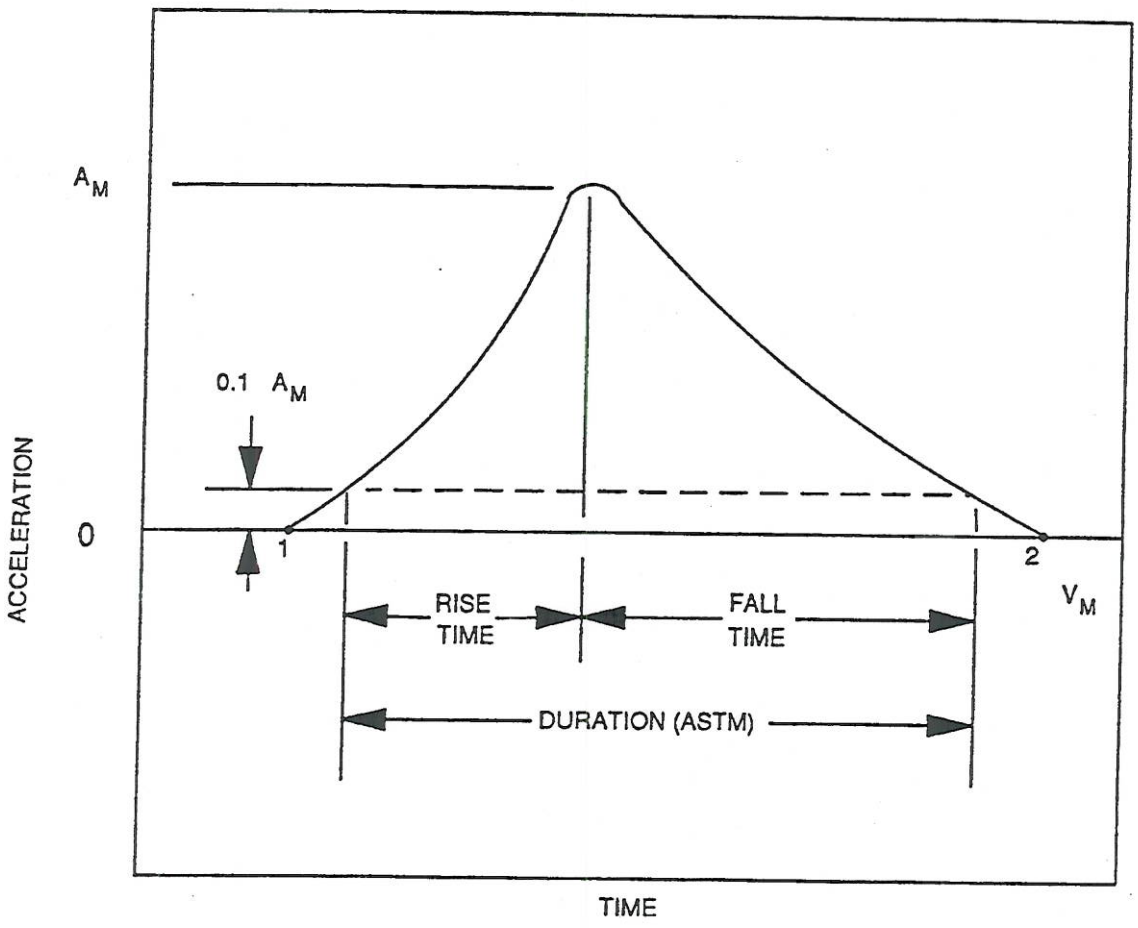

FIGURE 1. TERMS USED TO CHARACTERIZE SHOCKS

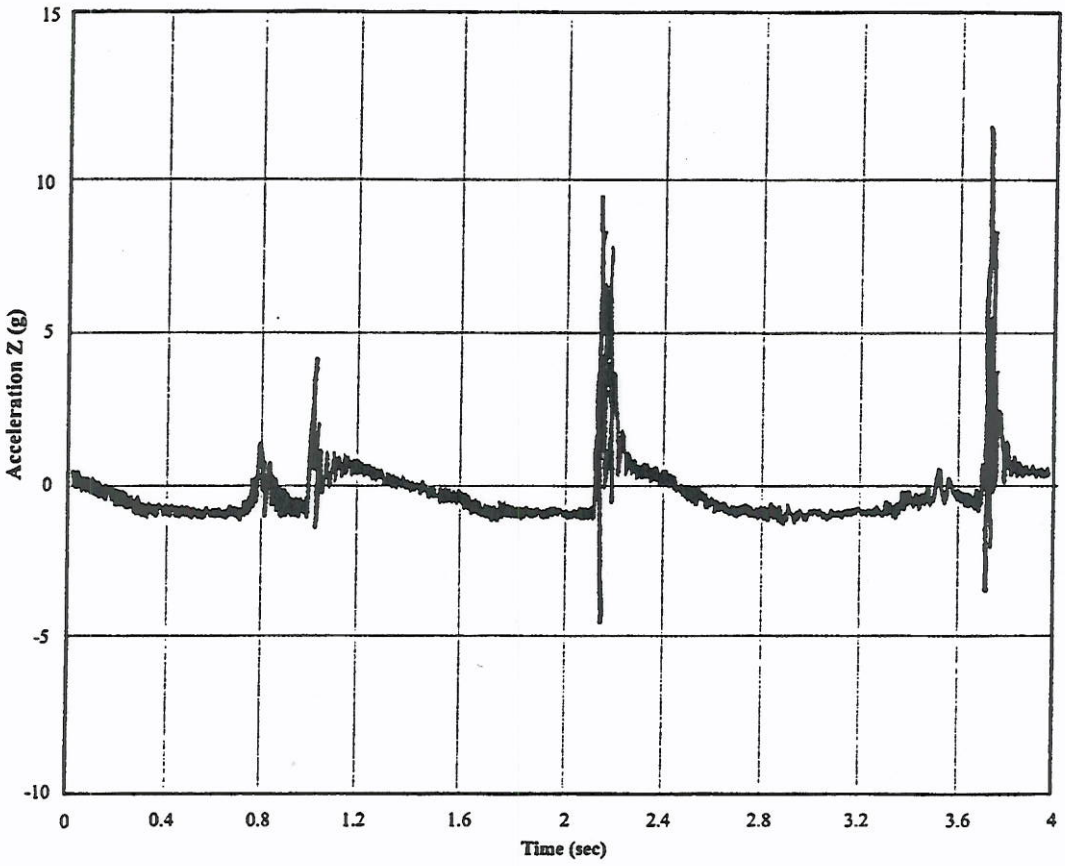

FIGURE 2. UNFILTERED ACCELERATION TIME HISTORY MEASURED WITH PIEZORESISTIVE ACCELEROMETER

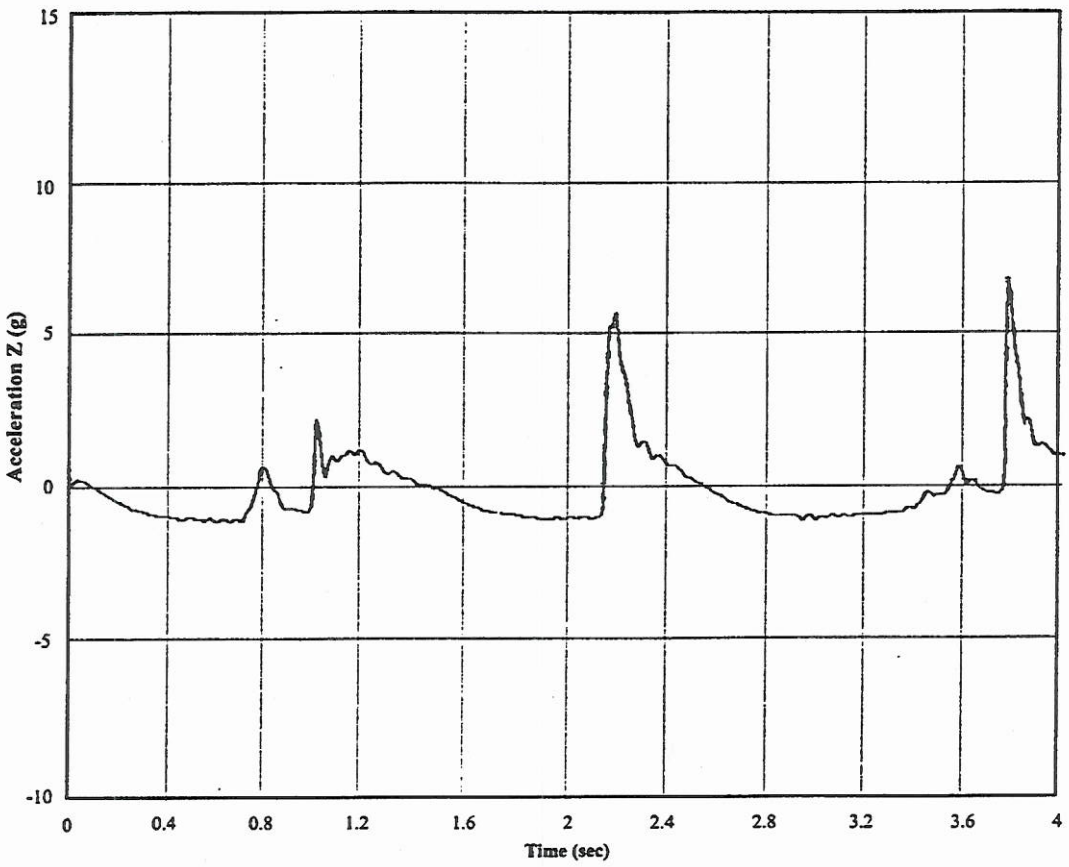

FIGURE 3. ACCELERATION TIME HISTORY MEASURED WITH PIEZORESISTIVE ACCELEROMETER, FILTERED AT 25 Hz

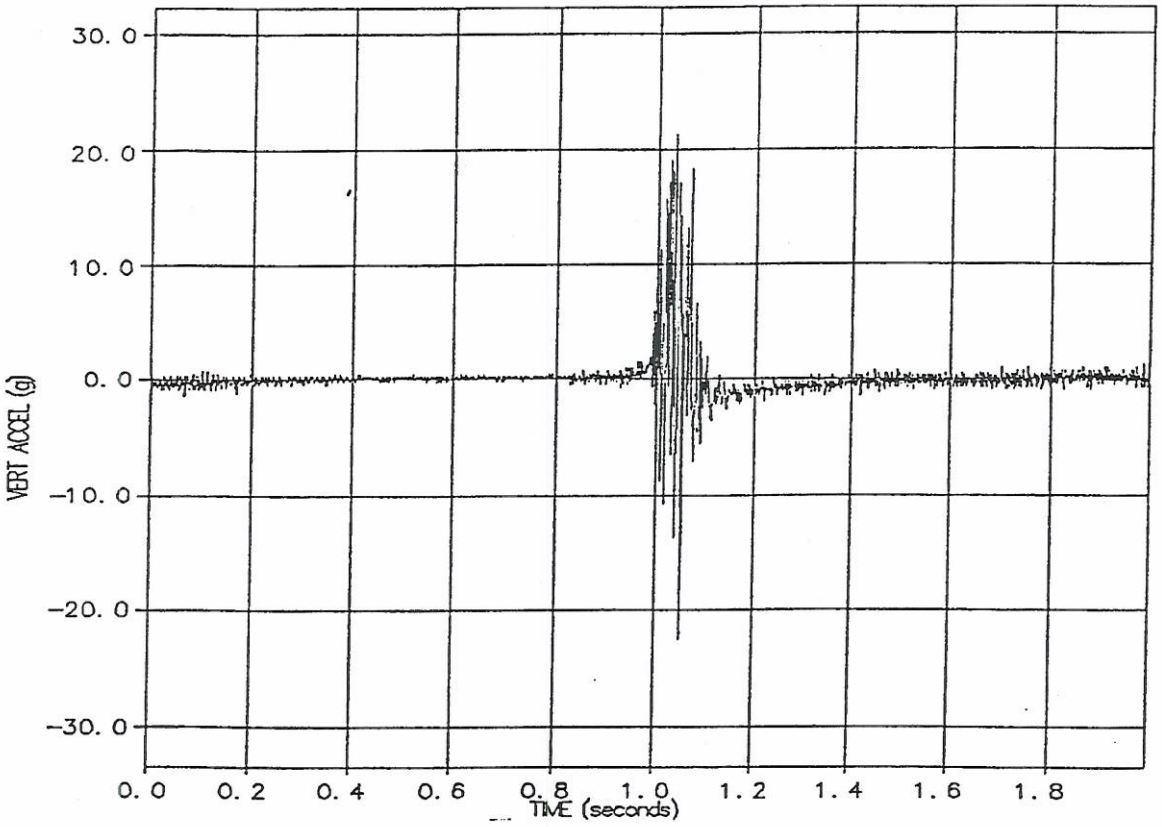

FIGURE 4. UNFILTERED ACCELERATION TIME HISTORY MEASURED WITH PIEZOELECTRIC ACCELEROMETER

