DOT/FAA/AR-07/8

Air Traffic Organization
Operations Planning
Office of Aviation Research
and Development
Washington, DC 20591

The Development of Ditching and Water Impact Design Limit Curves for Civil Rotorcraft

May 2007

Final Report

This document is available to the U.S. public through the National Technical Information Service (NTIS), Springfield, Virginia 22161.

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

This document is disseminated under the sponsorship of the U.S. Department of Transportation in the interest of information exchange. The United States Government assumes no liability for the contents or use thereof. The United States Government does not endorse products or manufacturers. Trade or manufacturer's names appear herein solely because they are considered essential to the objective of this report. This document does not constitute FAA certification policy. Consult your local FAA aircraft certification office as to its use.

This report is available at the Federal Aviation Administration William J. Hughes Technical Center's Full-Text Technical Reports page: actlibrary.tc.faa.gov in Adobe Acrobat portable document format (PDF).

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/AR-07/8		

4. Title and Subtitle	5. Report Date
THE DEVELOPMENT OF DITCHING AND WATER IMPACT DESIGN LIMIT CURVES FOR CIVIL ROTORCRAFT	May 2007
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Gil Wittlin and Max Gamon	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Dynamic Response Inc. 15207 Valley Vista Blvd. Sherman Oaks, CA 91403	11. Contract or Grant No.
12. Sponsoring Agency Name and Address	13. Type of Report and Period Covered
U.S. Department of Transportation Federal Aviation Administration Air Traffic Organization Operations Planning Office of Aviation Research and Development Washington, DC 20591	Final Report
	14. Sponsoring Agency Code
	ANM-100

15. Supplementary Notes

The Federal Aviation Administration Airport and Aircraft Safety R&D Division Technical Monitor was Timothy Smith.

16. Abstract

This report describes the further development of Design Limit Envelopes (DLE) for rotorcraft. A Bell Helicopter (BH) 205 was used as a prototype rotorcraft configuration upon which KRASH models were developed and analyses were performed. Included in the KRASH analysis of ditching and severe, but survivable, water impacts are structural integrity levels and occupant protection considerations. The DLE defines the vertical velocity versus longitudinal velocity relationship for which acceptable structural and occupant protection are provided.

Previously, two full-scale, fully instrumented water impact tests of a helicopter were performed. KRASH models were established and their results correlated with the test results. A correlation between test and analysis results was performed to validate the models and to develop an understanding of the significance of the test measurements, the analytical representation, and the differences between the two. Further confidence in the correlation procedures was established under a Federal Aviation Administration (FAA)-sponsored effort in which a comprehensive evaluation of various correlation techniques was performed. In addition, Title 14 Code of Federal Regulations Parts 27 and 29 requirements and compliance procedures were evaluated in a previous FAA-sponsored effort and shown to have limitations. Under this former effort, preliminary water impact DLEs were proposed based on UH-1H helicopter tests and analyses.

Under this current effort, a set of KRASH BH-205 helicopter structural and occupant models were established based on available data. These models were used to perform analyses for various sets of survivable water impact conditions. Consideration was given to rotorcraft impact velocity and attitude, rotorcraft weight, landing gear position, underside panel strength, mass item design load factors, fuel cell and surrounding structure, crash design load factors, flotation system performance, auxiliary fuel tanks, and water surface sea-state conditions. Acceptance criteria was established based on structural failure loads, occupant lumbar load, head injury, restraint system loads, underside panel failures, major mass item retention, interior structure impingement loads, and seat stroke limitations. A set of survivable water impact DLEs were presented. In addition, floor accelerations were provided for consideration and comparison with existing seat dynamic test requirements.

As a result of this effort, a better understanding of viable design requirements for different levels of water impacts has been achieved. There was also increased confidence in the ability of the analysis to represent all levels of water impacts, as well as evaluate design changes. These results can potentially be used for defining design standards and compliance procedures related to water impact scenarios.

17. Key Words	18. Distribution Statement
Design limit envelopes, DLE, Full-scale crash test, Analytical model, KRASH, Simulation, Water impact, Rotorcraft water impact, Rotorcraft	This document is available to the public through the National Technical Information Service (NTIS) Springfield, Virginia 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	137	

Form DOT F1700.7 (8-72) Reproduction of completed page authorize

ACKNOWLEDGEMENTS

This research was performed under an interagency agreement between the U.S. Naval Air Warfare Aircraft Division and the Federal Aviation Administration Airport and Aircraft Safety Research and Development Division at the William J. Hughes Technical Center in conjunction with Small Business Innovation Research. The contributions and technical support provided by Gary Frings, Timothy Smith, and Steve Soltis are gratefully acknowledged. The valuable inputs from Michael Smith of Bell Helicopter Textron Inc., Dr. Andrew Walton of the Cranfield Impact Center, and Simon Clifford of Westland Helicopters Limited are also greatly appreciated.

TABLE OF CONTENTS

		Page
EXECUTIVE SUMMARY		xv
1.	INTRODUCTION	1
2.	BACKGROUND	2
3.	DISCUSSION	3
3.1	The BH-205 KRASH Structural Models	4
3.2	Major Mass Representations	8
3.2.1	Fuel Mass	8
3.2.2	Occupants	10
3.2.3	Transmission	12
3.2.4	Engine	13
3.2.5	Flotation System	14
3.3	Criteria	15
3.3.1	Structural Integrity	15
3.3.2	Pressure Allowables	17
3.3.3	Occupant/Seat	21
4.	EVALUATION OF OTHER CURRENT ROTARY WING MODELS	21
5.	ANALYSIS RESULTS	24
5.1	Level 1 Water Impact	24
5.1.1	Maximum GTOW Configuration Skid Impact	27
5.1.2	All Configurations—Skid/Float Impact	31
5.1.3	Design Considerations	36
5.1.4	Sea State	51
5.1.5	Unsymmetrical Water Impact	55
5.1.6	Floor and Mass Item Accelerations	59
5.2	Level 2 Water Impact	67
5.2.1	BH-205 Analysis Results for the S1 and S2 Impact Conditions	69
5.2.2	Water Impact on Airframe—12- and 14.5-g LL Seats	73
5.2.3	Water Impact on Skids—12- and 14.5-g LL Seats	75
5.2.4	Civil Rotorcraft Accident Upper 95th Percentile Range	78
5.2.5	Design Allowables—Panel Underside and Bulkhead Pressures	81

5.2.6 Unsymmetrical Impacts 84
5.2.7 Floor and Mass Item Accelerations 88

6. DESIGN LIMIT ENVELOPES, TRENDS, AND TRADEOFFS 93

6.1 Level 1 Water Impact 93
6.2 Level 2 Water Impact 100

7. SEAT TEST PULSES AND SEAT OCCUPANT RESTRAINT LOADS 105

7.1 Floor Pulses/Seat Dynamic Test Requirements 105
7.2 Preliminary Assessment of Head Injury Potential and Restraint Belt Loads 111

8. CONCLUSIONS 120

9. REFERENCES 121

LIST OF FIGURES

Figure		Page
1	Test S1 and S2 Water Impact Scenarios	2
2	Preliminary DLEs	3
3	Line Drawing of the BH-205 Airframe	5
4	Overall View—KRASH BH-205 Basic Structural Model	7
5	Close-up View of Cabin—KRASH BH-205 Basic Model	7
6	Plan View of Cabin Floor Masses	8
7	Fuel-Loading Schedule for all Fuel Tanks	9
8	Overall Fuel c.g. Location Versus Fuel Volume	9
9	Floor Layout for BH-205	10
10	The KRASH Lower and Upper Torso—DRI Occupant Model	11
11	Vertical Load Deflection Curve for Transmission Mounts	13
12	Representative Nonlinear Beam Type Number Curves in KRASH	14
13	Flotation System Installation	14
14	Auxiliary Fuel Tank Installation (View Looking Aft)	16
15	Rotorcraft Water Landing Envelopes—Deployable Float Impact Survivability	35
16	Mass 31 Vertical Velocity Versus Time—20-ft/sec Vertical Velocity Impact	38
17	Mass 31 Hydronamic Pressure Versus Time—20-ft/sec Vertical Velocity Impact	39
18	Fuselage Station 42 Vertical Velocity Versus Hydrodynamic Pressure—20-ft/sec Vertical Velocity Impact	39
19	Fuselage Station 42 Vertical Acceleration Versus Time—20-ft/sec Vertical Velocity Impact	40
20	Fuselage Station 85 Vertical Acceleration Versus Time—20-ft/sec Vertical Velocity Impact	40
21	Floor Longitudinal Acceleration Versus Forward Velocity	46

22	Center of Gravity Longitudinal Acceleration Versus Forward Velocity	46
23	Floor Vertical Acceleration Versus Forward Velocity	47
24	Center of Gravity Vertical Acceleration Versus Forward Velocity	47
25	Pitch Attitude Versus Forward Velocity	48
26	Aircraft Pitch Attitude Comparisons for Suction Effects—10 ft/sec Vertical, 50 ft/sec Longitudinal, +10 Degree Pitch	50
27	Aircraft Pitch Attitude Comparisons for Suction Effects—12 ft/sec Vertical, 25 ft/sec Longitudinal, +5 Degree Pitch	51
28	Longitudinal, Lateral, and Vertical Floor Accelerations, Unsymmetrical Water Impact	59
29	Floor Vertical Acceleration—All Configurations, 20-ft/sec Vertical Impact on Skid/Float	60
30	Velocity Change at Floor Locations—20-ft/sec Impact	61
31	Floor Vertical Acceleration—20-ft/sec Vertical Impact on Airframe	61
32	Floor Vertical Acceleration—16-ft/sec Vertical, 50-ft/sec Longitudinal Impact on Skid	62
33	Floor Longitudinal Acceleration—16-ft/sec Vertical, 50-ft/sec Longitudinal Impact on Skid	62
34	Floor Vertical Acceleration—15-ft/sec Vertical Impact on Skid	63
35	Transmission Vertical Acceleration—20-ft/sec Vertical Impact on Skid/Float, all Configurations	63
36	Engine Vertical Acceleration—20-ft/sec Vertical Impact on Skid/Float, all Configurations	64
37	Fuel Mass Vertical Acceleration—20-ft/sec Vertical Impact on Skid/Float, Three Configurations	64
38	Fuel Mass Vertical Acceleration—15-ft/sec Vertical Impact on Skid/Float, Three Configurations	65
39	Transmission and Engine Vertical Acceleration—15-ft/sec Vertical Impact on Skid, GTOW	65
40	Floor Vertical Acceleration—8-ft/sec Vertical, 50-ft/sec Longitudinal, +10 Degree Pitch Impact on Airframe, GTOW	66

