serendipitous findings occurred during altitude exposures under three separate research protocols involving 79 subject exposures. The voluntary, fully informed consent of the subjects used in this research was obtained as required by AFR 169-3. A Hewlett Packard SONOS 1000 Echo Imaging System was used to monitor for precordial gas emboli. The improved resolution of the SONOS 1000 appears to account for these new findings. Four subjects had high incidence of DCS and VGE during previous research flights. One subject had only one flight. The altitudes and AGE onset times (hours) for the 5 cases were: 1) 25,500 ft/2:23, 2) 29,500 ft/0:27, 3) 19,500 ft/3:49, 4) 29,500 ft/3:15, 5) 29,500 ft/1:31. In all 5 cases, at the time of AGE onset, the VGE scores were high from all monitored locations. Four of the cases were symptomatic at the time of AGE onset (pain and skin mottling). No cerebral manifestations were reported. All subjects were immediately recompressed to ground level and successfully treated either with 2 hours of post-breathing or with hyperbaric oxygen therapy. In conclusion, previously undetected AGE were demonstrated, with and without DCS symptoms, during exposure to altitude. It is postulated that this gas transferred

from the venous side to the arterial side via either intracardiac defects or the pulmonary circulation. The clinical and operational implications of this finding are yet to be determined."

Pilmanis AA, Stegmann BJ. Decompression sickness and ebullism at high altitudes. In: "High Altitude and High Acceleration Protection for Military Aircrew." Proceedings of the NATO AGARD Symposium 71st Aerospace Medical Panel. Pensacola, FL. AGARD-CP-516. 1991:11pp.

<u>Abstract</u>: "A new generation of aircraft is expected to routinely fly above 45,000 feet of altitude. The inherent risk of rapid decompression must be considered. In addition, research and training altitude chamber activities involving rapid decompressions are expected to increase. Potential physiological hazards include hypoxia, ebullism, decompression sickness (DCS), cerebral arterial gas embolism and trapped gas problems. Studies on DCS above 45,000 feet are almost non-existent. However, a great deal of data exists for DCS below 40,000 feet. When plots of these data are extended to higher altitudes, DCS onset time goes to zero and risk of DCS approaches 100%. An altitude decompression model is currently being developed at USAFSAM. Based on DCS databases from the lower altitudes, this model is being applied to flight scenarios above 45,000 feet and will be described. Research to verify such model generated data is planned. This research will address the severity of clinical manifestation, onset times, and recompression effects in "get-me-down" scenarios. Exposure of unprotected humans to altitudes above 63,000 feet results in tissue fluid vaporization, increases body size, rapid loss of consciousness, cardiac vapor lock, and, if not recompressed, death. This condition is called ebullism. A new generation of aircraft is projected to routinely fly at or above these altitudes. At present, complete crew protection consists of cabin pressurization and full coverage pressure suits. Full coverage suits, however, severely limit mobility. In an effort to protect the pilot from both high altitude exposure and high acceleration, yet retain mobility, integrated partial pressure/G-suits are now being tested. The disadvantage of these suits is that no protection is provided to the head or upper extremities, resulting in the potential for severe injury in the event of rapid decompression. The pathophysiology of ebullism in animals was studied in the 1940s, 1950s and the 1960s. In addition, there is one case report in the literature of a prolonged unprotected exposure and several anecdotal reports of human exposures to vacuum. In these cases of human exposure, people survived despite limited or, in one case, no protection. During such unprotected exposures, the subjects lost consciousness rapidly and had varying degrees of injury--ranging from no significant symptoms to massive cerebral and pulmonary injury requiring intensive medical intervention. In the cases of partial protection, subjects described swelling and pain in exposed limbs. Whether these changes were severe enough to prevent a pilot from manipulating flight controls, or controlling the aircraft, is unknown. Of specific concern are the eyes. Unprotected exposure of the head may result in freezing corneal surfaces. While boiling of the intraocular fluid is unlikely until higher elevations and longer exposures, surface eye freezing may impair vision and further

compromise the pilot. At this time, little hard data are available on the efficacy of proposed treatment protocols for these conditions. However, survival can undoubtedly be improved with a better understanding of the pathophysiology of ebullism, improved protective measures, and the development of specific medical procedures."

Pilmanis AA, Stegmann BJ, Scoggins TE. 1990 hypobaric decompression sickness workshop: Summary and conclusions. (Abstract) Proceedings of the Fifth Annual Space Operations, Applications, and Research Symposium (SOAR '91). NASA Conference Publication 3127. 1992;2:609.

Abstract: "Decompression sickness resulting from exposure to the hypobaric environment was reviewed and discussed at a three-day workshop hosted by the US Air Force Armstrong Laboratory in October 1990 with co-sponsorship from NASA Johnson Space Center and the Air Force Office of Scientific Research. This milestone meeting, attended by over 50 participants representing the Department of Defense, NASA, European Space Agency and academia, updated the current understanding of altitude decompression sickness (DCS). Both research and operational aspects of this illness were addressed through presentations on the pathophysiology and clinical manifestations of DCS, its incidence in aviation and space operations, and existing and proposed measures for DCS prevention. Specific areas requiring further research were also identified. This paper summarizes the material presented at this workshop."

Scoggins TE, Ripley EP, Bauer DH, Pilmanis AA. Development of an altitude decompression sickness model. (Abstract) Aviat. Space Environ. Med. 1992;63:386.

Abstract: "INTRODUCTION. Availability of a computer model which could accurately predict the risk of altitude decompression sickness (DCS) for any given hypobaric exposure would be a great improvement over current risk assessment methods based on comparison of the planned mission profile with data from previous, often dissimilar exposures. METHODS. Equations for perfusion-limited inert gas exchange and bubble growth were used to compute tissue ratio (TR) and bubble volume data for 12 exposure profiles between 9,000 and 30,000 ft for which experimental DCS incidence data from 395 subjects had been previously collected. Three parameters, TR, maximum bubble volume (Vm) and bubble volume at onset of DCS (Vo), were linked with observed DCS incidence using the Hill equation with coefficients determined by non-linear regression analysis. RESULTS. The TR Vm models both predicted no DCS correctly in 96% of the cases while the Vo model correctly predicted 80%. The postive predictive capabilities were lower with the TR and Vm models predicting 74% and the Vo model predicting 67% of the DCS cases correctly. CONCLUSIONS. This approach shows promise as an objective computer-based method for predicting altitude DCS risk. Refinement of the algorithms based on additional experimental data should improve the validity of the models."