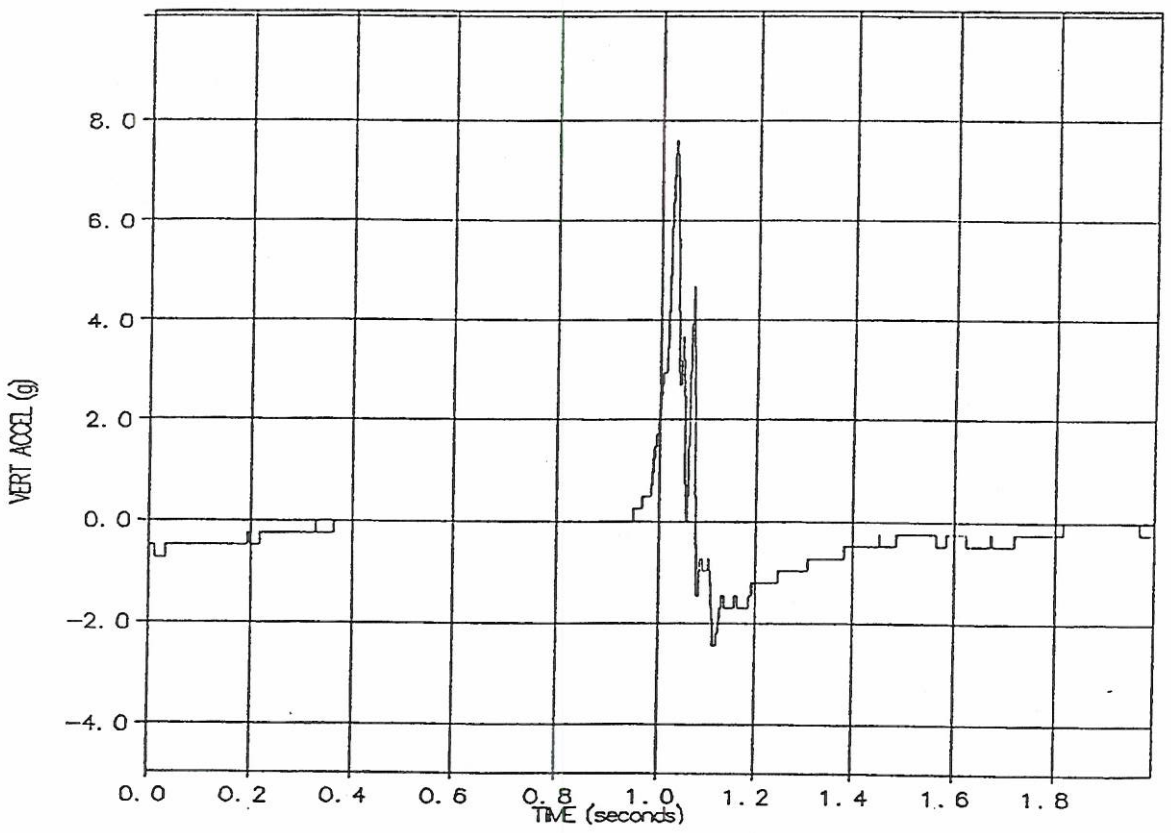

FIGURE 5. ACCELERATION TIME HISTORY MEASURED WITH PIEZOELECTRIC ACCELEROMETER, FILTERED AT 100 Hz

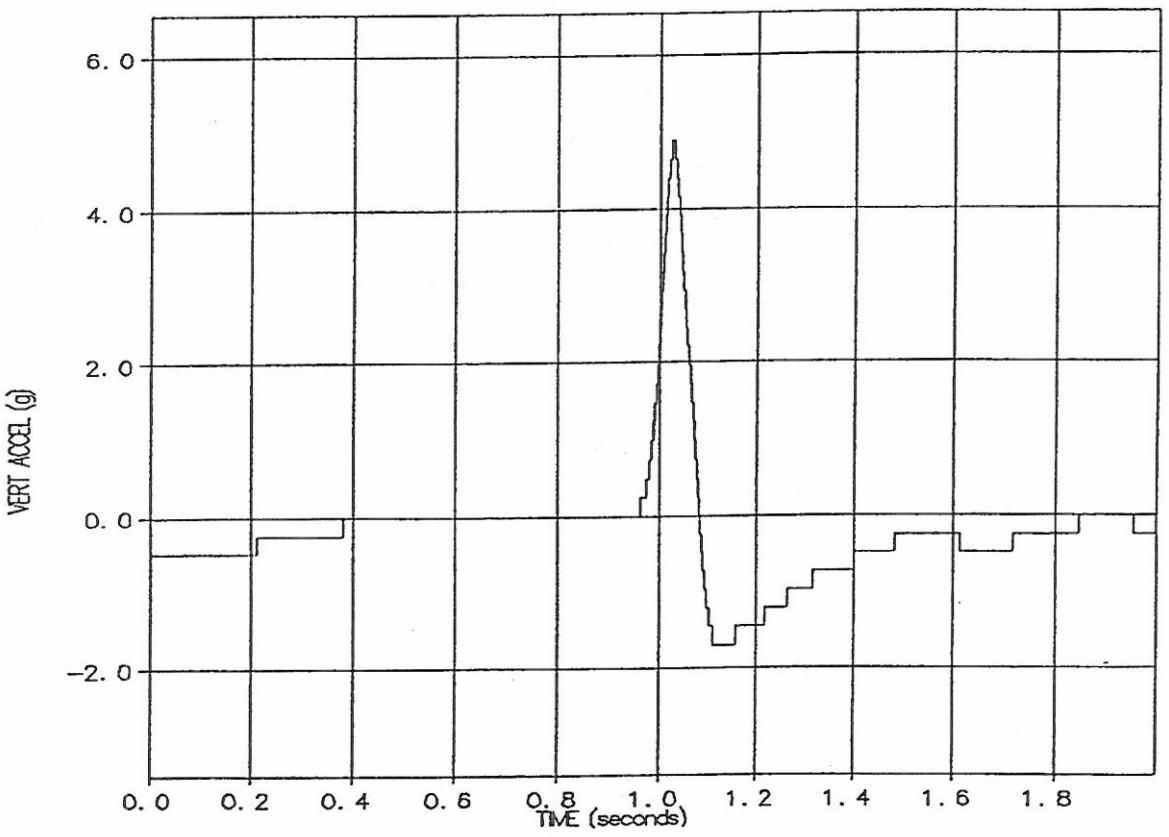

FIGURE 6. ACCELERATION TIME HISTORY MEASURED WITH PIEZOELECTRIC ACCELEROMETER, FILTERED AT 30 Hz

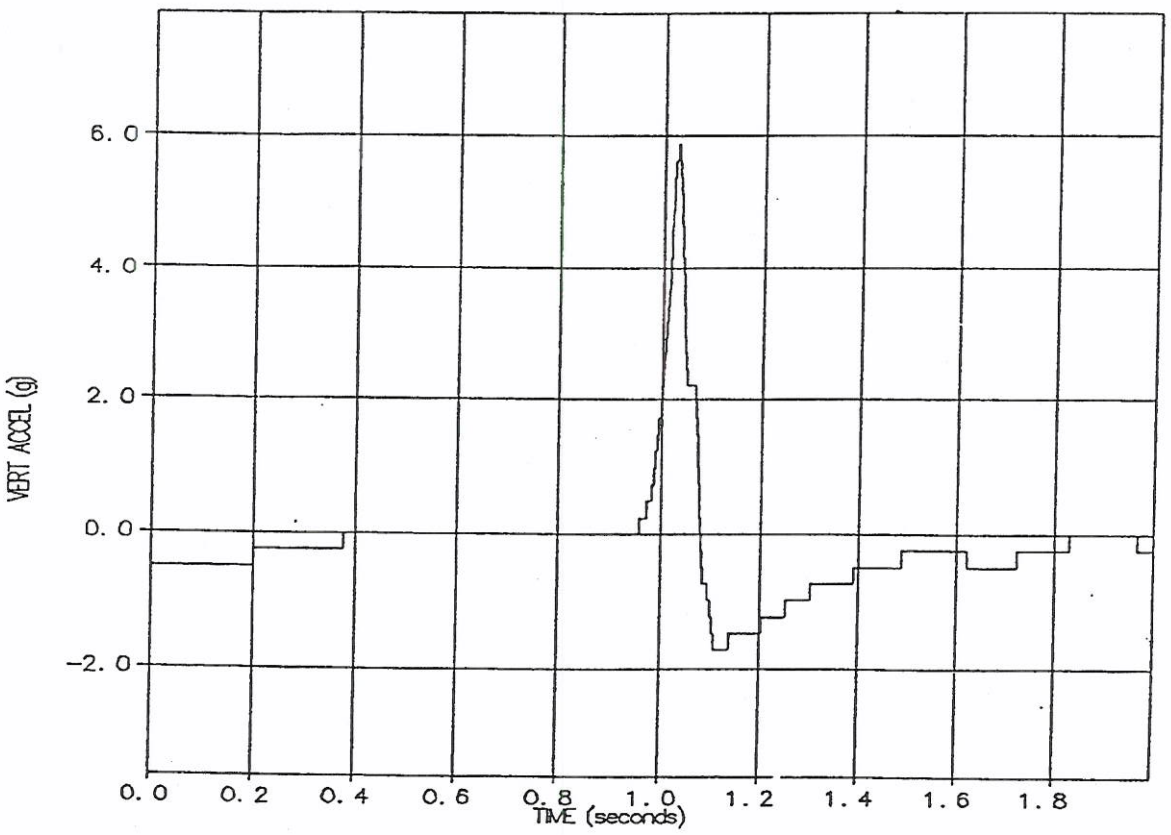

FIGURE 7. ACCELERATION TIME HISTORY MEASURED WITH PIEZOELECTRIC ACCELEROMETER, FILTERED AT 50 Hz

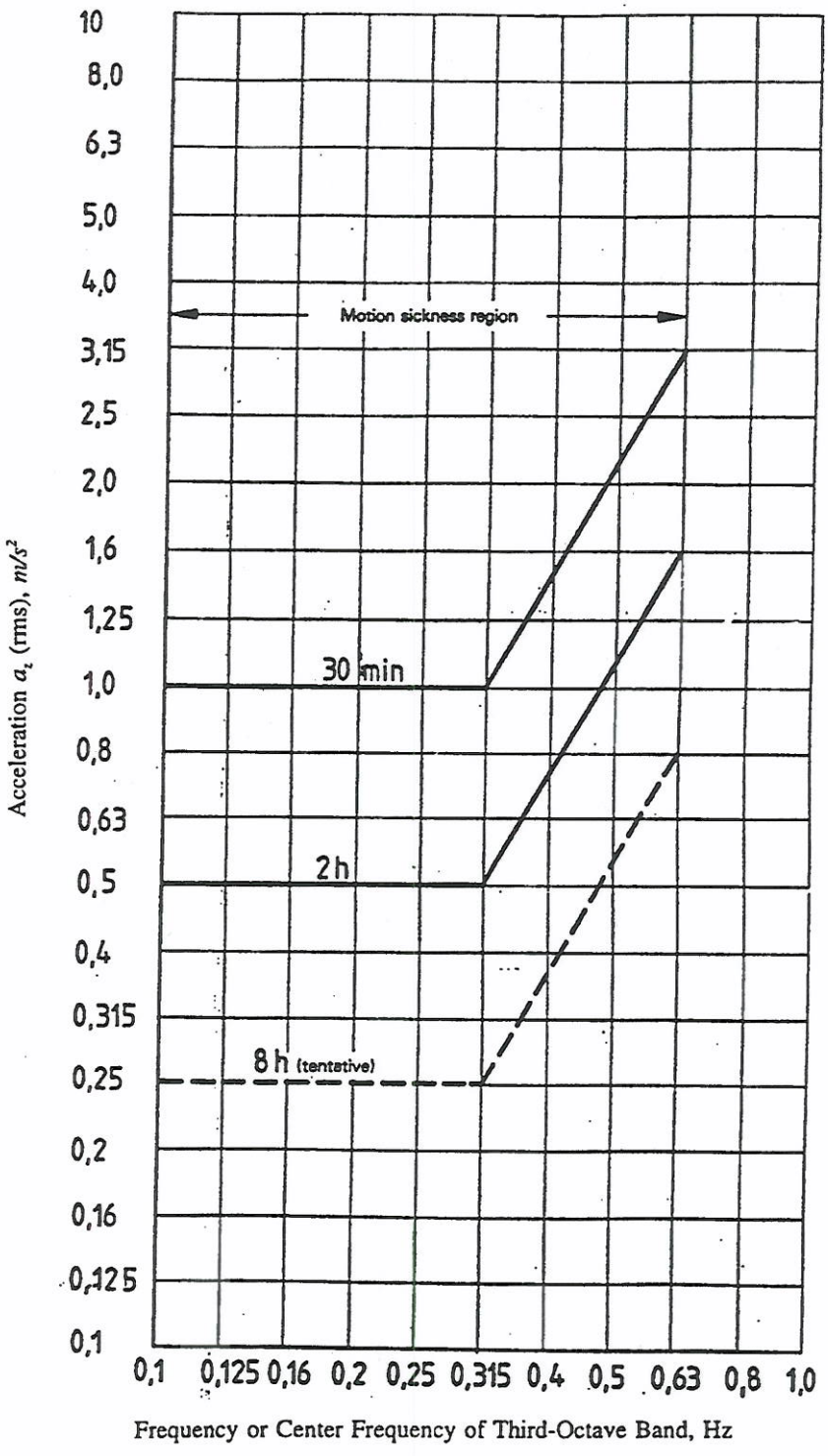

FIGURE 11. VIBRATION EXPOSURE CRITERIA FOR LOW FREQUENCY