41	Floor Longitudinal Acceleration—8-ft/sec Vertical, 50-ft/sec Longitudinal, +10 Degree Pitch Impact on Airframe, GTOW	67
42	Mass Item Accelerations—Ground Impact	87
43	Mass Item Accelerations—Water Impact	88
44	Floor Vertical Accelerations—All Configurations, 26 ft/sec Vertical, 0 ft/sec Longitudinal, 0 Degree Pitch	89
45	Floor Vertical Accelerations—All Configurations, 20 ft/sec Vertical, 40 ft/sec Longitudinal, +5 Degree Pitch	90
46	Floor Responses at FS 47 and FS 85—GTOW Configuration, 20-ft/sec Vertical Velocity, 40-ft/sec Longitudinal Velocity, +10 Degree Pitch	91
47	Floor Responses at FS 47 and FS 85—GTOW Configuration, 23-ft/sec Vertical Velocity, 39-ft/sec Longitudinal Velocity, +10 Degree Pitch	91
48	Floor Responses at FS 139—GTOW Configuration, 20-ft/sec Vertical Velocity, 40-ft/sec Longitudinal Velocity, +10 Degree Pitch	92
49	Transmission and Engine Accelerations—GTOW Configuration, Vertical and Combined Vertical and Longitudinal Impacts	92
50	Floor Acceleration at FS 42 and FS 85—Maximum GTOW Configuration, 24-ft/sec Vertical Velocity, and 20-ft/sec Longitudinal Velocity	93
51	Water Impact DLE for Calm Sea Scenario—GTOW Configuration	94
52	Water Impact DLEs for Sea-State Scenario—GTOW Configuration 1	95
53	Water Impact DLE Compared to Versus Current 14 CFR 27 and 29.563 Standard	96
54	Floor Peak Vertical Acceleration Versus Sink Speed and Panel Strength	96
55	Mass Item Peak Vertical Acceleration Versus Sink Speed and Panel Strength	98
56	Nose-Over Potential Versus Longitudinal Velocity	98
57	Vertical Velocity Capability Versus Float Design Pressure	99
58	Water Impact DLEs for Amphibian Configuration Versus Float Design Pressure and 14 CFR 29.519 Standard	99
59	Mass Item Vertical Acceleration Trends—Civil Rotorcraft 95th Percentile Upper Limit, 26/0 Impact Condition	100

60	Mass Item Vertical Acceleration Trends—Civil Rotorcraft 95th Percentile Upper Limit, 20/40 Impact Condition	100
61	Mass Item Vertical Acceleration Trends—Civil Rotorcraft 95th Percentile Upper Limit, 12.7/50 Impact Condition	101
62	Water Impact DLEs for Civil Rotorcraft 95th Percentile Limits; 0, +5, +10 Degree Pitch	102
63	Water Impact DLEs for 12- and 14.5-g LL Seats Versus Civil Rotorcraft 95th Percentile Limits	104
64	Fuselage Station 42 Floor Vertical Acceleration—16-, 20-, and 26-ft/sec Vertical Velocity	106
65	Fuselage Station 42 Idealized Floor Vertical Acceleration Pulses for SOMR Analysis	106
66	Fuselage Station 42 Floor Accelerations—20-ft/sec Vertical Velocity, 40-ft/sec Longitudinal Velocity, +10 Degree Pitch	107
67	Idealized Floor Accelerations for SOMR Analysis—20-ft/sec Vertical Velocity, 40-ft/sec Longitudinal Velocity, +10 Degree Pitch	107
68	Current 14 CFR Parts 27 and 29 Dynamic Test Accelerations	108
69	Comparison of Vertical Accelerations	108
70	Floor Accelerations—Water Impact Into a Wave	109
71	Center of Gravity Vertical Accelerations—Water Impact Into a Wave	109
72	Center of Gravity Longitudinal Accelerations—Water Impact Into a Wave	110
73	Center of Gravity and 14 CFR Parts and 27 and 29.562 Longitudinal Seat Test Pulses	110
74	Expanded Seat Occupant Restraint (KRASH-SOMR) Model	112
75	Restraint Belt Webbing Load Versus Elongation	113

LIST OF TABLES

Table		Page
1	Weight Buildup for all Configurations	6
2	Maximum GTOW Size for Basic Model	8
3	Occupants Represented in the BH-205 KRASH Models	12
4	Mass Item Failure Loads	16
5	Underside Panel Pressure Allowables	18
6	Interior Bulkhead Panel Pressure Allowables	19
7	Comparison of Fuel Cell Support Structure Design Pressure Versus KRASH Criteria	20
8	Weight Breakdown for Different Helicopter Configurations	22
9	Sizes and Features of AAIT and KRASH Models	22
10	Summary of Level 1 Water Impact Series Conditions	25
11	Hydrodynamic Surfaces and Locations	26
12	Underside Panel Failure—Base Model (Maximum GTOW), Configuration 1	27
13	Tradeoff Between Sink Speed, Lumbar Load, and Seat Deformation—Maximum GTOW with Attached Skid	29
14	Vertical Impact Results—Maximum GTOW 16 ft/sec	30
15	Lumbar Load Versus DRI Value—Maximum GTOW, Configuration 1	30
16	Engine Mount Failure Mode and NTYPE Versus Deflection	31
17	Underside Panel Failures—Configuration Comparisons	32
18	Comparison of Mass Acceleration and Seat Deflection	34
19	Flotation System Water Impact Performance	35
20	Comparison of Velocity Limits for all Configurations	36
21	Comparison of Gear Retracted Versus Gear/Float Extended	37
22	Tradeoff Between Panel Strength, Seat g Limit, Stroke, and Peak Acceleration	42

23	Float Design Failure Trends	43
24	Effect of Fuselage Contour Design on Responses	44
25	Drag Effects Versus Forward Velocity	45
26	Suction Forces	49
27	Comparison of Failures—Suction Versus Nonsuction, Airframe Impact	49
28	World Meteorological Oraganization Sea-State Code	51
29	Sea-State Panel Failure Results	53
30	Sea-State Bulkhead Panel Pressure Results	55
31	Symmetrical Versus Unsymmetrical Panel Failure Results, Airframe Impact	56
32	Symmetrical Versus Unsymmetrical Water Impact, Floor Responses	56
33	Symmetrical Versus Unsymmetrical Water Impact, Mass Item Responses	58
34	Summary of Level 2 Water Impact Series Conditions	68
35	Vertical Acceleration Results, S1 and S2 Impacts on Airframe	70
36	Longitudinal Acceleration Results, S1 and S2 Impacts on Airframe	70
37	Occupant/Seat Results, S1 and S2 Impacts on Airframe	71
38	Underside Panel Pressure Results, S1 and S2 Impacts on Airframe	72
39	Summary of Airframe Impact Responses—12-g LL Seat, Maximum GTOW Configuration 1	74
40	Comparison of Airframe Impacts With 2- and 14.5-g LL Seats, Maximum GTOW Configuration 1	75
41	Limits for the 14.5-g Seat Based on Initial Airframe Water Impact	75
42	Summary of Skid Impact Responses—12-g LL Seat, Maximum GTOW Configuration 1	76
43	Civil Rotorcraft 95th Percentile Data Points	78
44	Summary of Responses—Civil Rotorcraft Upper 95th Percentile Range, Pitch = 0 Degree, Maximum GTOW Configuration 1	79

45	Summary of Responses—Civil Rotorcraft Upper 95th Percentile Range, Pitch = +5 Degrees, Maximum GTOW Configuration 1	79
46	Summary of Responses—Civil Rotorcraft Upper 95th Percentile Range, Pitch = +10 Degrees, Maximum GTOW Configuration 1	80
47	Summary of Responses—Civil Rotorcraft Lower 95th Percentile Range, Pitch = +5 and +10 Degrees, Maximum GTOW Configuration 1	81
48	Summary of Responses—Civil Rotorcraft Upper 95th Percentile Range, Pitch = +0 and +5 Degrees, all Configurations	81
49	Bulkhead Pressures	83
50	Symmetrical Versus Unsymmetrical Mass Item Responses	85
51	Symmetrical Versus Unsymmetrical Floor Responses	86
52	Ground Versus Water Impact, Unsymmetrical Impact	87
53	Summary of DLEs and Design Criteria Development	104
54	Seat Occupant Model With Restraints Model Description	113
55	Seat Occupant Model With Restraints and BH-205 Analysis Results; Floor Vertical Pulse	115
56	Analysis Results of SOMR and BH-205 Floor; Combined Vertical and Longitudinal Pulse	116
57	Comparison of the 20/40 Impacts With 0, +5, and +10 Degree Pitch Results	117
58	Longitudinal Pulse Results of KRASH/SOMR	118

LIST OF ACRONYMS AND ABBREVIATIONS

AAIT	Air Accident Investigation Tool
axy	Lateral acceleration
ay	longitudinal acceleration
az	Vertical acceleration
BHTI	Bell Helicopter Textron, Inc.
BL	Buttock Line
c.g.	Center of Gravity
CFR	Code of Federal Regulations
DLE	Design landing envelope
DLW	Design landing weight
DRI	Dynamic Response Index
DR Inc.	Dynamic Response Incorporated
FS	Fuselage Station
ft/sec	Feet per second
fwd	Forward
g	Acceleration
GTOW	Gross takeoff weight
HIC	Head injury criteria
Hz	Hertz
IC	Impact condition
in.	Inch
KR	Krash
lb	Pound
L/H	Wave length to height ratio
LG	Landing gear
LHS	Left-hand side
LL	Load limit
msec	Millisecond
NTYPE	Nonlinear beam type number
OEW	Operating empty weight
psi	Pounds per square inch
RHS	Right-hand side
SBIR	Small Business Innovative Research
Sec	Second
SI	Severity index
SOMR	Seat occupant model with restraints
V2	Vertical velocity
WL	Water line
USAAMRDL	U.S. Army Air Mobility Research and Development Laboratory

EXECUTIVE SUMMARY

This report describes the further development of water impact Design Limit Envelopes (DLE) for rotorcraft. A Bell Helicopter BH-205 was used as a prototype aircraft configuration upon which KRASH models were developed and analyses were performed. Included in the KRASH analysis of ditching and severe, but survivable, water impacts are structural integrity levels and occupant protection considerations. DLE defines the vertical velocity versus longitudinal velocity relationship for which acceptable structural and occupant protection are provided.

Previously, two full-scale, fully instrumented water impact tests of a helicopter were performed. KRASH models were established and their results correlated with the test results. A correlation between test and analysis results was performed to validate the models and to develop an understanding of the significance of the test measurements, the analytical representation, and the differences between the two. Further confidence in the correlation procedures was established under a Federal Aviation Administration (FAA)-sponsored effort in which a comprehensive evaluation of various correlation techniques was performed. In addition, Title 14 Code of Federal Regulations Parts 27 and 29 standards and compliance procedures were evaluated in a previous FAA-sponsored effort. Under this former effort, preliminary water impact DLEs were proposed based on UH-1H helicopter tests and analyses.

