Free Authors PE - 62202F Authors PR - 7930 James T. Webb and Andrew A. Pilmanis TA - 18 WU- 01 PERORMING ORGANIZATION NAME(S) AND ADDRESS(S) KRI (C) Life Sciences, Inc. Distribution (C) COMMARK ORGANIZATION NAME(S) AND ADDRESS(S) Num Antonio Divusion PLECTE 9. SPONSORING, MONTONING AGENCY NAME(S) AND ADDRESS(S) AL/CF-PC-1993-0039 10. SPONSORING, MONTONING AGENCY NAME(S) AND PRETBOLINGS DIC SPONSORING, MONTORING AGENCY NAME(S) AND PRETBOLINGS 2. SPONSORING, MONTONING AGENCY NAME(S) AND PRETBOLINGS DIC SPONSORING, MONTORING AGENCY NAME(S) AND PRETBOLINGS Crew Technology Division ELECTE 2. SPONSORING, MONTORING AGENCY NAME(S) AND PRETBOLINGS DIC SPONSORING, MONTORING AGENCY REPORT NUMARER Proceedings: 31st Annue SCIENCE Notest REPORT NUMARER Crew Steinology Division Santonio 2.5011 Supretermentation of the Sciences (210) 536-3337 12. OUSTRIBUTION AVAILABILITY STATEMENT Inc. Spretermentation of the computer model to handle all of these variables is in development, the interim, a retrospective study from the Armstrong Laboratory Decompression Sickness (DCS) risk with any degree of accuracy, one must we variables such as produced bilogy, and profiles with multiple ascents and descents. The length of rescendamber exposures is fixed. Therefore, risk assessment is based on DCS incidence after this is p	REPORT DOC	UMENTATION P	AGE	Form Approved OMB No 0.204-0188
1. AGENCY USE ONLY LEASURE DUMA! 1. REPORT ONT: November 1993 1. REPORT TYPE AND DATIS COVENDER 1992-November 19 2. TITLE AND SUBTICE 1. SUNDERCONDENDER SUBSECTION 1. SUNDERCONDENDER 1992-November 1992 2. TITLE AND SUBTICE 1. SUNDERCONDENDER SUBSECTIVE 1. SUNDERCONDENDER 1992-November 1992 2. AUTHORIS 1. SUNDERCONDENDER SUBSECTIVE 1. SUNDERCONDENDER SUBSECTIVE 3. JAMES T. Webb and Andrew A. Pilmanis TA - 18 7. PERFORMING GRANIZATION NAME(S) AND ADDRESS(ES) REFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) RERUGATION COMMUNICA CENECY NAME(S) AND ADDRESS(ES) REFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) RERUGATION COMMUNICA CENECY NAME(S) AND ADDRESS(ES) REFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) RERUGATION COMMUNICA CENECY NAME(S) AND ADDRESS(ES) REFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) RERUGATION COMMUNICA CENECY NAME(S) AND ADDRESS(ES) REFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) SUB DISTRIBUTION COMMUNICA CENECY NAME(S) AND ADDRESS(ES) REFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) SUB DISTRIBUTION COMMUNICA CENECY NAME(S) AND ADDRESS(ES) REFORMING ORGANIZATION Cow Systems Directorate Communication	n sthern shert on state on the state of the	pleting and review no the Climits of St sectors to the sector of Alashing to the	information Gene Comments regained	ngeng this burden ear materier anventeer aspent of The timat on operation is and expensive Paria witter
Decompression Sickness Risk Versus Time and Altitude C - F33615-92-C-00 FAUTHOR(S) James T. Webb and Andrew A. Pilmanis PR - 7930 James T. Webb and Andrew A. Pilmanis TA - 18 VUI-01 PROBAMING ORGANIZATION NAME(S) AND ADDRESS(S) RKIKIG Life Sciences, Inc. Sun Antonio Division P.O. Dox 790644 San Antonio Division PLOCENTIC ORGANIZATION NAME(S) AND ADDRESS(S) KRIKIG Life Sciences, Inc. DIFFERD 11994 San Antonio Division PLOCENTIC ORGANIZATION NAME(S) AND ADDRESS(S) Schwing Laboratory (AFMC) DIFFERD 11994 Crew Technoley Division Division 2500 SGRAUCHONTOWIC ACHICK NAME(S) AND ADDRESS(S) B Armstrong Laboratory (AFMC) Division Crew Technoley Division B 2500 SGRAUCHON NOTES TX 78235-5104 11. SUPPLEMENTARY NOTES Armstrong Laboratory Technical Monitor: Larry J. Mecker (210) 536-3337 120. DISTRUCTION AVAILABULTY STATEMENT Approved for public release; distribution is unlimited. 121. ABSTRACT MARKED MORES Intervest which can be used to predict Decompression Sickness Resea 123. ABSTRACT MORES Structure transplation of the Armstrong Laboratory Decompression Sickness Resea 124. BUBECT TEAMS	ويراد ويعاد المستند كالمجير المحمي المتحدي والمحمي المتحدي	2. REPORT DATE	J. REPORT TYPE AN	D DATES COVERED
E. AUTHOR(S) PE - 62202F James T. Webb and Andrew A. Pilmanis PR - 7930 T. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(LS) TA - 18 KRUG Life Sciences, Inc. San Antonio Division P. O. Box 790644 Division San Antonio, TX 78279-0644 Division S PONSORING, MONITORING AGENCY NAME(S) AND ADDRESS(LS) Image: Comparison of Calibration (AFMC) Crew Technology Division Division 2504 D Drive, Suite 1 Division Browks Air Force Base, TX 78235-5104 Image: Sister 1 ITS SUPPLEMENTARY NOTES Armstrong Laboratory (AFMC) Crew Technology Division Sactor 1 Strangtrion Availability STATEMENT Approved for public release; distribution is unlimited. TO predict altitude decompression sickness (DCS) risk with any degree of accuracy, one must we variables such as prebreathe time, rate of ascent/descent, time at altitude, altitude, mixed breathing technoler, risk assessment is based on DCS incidence after this fit period at simulated altitude. From an operational standpoint, variables wit in development, the interim a terrospective study from the Armstrong Laboratory Decompression Sickness Resea Database has produced risk curves which can be used to predict due at the DCS or venous gas emboli (VCE) recearble with a 20,000 () threathing 10097 v.; 2) zero-prebreathe exposure so lises than 20,000 () threathing 10097 v.; 2) zero-prebreathe exposure so lises t	4. TITLE AND SUBTITLE		_	S. FUNDING NUMBERS
James T. Webb and Andrew A. Pilmanis TA - 18 2. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) WU- 01 RRIG Link Sciences, Inc. Sum Antonio Division P.O. Box 790641 DETECTE S. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) REPORT NUMBER Antonio Division DETECTE P.O. Box 790644 DETECTE S. PONSORING: MONITORING AGENCY NAME(S) AND ADDRESS(ES) REPORT NUMBER Autonio Division Detectorate Crew Systems Directorate DETECTE Crew Systems Directorate Detectorate Crew Systems Directorate Proceedings: 31st Annue Crew Technology Division B 2304 D1 Drive, Suite 1 B Browks Air Force Base, TX 78235-5104 Its Suppretention availability Statement TD predict altitude decompression sickness (DCS) risk with any degree of accuracy, one must we variables such as produced: Its ABSTRACT (Minmum 200 ward): TD predict altitude decompression sickness (DCS) risk with any degree of accuracy, one must we variables such as produced with the operational standpoint, variable time at altitude complicates and descents. The length of resea chamber exposures is fixed. Therefore, risk assessment is based on DCS incidence after this fis period at simulated altitude, from an operational standpoint, variable sis in development, the intertim, a retrospecti	Decompression Sickness Ris	sk Versus Time and Al	litude	