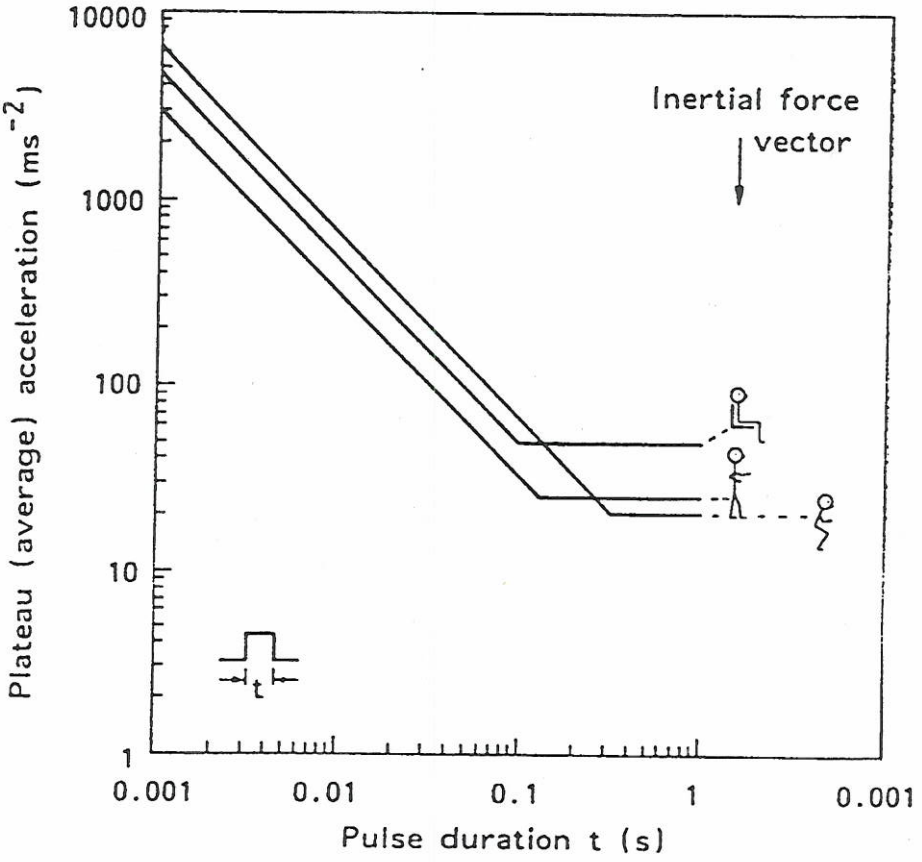

FIGURE 12. TOLERABLE PLATFORM ACCELERATION-DURATION LEVELS

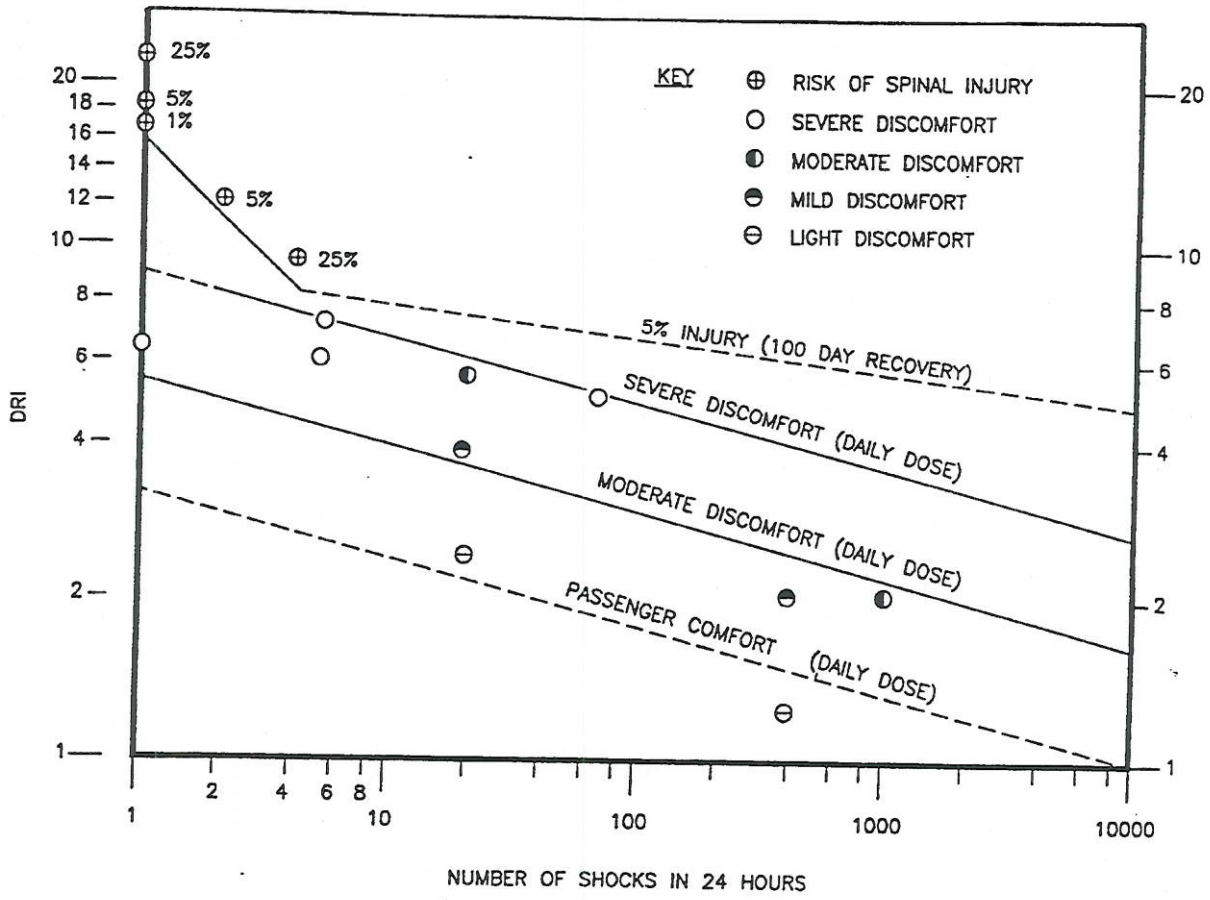

FIGURE 13. TOLERANCE LIMITS FOR EXPOSURE TO REPEATED DRIs

$$M_h \ddot{Z}_h = C_h (\dot{Z}_d - \dot{Z}_h) + K_h (Z_d - Z_h) - F_{hg}$$

$$M_d \ddot{Z}_d = C_h (\dot{Z}_h - \dot{Z}_d) + K_h (Z_h - Z_d) + C_i (\dot{Z}_b - \dot{Z}_d) + K_i (Z_b - Z_d) - F_{dg}$$

$$M_b \ddot{Z}_b = C_i (\dot{Z}_d - \dot{Z}_b) + K_i (Z_d - Z_b) - F_{bg} + F_w$$