Under this current effort, a set of KRASH BH-205 helicopter structural and occupant models were established based on available data. These models were used to perform analysis for various sets of survivable water impact conditions. Consideration was given to aircraft impact velocity and attitude, aircraft weight, landing gear position, underside panel strength, mass item design load factors, fuel cell and its surrounding structure crash design load factors, flotation system performance, auxiliary fuel tanks, and water surface sea-state conditions. Acceptance criteria was established based on structural failure loads, occupant lumbar load, head injury, restraint system loads, underside panel failures, major mass item retention, interior structure impingement loads, and seat stroke limitations. A set of survivable water impact DLE were presented. In addition, floor accelerations were provided for consideration and comparison with existing seat dynamic test requirements.

As a result of this effort, a better understanding of viable design requirements for different levels of water impacts has been achieved. There was also increased confidence in the ability of the analysis to represent all levels of water impacts, as well as evaluate design changes. These results can potentially be used for defining design standards and compliance procedures related to water impact scenarios.

1. INTRODUCTION.

The objective of this effort is to

- evaluate the structural integrity and injury potential for different levels of water impacts, ranging from ditching to severe but survivable.
- develop civil rotorcraft Design Limit Envelopes (DLE) for different levels of water impacts based on acceptable structure and occupant protection integrity.
- develop civil rotorcraft representative floor pulses for different levels of water impacts based on acceptable structure and occupant protection integrity.

The effort described herein discusses a wide range of water impact scenarios ranging from ditching to severe but survivable. It is recognized that

- amphibian rotorcraft standards address normal, water-landing procedures, not emergency landings on water.
- ditching standards address a controlled emergency landing on water. The assumption is the rotorcraft is intact prior to water impact and all controls and essential systems (except engines) are functioning properly. Current standards are impact velocities less than 30 knots (50.6 ft/sec) horizontal and 5 ft/sec vertical.
- crashworthiness standards are based on survivable impact conditions and human tolerance limits.

It is important to recognize from the results of this research that there are water-landing conditions, more severe than ditching, where both structural integrity and occupant protection are not exceeded. Thus, for purposes of this effort, different water impacts are defined as:

- Ditching: Control-defined impact scenario
- Level 1 water impact: Maintain structural integrity in the form of a protective shell
- Level 2 water impact: Stay within human tolerance limits in addition to level 1 water impact

A DLE is used in this report as a design condition based on ultimate capability of structure and/or occupant protection.

Several Bell Helicopter BH-205 models were developed using KRASH (KR) lumped mass modeling software. These included both structural and occupant/seat representations. The structural models took into consideration a maximum gross takeoff weight (GTOW) configuration, a design landing weight (DLW) low fuel configuration, an amphibious float configuration, and an auxiliary fuel tank configuration. The structural models provided for an assessment of structural loads, including mass retention and underside panel failures during a wide range of water impact scenarios. The occupant/seat representation, in conjunction with the structural models, provided for an assessment of occupant injury potential and restraint system performance under various water impact conditions. The results established design limits as a

function of aircraft impact velocity and attitude, aircraft sea state, wave orientation, aircraft weight, seat occupant structure integrity, and human tolerance limits.

2. BACKGROUND.

Two water impact tests and associated analyses have previously been performed on the Small Business Innovative Research (SBIR) effort and reported in several reports [1-3]. The first test, designated S1, was an impact at 26 feet per second (ft/sec) vertical, 0 ft/sec longitudinal, and 0 degree pitch with a truncated UH-1H airframe. The second test, designated S2, had impact conditions of 28-ft/sec vertical, 39-ft/sec longitudinal, and 4 degree nose-up pitch, using a full UH-1H aircraft with tail section and landing skids. These impacts are shown in figure 1.

S1 Vertical Impact

S2 Combined Vertical Longitudinal Impact

Figure 1. Test S1 and S2 Water Impact Scenarios

Both floor and mass item accelerations and underside panel pressures were measured on each test. The tests were simulated using a lumped mass KRASH model. Subsequent correlation between analysis and test results and parameter studies provided an analytical approach to develop preliminary UH-1H design limit curves [4]. The BH-205 is similar to the UH-1H with regard to airframe size and shape.

Figure 2 shows the preliminary DLEs presented previously [4] for various water impact scenarios. These curves were based on the design pressure allowables, calm seas, military personnel weights, and stroking limits of 12 inches and were presented to illustrate a potential form of DLEs.

- For the ditching conditions there is no fuselage underside panel pressure failure allowed. This is the design limit identified as NPF. This is a conservative criteria that does not allow for interior surface water penetration.

- For the more severe water impacts, the fuselage underside panel can fail, but there is to be no subsequent interior water impingement failure allowed as a consequence. This design limit is identified as SPF. For each outer panel, there can be an associated interior panel, i.e., floor structure, which can be subject to water pressure only if the exterior panel fails. SPF represents failures of such panels, which are referred to as secondary surfaces.

- Another design limit, identified as ST, precludes the maximum allowable seat stroke to be reached.

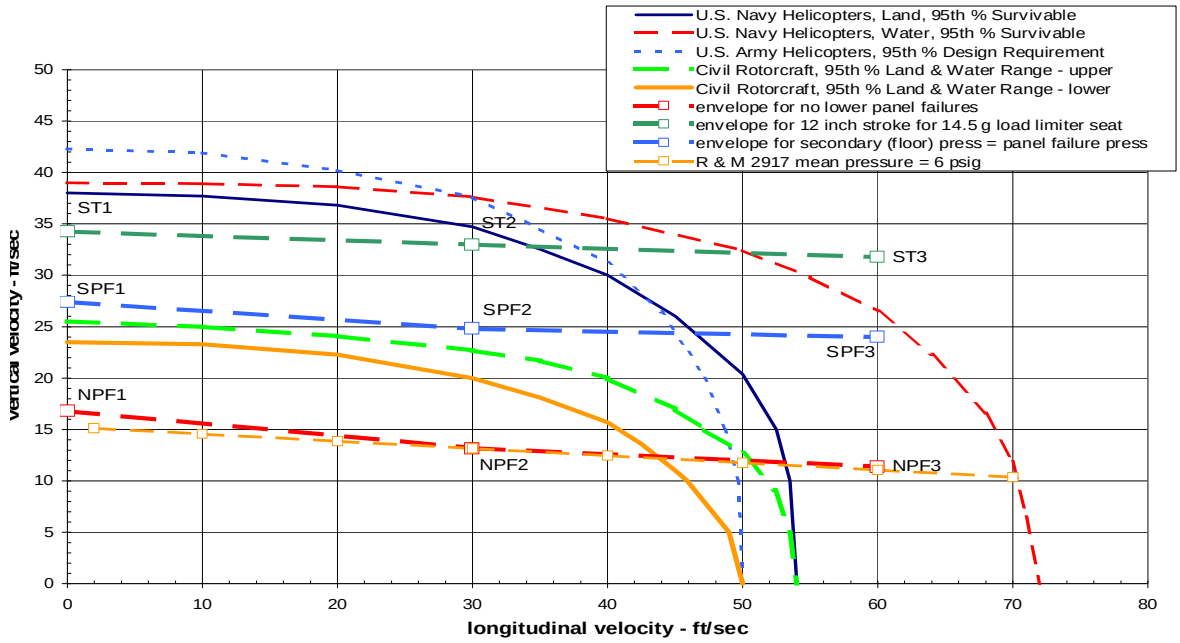


Figure 2. Preliminary DLEs [4]

There are several limitations associated with the ST, SPF, and NPF envelopes shown in figure 2, i.e., they do not take into account

- current civil rotorcraft 14 CFR Parts 27 and 29 design standards.
- mass item retention criteria and interior structure integrity limits.
- aircraft wave orientation effects.
- civil occupant weights, seat stroke limits, and restraint loads.

Thus, the effort described herein is an enhancement of the preliminary DLEs taking into consideration many more factors.

3. DISCUSSION.

The following sources of data are used in the development of BH-205 KRASH models:

- SBIR UH-1H water impact tests, analysis, and UH-1H KRASH models [1, 2, 3, and 4]

- BH-205A-1 flight manual, supplements, and discussions [5]

- BH-204/205A-1 installation kit 204-706-053-057; amphibious landing gear [6]

- BH-204/205A-1 installation kit 204- 706-044/045; auxiliary fuel system [7]

- U.S. Army Crash Survival Design Guide [8]

- 14 CFR Parts 27 and 29 Airworthiness Standards: Normal Category Rotorcraft [9] and Transport Category Rotorcraft [10]

- U.S. Army Air Mobility Research and Development Laboratory (USAAMRDL) 72-72A [11]

3.1 THE BH-205 KRASH STRUCTURAL MODELS.

- Configuration No. 1: Basic Structural Model (maximum GTOW)

  - Maximum GTOW 9500 lb

  - Center of gravity (c.g.) = Fuselage station (FS) 142.55 (forward-aft limit = 130-143.1)

  - Operating empty weight (OEW) = 5260 lb

  - Fuel = 220 gallons = 1435 lb

  - Pilot + copilot + 13 Passengers (170 lb/passenger) = 2550 lb

  - Baggage = 255 lb

- Configuration No. 2: Basic Structural Model with Minimum Fuel (design landing weight (DLW)):

  - Landing weight 8000 lb
  - c.g. = FS 138.79 (forward-aft limit = 130-143.1)
  - OEW = 5260 lb
  - Fuel = 40.4 lb
  - Pilot + copilot + 13 passengers (170 lb/passenger) = 2550 lb
  - Baggage = 149.6 lb

- Configuration No. 3: Amphibious Landing Gear Operations Structural Model (over water takeoff):

  - Maximum GTOW = 8500 lb
  - c.g. = FS 142.8 (forward-aft limit = 130-143.1)
  - OEW = 5260 lb
  - Amphibious gear weight = 328 lb
  - Fuel = 220 gallons = 1435 lb maximum
  - Pilot + copilot + 6 occupants = 1360 lb
  - Baggage = 233.3 lb

- Configuration No. 4: Auxiliary Fuel Tank Structural Configuration

- Maximum GTOW 9500 lb
- c.g. = FS 141.4 (forward-aft limit = 130-143.1)
- OEW = 5260 lb
- Auxiliary fuel tank weights = 74 lb (auxiliary fuel tank weight) + 1170 lb (180 gallons)
- Total fuel = 400 gallons = 2370 lb maximum (total = internal + auxiliary tanks)
- Pilot + copilot + 8 passengers (170 lb/passenger) = 1700 lb
- Baggage = 170 lb

The BH-205 Airframe line drawing in figure 3 illustrates the size, shape, and location of the cabin floor and bulkhead interior.

A summary of the weight buildup for these conditions is noted in table 1.