Stegmann BJ. Prebreathing theory and history. In: Proceedings of the 1990 hypobaric decompression sickness workshop. (Pilmanis AA, ed.). AL-SR-1992-0005. 1992:221-34.

Summary: Prebreathing is currently the most effective preventive measure available to decrease decompression

sickness (DCS) morbidity and mortality due to altitude exposures. Efforts to quantify the amount of nitrogen offgassing during prebreathing have led to a better understanding of DCS and have helped identify appropriate prebreathe schedules. The incidence of severe DCS symptoms has decreased dramatically with the use of oxygen prebreathing. This paper reviews the work leading to acceptance of prebreathing and the theory behind its use.

Stegmann BJ, Pilmanis AA. Inconsistencies in classification of Type I and Type II decompression sickness. (Abstract) Aviat. Space Environ. Med. 1991;62:453.
Abstract: "**INTRODUCTION.** Clinical manifestations of decompression sickness (DCS) are commonly grouped into two categories - Type I (minor) and Type II (major). In military aviation, the Type II classification may lead to permanent grounding. Yet the distinction between Type I and Type II is not always clear. **METHODS.** A survey of the specific DCS manifestations used to classify patients into Type I and Type II was conducted of various U.S. and international military organizations. This survey included flying and diving communities. **RESULTS.** The results indicate significant variations exist in the definition of DCS types. In turn, these variations lead to inconsistencies in treatment protocols and flight status disposition. In addition, comparison of DCS databases becomes difficult, if not impossible. **CONCLUSIONS.** Suggested solutions include more rigorous definitions for Type I and II, standardization of the definitions between various organizations, or substitution of clinical specifics for Type I and Type II terminology altogether."

Stegmann BJ, Pilmanis AA. Prebreathing as a means to decrease the incidence of decompression sickness at altitude. In: "High Altitude and High Acceleration Protection for Military Aircrew." Proceedings of the NATO AGARD Symposium 71st Aerospace Medical Panel. Pensacola, FL. AGARD-CP-516, 1991;Sect.4:1-8.
Abstract: "Prebreathing with 100% oxygen is a requirement for USAF personnel as a protective measure against altitude induced decompression sickness (DCS). Oxygen is used to "wash out" nitrogen from the tissues and prevent nitrogen bubble formation at low atmospheric pressure. These prebreathe times are defined in USAF regulations and are based on research performed in the 40's, 50's and 60's, as well as operational considerations of "what seems to work." While prebreathing currently appears to provide an operational "fix" to many altitude DCS scenarios, difficulties arise when using these old data to provide information on the specifics of DCS protection. Attitudes about the importance of DCS symptoms have shifted a great deal since the 1940's. These inconsistencies between data bases make it difficult if not impossible to draw comparisons about the effectiveness of prebreathing in preventing DCS symptoms. Since early researchers did not consider minor, nondebilitating, joint pain to be important, they usually only reported the occurrence of severe symptoms. The "old" data presented shows a significant reduction in the severe symptoms when prebreathing was noted, but little is said about reductions in the occurrence of mild symptoms. Today, concerns about career and mission impact may lead to underreporting of symptoms in the

operational setting. Data about the usefulness of prebreathing in the operational setting may be significantly altered by this problem. At USAFSAM, current work includes evaluation of prebreathe efficacy using both ECHO imaging/Doppler bubble detection and DCS symptom onset. An altitude decompression sickness model is being developed to provide risk assessment capability. This prebreathe data and standardized data collection based on improved reporting and current definitions of clinical DCS manifestations will be integrated into this model."

Stegmann BJ, Pilmanis AA, Derion T. Improving survival after tissue vaporization (Ebullism). (Abstract) Proceedings of the Fifth Annual Space Operations, Applications, and Research Symposium (SOAR '91). NASA Conference Publication 3127. 1992;2:610.

Abstract: "Exposure of unprotected humans to altitudes above 63,000 feet results in ebullism. Ebullism occurs when the vapor pressure of tissues is less than the ambient pressure and the tissues spontaneously "boil." This condition results in rapid loss of consciousness, cardiac "vaporlock," pulmonary collapse, cerebral anoxia and, in the absence of recompression, death. Potential scenarios for ebullism include extravehicular activity (EVA) accidents in space, aircraft experiencing rapid decompressions at high altitudes with cabin or pressure suit failure, and accidents during pressure suit training exercises in altitude chambers such as those exercises required for high altitude reconnaissance qualifications. However, there are no established medical protocols for the treatment of this condition. As the injury pattern of ebullism is better defined, improved protective measures and in-depth treatment protocols will be developed. The pathophysiology of ebullism was studied from the 1940s through the 1960s using animal models. Survival depended upon exposure times at altitude (30 seconds to 2.5 minutes) and was species specific. For example, chimpanzees survived 2.5-minute exposures to 120,000 feet and showed no drop in baseline neurologic task performance immediately after the exposure. However, rats did not survive exposures greater than 40 seconds. There is one report in the literature of a prolonged, unprotected, human exposure and several anecdotal reports of unprotected, short-term human exposures to near-vacuum. During these exposures, the individuals rapidly lost consciousness; however, the degree of sustained injury ranged from insignificant barotrauma to massive cerebral and pulmonary injury requiring intensive medical intervention. Reports of experiments in which subjects had partial protection against near-vacuum described swelling and pain in the unprotected limbs. These individuals required minor medical care and no resuscitation. In addition to pulmonary and neurologic concerns, unprotected exposure of the head may result in freezing of the corneal surface of the eye. Surface eye freezing may impair vision and significantly impact mission completion. The type and amount of damage done to the eye by this type of freezing is not known. At this time, little data are available on the effectiveness of conventional treatment protocols, such as hyperbaric oxygen (HBO), for ebullism-induced injuries. The Armstrong Laboratory at Brooks Air Force Base is currently evaluating the use of HBO in ebullism. Also, research is needed to assess the efficacy of other adjunctive therapies such as high

frequency ventilation and cerebral protective drugs that are still under development. Survival rates are expected to improve as a more complete understanding of the pathophysiology of ebullism is attained, as development of new protective measures progresses, and with the development of specific medical protocols."