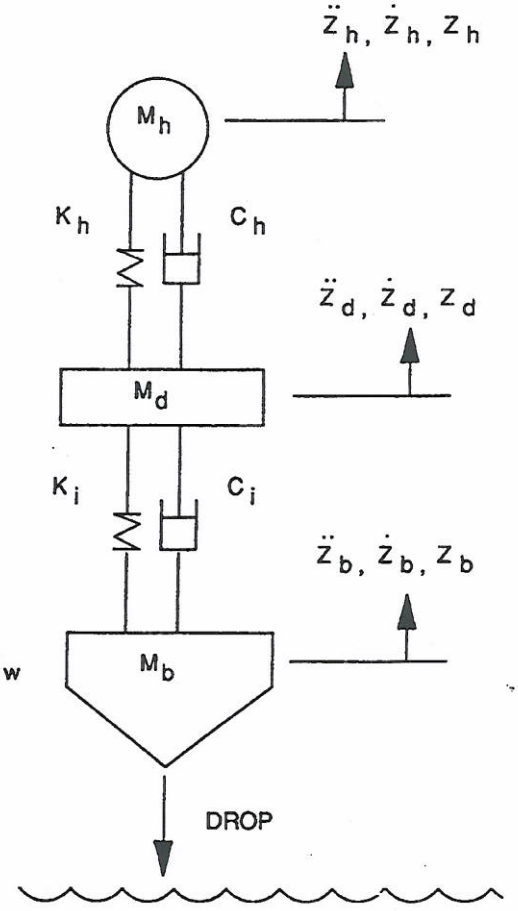

FIGURE 14. EQUATIONS OF MOTION FOR THREE DOF SIMULATION

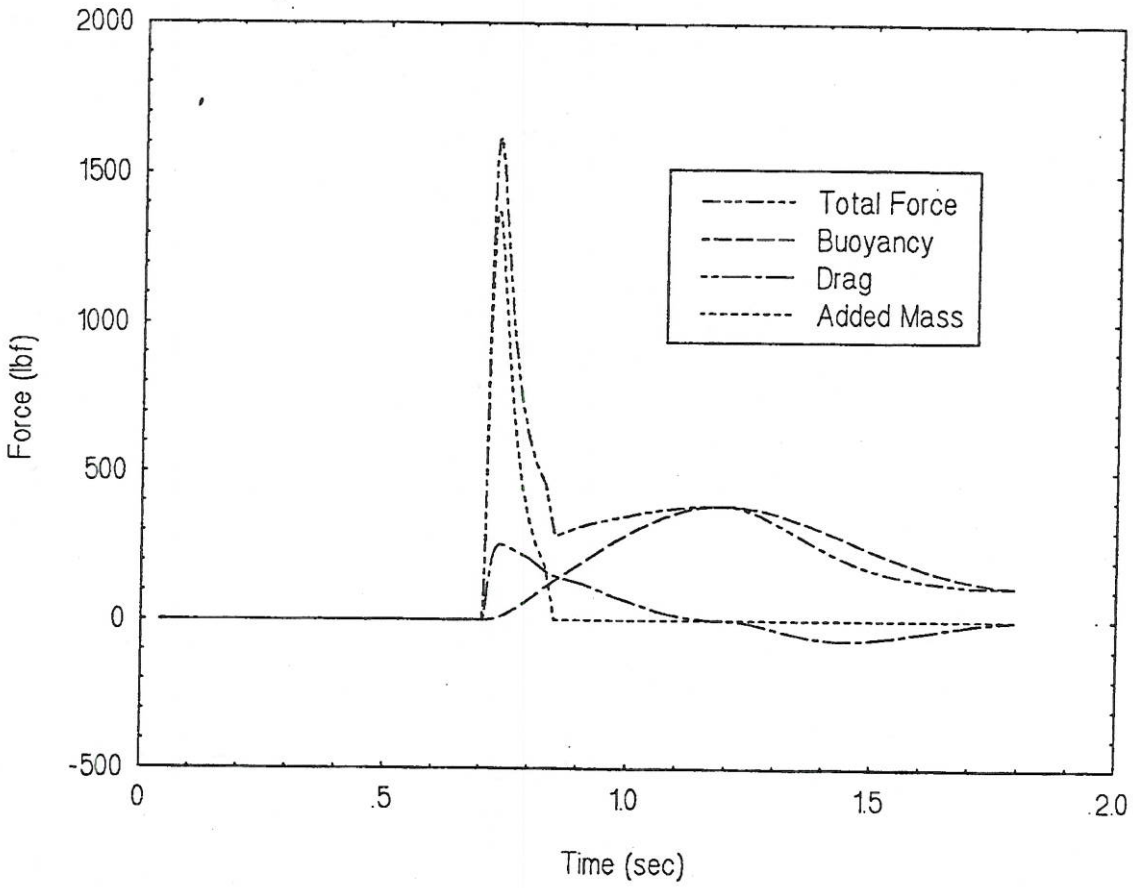

FIGURE 15. FORCE COMPOSITION, HSPB 8-FT DROP, WEDIM PREDICTION

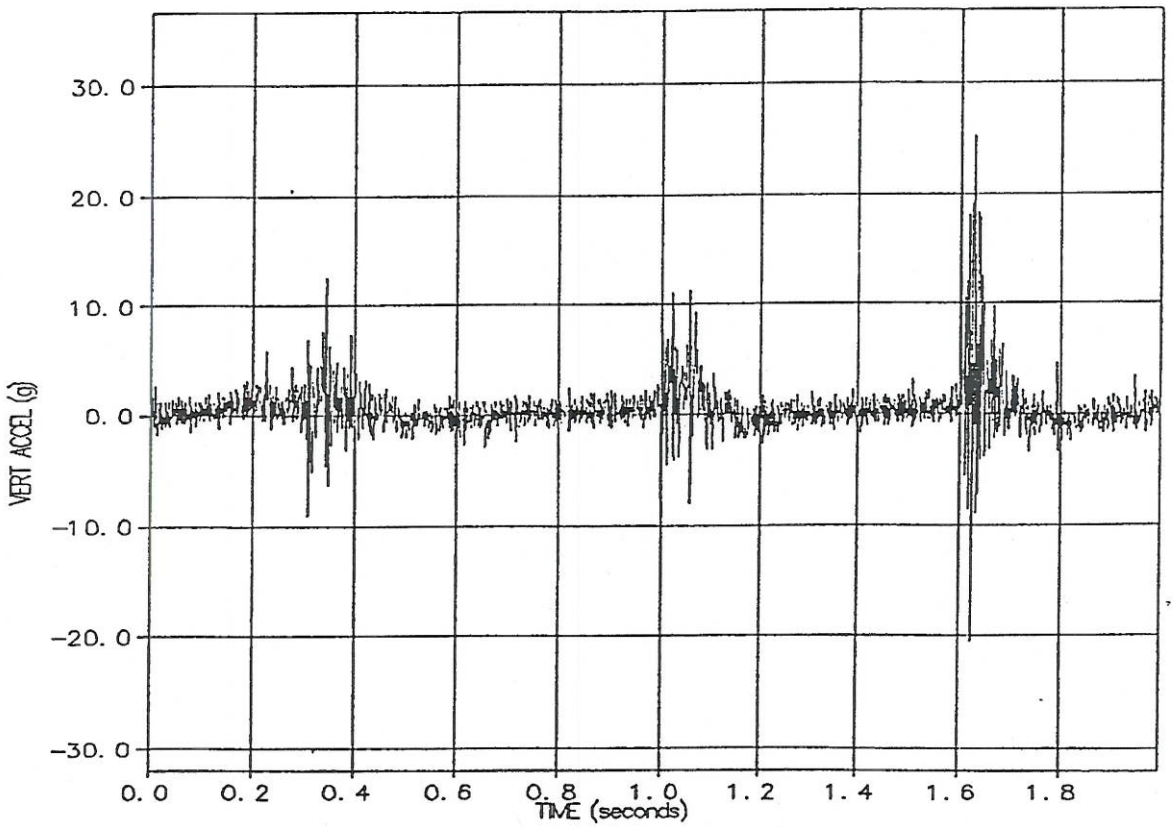

FIGURE 8. UNFILTERED ACCELERATION TIME HISTORY OF MULTIPLE EVENTS MEASURED WITH PIEZOELECTRIC ACCELEROMETERS

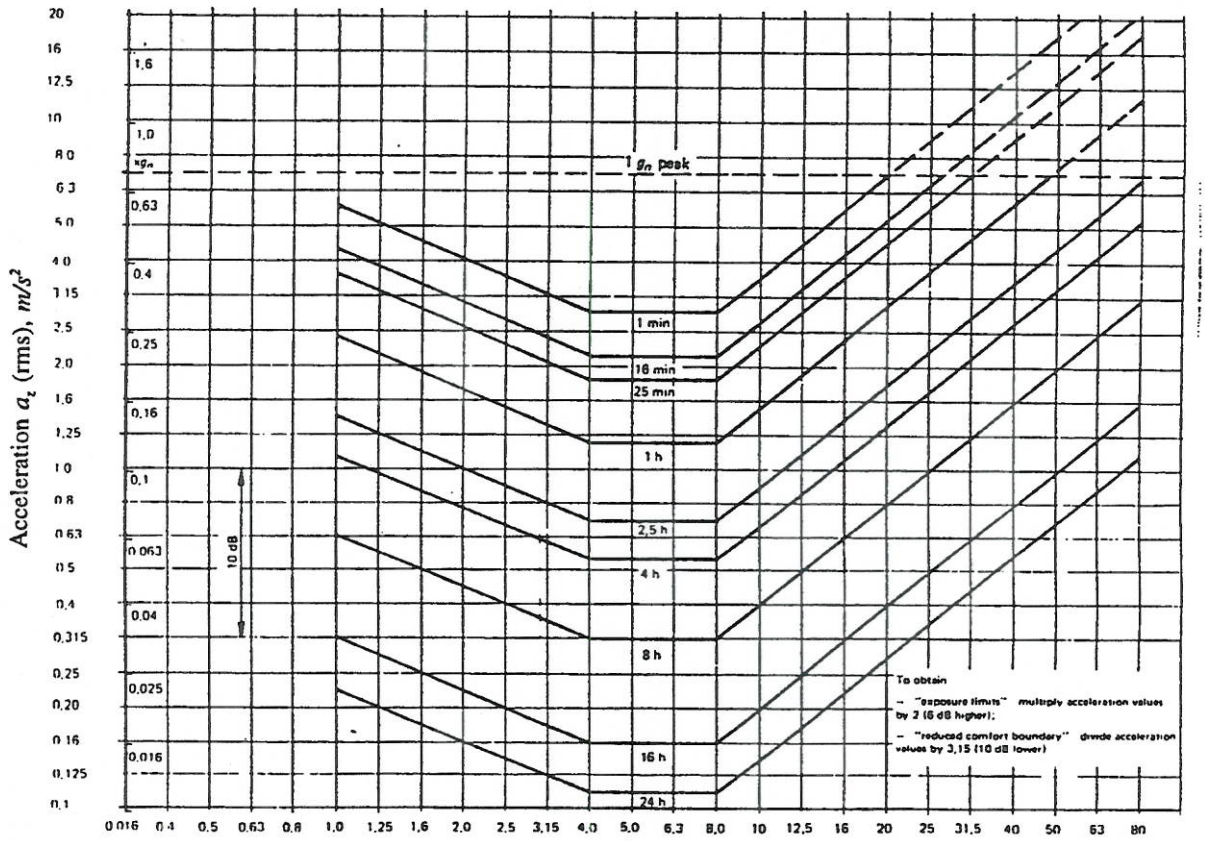

FIGURE 9. VIBRATION EXPOSURE CRITERIA FOR VERTICAL DIRECTION

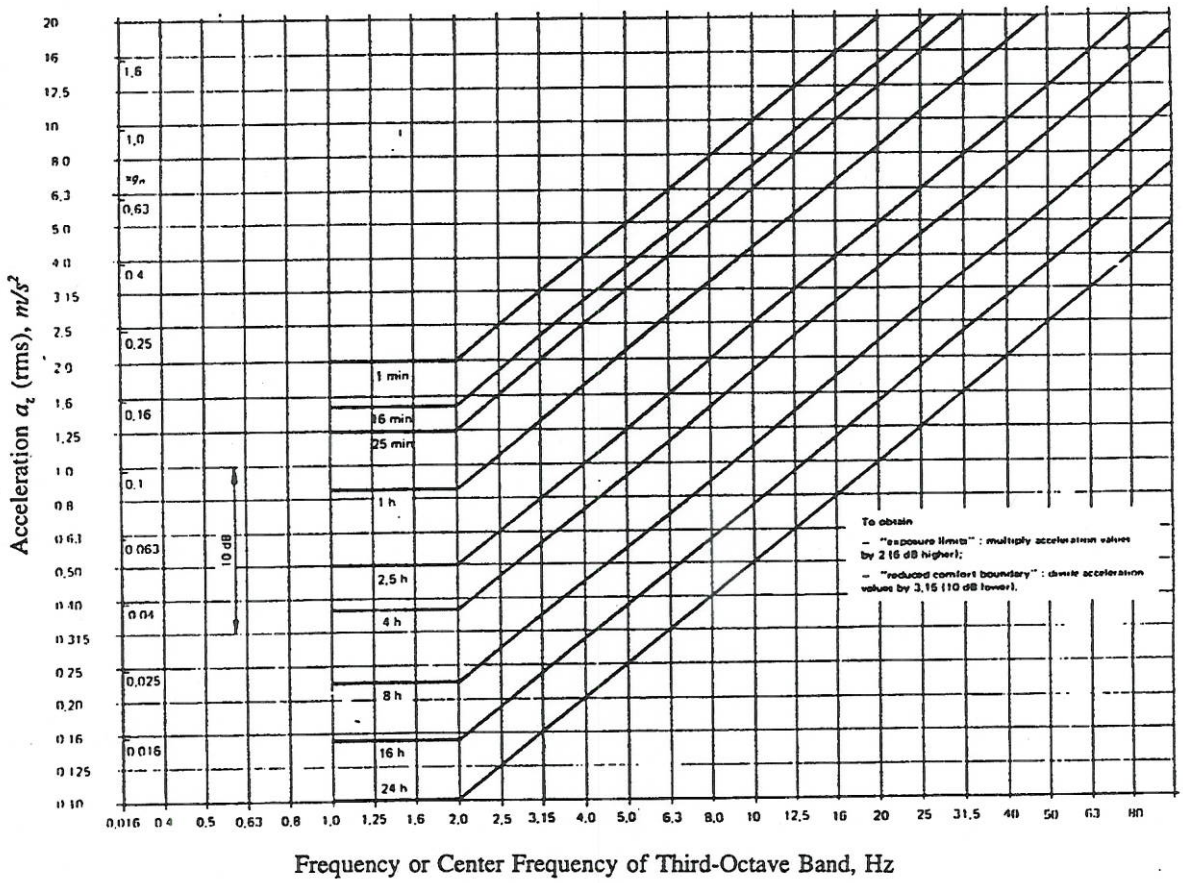

FIGURE 10. VIBRATION EXPOSURE CRITERIA FOR LATERAL DIRECTION

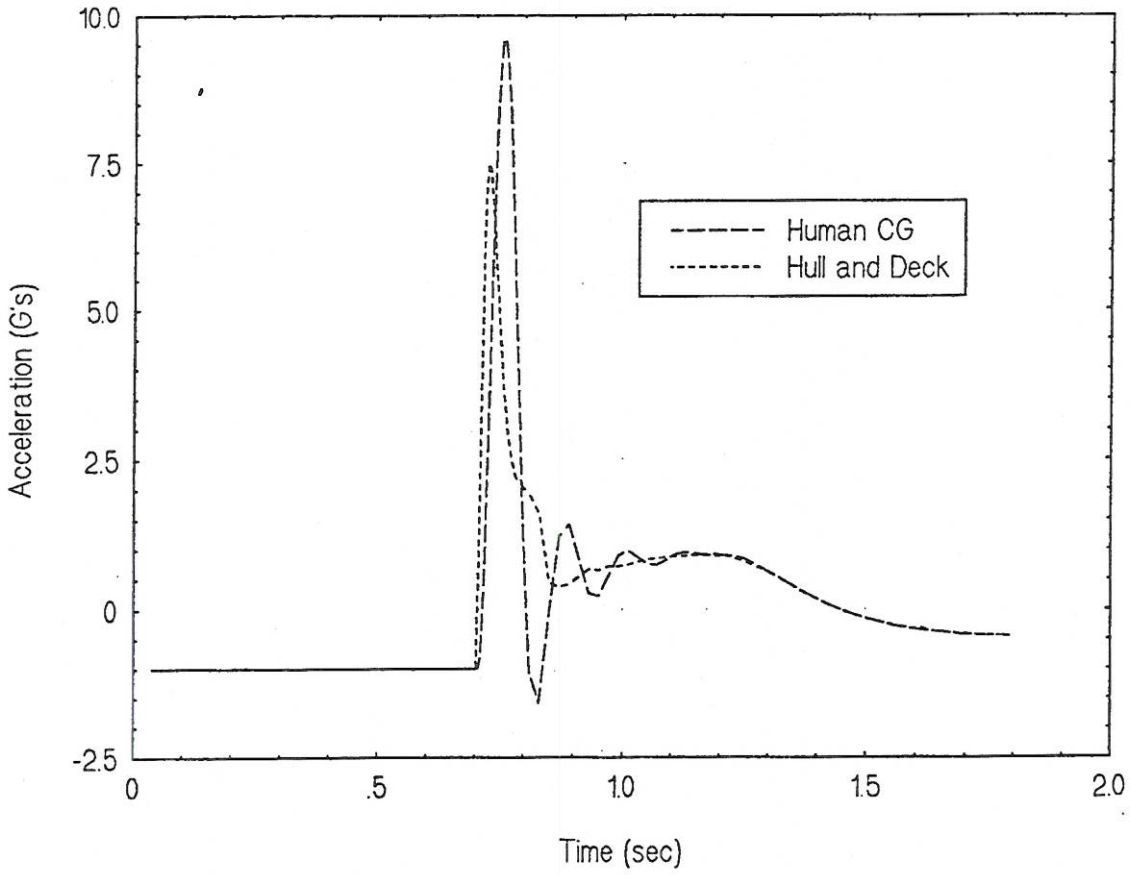

FIGURE 16. ACCELERATIONS, HSPB 8-FT DROP, WEDIM PREDICTION

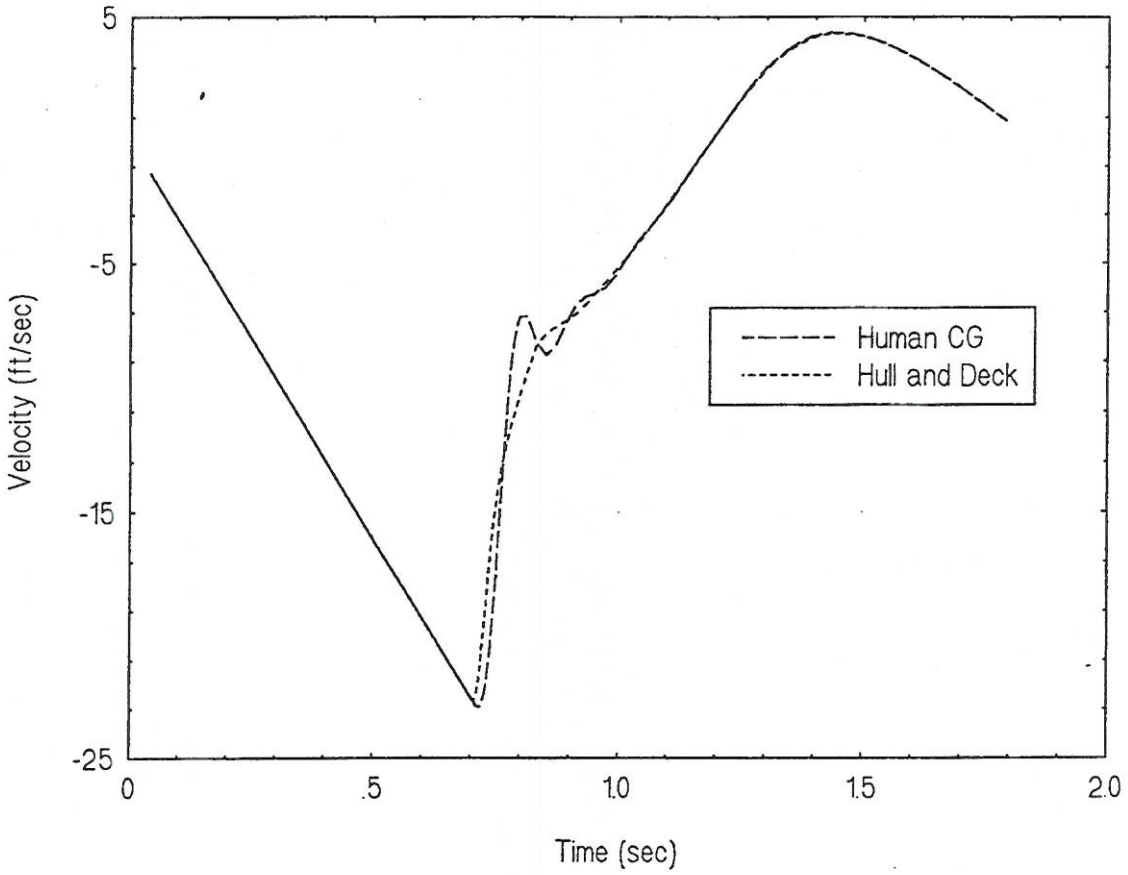

FIGURE 17. VELOCITIES, HSPB 8-FT DROP, WEDIM PREDICTION

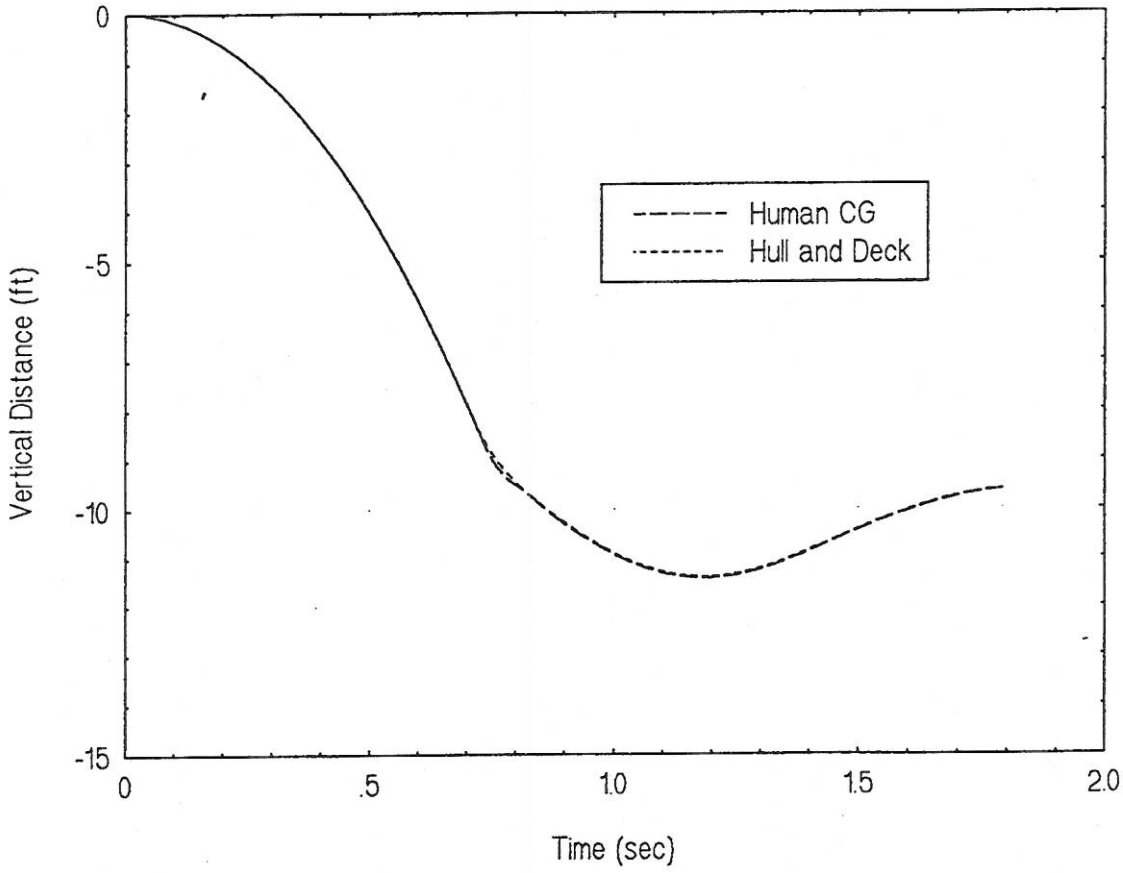

FIGURE 18. DISPLACEMENTS, HSPB 8-FT DROP, WEDIM PREDICTION

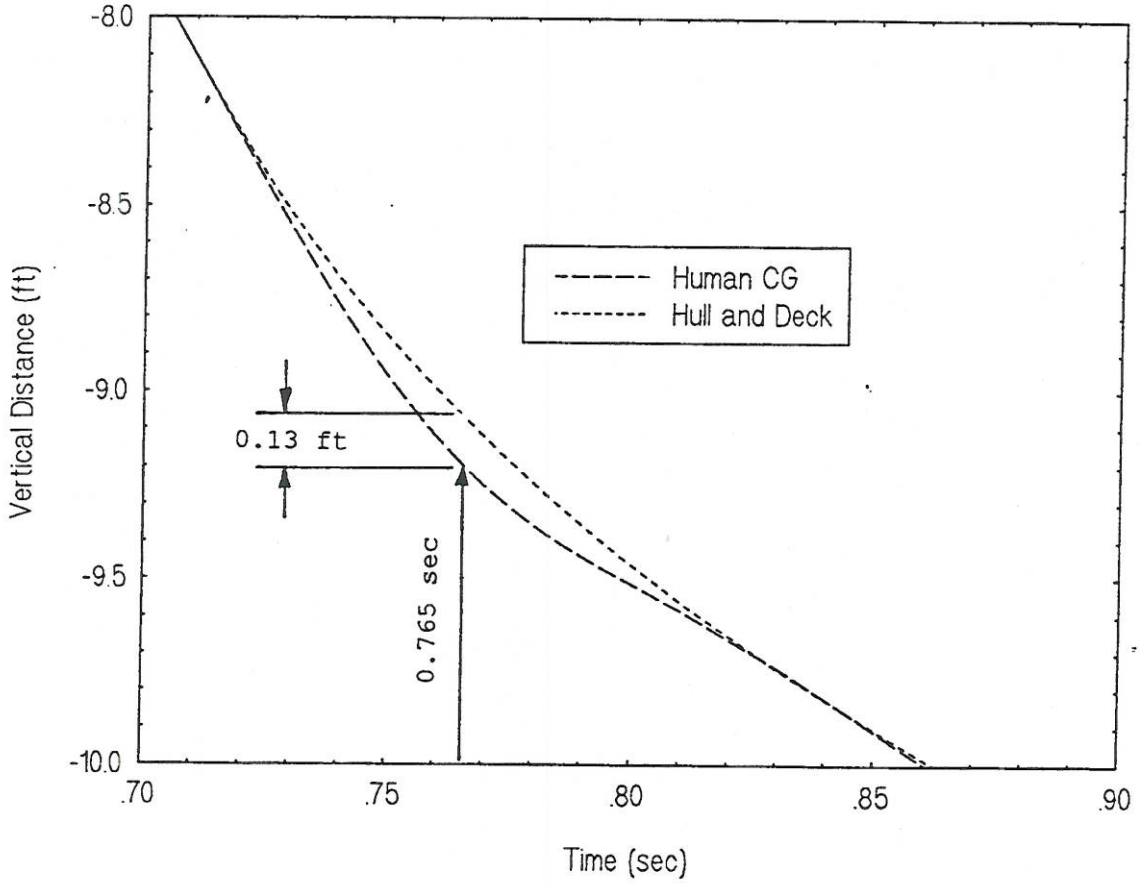

FIGURE 19. DISPLACEMENT-RESPONSE INJURY ASSESSMENT, HSPB 8-FT DROP, WEDIM PREDICTION

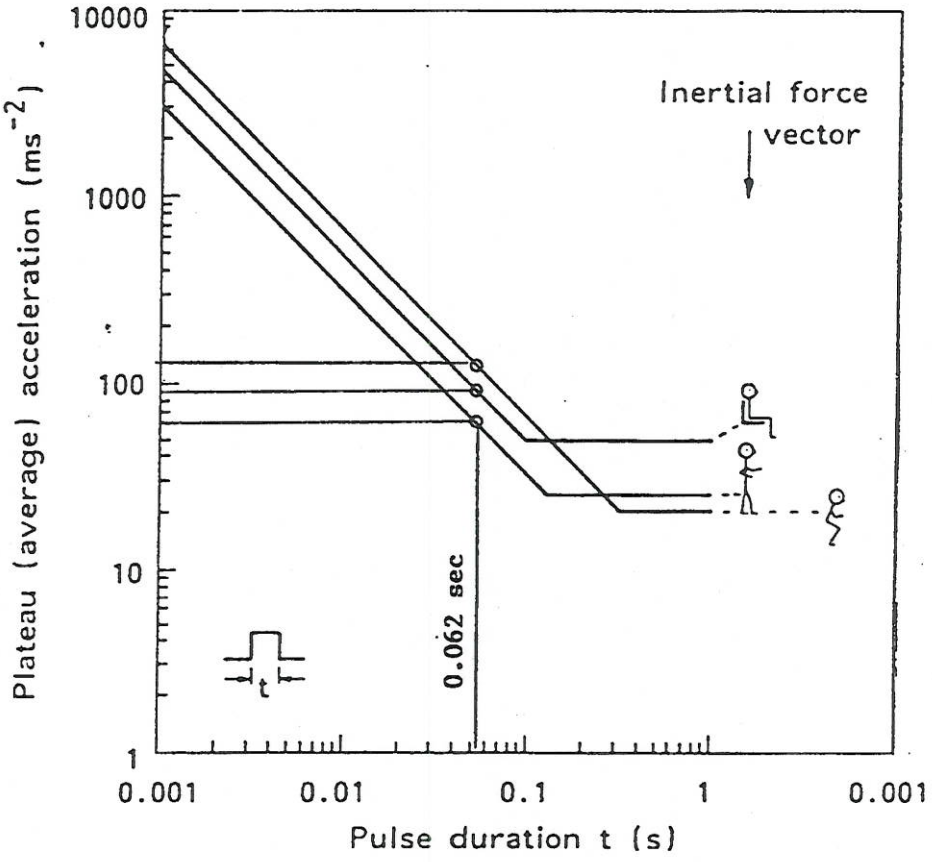

FIGURE 20. ACCELERATION-DURATION INJURY ASSESSMENT, HSPB 8-FT DROP, WEDIM PREDICTION

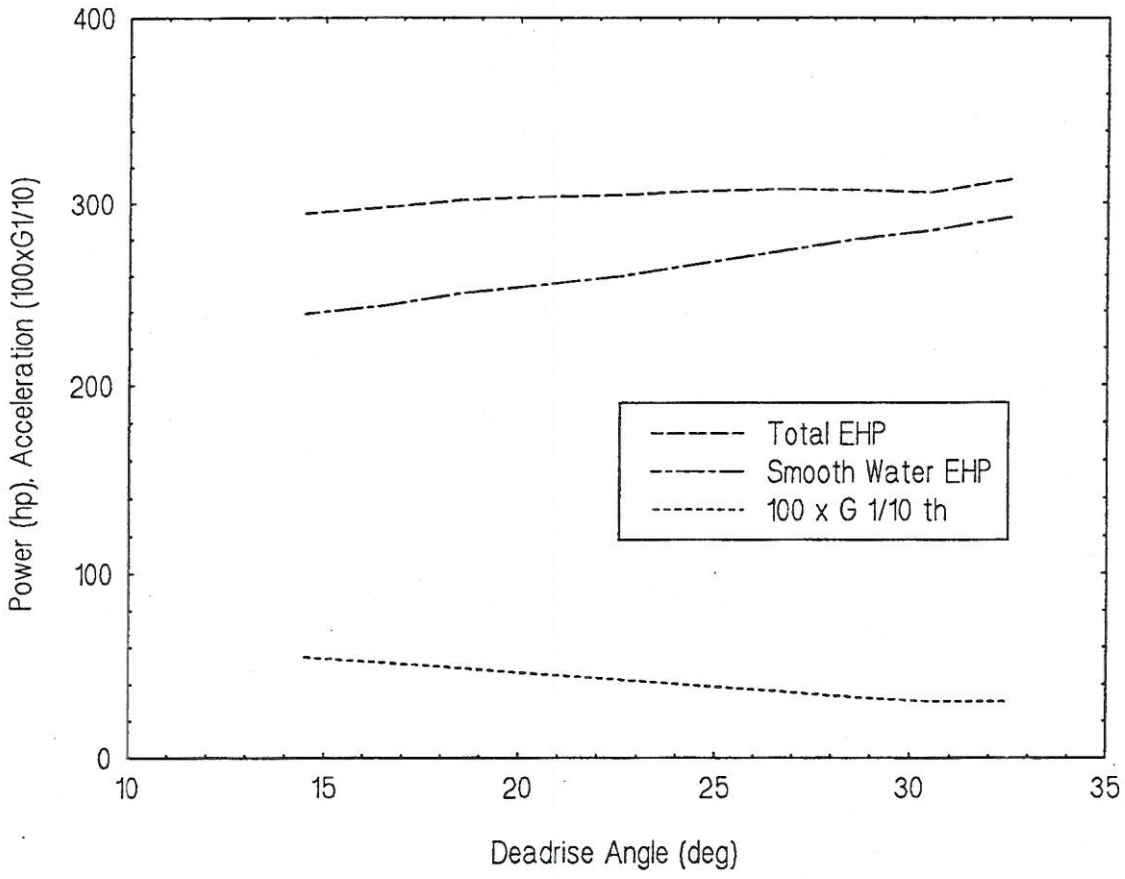