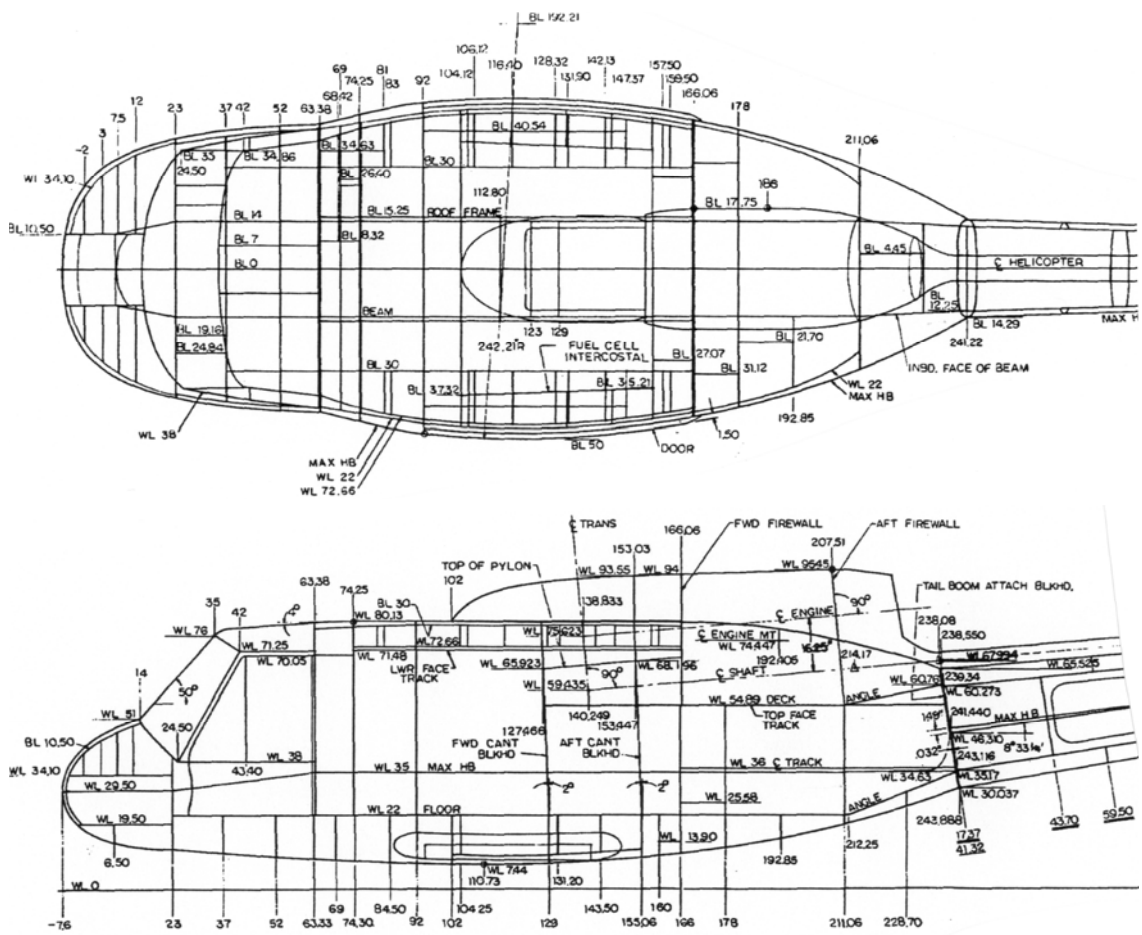


Figure 3. Line Drawing of the BH-205 Airframe

Table 1. Weight Buildup for all Configurations

Configuration Number	1	2	3	4
Description	Maximum Fuel, All Occupants	Minimum Fuel, All Occupants	Floats, Maximum Fuel, 8 Occupants	Auxiliary Fuel Tank, 10 Occupants
Total gallons of fuel (220 or 400 max)	220	6.2	220	358.923
Empty weight (lb)	5260	5260	5260	5260
Total fuel weight (lb)	1435	40.4	1435	2370
Baggage weight (400 max) (lb)	255	149.6	233.3	170
Total occupants weight (lb)	2550	2550	1360	1700
FS of fuel c.g.	153.2	143.6	153.2	149.0
FS of baggage c.g.	268.5	258.0	266.33	260.0
FS of total occupants c.g.	107.8	107.8	84.5	91.0
Overall weight (lb)	9500.0	8000.0	8500.0	9500.0
Overall FS (aft limit = 143.1)	142.6	138.8	142.8	141.4
Copilot or Fwd Pax - FS 47	1	1	1	1
Pilot - FS 47	1	1	1	1
Pax - fwd row - far left - FS 87	1	1	1	1
Pax - fwd row - center left - FS 87	1	1	1	1
Pax - fwd row - center right - FS 87	1	1	1	1
Pax - fwd row - far right - FS 87	1	1	1	1
Pax - mid row - far left - FS 117	1	1	1	1
Pax - mid row - center left - FS 117	1	1	0	1
Pax - mid row - center - FS 117	1	1	0	0
Pax - mid row - center right - FS 117	1	1	0	1
Pax - mid row - far right - FS 117	1	1	1	1
Pax - side facing - fwd - left – FS 139	1	1	0	0
Pax - side facing - fwd - right - FS 139	1	1	0	0
Pax - side facing - aft - left - FS 156	1	1	0	0
Pax - side facing - aft - right - FS 156	1	1	0	0

Fwd = Forward
Max = Maximum
Pax = Passenger

The overall model for the basic configuration is shown in figure 4, with a closer view of the cabin region in figure 5. Figure 6 shows a plan view of the floor masses in the cabin region, applicable to all configurations. The blue squares are seat occupant locations, while the red squares are the basic fuel tank locations. The side-facing occupants in figure 5 are not there for the auxiliary fuel tank configuration.

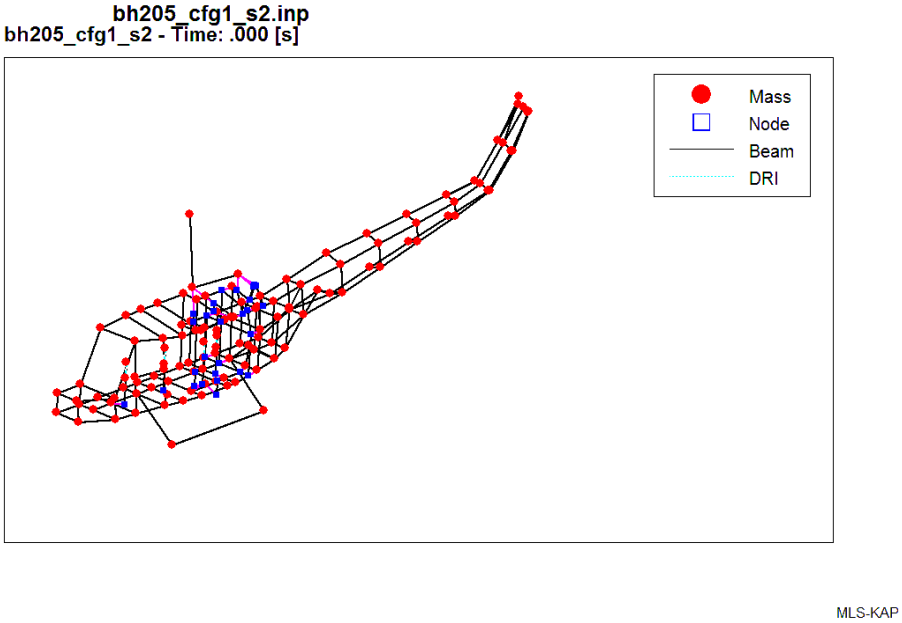


Figure 4. Overall View—KRASH BH-205 Basic Structural Model

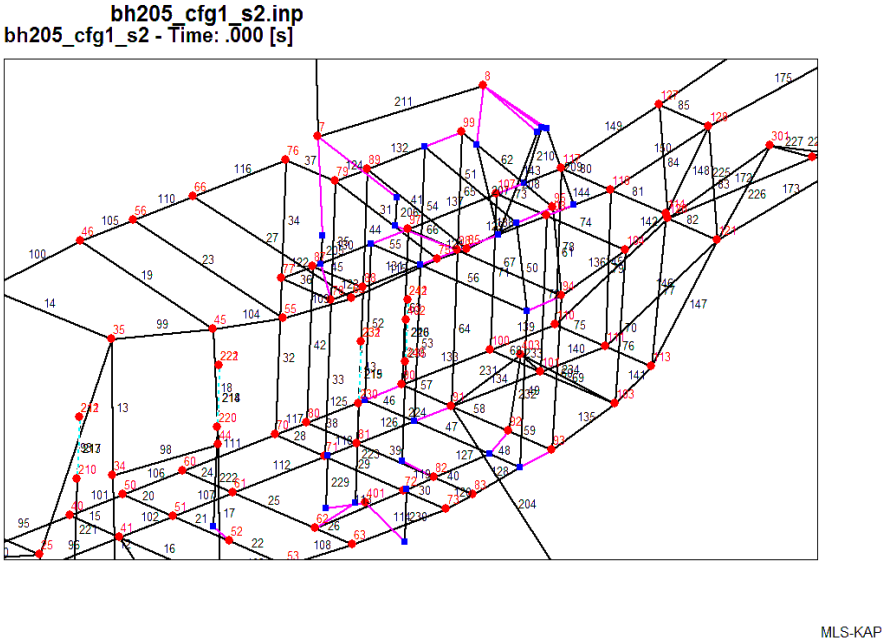


Figure 5. Close-up View of Cabin—KRASH BH-205 Basic Model

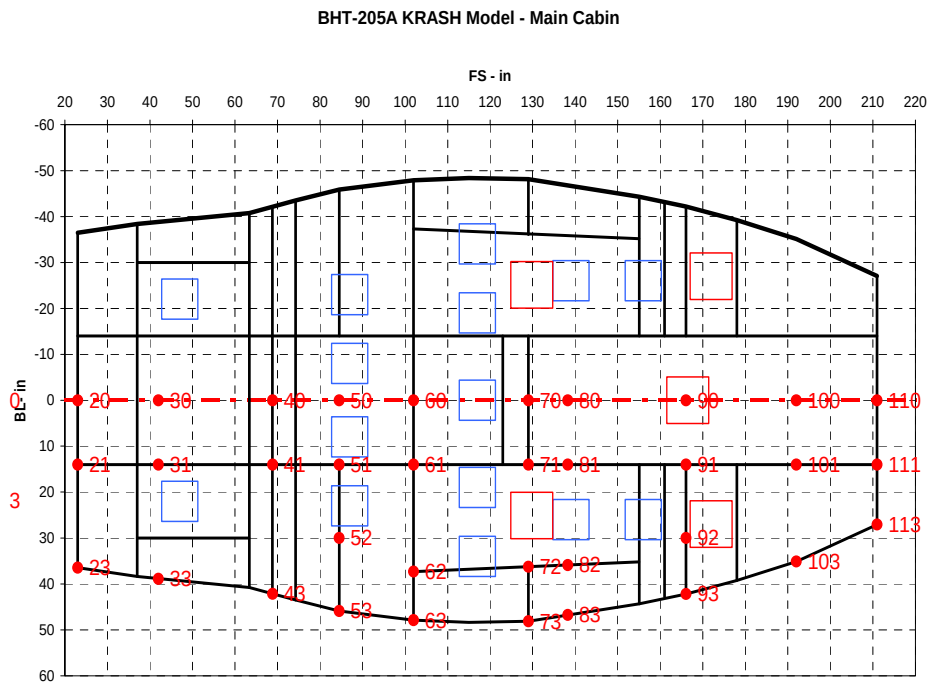


Figure 6. Plan View of Cabin Floor Masses

The KRASH model size varies somewhat between models. The basic model (maximum GTOW) size is shown in table 2.