Stegmann BJ, Pilmanis AA, Wolf EG, Derion T, Fanton JW, Davis H, Kemper GB, Scoggins T. Evaluation of medical treatments to increase survival of ebullism in guinea pigs. (Abstract) Sixth Annual Workshop on Space Operations, Applications, and Research (SOAR '92). NASA Conference Publication 3187. 1993;II:569.

Abstract: "**INTRODUCTION.** Space flight carriers run a constant risk of exposure to vacuum. Above 63,000 feet (47 mmHg), the ambient pressure falls below the vapor pressure of water at 37°C, and tissue vaporization (ebullism) begins. Little is known about appropriate resuscitative protocols after such an ebullism exposure. The study identified injury patterns and mortality rates associated with ebullism while verifying effectiveness of traditional pulmonary resuscitative techniques. **METHOD.** Male Hartley guinea pigs were exposed to 87,000 feet for periods of 40 to 115 seconds. After descent, those animals which did not breathe spontaneously were given artificial ventilation by bag and mask for up to 15 minutes. Those animals surviving were randomly assigned to one of three treatment groups--hyperbaric oxygen (HBO), ground level oxygen (GLO_2) and ground level air (GLAIR). The HBO group was treated on a standard treatment table 6A, while the GLO_2 animals received O_2 for an equivalent length of time. Those animals in the GLAIR group were observed only. All surviving animals were humanely sacrificed at 48 hours. **RESULTS.** Inflation of the animals' lungs after the exposure was found to be difficult and, at times, impossible. This may be due to surfactant disruption at the alveolar lining. Electron microscopy identified a disruption of the surfactant layer in animals that did not survive the initial exposure. Mortality was found to increase with exposure time: 40 seconds-0%, 60 seconds-6%, 70 seconds-40%, 80 seconds-13%, 100 seconds-38%, 110 seconds-40%, 115 seconds-100%. There was no difference in the delayed mortality between the treatment groups (HBO-15%, GLO_2-11%, GLAIR-11%). However, since resuscitation was ineffective, the effectiveness of any post-exposure treatment was severely limited. **CONCLUSIONS.** Preliminary results indicate that resuscitation of guinea pigs following ebullism exposure is difficult, and that current techniques (such as traditional CPR) may not be appropriate."

Webb JT. Decompression hazards research. In: Aircrew Life Support Systems Enhancement. (Krutz RW, Jr, et al.). USAFSAM-TR-89-26. 1990:4-9.

Summary: Development of a LOTUS 1-2-3 decompression sickness research cost analysis application program was discussed. The menu-driven application allows input of various parameters related to specific protocols and produces a printout of cost estimates for each parameter. A proposed method of Doppler bubble grading was also discussed. The scale is based on electronic counting of venous gas emboli and quantification as an exponential scale. Use of the exponential scale would result in much greater

discrimination yet be analogous to the Spencer scale in current use.

Webb JT. USAFSAM hypobaric decompression sickness research since 1983. In: Proceedings of the 1990 hypobaric decompression sickness workshop. (Pilmanis AA, ed.). AL-SR-1992-0005. 1992:337-45.

Summary: Six major decompression sickness (DCS) protocols, one of which includes five studies, were initiated or completed between 1983 and 1990. Data from these experiments have been entered on the USAFSAM VAX computer. Two protocols examined incidence of DCS at higher altitudes and the threshold of bubble formation at lower altitudes. The data contained in the USAFSAM Hypobaric Decompression Sickness Research Database on the USAFSAM VAX and other past, present, and future results will aid in completion of the DCS model discussed elsewhere in the Hypobaric DCS Workshop Proceedings. The database can also serve as a standardized reference for similar exposures of operational concern.

Webb JT, Krutz RW Jr, Dixon GA. An annotated bibliography of hypobaric decompression research conducted at the Crew Technology Division, USAF School of Aerospace Medicine, Brooks AFB, Texas, from 1983 to 1988. USAFSAM-TP-88-10R. 1990:22pp.

Abstract: "Four major protocols, one of which includes five studies, have been initiated or completed in the 5-year period from 1983 to 1988. The studies have resulted in numerous publications which are listed as the references for this review. The purpose of this review is to provide an accessible summary of these extensive efforts and document the history of their accomplishments. The cross-reference information contained in this review is intended to simplify data accession within both published and database records. A listing of the abbreviated title, protocol approval information, sponsorship information, computer database (HYPOB) retrieval numbers/titles, dates of exposure, and information about subjects, prebreathe, and exposure parameters for each study are followed by the published abstracts from each publication."

Webb JT, Olson RM, Baas CL, Hill RC. Bubble detection with an echo-image/Doppler combined probe versus separate probes: A comparison of results. (Abstract) Undersea Biomed. Res. 1989;16(Suppl):89-90.

Abstract: "The ability to monitor a subject for intravascular bubbles during decompression using precordial Doppler and 2-D echo-imaging in a single probe offers the advantage of simultaneous visual and audio observation. This advantage should result in better detection and fewer false negatives (cases where decompression sickness, DCS, occurred without detection of bubbles). Better methods of bubble detection should increase understanding of the bubble-DCS relationship. Records of decompression exposures from ground level to simulated altitudes of 22,500 and 25,000 ft from combined probes (112 subject exposures) or separate probes (65 subject exposures) have provided information on the sensitivity and specificity of each method. Sensitivity is defined here as the number of bubblers who had DCS divided by the total number with DCS. With separate probes, the sensitivity was 79% (31/39) and with the combined probes, the sensitivity was 90% (36/40). Specificity is defined here as the number of bubble-free subjects without DCS divided by the total number of subjects without DCS. The specificity was 33% (9/27) with separate probes and 31% (22/72) with combined probes. The combined probe allows higher sensitivity as a result of fewer false negatives compared to the single probes. The greater detection capability with the combined probe also increases the number of false positives (cases where bubbles were detected but DCS did not occur). While this refinement in equipment reinforces the theory that those who exhibit DCS also have bubbles, it does little to refine the value of bubble detection as a tool for DCS prediction."

Webb JT, Pilmanis AA. Resolution of high bubble grades at altitude. (Abstract) Aviat. Space Environ. Med. 1991;62:481.