FIGURE 21. DEADRISE/POWER TRADEOFF, HSPB MODEL PREDICTION

TABLE 1. VERTICAL, SEATED HUMAN DRI GUIDELINES

DESIGNATION	APPLICATION	PERCENT PROBABILITY OF SPINAL INJURY	DRI VALUE
Low	USAF Seat Ejection Training	0.5	15.2
Moderate	USAF Ejection Seat Design	5.0	18.0
High	Observed USAF Ejections	50.0	22.0

TABLE 2. PARAMETERS OF BODY-SEAT MODEL

DIRECTION	NATURAL FREQUENCY (rad/sec)	BODY MASS (slugs)	STIFFNESS (lbs/ft)	DAMPING (slugs/sec)	DAMPING RATIO
X (eyes in/out)	62.8	5.14	2.06E4	64.6	0.100
Y (eyes lft/rt)	58.0	5.14	1.71E6	53.7	0.090
Z (eyes down)	52.9	5.14	1.44E4	121.8	0.224

TABLE 3. DRI INJURY ASSESSMENT FOR 8-FT HSPB DROP

PARAMETER	VALUE
Maximum Displacement	0.130 ft
Displacement Response Index	10.0
Maximum Permissible DRI (Low Risk)	15.2
Ratio, Actual-to-Permissible	0.66

TABLE 4. PLATFORM INJURY ASSESSMENT FOR 8-FT HSPB DROP

PARAMETER	VALUE
Maximum Acceleration Equivalent Acceleration Duration	7.30 g 0.062 sec
Maximum Permissible Sitting Ratio, Actual-to-Permissible	7.80 g 0.93
Maximum Permissible Standing, Bent Ratio, Actual-to-Permissible	10.14 g 0.72
Maximum Permissible Standing, Straight Ratio, Actual-to-Permissible	5.31 g 1.37

TABLE 5. HSPB GEOMETRY AND CONDITIONS