Table 2. Maximum GTOW Size for Basic Model

Maximum GTOW Size	Half	Full
Number of masses	125	206
Number of beams	235	420
Number of node points	28	54
Number of hydrodynamic surfaces	21	32
Number of nonlinear beams	10	20
Number of Dynamic Response Index elements	4	8

3.2 MAJOR MASS REPRESENTATIONS.

3.2.1 Fuel Mass.

The fuel schedule curves for the forward (fwd), mid, aft, and auxiliary fuel tanks are shown in figure 7.

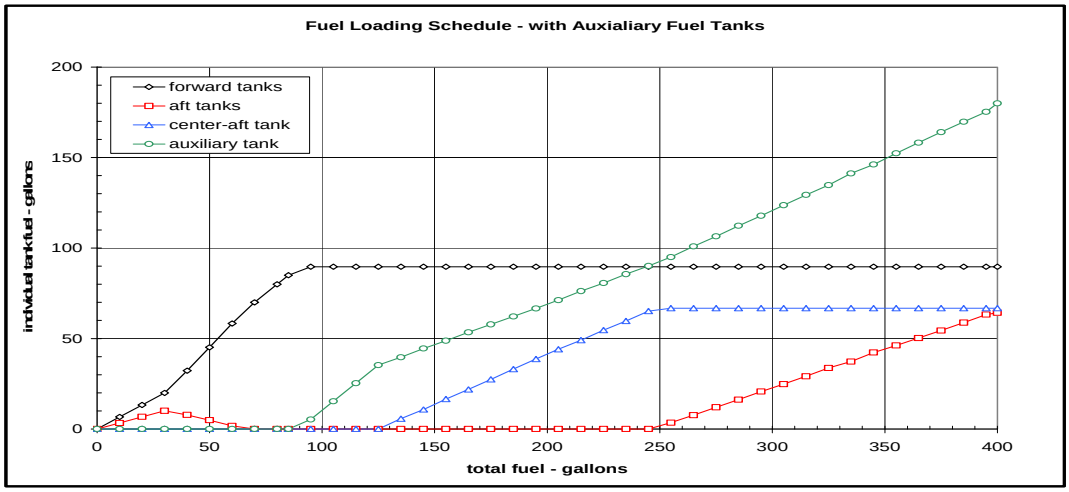


Figure 7. Fuel-Loading Schedule for all Fuel Tanks

The resulting overall fuel c.g. position is shown in figure 8 for all configurations. Also shown in figure 8 is the data provided in BH-205 manuals, as well as the approximation used in KRASH.

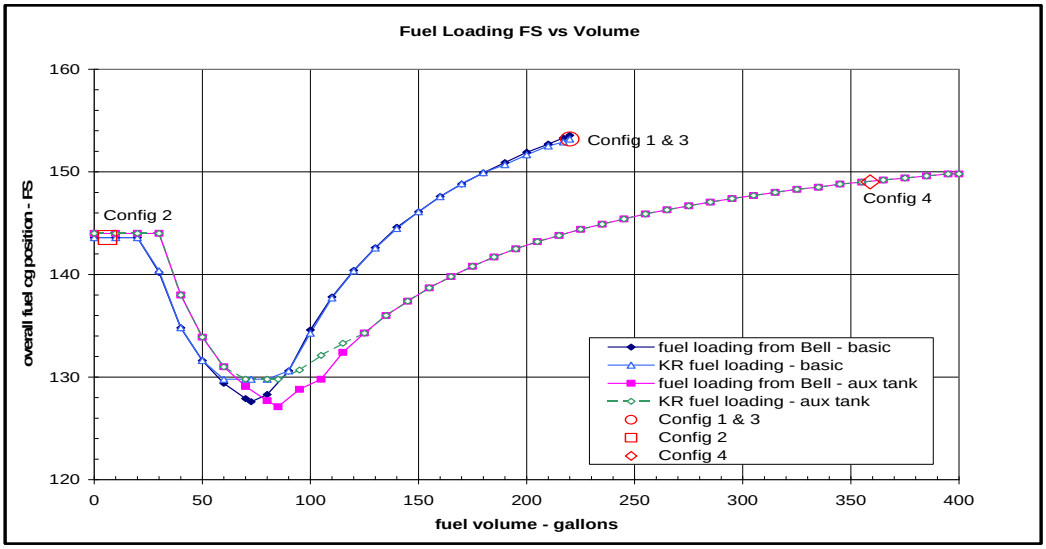


Figure 8. Overall Fuel c.g. Location Versus Fuel Volume

The KRASH curves are in agreement with the available data, except for the region around 60 to 130 gallons. BH-205 data for the fuel tank locations show the forward tanks to be at FS 129.8, with all other tanks aft of that. Therefore, if all fuel were in the forward tank, the most forward c.g. position would be 129.8. Thus, it is not possible to derive a fuel-loading sequence that will duplicate the fuel c.g. positions forward of FS 129.8. For the four fuel-loading test configurations developed, the KRASH and BH-205 data agree perfectly.

The fuel masses in KRASH are lumped at three locations, as follows:

- Forward fuel cell, mass 401: FS 129, water line (WL) 15.5, buttock line (BL) 25 ±25
- Center mass fuel cell, mass 402: FS 166, WL 35.5, BL 0
- Aft fuel cell, mass 403: FS 172, WL 35.5, BL 27 ±27

Each mass is attached to one or more passenger floor masses as follows:

- Mass 401 to floor mass 71 and 72, at FS 166, BL 14 and 36
- Mass 402 to floor mass 90, at FS 166, BL 0
- Mass 403 to floor masses 91 and 92, at FS 166, BL 14, and 30,
- Mass 403 to floor masses 100 and 103, at FS 192, BL 14, and 35

The fuel masses are represented this way to be able to monitor an overall acceleration. In reality, the fuel might be spread over several masses, which would require each mass to be monitored. Either way it is difficult to relate the fuel response to specific failure criteria. The lumped mass representation allows three specific masses to be compared on a relative basis.

3.2.2 Occupants.

A fully occupied seating configuration for the BH-205 has the following:

- Forward facing pilot and copilot at FS 47, BL ±22
- Four aft facing occupants at FS 87, BL ±8, ±23
- Five forward facing occupants at FS 117, BL 0, ±19, ±34
- Two opposite side facing seats at FS 139, BL ±26
- Two opposite side facing seats at FS 156, BL ±26

Figure 9 shows the layout of the BH-205 floor plan [2], including the location of the occupants and fuel cells. Also shown is the cargo region located between FS 243 and FS 327.

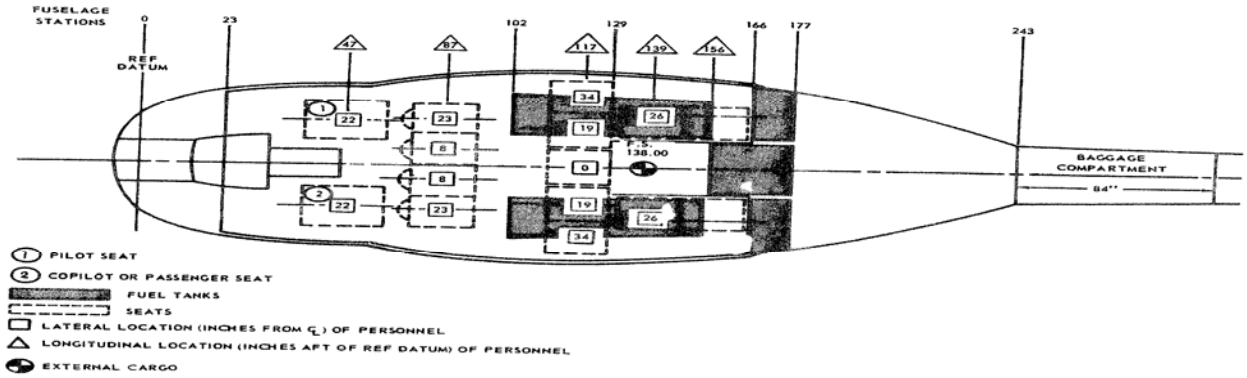


Figure 9. Floor Layout for BH-205

The KRASH occupant weight is included in all models either as a lumped mass attached to the floor or as a Dynamic Response Index (DRI) occupant model. When the DRI occupant model is incorporated, it consists of a mass representing the upper torso, a mass representing the lower torso, and a floor mass. The occupant weight is distributed 44% at the upper and lower torso masses and 12% at the floor. The seat mass is distributed as 50% at the lower torso and 50% at the floor. The DRI adds another mass equal to the upper torso mass, but that weight is not added to the model weight. Typically, for military aircraft, a 14.5-g load limit (LL) seat is applied. For the BH-205, a 12.0-g LL seat [9] was used initially. When a LL device is applied, i.e., 12.0 g, then the 12.0 g is applied for the combined weight of the upper and lower torso. The floor to lower torso beam is treated as a constant load element after the appropriate limit force is reached. This type of model, shown in figure 10, does not treat fore and aft loads appropriately. Where this DRI occupant model is not used, an appropriate seat occupant mass is included at the floor.

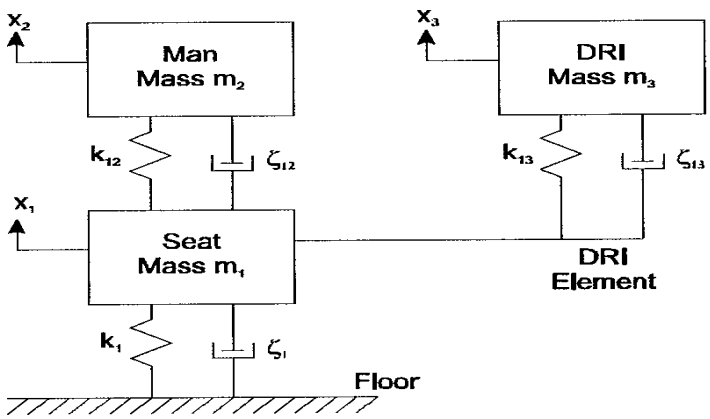


Figure 10. The KRASH Lower and Upper Torso—DRI Occupant Model

The DRI occupant model shown in figure 10 addresses the potential for spinal injury and not head injury or restraint system loads. It is also limited wherein the primary load may not be vertical.