Abstract: "INTRODUCTION. Appearance and resolution of venous gas bubbles after decompression from hyperbaric exposures have been documented by several investigators. The analogous event was examined during experimental hypobaric exposures at USAFSAM during the mid-1980s. METHODS. Male human subjects, breathing 100% oxygen, were exposed to decompressions from 745 mmHg (ground-level pressure at Brooks AFB, Texas) to 226-314 mmHg (simulated altitudes of 22,500, 25,000, 27,500, and 30,000 ft). During the 215, 7-8 hour chamber exposures, the subjects were monitored for bubble sounds by a Doppler ultrasound system. The Spencer scale was used for grading the bubble sounds. RESULTS. Sixty-six percent of the exposures resulted in symptoms of decompression sickness (DCS) and early termination of the exposure. Of the 35 exposures with high bubble grades (Spencer grade 3 or 4) but no symptoms of DCS, 13 showed a gradual reduction to low bubble grades (0 or 1) by the end of the exposure. CONCLUSIONS. Disappearance [of] high bubble grades while decompressed suggests that denitrogenation continues at altitude. Denitrogenation at altitude could reduce nitrogen levels to below that required for continued bubble formation and development of DCS symptoms. Denitrogenation while at altitude could help explain the low incidence of DCS reported after long (8-hour plus), exposures to subatmospheric pressures such as extravehicular activity in space and high altitude reconnaissance flights."

Webb JT, Pilmanis AA. Venous gas emboli detection and endpoints for decompression sickness research. SAFE J. 1992;22(3):22-5 and 29th Annual SAFE Symposium Proceedings. 1992:20-3.

Abstract: "For many years, altitude decompression sickness (DCS) research has attempted to use precordial Doppler ultrasound detection of venous gas emboli (VGE) to estimate the probability of developing DCS during hypobaric decompression exposures. A review of results from current and previous hypobaric experiments as recorded on the Armstrong Laboratory's hypobaric DCS database indicated that use of VGE to predict DCS would have been correct only about 65% of the time. The use of VGE is not considered practical by either USAF or NASA operations, neither of which currently use VGE detection as an abort criterion; they rely instead on symptoms of DCS as the only indication of impending functional impairment. Grading of joint pain, the predominant symptom of altitude DCS, has been used to quantify the severity of altitude DCS symptoms since World War II. A specific grade of joint pain has usually been established as an endpoint for protocol exposures. The different grading scales used by researchers creates difficulties for those wishing to compare findings between studies. A suggested compromise (conversion) scale is presented and compared with the earlier joint pain scales. The compromise scale is based on pain and quantification of impairment in function or performance as evaluated with performance assessment battery results."

Webb JT, Pilmanis AA. Decompression sickness protection using a 100% oxygen pressure suit environment. (Abstract) Aviat. Space Environ. Med. 1992;63:386.

<u>Abstract</u>: "**<u>INTRODUCTION</u>**. Selection of the lowest safe pressure for an extravehicular activity (EVA) suit which eliminates the requirement for prebreathing depends on demonstrating an acceptable risk of venous gas emboli (VGE; precordial Doppler grades 3 and 4) and decompression sickness (DCS). The EVA suit target pressure of 8.3 psia was set by NASA several years ago based on results of breathing 50% oxygen and 50% nitrogen during zero-prebreathe exposures. The present work investigated the effects of zero-prebreathe exposures at and below 8.3 psia while breathing 100% oxygen. **<u>METHODS</u>**. Thirty male human subjects were exposed for 6 hours, without prebreathing, to pressures of 8.3 (n=10), 7.8 (n=10), and 7.3 (n=10) psia while performing moderate exercise. Subjects were monitored for Doppler-detected VGE using Hewlett-Packard SONOS systems and observed for DCS symptoms. **<u>RESULTS</u>**. No cases of DCS were present at 8.3, 7.8, or 7.3 psia. Grade 3 or 4 VGE were not detected at 8.3 psia but were present during 10% and 20% of the exposures at 7.8 and 7.3 psia respectively. **<u>CONCLUSION</u>**. EVA suit pressure with a 100% oxygen environment could be established at 7.3 psia and maintain lower DCS and VGE risk levels compared to an 8.3 psia suit pressure with a 50% oxygen:50% nitrogen environment."

Webb JT, Pilmanis AA. Hypobaric decompression prebreathe requirements and breathing environments. (Abstract) Sixth Annual Workshop on Space Operations, Applications, and Research (SOAR '92). NASA Conference Publication 3187. 1993;II:544.

<u>Abstract</u>: "To reduce incidence of decompression sickness (DCS), prebreathing 100% oxygen to denitrogenate is required prior to hypobaric decompressions from a sea level pressure breathing environment to pressures lower than 350 mmHg (20,000 ft; 6.8 psia). The tissue ratio (TR) of such exposures equals or exceeds 1.7; TR being the tissue nitrogen pressure prior to decompression divided by the total pressure after decompression ([0.781*14.697]/6.758). Designing pressure suits capable of greater pressure differentials, lower TRs, and procedures which limit the potential for occurrence DCS would enhance operational efficiency. The current 10.2 psia stage decompression prior to extravehicular activity (EVA) from the Shuttle in the 100% oxygen, 4.3 psia suit, results in a TR of 1.65 and has proven to be relatively free of DCS. Our recent study of zero-prebreathe decompressions to 6.8 psia breathing 100% oxygen (TR = 1.66) also resulted in no DCS (N = 10). The level of severe, Spencer Grades 3 or 4, venous gas emboli (VGE) increased from 0% at 9.5 psia to 40% at 6.8 psia yielding a Probit curve of VGE risk for the 51 male subjects who participated in these recent studies. Earlier,

analogous decompressions using a 50% oxygen, 50% nitrogen breathing mixture resulted in one case of DCS and significantly higher levels of severe VGE, e.g., at 7.8 psia, the mixed gas breathing environment resulted in a 56% incidence of severe VGE versus 10% with use of 100% oxygen. The report of this study recommended use of 100% oxygen during zero-prebreathe exposure to 6.8 psia if such a suit could be developed. For future, long-term missions, we suggest study of the effects of decompression over several days to a breathing environment of 150 mmHg O_2 and approximately 52 mmHg He as a means of eliminating DCS and VGE hazards during subsequent excursions. Once physiologically adapted to a 4 psia vehicle, base, or space station segment, crewmembers could use greatly simplified EVA suits with greater mobility and no prebreathe requirement."