GEOMETRY	VALUE
Shaft angle relative to keel	0.0 deg
Distance from shaft line to CG	2.7 ft
Distance from keel to CG	3.1 ft
Distance from transom to CG	10.0 ft
Nominal beam in planing region	8.2 ft
Length on waterline	29.0 ft
Boat weight, fully loaded	19,000 lb
CONDITIONS	**VALUE**
Speed	21 kt
Sea State (significant wave height)	5.5 ft

REFERENCES

1. Gollwitzer, Richard M. and Peterson, Ronald S., *Shock Mitigation on Naval Special Warfare High-Speed Planing Boats Technology Assessment*, CSS/TR-94/33, Nov 1994, Coastal Systems Station, Panama City, FL.

2. Beer, Ferdinand P. and Johnston Jr., E. Russel, *Vector Mechanics for Engineers*, McGraw-Hill Book Co., NY, 1962, pp. 516-523.

3. Hibbeler, R. C., *Engineering Mechanics: Dynamics*, Macmillan Publishing Co. Inc., NY, 1978, p. 185.

4. Harris, Cyril M. and Crede, Charles E., *Shock and Vibration Handbook, Second Edition*, McGraw-Hill Book Co., NY, 1976, p. 1-20.

5. Doebelin, Ernest O., *System Dynamics: Modeling and Response*, Charles E. Merrill Publishing Co., 1972, pp. 100-114.

6. *Standard Test Methods of Mechanical Shock Fragility of Products, Using Shock Machines,* ASTM-D-3332-88, American Society of Testing and Materials, 1988.