An occupant sample layout of mass and DRI representations in two of the configurations is shown in table 3.

Table 3. Occupants Represented in the BH-205 KRASH Models

Occupants	15-Occupant Model				8-Occupant Model			
	Representation	Occupant Weight (lb)	FS	BL	Representation	Occupant Weight (lb)	FS	BL
Pilot	DRI	170	42	22	DRI	170	42	22
Copilot	DRI	170	42	-22	DRI	170	42	-22
Pass aft	DRI	170	87	23	DRI	170	87	23
Pass aft	mass	170	87	8				
Pass aft	mass	170	87	-8				
Pass aft	DRI	170	87	-23	DRI	170	87	-23
Pass fwd	DRI	170	117	34	DRI	170	117	34
Pass fwd	mass	170	117	19				
Pass fwd	mass	170	117	0				
Pass fwd	mass	170	117	-19				
Pass fwd	DRI	170	117	-34	DRI	170	117	-34
Pass side	mass	170	139	26				
Pass side	mass	170	139	-26				
Pass side	DRI	170	156	26	DRI	170	156	26
Pass side	DRI	170	156	-26	DRI	170	156	-26
Total		2550				1360		

3.2.3 Transmission.

The following describes changes that were made to the 5152 models concerning the transmission and main rotor hub:

- Main rotor, tail rotors, and hub were modeled with proper mass and inertia.

- The vertical beams from transmission to rotor/hub (beams 7 to 9) were revised to include the area and cross-sectional inertia data from the earlier UH-1H model. Since the beam length of the current model is much longer than the corresponding older model, the beam cross-sectional area was increased to match the beam axial stiffness between old and new models. Appropriate bending stiffness were selected to represent frequencies in the 8-to 20-Hz range

- The transmission mounts (beams 7,1 to 78,1 and 7,2 to 98,3) are 6-inch-long vertical beams, two per side, that support the transmission. The stiffness data for these beams comes from Bell Helicopter Textron, Incorporated (BHTI) NASTRAN model data. The total vertical (axial) stiffness of the four transmission support beams is 23,400 lb/in.

- For the revised current model, the two side transmission support beams are modeled as type-10 nonlinear beams (see figure 11), with total initial stiffness of 23,400 lb/in., and

final bottomed stiffness of 2.04e6 lb/in. This uses the BHTI NASTRAN data, which is soft enough that it appears to represent the transmission isolators rather than metal-to-metal contact.

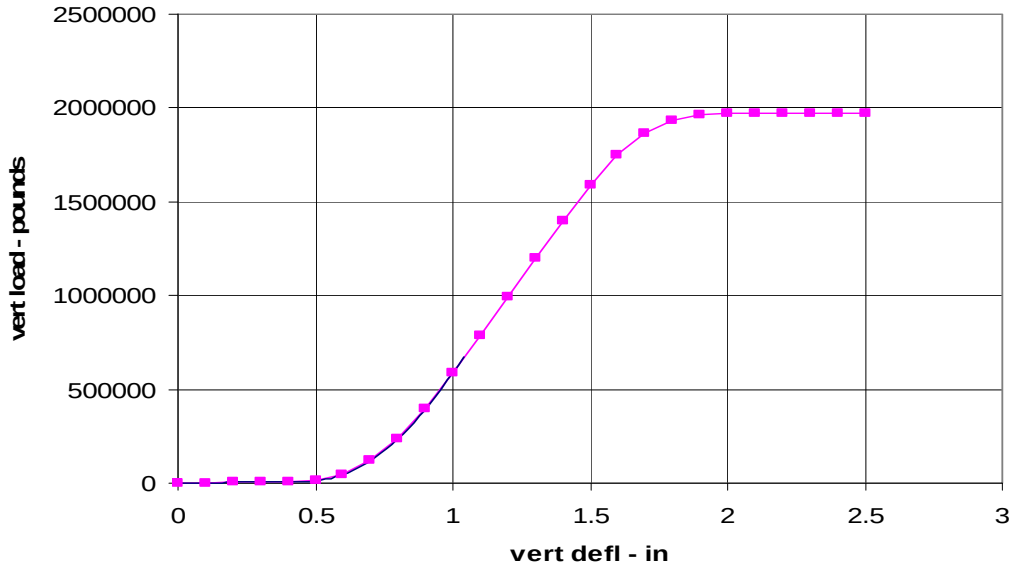


Figure 11. Vertical Load Deflection Curve for Transmission Mounts

3.2.4 Engine.

The engine (mass 8, figure 5) is supported by four beams per side. The linear properties for the engine support beams were taken from a NASTRAN model. Two mount failure modes are considered. For the compressive yield mode, the axial nonlinearities are set to deflections corresponding to 1.2 x-axial yield stress, with type 5 KR curves. These deflections are set at 0.06 inch. This failure mode was initially used. Another consideration is for the supports to buckle. For the long column buckling mode, the yield deflections were set between 0.030 and 0.040 inch. Type 5, 6, and 7 KR curve types (figure 12) were considered. Type 5 provides lesser deflection than type 6 and type 7 greater deflection. If all supports contribute to the engine responses with peak load simultaneously (unlikely), the maximum peak vertical acceleration would be between 35 and 62 g.

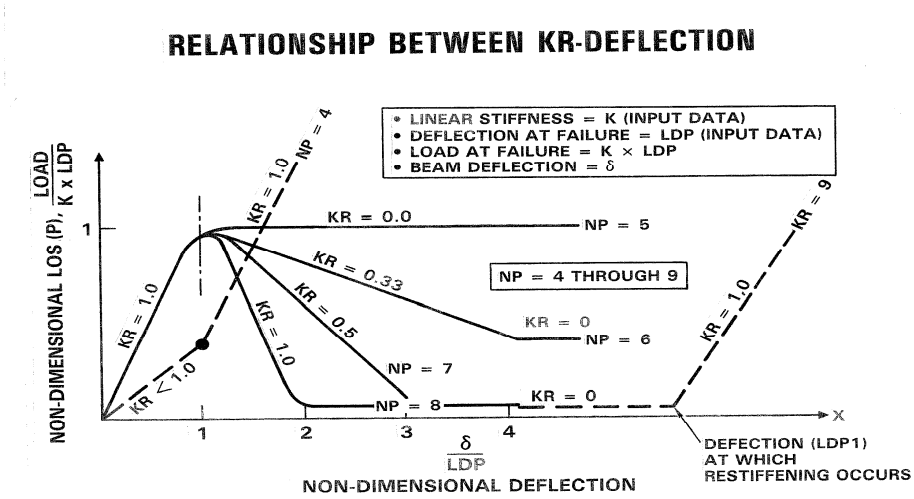


Figure 12. Representative Nonlinear Beam Type Number Curves in KRASH

3.2.5 Flotation System.

The flotation system weighs 328 lb and is centered at FS 120. It attaches to the skid at FS 71.62 and FS 163. The installation, obtained from reference 3, is illustrated in figure 13. The float is shaped like a cylinder and treated as three-additional masses per side. The float is also treated as lifting surfaces with an area consistent with its shape and size.

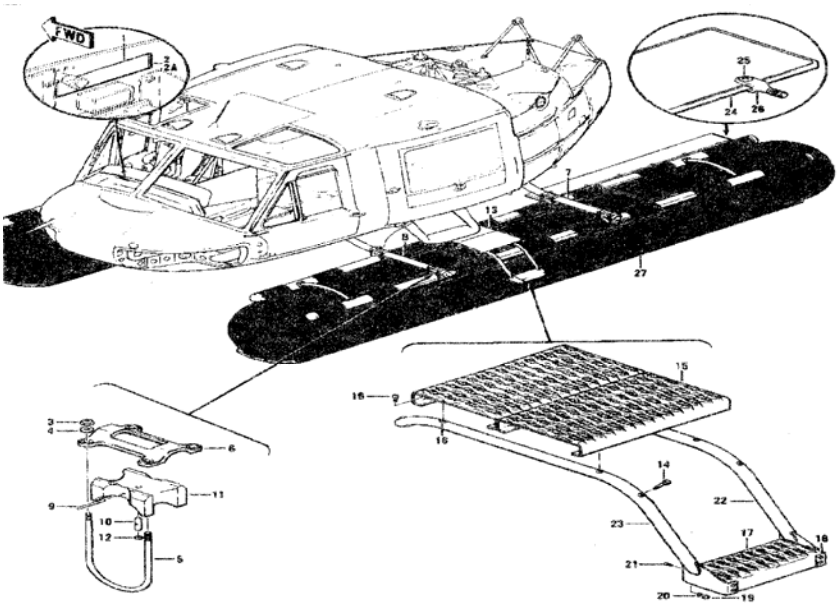


Figure 13. Flotation System Installation

3.3 CRITERIA.

3.3.1 Structural Integrity.

Strength allowable for major mass items, as defined in 14 CFR 27.561 (14 CFR 29.561) and fitting factors defined in 14 CFR 27.625 (14 CFR 29.625) are used to establish failure criteria for masses above and behind the crew and passenger [7 and 8]. This is applicable to the engine, transmission, cargo, and fuel tanks above the floor and auxiliary fuel mass on their supports. These inertia loads, in the most significant directions during a crash, are:

- Upward and forward: 12 g x 1.15 = 13.8 g
- Sideward: 6 g x 1.15 = 6.9 g

The S2 test [12], which contained an actual engine and transmission, measured peak accelerations that showed no indication of failure of these mass items and responses of

- 15.6-g vertical and 12.3-g longitudinal for the transmission and
- 19.7-g vertical and 14.6 g-longitudinal for the engine.

In addition, UH-1H crash test results indicated that for a 23-ft/sec vertical velocity and 18-ft/sec lateral velocity impact both the transmission and engine sustained peak vertical acceleration between 25 and 30 g, with deformation but not catastrophic failure. Lateral accelerations on that same test reached 12 g on the engine and 9 g on the transmission.

The design crash load factors for the BH-205 fuel cells are 20 g vertical, 20 g longitudinal, and 10 g lateral with full fuel tanks. The criteria and design pressures for the cell support structure is discussed in section 3.3.2.

Thus, for purposes of providing mass failure and retention criteria, dynamic load factors of 30 g vertical, 30 g longitudinal, and 15 g lateral were initially used for the transmission, engine, and fuel masses. For the engine and transmission, these load factors provided a margin above both the specified load factors and the known test results. For the fuel cell support structure, these load factors are also conservative, as is noted in section 3.3.2. The main rotor mass will be included as part of the transmission mass. The engine and transmission support mass attachment deflections can be monitored as well, if required.