James T. Webb and Andrew A. Pilmanis WU- 01 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) KRUICE Life Sciences, Inc. San Antonio Division P.O. Box 790644 Image: Comparison of Comparison Comparison Comparison Comparison of Comparison of Co	6. AUTHOR(S)			PR - 7930
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) IVENOMING ORGANIZATION NAME(S) AND ADDRESS(ES) KRUG Life Sciences, Inc. San Antonio Division P. O. Box 709644 IVENOMING ORGANIZATION 9. SPONSORING MONITORING AGENCY NAME(S) AND ADDRESS(ES) IVENOMING ORGANIZATION 7. WINDER SPONSORING MONITORING AGENCY NAME(S) AND ADDRESS(ES) 8. SPONSORING MONITORING AGENCY NAME(S) AND ADDRESS(ES) IVENOMING ORGANIZATION 9. SPONSORING MONITORING AGENCY NAME(S) AND ADDRESS(ES) IVENOMING ORGANIZATION 9. SPONSORING MONITORING AGENCY NAME(S) AND ADDRESS(ES) IVENOMING ORGANIZATION 7. WINDER DEVENOMING ORGANIZATION 9. SPONSORING MONITORING AGENCY NAME(S) AND ADDRESS(ES) IVENOMING ORGANIZATION 7. SPONSORING MONITORING AGENCY NAME(S) AND ADDRESS (DCS) TISK IVENOMING ORGANIZATION 7. SUPPLEMENTARY NOTES Armstrong Laboratory Technical Monitor: Larry J. Meeker (210) 536-3337 7. ADDRESS (DC public release; distribution is unlimited. IVENOMING ORGANIZATION CODE 7. ADDRESS AND ADDRESSION SICKNESS (DCS) risk with any degree of accuracy, one must we variables us a probreathe time, rate of accurd/descent, time at altitude, altitude, mixed breating of research and the accents and descents, The length of research and the as probreathe time, rate of accurd/descent, time at altitude, altitude, mixed breating of report the attribute for public release; tis tixed. Therefore, risk assessment is based	James T. Wabb and Andrew A. Bilmonia			
KR11G Life Sciences, Inc. San Antonio Division P.O. Box 70644 REPORT NUMBER 19. Obs 700644 Softward Sciences, Market Sciences, Marke		A. I milants		WU- 01
AL/CF-PC-1993-0039 AL/CF-PC-193-0039 AL/CF-PC-193 AL/CF-PC-193-0039 AL/CF-PC-193 AL/CF-PC-193-0039 AL/CF-PC-193 AL/CF-PC-193 AL/CF-PC-193-0039 AL/CF-PC-193 AL/CF-PC-193-0039 AL/CF-PC-193 AL/CF-PC-193 AL/CF-PC-193 AL/CF-PC-193-0039 AL/CF-PC-193 AL/		(S) AND ADDRESS(ES)		
P. O. Box 790644 San Antonio, TX 78279-0644 A sponsoring aboratory (AFMC) Crew Systems Directorate Crew Vechnology Division 2504 D Drive, Suite 1 Brooks Air Force Base, TX 78235-5104 It. Supplementation of the association of the astociation astociatisthe astociation of the astociatis astociatio	· · · · · · · · · · · · · · · · · · ·			
9: SPONSORING, MONITORING AGENCY NAME(S) AN ADECTED 11991 10. SPONSORING, MONITORING AGENCY NAME(S) AN ADECTED 11991 9: SPONSORING, MONITORING AGENCY NAME(S) AN ADECTED 11991 10. SPONSORING, MONITORING AGENCY REPORT NUMBER AGENCY REPORT NUMBER Proceedings: 31st Annua SAFE Symposium Proceedings: 31st Annua SAFE Symposium 204 D Drive, Suite 1 Brooks Air Force Base, TX 78235-5104 Brows Air Force Base, TX 78235-5104 11: SUPPLEMENTARY NOTES Armstrong Laboratory Technical Monitor: Larry J. Meeker (210) 536-3337 12: OISTRIBUTION AVAILABILITY STATEMENT Approved for public release; distribution is unlimited. 12: DISTRIBUTION CODE 13: ABSTRACT (Minimum 200 works) 12: DISTRIBUTION CODE 14: ABSTRACT (Minimum 200 works) Therefore, risk assessment is based on DCS incidence after this for period at simulated altitude, From an operational standpoint, variable time at altitude complicates a predictive capability, although a computer model to handle all of these variables is in development, the interim, a retrospective study from the Armstrong Laboratory Decompression Sickness Resea Database has produced risk curves which can be used to predict DCS or venous gas emboli (VC incidence as a function of time at various altitude, stude to the yor venous gas emboli (VC incidence as a function of time at various altitude. Stude COMPRESSION Sickness Resea Database has produced risk curves which can be used to predict DCS or venous gas emboli (VC incidence as a function of time at various altitude. Stude Studes WC incidence as a function of time at various altitude. Stude COMPRESSION Sickness Resea Database has produced risk curves which can be used to pre		n 7		AL/Cr=rC=1995=0059
Amstrong Laboratory (AFMC) Crew Systems Directorate (rew Technology Division 2504 D Drive, Suite 1 Brooks Air Force Base, TX 78235-5104 AGENCY REPORT NUMBER Proceedings: 31st Annue SAFE Symposium 11. SUPPLEMENTARY NOTES Armstrong Laboratory Technical Monitor: Larry J. Meeker (210) 536-3337 12a. DISTR/BUTION AVAILABILITY STATEMENT Approved for public release; distribution is unlimited. 12b. DISTR/BUTION CODE 13. ABSTRACT (Misemum 200 word); (dependent upon altitude), and profiles with multiple ascents and descents. The length of resea chamber exposures is fixed. Therefore, risk assessment is based on DCS incidence after this fit period at simulated altitude. From an operational standpoint, variable time at altitude complicates is predictive capability, although a computer model to handle all of these variables is in development, the interim, a retrospective study from the Armstrong Laboratory Decompression Sickness Resea Database has produced risk curves which can be used to predict DCS or venous gas emboli (VOC incidence as a function of time at various altitudes. We limited the data to: 1) zero-prebreathe exposures to less than 20,000 ft breathing 50% OL. 50% NL; 2) zero-prebreathe exposures to less than 20,000 ft breathing 50% OL. 50% NL; 2) zero-prebreathe exposures to less than 20,000 ft breathing 50% OL. 50% NL; 2) zero-prebreathe exposures to less than 20,000 ft breathing 100% OL using the curves, one can select a time/altitude of exposure and estimate the DCS and VGE percenta 14. SUBJECT TERMS Decompression sickness. Venous gas emboli, Prebreathe, Latency 15. NUMBER OF PAGES 16. PRICE CODE 14. SUBJECT TERMS Decompression sickness. Venous gas emboli, Prebreathe, Latency 15. NUMBER OF PAGES 20 terming the curves, one can select a time/altitude of exposure and estimate			FCTE	