7. von Karman, Theodore, *The Impact on Seaplane Floats During Landing*, NACA TN 321, 1929.

8. Wagner, H., *Landing of Seaplanes,* NACA TM 622, May 1931.

9. Milburn, Darrell E., *Technical Characteristics Verification of the 47 FT MLB*, USCG Report CG-D-02-92, U. S. Coast Guard, 1992.

10. Purcell, Edward S.; Allen, Stephen J.; and Walker, Richard T., *Structural Analysis of the U.S. Coast Guard Island Class Patrol Boat*, presented at SNAME Annual Meeting, NY, Society of Naval Architects and Marine Engineers, Nov 1988.

11. Coe, Thomas J., *Seakeeping and Vibration Tests of the 110' Surface Effect Ship Sea Bird Class (WSES)*, USCG Report CG-D-32-84, U. S. Coast Guard, Sep 1984.

12. Lacey, P. and Edwards, R., "ARCO Tanker Slamming Study," *Marine Technology*, Vol. 30, No. 3, Jul 1993.

13. Willems, G.; Muzzy, W.; Knouse, D.; and Gilbreath, F., *Dynamic Response of the Hybrid III Dummy to +Gz Simulated Ship Shock -- Cushioned vs Hard Seats*, NBDL-91R002, Nov 1991, Naval Biodynamics Laboratory, New Orleans, LA.

14. Resource Consultants Incorporated, *LCAC Ride Quality Analysis*, NCSC TM Draft, 1989, Naval Coastal Systems Center, Panama City, FL.