Wiegman JF, Ohlhausen JH, Webb JT, Pilmanis AA. Validation of dual-cycle ergometer for exercise during 100% oxygen prebreathing. 29th Annual SAFE Symposium Proceedings. 1992:231-5.

Abstract: "A study has been designed to determine if exercise, while prebreathing 100% oxygen prior to decompression, can reduce the current resting-prebreathe time requirements for extravehicular activity and high altitude reconnaissance flight. For that study, a suitable exercise mode was required. Design considerations included space limitations, cost, pressure suit compatibility, ease and maintenance of calibration, accuracy of work output, and assurance that no significant mechanical advantage or disadvantage would be introduced into the system. In addition, the exercise device must enhance denitrogenation by incorporation of both upper and lower body musculature at high levels of oxygen consumption. The purpose of this paper is to: (1) describe the specially constructed, dual-cycle ergometer developed for simultaneous arm and leg exercise during prebreathing, and (2) compare maximal oxygen uptake obtained on the device to that obtained during leg-only cycle ergometry and treadmill testing. Results demonstrate the suitability of the dual-cycle ergometer as an appropriate tool for exercise research during 100% oxygen prebreathing."

B.6 Molecular Sieve Technology

B.6.1 Objective

KRUG Life Sciences, Incorporated, was to perform chemical procedures to include, but not be limited to, weighing, recording temperatures, and measuring pressure, collection of product gas samples from molecular sieve oxygen generation systems, analysis of these samples using mass spectrometry, analysis of the molecular sieve for contamination from hydrocarbons, and performance of RDT&E to increase sieve efficiency.

B.6.2 Accomplishments

Scientific research, engineering, and technical support activities contributed to the following publications and presentations:

Ikels KG, Shakocius AM. Refurbishing AV-8 On-Board Oxygen Generation System beds. USAFSAM-TP-90-22. 1990:27pp

Abstract: "The Crew Systems Branch, Crew Technology Division, USAF School of Aerospace Medicine has carefully prepared specific procedures and instructions to provide users of the AV-8 "HARRIER" On-board Oxygen Generation System (OBOGS) with detailed information and requirements on refurbishing OBOGS beds. Included in the instructions on disassembling, repacking, and assembling the OBOGS beds, are specific procedures for determining the activity and, if necessary, activating the molecular sieve before the beds are repacked. In addition, technics and procedures are detailed for testing the repacked beds prior to reassembly of the concentrator to ensure efficient air separation."

Scheie PO, Shakocius AM, Ikels KG. The purification of air by pressure-swing adsorption utilizing VYCOR® 7930 Glass as bed adsorbent. SAFE J. 1991;21(4):21-4 and 28th Annual SAFE Symposium Proceedings. 1991:55-8.
Abstract: "Pressure-swing adsorption is a dynamic method which could be used to remove unwanted gas and/or vapor from air. To determine the viability of air purification by pressure swing adsorption, a laboratory scale pressure-swing adsorption (PSA) unit was constructed utilizing VYCOR® 7930 porous glass as the bed adsorbent. This adsorbent, prepared by crushing porous glass tubing and sieving to a 16 X 40 mesh size, has demonstrated a high mechanical strength and produces little, if any, dust. The glass has an average pore size of 40 Å, an internal surface area of 250 m^2/g, and a void space which is 28% of its volume. The PSA unit was subsequently challenged with water vapor, carbon dioxide, carbon monoxide, ethylene, and freon-12 while varying parameters such as bed length, purge volume, cycle time, and effluent flow rate. The apparatus demonstrated an ability to separate, and essentially remove, all of the above contaminants, except carbon monoxide which was only partially removed, from the inlet air stream. However, this study has clearly shown that porous glass possesses definite potential as a PSA adsorbent when used to remove gaseous and vapor contaminants from air."

Shakocius AM. An improved process control and data acquisition system for studying contaminant behavior in the 99% purity molecular sieve oxygen concentrator. 29th Annual SAFE Symposium Proceedings. 1992:113-6.
Abstract: "Pressure-swing adsorption (PSA) technology has advanced such that a Molecular Sieve Oxygen Concentrator (MSOC) utilizing PSA technology is capable of concentrating oxygen to an excess of 99% (U.S. Patent No. 4,880,443). Preceding PSA systems have demonstrated a capability to remove vapor contaminants, thus producing filtered and purified gas. At present, the filtering ability of a 99% purity MSOC has not been assessed, and a contaminant study is warranted. The most efficient method of assessing the filtering ability of a 99% purity MSOC is to utilize a computer driven, process control and data acquisition system with a graphical user interface (GUI). Traditionally, the realization of such a system entails extensive development which consumes numerous man-hours and requires substantial effort for maintenance. Also, until recently, such laboratory instrumentation incorporated with a GUI has not been available in a microcomputer environment. This paper describes a microcomputer based, process control and data acquisition system with a GUI for the 99% purity MSOC

contaminant study, which will be implemented on an Apple Macintosh II series microcomputer with LabVIEW®. System inputs, outputs, software, and operation will be discussed."

Shakocius AM, Miller GW. A hollow-fiber permeable membrane oxygen sensor for Molecular Sieve Oxygen Generating Systems (MSOGS). 30th Annual SAFE Symposium Proceedings. 1993:94-101.

Abstract: "The purpose of this work was to develop a new oxygen sensing concept that possessed characteristics such as high reliability, low long-term drift, long operating life, and very low maintenance. A permeable membrane oxygen sensing device was developed (U.S. Patent No. 5,101,656) that possessed many advantages which may make it suitable for use on-board aircraft, and was capable of measuring the oxygen concentration of a gas mixture composed primarily of oxygen, nitrogen, and argon. Oxygen concentration was determined by measurement of the shell-side flow through a hollow-fiber permeable membrane (DX-810 poly-4-methyl-1-pentene) module. A limited amount of data was collected over a temperature range of 288°K to 308°K, and at simulated altitudes ranging from sea level to 40,000 feet. The sensor measured gases containing oxygen concentrations spanning from 20.8% (air) to 99.8%. In general, the experimental results indicate that the sensor module produced a shell-side flow which varied nearly linearly with the inlet gas oxygen concentration, regardless of ambient temperature or altitude. Equations were fitted to the experimental data so that oxygen concentration, in percent, could be directly calculated from the shell-side flow of the membrane module. This effort showed the feasibility of using a hollow-fiber permeable membrane module as an oxygen sensing device."