Amstrong Laboratory (AFMC) Crew Systems Directorate (rew Technology Division 2504 D Drive, Suite 1 Brooks Air Force Base, TX 78235-5104 AGENCY REPORT NUMBER Proceedings: 31st Annue SAFE Symposium 11. SUPPLEMENTARY NOTES Armstrong Laboratory Technical Monitor: Larry J. Meeker (210) 536-3337 12a. DISTR/BUTION AVAILABILITY STATEMENT Approved for public release; distribution is unlimited. 12b. DISTR/BUTION CODE 13. ABSTRACT (Misemum 200 word); (dependent upon altitude), and profiles with multiple ascents and descents. The length of resea chamber exposures is fixed. Therefore, risk assessment is based on DCS incidence after this fit period at simulated altitude. From an operational standpoint, variable time at altitude complicates is predictive capability, although a computer model to handle all of these variables is in development, the interim, a retrospective study from the Armstrong Laboratory Decompression Sickness Resea Database has produced risk curves which can be used to predict DCS or venous gas emboli (VOC incidence as a function of time at various altitudes. We limited the data to: 1) zero-prebreathe exposures to less than 20,000 ft breathing 50% OL. 50% NL; 2) zero-prebreathe exposures to less than 20,000 ft breathing 50% OL. 50% NL; 2) zero-prebreathe exposures to less than 20,000 ft breathing 50% OL. 50% NL; 2) zero-prebreathe exposures to less than 20,000 ft breathing 100% OL using the curves, one can select a time/altitude of exposure and estimate the DCS and VGE percenta 14. SUBJECT TERMS Decompression sickness. Venous gas emboli, Prebreathe, Latency 15. NUMBER OF PAGES 16. PRICE CODE 14. SUBJECT TERMS Decompression sickness. Venous gas emboli, Prebreathe, Latency 15. NUMBER OF PAGES 20 terming the curves, one can select a time/altitude of exposure and estimate	9. SPONSORING MONITORING AGENCY	NAME(S) AND DESTIN		10. SPONSORING / MONITORING
Crew Technology Division 2004 D Drive, Suite 1 Brooks Air Force Base, TX 78235-5104 Free Base, TX 78235-5104 II. SUPPLEMENTARY NOTES Armstrong Laboratory Technical Monitor: Larry J. Meeker (210) 536-3337 122. DISTRIBUTION_AVAILABILITY STATEMENT 12b. DISTRIBUTION_AVAILABILITY STATEMENT Approved for public release; distribution is unlimited. 12b. DISTRIBUTION_CODE 12. ABSTRACT (Maximum 200 works) 12b. DISTRIBUTION_CODE To predict altitude decompression sickness (DCS) risk with any degree of accuracy, one must we variables such as prehreathe time, rate of ascent/descent, time at altitude, altitude, mixed breathing, (dependent upon altitude), and profiles with multiple ascents and descents. The length of resea chamber exposures is lixed. Therefore, risk assessment is based on DCS incidence after this figure/ideite capability, although a computer model to handle all of these variables is in development, the interim, a retrospective study from the Armstrong Laboratory Decompression Sickness Resea Database has produced risk curves which can be used to predict DCS or venous gas emboli (VC incidence as a function of time at various altitudes. We limited the data to: 1) zero-prehreathe exposure to less than 20,000 th breathing 50% O., 50% N.; 2) zero-prehreathe exposures to less than 20,000 th breathing 100% O.; and 3) 1-h prehreathe exposures to greater than 20,000 th breathing 100% O.; and 3) 1-h prehreathe exposure and estimate the DCS and VGE percenta 14. SUBJECT TERMS 12. SECURITY CLASSIFICATION 13. NUMBER OF PAGES 14. SUBJECT TERMS 14. SICURITY CLASSIFICATION 19. SECURITY CLASSIFICATION 20. LIMITATION 0F	Armstrong Laboratory (AFMC)	FLD		
Clear Technology Division SAFE Symposium 2504 1D Drive, Suite 1 Brooks Air Force Base, TX 78235-5104 11. SUPPLEMENTARY NOTES Armstrong Laboratory Technical Monitor: Larry J. Meeker (210) 536-3337 12a. OISTRIBUTION_AVAILABILITY STATEMENT 12b. DISTRIBUTION_CODE Approved for public release; distribution is unlimited. 12b. DISTRIBUTION_CODE 13. ABSTRACT (Maximum 200 wards); 12b. DISTRIBUTION_CODE To predict altitude decompression sickness (DCS) risk with any degree of accuracy, one must we variables such as prebreathe time, rate of ascent/descent, time at altitude, altitude, mixed breathing (dependent upon altitude), and profiles with multiple ascents and descents. The length of resea chamber exposures is fixed. Therefore, risk assessment is based on DCS incidence after this file period at simulated altitude. From an operational standpoint, variable time at altitude complicates a predictive capability, although a computer model to handle all of these variables is in development. the interim, a retrospective study from the Armstrong Laboratory Decompression Sickness Resea Database has produced risk curves which can be used to predict DCS or venous gas emboli (VC incidence as a function of time at various altitudes. We limited the data to: 1) zero-preheather exposure to less than 20,000 ft breathing 50% O. 50% N: 2) zero-preheathe exposure to less than 20,000 ft breathing 50% O. 50% N: 2) zero-preheathe the DCS and VGE percenta 14. SUBJECT TERMS 15. NUMBER OF PAGES Decompression sickness, Venous gas emboli, Prebreathe, Latency 5 14. SUBJECT TERMS 16. TEC				Proceedings: 31st Annual