The basic aircraft holds up to a total of 220 U.S. gallons of fuel. The auxiliary fuel tanks are bolted to structure in one of the following possible configuration combinations:

- Two 20-gallon tanks
- One 20- and one 90-gallon tank
- Two 90-gallon tanks

The KRASH model considers the maximum addition of 180 gallons (1208 lb) to the otherwise maximum fuel of 1476 lb. For this configuration, the tank weight adds 73.8 lb total at FS 149.2 for the empty weight plus the weight of the fuel. The tanks attach at FS 133 and FS 166, at BL

14, and at WL 32 and WL 51. Each tank extends out to BL 60 and down to WL 22. A view looking aft [5] is shown in figure 14. The location of the auxiliary fuel tanks above WL 22 from FS 133 to FS 166 would preclude occupants seating aft of FS 129.

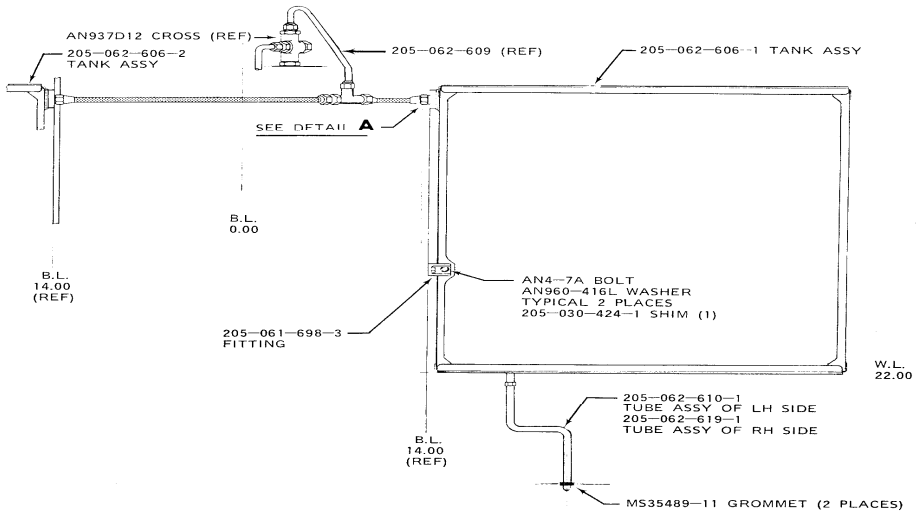


Figure 14. Auxiliary Fuel Tank Installation (View Looking Aft)

A summary of mass locations and failure loads based on that criteria is shown in table 4.

Table 4. Mass Item Failure Loads

Mass Item	Location				Failure Loads (lb)		
	Weight (lb)	FS	BL	WL	Longitudinal Fx = 30 g	Lateral Fy = 15 g	Vertical Fz = 30 g
Engine	629	187	0	79.2	18870	9435	18870
Transmission + rotor	634	138	0	85.3	19020	9510	19020
Fuel							
Right fwd	291.5	130	25	15.5	8745	4372.5	8745
Left fwd	291.5	130	-25	15.5	8745	4372.5	8745
Center	434	167	0	35.5	13020	6510	13020
Right aft	209	172	27	35.5	6270	3135	6270
Left aft	209	172	-27	35.5	6270	3135	6270
Cargo	214	243	0	36	6420	3210	6420
Auxiliary fuel							
Right side	641	150	37	41.5	19230	9615	19230
Left side	641	150	-37	41.5	19230	9615	19230

Float loads should be less than typical landing gear and skid load capabilities, which are about 1.5 to 2.0 g vertical times the aircraft weight (8500 lb) per side to be consistent with design capability. Thus, a range of 25,500 to 34,000 lb appears realistic. Also, previous UH-1H model landing gear attachment failure loads developed from past manufacturer data indicates that the

attachments to the airframe are designed to take a total of approximately 32,400 lb in the vertical direction.

Normal category rotorcraft floats that are fixed or deployed prior to initial water contact must adhere to 14 CFR 27.563(a) and (b) [9]. Title 14 CFR 27.563(a) defines the landing conditions, i.e., sink speed (<5 ft/sec), forward velocity (0 to 50 ft/sec), reasonable water conditions, and probable attitudes. Title 14 CFR 27.563(b) states that support and attachments in the airframe must be capable of loads from a fully immersed float unless full immersion is not possible.

Transport category rotorcraft floats that are fixed or deployed prior to initial water contact must adhere to Title 14 CFR 29.519(a) and (b) [7]. Title 14 CFR 29.519(a) and (b) defines the landing conditions, i.e., sink speed (<6.5 ft/sec) and forward velocity (0 to 50 ft/sec) for the most critical wave condition. If a normal one-out engine conditions results in a forward velocity <50 ft/sec, than that condition can be reduced. Title 14 CFR 29.519(d) states that support and attachments in the airframe must be capable of loads from a fully immersed float, unless full immersion is not possible.

In addition, Title 14 CFR 29.521 discusses float-landing conditions and refers to 14 CFR 29.725 (via 14 CFR 29.473(b)) that discusses landing gear loads.

Regarding failure criteria, it must be recognized that the transmission retention may be the most significant, because any such failure that allows intrusion of the occupiable cabin below is prohibitive. The engine can fail and usually will deform somewhat in doing so. However, the engine is located aft of the occupiable region and its failure is not as critical as the transmission with regard to occupant safety. The fuel behavior is difficult to represent because the KRASH model does not address fuel structure interaction other than as a lumped mass attached via a stiff spring to structure or by distributing the fuel weight among several mass points.

KRASH allows for failure criteria to be instituted using either an allowable beam failure load or beam failure deflection. It does not allow for a mass acceleration failure exceedance. Because some masses are supported on several beams (i.e., engine and transmission), it was decided that the modeling simulations would not impose the failure criteria as cutoff forces or deflections, but instead monitor the loads and deflections and provide summary tables wherein the exceedance of the maximum allowable acceleration or stroke is noted.

3.3.2 Pressure Allowables.

For panel underside failure criteria, the allowable pressures, which varied from station to station, were calculated and applied during the SBIR effort [1]. These initial underside design allowable pressures, for a full model by region, are presented in table 5.

Table 5. Underside Panel Pressure Allowables

Surface Number	KRASH Mass	Mid FS	Mid BL	From BL	To BL	Effect. Width (in.)	From FS	to FS	Effect. Length (in.)	Area (in.^{2})	Radius (in.)	WL Ref	WL Length (in.)	Allowable Pressure (psi)
1	20	30	0	-14	14	28	23	37	14	392	100	12.15	9.85	25.4
2	21	30	22	14	28	14	23	37	14	196	100	12.15	9.85	41.7
101	521	30	-22	-14	-28	14	23	37	14	196	100	12.15	9.85	41.7
3	30	46.5	0	-14	14	28	37	63	26	728	100	10.5	11.5	24.3
4	31	46.5	25.5	14	28	14	37	63	26	364	100	10.5	11.5	36.9
102	531	47	-25.5	-14	-28	14	37	63	26	364	100	10.5	11.5	36.9
5	50	88	0	-14	14	28	74	102	28	784	100	8.2	13.8	34.3
6	51	88	22	14	30	16	74	102	28	448	100	8.2	13.8	35.3
7	52	88	35.5	30	42	12	74	102	28	336	50	10.3	11.7	37.7
103	551	88	-14	-14	-30	14	74	102	28	784	100	8.2	13.8	35.3
104	552	88	-31.5	-30	-42	12	74	102	28	336	50	10.3	11.7	37.7
8	60	101.5	0	-7	7	14	102	129	20	280	100	7.5	14.5	21.3
9	61	108.5	14	7	21	14	92	125	28	392	100	7.5	14.5	27.7
10	62	108.5	31.5	21	42	21	92	125	28	588	50	11.6	10.4	63.9
105	561	108.5	-14	-7	-21	14	92	125	28	392	100	7.5	14.5	27.7
106	562	108.5	-31.5	-21	-42	21	92	125	28	588	50	11.6	10.4	63.9
11	80	140	0	-7	7	14	125	155	30	420	100	8.5	13.5	25.0
12	81	140	14	7	21	14	125	155	30	420	100	8.5	13.5	28.7
13	82	140	31.5	21	42	21	125	155	30	630	50	15.3	6.7	66.4
107	591	140	-14	-7	-21	14	125	155	30	420	100	8.5	13.5	28.7
108	592	140	-31.5	-21	-42	21	125	155	30	630	50	15.3	6.7	66.4
14	100	190.2	0	-14	14	28	166	211	45	1260	100	15.3	6.7	29.7
15	103	190.2	26	14	28	14	166	211	45	630	100	17.0	5.0	17.0
109	603	190.2		-14	-28	14	166	211	45	630	100	17.0	5.0	17.0
16	110	211	0	-14	14	28	191	231	40	1120	100	19.4	2.6	19.8
17	40	68.84	0	-14	14	28	63	74	11	308	100	8.9	13.1	40.5
18	90	155	0	-14	14	28	155	166	11	308	100	10.8	11.2	40.5
19	41	68.84	22	14	30	16	63	74	11	176	100	8.9	13.1	58.4
20	91	158	22	14	30	16	155	166	11	176	100	10.8	11.2	58.4
112	541	68.84	22	-14	-30	16	63	74	11	176	100	8.9	13.1	58.4
113	591	158	22	-14	-30	16	155	166	11	176	100	11.5	11.2	58.4
21	70	128.5	0	-14	14	28	111	155	44	1232	100	7.9	14.1	25.0

The interior (secondary) surfaces, such as the floor or bulkheads, are designed to withstand fuel cell crash pressures. In the region of the fuel cells, the secondary lift surface allowable design pressures are the top and bottom pressures noted below for the fuel cell supporting structure.

The fuel cell backup structure design allowables are as follows:

- Forward right-hand side (RHS) and left-hand side (LHS) cells FS 102 to FS 156, i.e., vertical 30 psi, forward bulkhead 60 psi, aft bulkhead 30 psi, and lateral 25 psi

- Center cell FS 157 to FS 177, i.e., top and bottom 17 psi, forward on aft bulkhead 23 psi, and 25 psi lateral

- Aft RHS and LHS cells, i.e., FS 166 to FS 177, vertical 17 psi, forward and aft bulkhead 23 psi, and lateral 25 psi

From table 4, it can be noted that the forward fuselage cell is located below the passenger floor at WL 22, while other fuel cells are above the floor. The pressures acting on the structure are simulated equating the pressure acting over the fuel cell surface to a force that acts on the surface represented by a mass in KRASH. The location of the drag surfaces, which are shown in table 6, are representative of interior bulkheads. Shown in table 6 are the allowable pressures for a symmetrical half model. Surfaces at masses 61, 71, and 81 are representative of bulkheads in the region of the forward fuel cell, which is located below the floor. Masses 90 and 100 are representative of the floor location between which the center tank (mid tank) is attached. Masses 91 and 103 are representative of the floor location between which the aft tanks are attached. The drag surfaces are below the floor, whereas the tanks are above the floor.

The allowable pressures for the underside panels are used directly in the KRASH models to determine such failures if they occur. This is because such failures violate ditching criteria. However, during the water impact scenarios, the criteria allow for underside panel failure. During the water impact scenarios, both the underside panel pressures and the secondary (interior) pressure allowables are monitored to see when both types of failures might occur.