B.7 Centrifuge Testing of Life Support Equipment

B.7.1 Objective

KRUG Life Sciences, Incorporated, was to perform tests on various life support items or equipment on the United States Air Force School of Aerospace Medicine (USAFSAM) Centrifuge as directed by the Contracting Officer. The life support equipment shall include, but not be limited to: Anti-G valves, anti-G suits, transducers, regulators, and oxygen masks.

B.7.2 Accomplishments

Technical support activities were provided to test equipment as needed. This effort partly supported task order research detailed in Volume 2 under Task Orders 1, 26, 34, and 37, by providing scientific research, engineering, and technical personnel.

B.8 Centrifuge Support

B.8.1 Objective

KRUG Life Sciences, Incorporated, was to provide technician support to perform scheduled and unscheduled maintenance of the USAFSAM Centrifuge and required associated systems in support of the research effort. Additionally, the contractor shall perform modifications to the centrifuge systems as approved by the technical contract monitor. Contractor technical personnel shall be trained to independently operate the USAFSAM Centrifuge in accordance with approved Technical Orders and Operating Instructions (OIs).

B.8.2 Accomplishments
Technical support activities were provided as stipulated. This effort partly supported task order research detailed in Volume 2 under Task Order 12 by providing engineering and technical personnel.

B.9 Cockpit Integration and Crew Performance

B.9.1 Objective
KRUG Life Sciences, Incorporated, was to gather anthropometric data, write test plans and procedures, prepare software applications programs, and evaluate, from a performance perspective, developmental life support systems and equipment including items designed, fabricated, and developed in the Experimental Life Support Equipment Development Laboratory. A crew performance database was also to be maintained by the contractor.

B.9.2 Accomplishments
Human factors research, engineering, and technical support activities contributed to the following publications and presentations:

Nesthus TE. The role of the Cockpit and Equipment Integration Laboratory (CEIL) in personal protective equipment research and development. Quarterly Bulletin of the Ibero-American Association of Aerospace Medicine. 1991;2(Jan/Feb/Mar):3pp.

Summary: Modern aircraft have extended operational envelopes and expose aircrew to increased hazards. Historically, protection from these hazards has been made by retrofit and add-on equipment, often forcing crew members to tolerate inadequate and poorly integrated life support and personal protective equipment. Under these circumstances, mission effectiveness can be compromised by the very equipment designed to protect aircrew members in the extended operational arena. The USAF CEIL was developed to change this deficiency. Its objectives are to provide the tools and technology necessary to evaluate PPE regarding acceptable physiologic function without compromising aircrew performance.

Nesthus TE, Bomar JB Jr, Holden RD. Hypoxia symptoms resulting from various breathing gas mixtures at high altitude. SAFE J. 1989;19(2):20-6 and 26th Annual SAFE Symposium Proceedings. 1989:16-21.

Abstract: "Subjective hypoxia symptoms reported by subjects breathing different oxygen mixtures, before a rapid decompression from 20,000 to 50,000 ft. have been compared. The breathing gas mixtures included 100, 93, 90, and 85% oxygen, under both the non-dilution and dilution modes of the oxygen regulator. The number of symptoms reported were not appreciably different across concentration conditions. The symptom score data, derived by summing the severity levels of the symptoms reported, showed that the recognition of more pronounced hypoxia did not occur under the most severe 85% dilution condition. We believe that the ability of the individual to recognize the extent of his incapacitation is impaired by the severity of the hypoxic episode experienced. This impairment effect was most evident under the 85% dilution condition. The effect may also confound the results of concentrations producing less severe hypoxia."

Nesthus TE, Schiflett SG, Eddy DR, Whitmore JN. Cognitive and psychomotor task performance under two antihistamine conditions. Proceedings of the 1st Annual Human Performance Symposium of the International Institute for Human Performance. Lisbon, Portugal, Spring 1991:8pp.

<u>Abstract</u>: "<u>INTRODUCTION</u>. Cognitive and psychomotor skills were evaluated under terfenadine (Seldane) and diphenhydramine (Benadryl) using a battery of selected computerized tests. <u>METHODS</u>. Thirty-six subjects formed 3 groups and were tested for three days. Single blind on Day 1, all <u>S</u>s received placebo; double blind on Days 2 and 3 <u>S</u>s received either Seldane (60 mg/12 h tid), Benadryl (25 mg/4 h qid), or Placebo (lactose). Eight performance tests, selected from existing performance assessment batteries, were given each day. <u>RESULTS</u>. The Benadryl group showed performance degradation on 7 of 8 significant test variables during Day 2 (first day of drug ingestion), relative to Day 1 (placebo baseline). The Seldane and Placebo groups showed no impairment and were not different from one another on Day 2. Subjective measures of fatigue and antihistamine side effects corroborate the Day 2, Benadryl impairment. The results of performance score comparisons on Day 3 (second day of drug ingestion) were not clear. Subjective data showed evidence that the Benadryl group slept better the night before and were significantly less fatigued during Day 3 compared to the Seldane and Placebo groups. This may have contributed to a rebound trend seen in the performance data for the Benadryl group. <u>CONCLUSION</u>. The use of terfenadine does not produce the cognitive and/or psychomotor task impairment found with diphenhydramine during the first day of ingestion."

Nesthus TE, Schiflett SG, Eddy DR, Whitmore JN. Comparative effects of antihistamines on aircrew performance of simple and complex tasks under sustained operations. AL-TR-1991-0104. 1991:40pp.