Brooks Air Force Base, TX 78235-5104 11. SUPPLEMENTARY NOTES Armstrong Laboratory Technical Monitor: Larry J. Meeker (210) 536-3337 12a. DISTRIBUTION AVAILABILITY STATEMENT Approved for public release; distribution is unlimited. 13. ABSTRACT (Maximum 200 wards); To predict altitude decompression sickness (DCS) risk with any degree of accuracy, one must we variables such as prebreathe time, rate of ascent/descent, time at altitude, mixed breathing (dependent upon altitude), and profiles with multiple ascents and descents. The length of resea chamber exposures is fixed. Therefore, risk assessment is based on DCS incidence after this fip period at simulated altitude. From an operational standpoint, variable time at altitude complicates a predictive capability, although a computer model to handle all of these variables is in development. the interim, a retrospective study from the Armstrong Laboratory Decompression Sickness Resea Database has produced risk curves which can be used to predict DCS or venous gas emboli (VC incidence as a function of time at various altitudes. We limited the data to: 1) zero-prebreathe exposure to less than 20,000 ft breathing 50% O.; 50% N; 2) zero-prebreathe exposures to less than 20,000 ft breathing 50% O.; 50% N; 2) zero-prebreathe exposures to less than 20,000 ft breathing 100% O; and 3) 1-h prebreathe exposures to greater than 20,000 ft breathing 10% O, 50% N; 2) zero-prebreathe exposures to less than 20,000 ft breathing 10% O; 50% N; 2) zero-prebreathe exposures to less than 20,000 ft breathing 10% O; 0, 50% N; 2) zero-prebreathe exposures to less than 20,000 ft breathing 10% O; 0, 50% N; 2) zero-prebreathe exposures to less than 20,000 ft breathing 10% O; 0, 50% N; 2) zero-prebreathe exposures to less than 20,000 ft breathing 10% O; 0, 50% N; 2) z				1 –
Armstrong Laboratory Technical Monitor: Larry J. Meeker (210) 536-3337 12. DISTRIBUTION AVAILABILITY STATEMENT Approved for public release; distribution is unlimited. 13. ABSTRACT (Minimum 200 wards) To predict altitude decompression sickness (DCS) risk with any degree of accuracy, one must we variables such as prebreathe time, rate of ascent/descent, time at altitude, altitude, mixed breathing (dependent upon altitude), and profiles with multiple ascents and descents. The length of researchamber exposures is fixed. Therefore, risk assessment is based on DCS incidence after this fix period at simulated altitude. From an operational standpoint, variable time at altitude complicates a predictive capability, although a computer model to handle all of these variables is in development, the interim, a retrospective study from the Armstrong Laboratory Decompression Sickness Resea Database has produced risk curves which can be used to predict DCS or venous gas emboli (VC incidence as a function of time at various altitudes. We limited the data to: 1) zero-prebreathe exposure to less than 20,000 ft breathing 50% O 50% N.; 2) zero-prebreathe exposures to less than 20,000 ft breathing 50% O 50% N.; 2) zero-prebreathe the DCS and VGE percenta 14. SUBJECT TERMS 15. NUMBER OF PAGES 14. SUBJECT TERMS 15. SECURITY CLASSIFICATION 15. SECURITY CLASSIFICATION 16. ECCODE 17. SECURITY CLASSIFICATION 19. SECURITY CLASSIFICATION 18. ABSTRACT TERMS 10. INTITION OF ABST		5-5104		
122. DISTRIBUTION AVAILABILITY STATEMENT 12b. DISTRIBUTION CODE Approved for public release; distribution is unlimited. 12b. DISTRIBUTION CODE 13. ABSTRACT (Miximum 200 wards); To predict altitude decompression sickness (DCS) risk with any degree of accuracy, one must we variables such as prebreathe time, rate of ascent/descent, time at altitude, altitude, mixed breathing (dependent upon altitude), and profiles with multiple ascents and descents. The length of resea chamber exposures is fixed. Therefore, risk assessment is based on DCS incidence after this fix period at simulated altitude. From an operational standpoint, variable time at altitude complicates a predictive capability, although a computer model to handle all othese variables is in development, the interim, a retrospective study from the Armstrong Laboratory Decompression Sickness Resea Database has produced risk curves which can be used to predict DCS or venous gas emboli (VC incidence as a function of time at various altitudes. We limited the data to: 1) zero-prebreathe exposure to less than 20,000 ft breathing 50% O. SO% N; 2) zero-prebreathe exposures to less than 20,000 ft breathing 100% O; and 3) 1-b prebreathe exposure sto greater than 20,000 ft breathing 100% Using the curves, one can select a time/altitude of exposure and estimate the DCS and VGE percenta 14. SUBJECT TERMS 15. NUMBER OF PAGES 14. SUBJECT TERMS 15. SECURITY CLASSIFICATION OF ABSTRACT 17. SECURITY CLASSIFICATION OF THIS PAGE 19. SECURITY CLASSIFICATION OF ABSTRACT	11. SUPPLEMENTARY NOTES			
To predict altitude decompression sickness (DCS) risk with any degree of accuracy, one must we variables such as prebreathe time, rate of ascent/descent, time at altitude, altitude, mixed breathing (dependent upon altitude), and profiles with multiple ascents and descents. The length of research amber exposures is fixed. Therefore, risk assessment is based on DCS incidence after this fit period at simulated altitude. From an operational standpoint, variable time at altitude complicates a predictive capability, although a computer model to handle all of these variables is in development, the interim, a retrospective study from the Armstrong Laboratory Decompression Sickness Resea Database has produced risk curves which can be used to predict DCS or venous gas emboli (VC incidence as a function of time at various altitudes. We limited the data to: 1) zero-prebreathe exposure to less than 20,000 ft breathing 50% O., 50% N.; 2) zero-prebreathe exposures to less than 20,000 breathing 100% O.; and 3) 1-h prebreathe exposures to greater than 20,000 ft breathing 100% Using the curves, one can select a time/altitude of exposure and estimate the DCS and VGE percenta 14. SUBJECT TERMS Decompression sickness. Venous gas emboli, Prebreathe, Latency 15. NUMBER OF PAGES 16. PRICE CODE 17. SECURITY CLASSIFICATION 19. SECURITY CLASSIFICATION 10. CLASSIFICATION 10. CLASSIFICATION 10. CLASSIFICATION 10. SUBJECT TERMS 11. SUBJECT TERMS 11. SUBJECT TERMS 12. LECURITY CLASSIFICATION 13. SECURITY CLASSIFICATION 14. SUBJECT TERMS 15. NUMBER OF PAGES 16. PRICE CODE 17. SECURITY CLASSIFICATION 16. SECURITY CLASSIFICATION 19. SECURITY CLASSIFICATION 19. SECURITY CLASSIFICATION 10. CLASSIFICATION 11. CLEURATY CLASSIFICATION 12. LECURITY CLASSIFICATION 13. SECURITY CLASSIFICATION 14. SUBJECT TERMS 15. NUMBER 15. NUMBER 16. PRICE 17. SECURITY CLASSIFICATION 16. PRICE 17. SECURITY CLASSIFICATION 16. SUBJECT 17. SECURITY CLASSIFICATION 16. SUBJECT 17. SECURITY CLASSIFICATION 16. THIS PAGE 17. SECURITY 17. SECURITY 17. SECURITY 17. SECURITY 17			ed.	