15. Jasper, N. H., *Dynamic Loading of Motor Torpedo Boat (YP110) During High-Speed Operation in Rough Water*, DTMB Structural Mechanics Laboratory R&D Report C-175, Sep 1949, David Taylor Model Basin, Carderock, MD.

16. Heller, S. R., Jr. and Jasper, H. H., "On the Structural Design of Planing Craft," *Quarterly Transactions of the Royal Institution of Naval Architects*, 1961.

17. Reichard, R. P., *Structural Developments in High Speed Offshore Powerboats*, presented at Intersociety High Performance Marine Vehicle Conference and Exhibition, Arlington, VA, Jun 1992.

18. Fridsma, G., *A Systematic Study of the Rough-Water Performance of Planing Boats*, SIT-DL-69-1275, Nov 1969, Stevens Institute of Technology Davidson Laboratory, Hoboken, NJ.

19. Fridsma, G., *A Systematic Study of the Rough-Water Performance of Planing Boats (Irregular Waves - Part II)*, SIT- DL-71-1495, 1971, Stevens Institute of Technology Davidson Laboratory, Hoboken, NJ.

20. Savitsky, D. and Brown, W., "Procedures for Hydrodynamic Evaluation of Planing Hulls in Smooth and Rough Water," *Marine Technology*, Vol. 13, No. 4, Oct 1976.

21. Zseleczky, J., *Seakeeping Model Tests of the U. S. Coast Guard 47- Motor Lifeboat (MLB)*, U. S. Naval Academy Hydromechanics Laboratory Report, prepared for U. S. Coast Guard under MIPR No. Z70098-4-31047, Jun 1988.

22. Boef, W. C. J., "Launch and Impact of Free Fall Lifeboats. Part I. Impact Theory," *Ocean Engineering*, Vol. 30, No. 4, Oct 1992, pp. 119-138.

23. Boef, W. C. J., "Launch and Impact of Free Fall Lifeboats. Part II. Implementation and Applications," *Ocean Engineering*, Vol. 30, No. 4, Oct 1992, pp. 139-159.

24. Ochi, M. D. and Bonilla-Norat, J., *Pressure-Velocity Relationship in Impact of a Ship Model Dropped onto the Water Surface and in Slamming in Waves*, NSRDC Department of Ship Hydromechanics R&D Report 3153, Jun 1970, Naval Ship Research and Development Center, Carderock, MD.

25. Ochi, M. and Schwartz, F., *Two-Dimensional Experiments on the Effect of Hull Form on Hydrodynamic Impact*, DTMB Hydromechanics Laboratory R&D Report 1994, May 1966, David Taylor Model Basin, Carderock, MD.

26. Chuang, S. L., *Investigation of Impact of Rigid and Elastic Bodies with Water*, NSRDC Report 3248, Feb 1970, Naval Ship Research and Development Center, Carderock, MD.

27. Sellars, F. H., "Water Impact Loads," *Marine Technology*, Vol. 13, No. 1, Jan 1976.

28. Gollwitzer, Richard M. and Peterson, Ronald S., *Drop Tests and Computer Modeling for High-Speed Planing Boat Water-Entry Dynamics*, CSS/TR-96/15, Draft, Coastal Systems Station, Panama City, FL.

29. Amatucci, V. A.; Cole, J. K.; and Hailey, C. E., *Air-Dropped Surface Craft Scale-Model Water Entry Experiments*, SAND91-2244, Oct 1991, Sandia National Laboratories, NM.

30. Brinkley, J. W., "Acceleration Exposure Limits for Escape System and Advanced Development," *Safe Journal*, Vol. 15, No. 5, 1985.

31. *Evaluation of Human Exposure to Whole-Body Vibration*, ISO 2631, International Standards Organization; *Part 1, General Requirements*, 1985; *Part 2, Continuous and Shock-Induced Vibration in Buildings (1 to 80 Hz)*, 1989; *Part 3, Evaluation of Exposure to Whole-Body Z-axis Vertical Vibration in the Frequency Range 0.1 to 0.63 Hz*, 1985.

32. *Guide to Measurement and Evaluation of Human Exposure to Whole-Body Mechanical Vibration and Repeated Shock*, BS 6841, British Standards Institution, 1987.

33. Glaister, D. H., "Human Tolerance to Impact Acceleration Injury," *The British Journal of Accident Surgery*, Vol. 9, 1978, pp. 191-198.

34. Hirsch, T. J., *Acceleration Levels for Freefall Lifeboats*, report submitted to Sonat Offshore Drilling, Inc., Texas Transportation Institute, College Station, TX, Jan 1986.

35. Brinkley, J. W., "Acceleration Exposure Limits for Escape System and Advanced Development," *Proceedings of the 22nd Annual Symposium -- SAFE Association*, Vol. 15, No. 5, 1985.

36. Payne, P. R., "Spinal Injury in the Crash Environment," *Aircraft Crashworthiness*, 1975, pp. 273-298.

37. Village, Judy, *Development of a Standard for the Health Hazard Assessment of Mechanical Shock and Repeated Impact in Army Vehicles, Phase 1 Report*, British Columbia Research Corporation, Jul 1992.

38. Village, Judy, *Development of a Standard for the Health Hazard Assessment of Mechanical Shock and Repeated Impact in Army Vehicles, Phase 2 Report*, British Columbia Research Corp., Feb 1993.

39. Gollwitzer, Richard M. and Peterson, Ronald S., *Drop Tests and Planing Boat Dynamics Modeling for Mitigation of Repeated Water-Entry Shocks*, accepted for presentation at Small Craft Symposium '96, Ann Arbor, MI, May 1996.

40. Griffin, M. J., *Human Vibration Handbook*, Academic Press, 1990.

41. *Guide to the Evaluation of Human Exposure to Whole-Body Vibration*, ISO 2631, International Standards Organization; Original, 1974; Revised, 1978; Amendment 1, 1982; Addendum 2, 1982.

42. Military Standard, *Human Engineering Design Criteria for Military Systems, Equipment, and Facilities*, MIL-STD-1472D, Mar 1991.

43. *Air Standardization Agreement, Ejection Acceleration Limits*, Air Standard 61/1A, Air Standard Coordinating Committee, Oct 1977.

44. Brinkley, J. W., "Personnel Protection Concepts for Advanced Escape System Design," *AGARD Conference Proceedings, Human Factors Considerations in High Performance Aircraft*, 1984, pp. G-1 to G-12.

45. Brinkley, J. W. and Shaffer, J. T., *Dynamic Simulation Techniques for the Design of Escape Systems: Current Applications and Future Air Force Requirements*, AMRL-RT-71-29, 1971, Aerospace Medical Research Laboratory, Wright-Patterson AFB, OH.

46. Brinkley, J. W. and Rock, J. T., "Advanced Concepts and Biotechnology for Future Escape Systems," USAF Medical Service Digest, Vol. 34, No. 4, 1983.

47. Amatucci, V. A.; Cole, J. K.; and Hailey, C. E., *Air Dropped Surface Craft Scale-Model Water Entry Experiments*, SAND91-2242, Oct 1991, Sandia National Laboratories, NM.

48. Meier-Dornberg, K. E., "Reference Parameters for Shock Inputs and Shock Tolerance Limits," AGARD-CP-253, *AGARD Conference Proceedings CP-253*, Neuilly-sur-Seine, 1979.

49. *Rules for Construction and Certification of Lifeboats*, Rule Proposal RP-SD-3-86, Det Norske Veritas, Hovik, Norway, 1986.

50. Nelson, J. K.; Hirsch, T. J.; and Phillips, N. S., "Evaluation of Occupants' Accelerations in Lifeboats," *Transactions, ASME, Journal of Offshore Mechanics and Arctic Engineering*, Vol. 11, 1989.

51. *Human Tolerance to Repeated Shock*, ASCC Adv Pub 61/1A, Air Standard Coordinating Committee, 1982.

52. Allen, G., "Human Tolerance to Repeated Shocks," *ESA Life Science Research in Space Conference Proceedings*, Cologne, 1978, pp. 343-349.

53. Allen, G., "The Use of a Spinal Analogue to Compare Human Tolerance to Repeated Shocks with Tolerance to Vibration," AGARD-CP-253, *AGARD Conference Proceedings CP-253*, Neuilly-sur-Seine, 1979.

54. *Guide to Measurement and Evaluation of Human Exposure to Whole-Body Mechanical Vibration and Repeated Shock*, BS 6841, British Standards Institution, 1987.

55. *Third Committee Draft, Guide to the Evaluation of Human Exposure to Whole-Body Mechanical Vibration, Revision of ISO 2631*, ISO TC108/SC4 N190 Third Draft 1-27, International Standards Organization, 1991.

56. Troesch, A. W. and Kang, C. G., "Hydrodynamic Impact Loads on Three-Dimensional Bodies," *Proceedings of the 16th Symposium on Naval Hydrodynamics*, 1986.

57. Purcell, E. S.; Allen, S. J.; and Walker, R. T., *Structural Analysis of the U. S. Coast Guard Island Class Patrol Boat*, presented at SNAME Annual Meeting, New York, NY, Nov 1988.

58. Cole, J. K. and McBride, D. D., *Air Dropped Surface Craft*, Sandia National Laboratories Memorandum to J. Crane, Mar 1994.

59. Gwaltney, R. C., *Analysis Procedure for the Rubber Bladders in the Variable Deadrise Boat*, Oak Ridge National Laboratory Memorandum to R. Gollwitzer, dated 27 Sep 1993.

60. MacDonald, J. F., *Status Report on Finite Element Analysis of Boat*, Coastal Systems Station, Code 3230 Memorandum to R. Gollwitzer, 18 Oct 1993.

61. Savitsky, D., "Hydrodynamic Design of Planing Hulls", *Marine Technology*, Oct 1964.

62. Zarnick, E. E., *A Nonlinear Mathematical Model of the Motions of a Planing Boat in Regular Waves*, DTNSRDC Report 78/032, 1978, David Taylor Naval Ship Research and Development Center, Carderock, MD.

63. Payne, P. R., *Boat 3D - A Time-Domain Computer Program for Planing Craft*, Payne Associates, Tenensville, MD, 1990.

64. Vorus, W. S., "Hydrodynamic Impact and Penetration of Flat Cylinders," *Journal of Fluid Mechanics*, to appear, Jun, 1996.

65. Troesch, A. W. and Falzarano, J. M., "Modern Nonlinear Dynamical Analysis of Vertical Plane Motion of Planing Hulls," *Journal of Ship Research*, Vol. 37, No. 3, Sep 1993.

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