<u>Abstract</u>: "Airborne Warning and Control System (AWACS) Weapons Director (WD) cognitive and psychomotor skills were evaluated with terfenadine (Seldane) and diphenhydramine (Benadryl) using a performance assessment battery (PAB). After nondrug Day 1 training, twelve 3 member teams were tested with Placebo on Day 2, then randomly assigned to Seldane (60 mg/12h TID), Benadryl (25 mg/4h QID), or Placebo groups on Days 3 and 4. An 8-test PAB was given at 1230 and 1330 each testing day. The Seldane and Placebo groups did not differ appreciably from each other on Days 3 or 4, but differed significantly from the Benadryl group. The group showed degraded performance for 7 variables on Day 3 and for 3 variables on Day 4 compared to the Seldane and/or Placebo groups. Subjective measures of fatigue and antihistamine symptoms supported the Day 3 Benadryl impairment. Overall results were consistent with previous research demonstrating cognitive and psychomotor task impairment with Benadryl but not with Seldane. Support for awarding medical flying waivers to non-pilot aircrew who are taking Seldane under the supervision of flight surgeons is offered."

Nesthus TE, Schiflett SG, Oakley CJ. Tracking performance with two breathing oxygen concentrations after high altitude rapid decompression. Proceedings of the Fifth Annual Space Operations, Applications, and Research Symposium (SOAR '91) Symposium. NASA Conference Publication 3127. 1991;2:590-4.

Abstract: "Current military aircraft Liquid Oxygen (LOX) systems supply 99.5% gaseous Aviator's Breathing Oxygen (ABO) to aircrew. Newer Molecular Sieve Oxygen Generation Systems (MSOGS) supply breathing gas concentrations of 93-95% oxygen. This study compared the margin of hypoxia protection afforded by ABO and MSOGS breathing gas after a 5 psi differential rapid decompression (RD) in a hypobaric research chamber. The barometric pressures equivalent to the altitudes of 46,000, 52,000, 56,000, and 60,000 ft were achieved from respective base altitudes in 1-1.5 s decompressions. During each exposure subjects remained at the simulated peak altitude breathing either 100% or 94% O_2 with positive pressure for 60 s, followed by a rapid descent to 40,000 ft. Subjects used the Tactical Life Support System (TLSS) for high altitude protection. Subcritical tracking task performance on the Performance Evaluation Device (PED) provided psychomotor test measures. Overall tracking task performance results showed no differences between the MSOGS breathing oxygen concentration of 94% and ABO. Significant RMS error differences were found between the ground level and base altitude trials compared to peak altitude trials. The high positive breathing pressures occurring at the peak altitudes explained the differences. Considered with the physiologic data, an acceptable degree of hypoxia protection was met with both oxygen concentrations using TLSS at altitudes >60,000 ft for >60 s durations."

Nesthus TE, Whitmore JN, Eddy DR, Shiflett SG. The comparative effects of terfenadine and diphenhydramine on individual performance under sustained operations. (Abstract) Aviat. Space Environ. Med. 1991;62:451.

Abstract: "INTRODUCTION. AWACS Weapons Director (WD) cognitive and psychomotor skills were evaluated under terfenadine (Seldane) and diphenhydramine (Benadryl) using a battery of computerized tests. METHODS. Twelve teams of 3 AWACS WDs (n=36) were tested under placebo and either Seldane (60 mg/12 h TID), Benadryl (25 mg/4 h QID), or Placebo conditions for 2 days. The performance assessment battery was given during the middle of each testing day, between two-3.5 h interactive AWACS simulation scenarios. RESULTS. The positive control--Benadryl condition showed significantly degraded performance for 7 of 8 test variables during Day 2 (first day of drug ingestion), relative to Day 1 (placebo baseline). The Seldane and Placebo conditions for these variables were not different from one another but did differ from the impaired Benadryl group. Subjective measures of fatigue and antihistamine symptoms supported the Day 2 Benadryl vs. Seldane and Placebo effect. The results of the performance tests on Day 3 (second day of drug ingestion) were equivocal. Subjective data revealed that the Benadryl group slept better and were less fatigued during Day 3, which possibly contributed to a performance rebound trend seen in the performance data. CONCLUSION. The use of terfenadine does not produce the cognitive and/or psychomotor task impairment found with diphenhydramine."

B.10 Spatial Disorientation Research

B.10.1 Objective

KRUG Life Sciences, Incorporated, was to perform Spatial Disorientation Research to include but not be limited to the following:

a. Assist in concept/design of experimental flight instruments and displays, to reduce the effects of spatial disorientation.
b. Design/Develop and conduct simulator-based and inflight evaluations of flight instruments and displays developed to assist pilots in resisting and coping with spatial disorientation.
c. Develop and evaluate ground-bases and inflight spatial disorientation training curricula for aircrew members.

B.10.2 Accomplishments

Scientific research, engineering, and technical support activities contributed to the following publications and presentations.

Ercoline WR, Gillingham KK. Effects of variations in Head-Up Display airspeed and altitude representations on basic flight performance. Human Factors Society 34th Annual Proceedings, Visual Performance Section. 1990;2:1547-51.

Abstract: "Five different head-up display (HUD) airspeed and altitude symbol sets were examined for efficacy in a basic instrument crosscheck during visually simulated flight. Twenty-five pilot subjects used each HUD symbol set while tasked to maintain straight and level flight for 200 seconds. Airspeed and altitude were caused to vary during the flight profile, requiring the pilots to recognize deviations and correct back to target conditions. Root mean square (RMS) performance errors (deviations from assigned airspeed and altitude) were measured. The pilots' airspeed and altitude performance was significantly better ($p<0.01$) with two new formats--rotating pointers with dot scales and plain rotating pointers--than with two more common formats--boxed digits and moving vertical tapes. Another novel format, boxed digits with trend bars, provided the best performance with respect to altitude error, but not airspeed error. Measures of subjects' confidence in their ability to use the different displays for basic instrument flight were significantly different ($p<0.001$) and consistent with the performance measures. The results of this study are important because of the need to standardize HUD symbology, and because of the trend to make the HUD, rather than the panel instruments, serve as the single-source primary flight reference in military aircraft."

Ercoline WR, Gillingham KK, Greene FA, Previc FH. Effects of variations in Head-Up Display pitch-ladder representations on orientation recognition. (Abstract) Human Factors Society 33rd Annual Proceedings, Visual Performance Section. 1989;2:1401-5.