To predict altitude decompression sickness (DCS) risk with any degree of accuracy, one must we variables such as prebreathe time, rate of ascent/descent, time at altitude, altitude, mixed breathing (dependent upon altitude), and profiles with multiple ascents and descents. The length of research amber exposures is fixed. Therefore, risk assessment is based on DCS incidence after this fit period at simulated altitude. From an operational standpoint, variable time at altitude complicates a predictive capability, although a computer model to handle all of these variables is in development, the interim, a retrospective study from the Armstrong Laboratory Decompression Sickness Resea Database has produced risk curves which can be used to predict DCS or venous gas emboli (VC incidence as a function of time at various altitudes. We limited the data to: 1) zero-prebreathe exposure to less than 20,000 ft breathing 50% O., 50% N.; 2) zero-prebreathe exposures to less than 20,000 ft breathing 50% O., 50% N.; 2) zero-prebreathe exposures to less than 20,000 ft breathing 100% Using the curves, one can select a time/altitude of exposure and estimate the DCS and VGE percenta 14. SUBJECT TERMS Decompression sickness. Venous gas emboli, Prebreathe, Latency 15. NUMBER OF PAGES 16. PRICE CODE 17. SECURITY CLASSIFICATION 18. SECURITY CLASSIFICATION 19. SECURITY CLASSIFICATION 20. LIMITATION OF ABS				
Variables such as probreathe time, rate of ascent/descent, time at altitude, altitude, mixed breathing (dependent upon altitude), and profiles with multiple ascents and descents. The length of resea chamber exposures is fixed. Therefore, risk assessment is based on DCS incidence after this fix period at simulated altitude. From an operational standpoint, variable time at altitude complicates a predictive capability, although a computer model to handle all of these variables is in development, the interim, a retrospective study from the Armstrong Laboratory Decompression Sickness Resea Database has produced risk curves which can be used to predict DCS or venous gas emboli (VC incidence as a function of time at various altitudes. We limited the data to: 1) zero-prebreathe exposu to less than 20,000 ft breathing 50% O., 50% N.; 2) zero-prebreathe exposures to less than 20,000 ft breathing 50% O., 50% N.; 2) zero-prebreathe exposures to less than 20,000 ft breathing 100% O.; and 3) 1-h prebreathe exposures to greater than 20,000 ft breathing 100% Using the curves, one can select a time/altitude of exposure and estimate the DCS and VGE percenta 14. SUBJECT TERMS 15. NUMBER OF PAGES 14. SUBJECT TERMS 5 15. NUMBER OF PAGES 16. PRICE CODE 17. SECURITY CLASSIFICATION OF THIS PAGE 19. SECURITY CLASSIFICATION OF ABS 17. SECURITY CLASSIFICATION OF THIS PAGE 19. SECURITY CLASSIFICATION OF ABS				
Decompression sickness. Venous gas emboli, Prebreathe, Latency 5 16. PRICE CODE 17. SECURITY CLASSIFICATION 10. CECURITY CLASSIFICATION 19. SECURITY CLASSIFICATION 20. LIMITATION OF ABS OF REPORT 0F ABSTRACT 20. LIMITATION OF ABST		·		
OF REPORT OF THIS PAGE OF ABSTRACT	(dependent upon altitude), a chamber exposures is fixed, period at simulated altitude, predictive capability, althoug the interim, a retrospective s Database has produced risk incidence as a function of tim to less than 20,000 ft breathi breathing 100% O ₃ ; and 3)	time, rate of ascent/des nd profiles with multi Therefore, risk asses From an operational s h a computer model to tudy from the Armstro curves which can be to e at various altitudes. Y ng 50% O., 50% N.; 2 1-h prebreathe expose	cent, time at altitude ple ascents and des isment is based on I landpoint, variable ti handle all of these v ong Laboratory Deco used to predict DCS We limited the data to 2) zero-prebreathe en uses to greater than	e, altitude, mixed breathing ga cents. The length of researc DCS incidence after this fixe me at altitude complicates an variables is in development. I compression Sickness Researc or venous gas emboli (VGE or 1) zero-prebreathe exposure sposures to less than 20,000 20,000 ft breathing 100% O
	To predict altitude decompre- variables such as prebreather (dependent upon altitude), a chamber exposures is fixed, period at simulated altitude, predictive capability, althoug the interim, a retrospective s Database has produced risk incidence as a function of tim to less than 20,000 ft breathi breathing 100% O ₂ ; and 3) Using the curves, one can sele	time, rate of ascent/des nd profiles with multi Therefore, risk asses From an operational s h a computer model to tudy from the Armstro curves which can be t e at various altitudes. V ng 50% O., 50% N.; 2 1-h prebreathe exposu ect a time/altitude of ex	cent, time at altitude ple ascents and des sement is based on I tandpoint, variable ti handle all of these v ong Laboratory Deco used to predict DCS We limited the data to 2) zero-prebreathe en tres to greater than sposure and estimate	e, altitude, mixed breathing ga cents. The length of researc DCS incidence after this fixe me at altitude complicates an variables is in development. I ompression Sickness Researc or venous gas emboli (VGE or 1) zero-prebreathe exposure (posures to less than 20,000) 20,000 ft breathing 100% O the DCS and VGE percentage
	To predict altitude decompre- variables such as prebreather (dependent upon altitude), a chamber exposures is fixed, period at simulated altitude, predictive capability, althoug the interim, a retrospective s Database has produced risk incidence as a function of tim to less than 20,000 ft breathi breathing 100% O ₂ ; and 3) Using the curves, one can sele	time, rate of ascent/des nd profiles with multi Therefore, risk asses From an operational s th a computer model to tudy from the Armstro curves which can be to e at various altitudes. M ng 50% O., 50% N.; 2 1-h prebreathe exposu ect a time/altitude of ex tous gas emboli, Prebr	cent, time at altitude ple ascents and des sement is based on I tandpoint, variable ti handle all of these v ong Laboratory Deco used to predict DCS We limited the data to 2) zero-prebreathe es tres to greater than sposure and estimate	e, altitude, mixed breathing ga cents. The length of researc DCS incidence after this fixe me at altitude complicates an variables is in development. I compression Sickness Researc or venous gas emboli (VGE or venous gas emboli (VGE 0: 1) zero-prebreathe exposure cposures to less than 20,000 20,000 ft breathing 100% O the DCS and VGE percentage

DECOMPRESSION SICKNESS RISK VERSUS TIME AND ALTITUDE

James T. Webb, Ph.D. Senior Research Scientist KRUG Life Sciences Inc., San Antonio, TX 78279-0644

> Andrew A. Pilmanis, Ph.D. Research Physiologist Armstrong Laboratory Brooks AFB, TX 78235-5301



ABSTRACT To predict altitude decompression sickness (DCS) risk with any degree of accuracy, one must weigh variables such as prebreathe time, rate of ascent/descent, time at altitude, altitude, mixed breathing gas (dependent upon altitude), and profiles with multiple ascents and descents. The length of research chamber exposures is fixed. Therefore, risk assessment is based on DCS incidence after this fixed period at simulated altitude. From an operational standpoint, variable time at altitude complicates any predictive capability, although a computer model to handle all of these variables is in development. In the interim, a retrospective study from the Armstrong Laboratory Decompression Sickness Research Database has produced risk curves which can be used to predict DCS or venous gas emboli (VGE) incidence as a function of time at various altitudes. We limited the data to: 1) zero-prebreathe exposures to less than 20,000 ft breathing 50% O_2 , 50% N_2 ; 2) zero-prebreathe exposures to less than 20,000 ft breathing 100% O₂; and 3) 1-h prebreathe exposures to greaver than 20,000 ft breathing 100% O_2 . Using the curves, one can select a time/altitude of exposure and estimate the DCS and VGE percentage.

THE PROBLEM lies with the difficulty in predicting DCS risk during hypobaric exposures which do not follow precise ascent, isobaric altitude, and descent profiles matching appropriate research data. For example, a fighter pilot who cruises to the target area at high altitude, descends to deliver ordnance, and reascends for cruise to the recovery base experiences a cockpit pressurization schedule for which there is no available research data. A tactical airlift profile with repeated drops of equipment or personnel may involve several decompressionrecompression events throughout the mission or on separate sorties the same day. We are frequently asked about DCS risk associated with scenarios such as these. The Armstrong Laboratory DCS research database contains data throughout the duration of exposure, typically 4-8 h. However, response to most requests has been based on DCS incidence at the end of the exposures. It might be preferable to present information based on altitude and length of exposure.