Abstract: "Head-up display (HUD) research has centered on modifications to the basic aircraft control symbology--the pitch-ladder lines. Although some of these modifications have led to minor improvements in attitude recognition, major problems still exist: pilots continue to experience spatial disorientation and to complain of occlusion due to

the HUD symbols. This experiment compared four variations of a basic HUD pitch ladder: Display A, double articulation; Display B, single negative articulation; Display C, single negative articulation with gradually increasing thickness; and Display D, single negative articulation with gradually increasing thickness in a global arrangement. Accuracy of bank recognition was best when pitch-ladder symbology incorporated noticeable asymmetry. Double articulation and graduated thickness were associated with greater accuracy of pitch recognition. Studies under dynamic conditions are recommended."

Ercoline W, Weinstein L, Gillingham K. An aircraft landing accident caused by visually induced spatial disorientation. In: R. Jensen (ed.) Proceedings of the Sixth International Symposium on Aviation Psychology, Columbus, OH, 1991:619-23.

<u>Abstract</u>: "After years of studying and investigating aircraft accidents, researchers have determined that there are four basic causes of aircraft accidents--aircraft malfunctions, procedural malfunctions, body malfunctions, and sensory malfunctions. It is this fourth malfunction that intrigues the researchers most of all. Few pilots like to admit susceptibility to a sensory malfunction, yet most are quick to understand when another pilot experiences the same type of problem. Let's consider the landing, the task most people use to separate the good pilots from the bad pilots. The landing can be described as the skillful integration of the most variables a pilot can ever hope to assimilate. The pilot constantly receives simultaneous information from visual, vestibular, auditory, and several other sensory systems, while making decisions, evaluating alternatives, and comparing known to unknown. If it looks good, feels good, and sounds good, then it generally must be good. Unfortunately, as is often the case in a bad landing, the pilot can erroneously interpret sensory stimuli and, knowingly or unknowingly, become spatially disoriented. Spatial orientation in flight is the accurate assessment of the aircraft position and motion with respect to the three aircraft axes of translation (Gillingham, 1990). In operational terms, spatial disorientation (SD) occurs when pilots experience an erroneous sense of the aircraft control and performance parameters normally displayed by the flight instruments. A description of this type is fundamental to and understanding of the role SD can have on aircraft flight. Contrary to popular belief, the causes of SD are not limited to false vestibular sensations: there are several other sensory systems that can contribute to the development of SD. There may be as many aircraft mishaps resulting from visually induced SD as there are from vestibular SD (Lyons and Freeman, 1990)."

Lyons TJ, Ercoline WR, Freeman JE, Gillingham KK. Epidemiology of USAF spatial disorientation accidents: Definitional and semantic pitfalls. In: "AGARD Aircraft Accidents: Trends in Aerospace Medical Investigation Techniques." Proceedings of the NATO AGARD Symposium Aerospace Medical Panel. AGARD-CP-532. 1992;Sect.31:1-11.

<u>Abstract</u>: "Spatial disorientation (SD) continues to be a contributing factor to a fairly constant proportion of military aircraft accidents. The United States Air Force (USAF) fielded a new accident investigation reporting form in July 1989, which for the first time specified SD Type I,

Type II, and Type III as possible causes of aircraft accidents. Of a total of 91 major accidents that occurred over the 2-year period beginning in October 1989, SD contributed significantly to 13 (14%). Coding for SD on accident investigation reporting forms, however, was not consistent. There were both individual differences between flight surgeons, differences between flight surgeons and pilots, and trends in reporting over time. There is a consensus that SD represents a major problem in military aviation, but a scientific approach to this important problem would be facilitated if agreement could be reached on definitional and semantic issues."

Thomas SR, Ercoline WR, Weinstein LF, Saflarski EG, Cartledge RM. A preliminary field investigation on the visibility of head-up display symbology through laser eye protection devices. 30th Annual SAFE Symposium Proceedings. 1993:37-44.

Abstract: "The effects of wearing laser eye protection devices (LEPDs) on the visibility of head-up display (HUD) symbology were evaluated using a T-38 aircraft equipped with an F-16 HUD. Eight pilots rated the visibility of HUD flight symbology under six viewing conditions using a seven-point scale. The no-visor daylight (NV-day), USAF sun visor (SV), and FV-7 LEPD (FV-7) viewing conditions were performed under daylight conditions, and the no-visor nighttime (NV-night), FV-6 LEPD (FV-6), and FV-6 Minus Ruby LEPD (FV-6MR) viewing conditions were performed under simulated nighttime conditions. The mean ratings for all conditions were between "6" and "7", indicating that the HUD symbology was visible under all viewing conditions. Pilots commented that wearing the FV-6 and FV-6MR LEPDs reduced "blooming" of the symbology and improved visibility. Flight testing should be conducted before final conclusions can be drawn regarding HUD symbology visibility through LEPDs."

Thomas SR, Ercoline WR, Pole D, Graham MR, Patterson JA, McLin LN. The effects of laser eye protection devices (LEPDs) on simulated and actual F-15E cockpit visibility. 30th Annual SAFE Symposium Proceedings. 1993:45-57.

Abstract: "The effects of wearing laser eye protection devices (LEPDs) on the visibility and color appearance of simulated and actual F-15E cockpit displays were determined. Two laboratory experiments were performed to test the compatibility of three LEPDs with simulated F-15E head-down displays (HDDs). Two field investigations using the F-15E Weapons Systems Trainer (WST) and two ground tests with the F-15E aircraft were performed to test the compatibility of the FV-6 Minus Ruby (FV-6MR) and FV-7 LEPDs with F-15E cockpit lighting. Laboratory experimental results indicated that LEPD use significantly affected the readability and color appearances of HDD symbology, but these effects were highly dependent on the size and color of the symbology. LEPD use did not significantly affect aircrew members' ability to identify low-level flight symbology or terrain colors on tactical pilotage charts; however, some terrain color contours were missed more frequently than others. The results of the F-15E WST and ground tests indicated that the majority (92.3%) of the aircrew members rated FV-6MR LEPDs safe for nighttime air operations, and all of the aircrew members rated the FV-7 safe for daytime air operations. The visibility of two navigational displays on the color HDD were affected by wearing the LEPDs. Suggestions for

improving the compatibility of these two displays with LEPDs are offered. Flight testing is recommended to obtain additional information about LEPD cockpit and mission compatibility."

PART C:

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PART D:

AUTHOR CROSS-REFERENCE

The contractor-authors cited in Part B are listed here in alphabetical order, cross-referenced to the Part B section where citations and abstracts of their published report/s are printed.