THE LONG-TERM SOLUTION will be an Armstrong Laboratory decompression model now under development that can provide predictive and real-time feedback on DCS risk during any hypobaric profile. The model will be based on currently available research data and on new data being collected during on-going exerimental protocols. VGE data will be included in the model because further decompression is possible after VGE formation that could promote growth of the gas emboli and increase DCS risk. This model will not be fielded for several years; however, there is an interim need for some method to estimate decompression risk versus time of exposure.

φpž

AN INTERIM SOLUTION to estimate decompression risk during relatively short exposures meand extracting experimental decompression risk data from the first 2 h of longer exposures. We retrieved this data from the Armstrong Laboratory DCS Research Database which included 301 relevant experimental exposures of male subjects to altitudes between 15,000 and 30,000 $ft^{1,4,5,8}$. The voluntary, fully informed consent of the subjects used in this research was obtained an required by AFR 169-The subjects had passed a USAF Flying Class II physical examination and were otherwish representative of the USAF population. The subjects were exposed in groups of 3 or less, to decompression at 5,000 ft/min from ground-level pressure at Brooks AFB, Texas (745 mmHg) to chamber pressures of 8.3-4.3 psia (simulated altitudes of 15,000 ft - 30,000 ft) for 4-8 The breathing mixture at simulated h. altitudes exceeding 20,000 ft was 100% O2 and was preceeded by 60 min of prebreathe with 100% O2. At altitudes below 20,000 ft, no prebreathe was performed; the breathing mixture during exposure was 50% O2 and 50% N2 or 100% O2. Each of the subjects was exposed from one to three times to a given pressure depending upon subject availability and protocol requirements, but only the results of the first exposure are used to provide consistent treatment of subject data. At altitude, the subjects performed exercises as described in TABLE 1.

During the chamber exposures, two different systems were used to monitor VGE⁹. The earlier dual-probe system consisted of a System 3 echo-imaging system from IREX Medical Systems and a Doppler ultrasound system consisting of a Bidirectional Doppler Model 1053 from the Institute of Applied Physiology and Medicine, Sound Products Division. The follow-on system consisted of a single-probe Hewlett-Packard SONOS 500 or 1000 precordial Doppler ultrasound and echo-imaging system. The sounds were recorded and graded according to the Spencer scale⁶. The time between VGE recordings was

9

TABLE 1. Profile Exercises and Number of Subjects versus Exposure Altitude

Exposure Altitude	Number of Subjects	Exercise, Exposure Duration, and Breathing Gas during Exposure
30,000'	31	Knee bends/Arm lifts ¹ ; 8-hours; 100% O ₂
30,000'	23	Simulated EVA ² ; 4-hours; 100% O ₂
29,500'	28	Rope pull ³ ; 4-hours; 100% O ₂
29,500'	8	Isotonic arm ⁴ ; 4-hours; 100% O ₂
27,500'	33	Knee bends/Arm lifts ¹ ; 8-hours; 100% O ₂
27,500'	2	Isotonic arm ⁴ ; 4-hours; 100% O ₂
25,000'	27	Knee bends/Arm lifts ¹ ; 8-hours; 100% O ₂
25,000'	13	Knee bends/Arm lifts ¹ ; 6-hours; 100% O ₂
22,500'	19	Knee bends/Arm lifts ¹ ; 8-hours; 100% O ₂
19,700'	10	Simulated EVA ² ; 6-hours; 100% O ₂
18,000'	10	Simulated EVA ² ; 6-hours; 100% O ₂
16,500'	10	Simulated EVA ² ; 6-hours; 100% O ₂
16,500′	32	Simulated EVA ² ; 6-hours; 50% O_2 :50% N_2
16,000'	25	Simulated EVA ² ; 6-hours; 50% O ₂ :50% N ₂
15,000'	10	Simulated EVA ² ; 6-hours; 100% O ₂
15,000'	20	Simulated EVA ² ; 6-hours; 50% O ₂ :50% N ₂

Note: Some studies involved identical exercises and altitudes, but had different breathing mixtures during exposure or different total exposure durations as listed. A 1-h prebreathe with 100% O₂ preceeded all exposures above 20,000 ft.

- Five chair-height deep knee bends and five arm-lifts of 5# weights every 15 min³;
 Cycle ergometer hand-cranking (24 rpm; 4 Newtons resistance), torque wrench actuation (25
- ft-lbs), and rope pulling (76.6 Newtons resistance), for 4-min each, 3-4 cycles/h⁸;
- 3 Rope pulling (76.6 Newtons resistance) for 5-min, 4 cycles per h⁴; or
- 4 Isotonic arm exercise for 5 min, 3 cycles/h².

approximately 15 min. The protocol called for descent at the first report of Grade 2 DCS joint pain (mild to moderate, constant pain¹⁰) or any more severe symptom, e.g. neurologic manifestations.

RESULTS in Figures 1-2 show cumulative DCS and VGE incidence versus time at altitudes from 22,500 to 30,000 ft. There was, in general, an increase in VGE and DCS incidence with higher altitude and with greater time at altitudes above 20,000 ft. Although the zero-prebreathe exposures to less than 20,000 ft produced no DCS within 2 h, VGE formation was observed within 25-50 min (Fig. 3 & 4) and 25-45% of the subjects breathing 50% O2 and 50% N₂ had VGE at the end of 2 h at 15,000-16,500 ft. While breathing 100% O2, the incidence of VGE at 15,000 and 16,500 ft was lower. This was shown more clearly in a direct comparison of severe (Grades 3 and 4) VGE data after 6 h exposures of subjects breathing either 50% O2 and 50% N2 or 100% O_2^{11} . Use of 100% O_2 was shown to be advantageous in reduction of VGE.

LIMITATIONS include inability to predict risk when cockpit pressurization varies within a flight. If prebreathe varies from these experimental conditions or if other breathing mixtures are used, the validity of risk assessment becomes degraded. Variation in ascent rate or environmental temperature could influence the outcome as could variation in individual susceptibility, exercise performed while decompressed, and freedom to report symptoms without consequence. ş

DISCUSSION AND RECOMMENDATIONS center on use of the DCS/VGE prediction curves as an interim measure until the altitude decompression model is operational. The pilot of a USAF fighter aircraft with a 5psid cockpit flying at 36,000 ft is breathing a mixed gas at a cockpit altitude of approximately 15,000 ft. An example of applying these curves would be for the pilot to refer to the 15,000 ft curve to determine risk level. Such an exposure while breathing



ł

Figure 1. DCS versus Time at 22,500-30,000 ft (1-h prebreathe); 100% O₂ breathing gas during exposure

ì





ł

Figure 3. VGE versus Time at 15,000-16,500 ft (zero prebreathe); 50% O_2 :50% N_2 breathing gas during exposure

-



Figure 4. VGE versus Time at 15,000-19,700 ft (zero prebreathe); 100% O₂ breathing gas during exposure

50% O_2 and 50% N_2 (approximate mixture delivered to the pilot) is predicted to be DCS-free, but there is a 15% chance of VGE after 1 h (Fig 3). In the case of rapid decompression at that point from the loss of cabin pressure, the gas emboli would expand (Boyles Law). DCS symptoms may then develop with reduced or very limited latency. This risk would not be apparent to the pilot (unmonitored for VGE) without reference to the VGE curves. To reduce the risk of developing VGE at cockpit altitudes below 20,000 ft, breathing 100% O_2 during flights exceeding 30,000 ft in 5-psid cockpits is recommended as described in Webb et al.⁷

Incidence of DCS and VGE after only 1-2 h of exposure at 22,500 ft (Fig. 1-2) should raise concern since that level of decompression is consistent with future fighter operations at 60,000 ft with a 5-psid cockpit pressurization system. Flight at 60,000 ft should require, at a minimum, use of 100% O2 from takeoff to descent⁷. An engineering solution could provide additional protection from DCS in future fighter aircraft. If such a solution is not constrained to the precedent of 40 years of fighter aircraft cockpit pressurization system design, changing the differential pressure maintained in the cockpit to 7 psid would provide considerably increased protection from DCS and VGE formation. Advanced personal equipment consisting of upper-torso counter-pressure garments may ameliorate the increased hazard due to the greater differential pressure experienced by the lungs during an explosive decompression at 60,000 ft. Further research is needed to demonstrate the adequacy of such protection and to confirm the effects of zero-prebreathe exposures to pressures simulating the full range of cockpit pressures expected in future aircraft.

ACKNOWLEDGMENTS This research was sponsored by the Armstrong Laboratory, Brooks AFB, TX, USAF Contracts F-33615-85-C-4503, F-33615-89-C-0603 and F-33615-92-C-0018 and NASA Contract T-82170.

REFERENCES

ł

....

i

Ţ

- 1. Dixon GA, Adams JD, Harvey WT. Decompression sickness and intravenous bubble formation using a 7.5 psia simulated pressure-suit a simulated pressure-suit a simulated Aviat. Space Environ. Ned. 1986;57:223-228.
- Fischer ND, Wiegman JF, NcLean SA, Olson RN. Evaluation of four different exercise types for use in altitude decompresion sickness studies. 30th Annual SAFE Symposium Proceedings. 1993;102-5.
- 3. Krutz RW Jr, Dixon GA. The effects of exercise on bubble formation and susceptibility at 9,100 m (30,000 ft; 4.3 psia). Aviat. Space Environ. Ned. 1987;58:A97-A99.
- Pilmanis AA, Olson RN. The effect of inflight deN2ation on altitude decompression sickness risk. [Abstract] Aviat. Space Environ. Ned. 1991;62:452.

5. Smead KW. Preliminary findings: Bends screening index study. Space Life Sciences Symposium, Abstracts (unpaginated, unindexed addendum), Washington, DC, June 21-26. 1987. ł

- Spencer MP. Decompression limits for compressed air determined by ultrasonically detected blood bubbles. J. Appl. Physiol. 1976;40:229-35.
- Webb JT, Balldin UI, Pilmanis AA. Prevention of decompression sickness in current and future fighter aircraft. Aviat. Space Environ. Med. 1993a;64:1048-50.
- Webb JT, Fischer M, Wiegman J, Pilmanis AA. Prebreathe enhancement with dual-cycle ergometry may increase decompression sickness protection. (Abstract) Aviat. Space Environ. Med. 1993b;64:420.
- 9. 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(supplement):89-90.
- 10. Webb JT, Pilmanis AA. Venous gas emboli detection and endpoints for decompression sickness research. 29th Annual SAFE Symposium Proceedings. 1991;20-3. SAFE J. 1992;22:22-5.
- 11. Webb JT, Pilmanis AA. Breathing gas of 100% oxygen compared with 50% oxygen:50% N2 reduces altitude-induced venous gas emboli. Aviat. Space Environ. Med. 1993;64:808-12.

BIOGRAPHIES

James T. Webb is a senior research scientist for KRUG Life Sciences Inc. in San Antonio. He has M.S. and Ph.D. degrees from the University of Washington and is board certified in Aerospace Physiology via the Aerospace Medical Association. Dr. Webb holds an Airline Transport Pilot certificate and has over 4300 flying hours including 250 combat hours in Vietnam (F-4Ds) and 2800 hours of C-141A experience. He is the 1993-1994 President of the Aerospace Physiology Society and is a principal investigator on reveral decompression sickness research protocols at Brooks AFB, TX.

Andrew A. Pilmanis is a research physiologist and Chief of the High Altitude Protection Function of the USAF Armstrong Laboratory's Crew Technology Division. He has N.S. and Ph.D. degrees in physiology from the University of Southern California (USC). Previously, he was on the faculty of the USC School of Nedicine and director of their Hyperbaric Research and Treatment Facility on Santa Catalina Island. He was Program Director (1980-1985) for the joint NOAA/USC Undersea Research Program, responsible for the design and construction of the laboratory's saturation diving system (underwater habitat) Aquarius.