Table 6. Interior Bulkhead Panel Pressure Allowables

Surface Number	KRASH Mass	Mid FS	From BL	To BL	Bottom WL	Floor WL	Depth (in.)	Effective Width (in.)	Effective Area (in^2)	Radius (in.)	Allowable Pressure (psi)	Allowable Force (lb)
1	20	23	-14	14	12.2	22	9.8	28	274	100	25	6860
2	21	23	14	30	12.2	22	9.8	16	157	100	25	3920
3	30	37	-14	14	10.5	22	11.5	28	322	100	25	8050
4	31	37	14	30	10.5	22	11.5	16	184	100	25	4600
5	50	92	-14	14	7.8	22	14.2	28	398	100	25	9940
6	51	92	14	30	9	22	13	16	208	100	25	5200
7	52	92	30	45	10.6	22	11.4	15	171	50	25	4275
8	60	102	-14	14	7.4	22	14.6	28	409	100	60	24528
9	61	102	14	30	9	22	13	16	208	100	60	12480
10	62	102	30	45	10.6	22	11.4	15	171	50	60	10260
11	80	155	-14	14	8.4	22	13.6	28	381	100	23	8758.4
12	81	155	14	30	10	22	12	16	192	100	23	4416
13	82	155	30	45	11.5	22	10.5	15	158	50	23	3622.5
14	100	178	-14	14	14.6	22	7.4	28	74	100	23	1702
15	103	178	-14	30	17	22	5	16	74	100	23	1702
16	110	178	30	40	18.6	22	3.4	10	102	50	23	2346
17	40	68	-14	14	10.5	22	11.5	28	92	100	25	2300
18	90	166	-14	14	11.5	22	10.5	28	92	100	23	2116
19	41	68	14	30	10.5	22	11.5	16	92	100	25	2300
20	91	166	14	30	11.5	22	10.5	16	92	100	23	2116
21	72	129	30	45	10.6	22	11.4	15	171	50	30	5130

Table 7 compares the uniformly generated pressure that the fuel developed with the 30/15/30 mass item criteria that is applied with the fuel cell support structure design pressure. Table 7 shows that, for the most part, the application of the 30/15/30 criteria will result in distributed pressures that are less than the backup structure allowable, except at the aft fuel cells.

Table 7. Comparison of Fuel Cell Support Structure Design Pressure Versus KRASH Criteria

Fuel Tank	Weight (lb)	Location			Uniformly Distributed Pressure Based on Fuel Weight x Load Factor (psi)			Crash Fuel Design Pressure for Cell Support Structure (psi)		
		FS	BL	WL	Fore/Aft Fx = 30 g	Lateral Fy = 15 g	Vertical Fz = 30 g	Fore/ Aft	Lateral	Vertical
Right fwd	291.5	102-156	19 to 34	7-22	39	5.4	10.8	60/30	25	30
Left fwd	291.5	102-156	-19 to -34	7-22	39	5.4	10.8	60/30	25	30
Center	434	156-177	-19 to +19	22-50	12.2	11	16	23	25	17
Right aft	209	166-177	19 to 42	22-50	9.7	10	24.8	23	25	17
Left aft	209	166-177	-19 to -42	22-50	9.7	10	24.8	23	25	17

The determination of float design pressures is based on limited available information. The BH-205 installation manual states that the float has been demonstrated for 36-inch wave heights, but gives no specifics regarding the associated conditions (i.e., impact direction and location, wave length, or velocity). The BH-205 has been certified for current ditching standards in the range of up to 5-ft/sec vertical and longitudinal velocity of up to 50 ft/sec. Previous floatation system studies [10] have shown that some float systems have performed without damage on occasions with water impacts in the range of 10- to 20-ft/sec vertical and above and with some forward velocity.

The float system pressure criteria takes the following into consideration:

- The float loads are determined by hydrodynamic force that is developed as the float is submerged, which provides an allowable hydrodynamic pressure based on the hydrodynamic force and a designated contact surface area. This load should be consistent with loads associated with typical landing gear or skid load capabilities and previous UH-1H landing skid design data, both of which are discussed in section 3.3.1

- The underside of the vehicle contains hydrodynamic lift and drag surface elements, using the same data as for the SBIR UH-1H models. For the amphibious configuration of the BH-205A, the flotation bags are modeled with three masses and hydrodynamic lift and drag surfaces, per side.

The KRASH program relates the hydrodynamic lift force based on surface lift shapes. One of the standard shapes in KRASH is a horizontal cylinder, which is compatible with the float shape. The initial failure load is based on the 32,400-lb total skid yielding load. Thus, the combination of design pressure and equivalent surface area is set to 32,400 lb. If 10 psi is selected as the initial design criteria, then the equivalent individual float segment area is 539 square in. (six segments per aircraft). If a 1.5-g failure criteria were used, the design pressure would drop to 7.7 psi resulting in a 25,500-lb failure load. Using a margin of safety of 2, the design pressure would

reduce to 5 psi or less. Some variations in design pressure allowables were included to determine impact failure velocities versus design pressure because

- there is no flotation test or design data to verify what level to use
- there is no verification of the accuracy and representation of the KRASH float

3.3.3 Occupant/Seat.

The following criteria apply for spinal injury assessment:

- Lumbar load <1500 lb [9 and 10]
- Seat stroke <5 inches
- DRI <20

If head injury and fore and aft loads are considered in post-KRASH analysis, then the following criteria applies:

- Head injury criteria (HIC) and severity index (SI) <1000 [9 and 10]
- Individual upper torso straps tension load <1750 lb [9 and 10]
- Dual upper torso strap tension load <2000 lb [9 and 10]

4. EVALUATION OF OTHER CURRENT ROTARY WING MODELS.

There are several existing Air Accident Investigation Tool (AAIT) KRASH rotary wing models. These models represent aircraft configurations that vary in weight from 8000 to 21,000 lb and thus are representative of 14 CFR Part 29 rotorcraft. While some models are military versions, they most likely have a civil counterpart or are close enough in design for use with civil design standards. However, depending on their current capability, the models may need additional data and upgrades to be suitable for further design limit evaluations.

The following is an evaluation of the status and the potential additional needs of these KRASH models. The existing AAIT models are representative of the following rotorcraft:

- Lynx MK 8: 7295 lb
- Sea King: 11,215 lb
- Chinook: 17,234 lb
- Merlin EH 101: 26,778 lb

All of these rotorcraft are Westland manufactured except the Chinook. The Lynx, Chinook and Sea King are military helicopters. The S-61 manufactured by Sikorsky, and the civil variant of the Merlin EH 101 fall into the 14 CFR Part 29 rotorcraft category.

Table 8 provides a comparison of the pertinent weight breakdown for the BH-205, Lynx, Sea King, and Merlin models. Table 9 provides a comparison of the KRASH size and the features of each of these full models, as well as that of the current BH-205 full model.

Table 8. Weight Breakdown for Different Helicopter Configurations

Weight (lb)	BH205	Sea King	Lynx	EH101
Maximum GTOW	9500	23379	11726	32120
Design landing	8000	16678	9460	28600
OEW	5260	10520	8789	21648
Maximum fuel	1476	6693	1764	9295
Maximum payload	4240	6166	1661	10472*
Number of passengers	13	22	6	30
Number of crew	2	2	2	2

* no fuel

Table 9. Sizes and Features of AAIT and KRASH Models

Configuration		Lynx	UH-1H	BH-205	Sea King	Chinook	Merlin	Merlin
Model		MK8					EH-101	EH-101
Source		AAIT	DR Inc.	DR Inc.	AAIT	AAIT	AAIT	Westland
Weight (lb)		7295	7956	8000-9500	11215	17234	26778	32120
Parameter	Symbol							
Masses	NM	48	172	212	58	42	35	70
Beams	NB	81	350	426	103	82	71	128
Node points	NNP	25	63	58	27	28	46	15
Crush springs	NSP	23	0	0	34	26	23	28
Hydrodynamic surfaces	NHYD	0	33	38	0	0	0	0
Nonlinear beams	NLB	15	8	20	3	22	0	24
Pinned beams	NPIN	1	0	0	1	0	0	13
Unsymmetrical beams	NUB	0	16	0	1	0	0	0
Force failures	NFBMN	3	0	0	0	7	0	0
Occupant DRI	NDRI	0	6	8	0	0	0	2
Volume penetration	MVP	1	0	0	0	1	1	0

Note: Model weights, not design weights.
MVP = Mass volume penetration

In addition to the AAIT models, Westland has several KRASH models:

- Lynx (no undercarriage)
- Lynx (undercarriage)
- Lynx (water impact model)
- EH-101(no undercarriage)
- EH101 (undercarriage)

Table 8 shows various maximum levels, including GTOW, DLW, OEW, fuel capacity, payload capacity, and number of passengers and crew. Typically, flight configurations do not have maximum fuel and payload simultaneously.

Table 9 shows that the AAIT full models

1. vary in number of masses (NM) from 35 to 58.

2. vary in beam size (NB) from 71 to 103 .

3. contain from 25 to 46 mass-less node points (NNP).

4. are ground impact models as denoted by NSP and allow for contact from 23 to 34 surfaces.

5. contain from 0 to at most 22 nonlinear beams (NLB).

6. only contain a pinned beam (NPIN) for the Lynx and the Sea King.

7. only contain an unsymmetrical beam (NUB) for the Sea King.

8. only contain failure cutoff loads for the Lynx and the Chinook.

9. do not include any occupant representations (NDRI = 0).

Because the AAIT models are presented as full size models (RUNMOD = 0), they would have to be revised to analyze symmetrical impacts more efficiently. The BH-205 KRASH models are developed as symmetrical model and then expanded to full models for unsymmetrical impacts. This is done by allowing the program to develop a full model with a simple input (RUNMOD = 3) and then modifying it for unsymmetrical features.

In contrast to the existing BH-205 KRASH model, the existing AAIT models might be undersized with regard to NM, NB, NNP, and potential hydrodynamic contact surfaces (NHYD). It is assumed that the number of ground surface contact points could be converted to an equal number of NHYD. The lack of NM, NB, NNP, and NHYD points does not necessarily make the model deficient for water impact studies, but could compromise the ability to adequately define the structure. The reduced number of NLB and NUB also might be acceptable depending on the detail one would want to represent.

Any model that is used to assess or develop design limit capability should include a seat occupant representation at several locations. For a full model, there should be at least four to eight NDRI elements.

Furthermore, if at least one comprehensive seat occupant restraint system were included as part of the overall structural model, it would add a significant number of masses, pinned elements, node points, nonlinear, and unsymmetrical beams. This can be observed from the discussion of an expanded seat occupant restraint model in section 6.4.

For the ditching and water impact-modeling aspects, the crush spring (NSP) properties are not appropriate and would have to be replaced by water impact surface dimensions and design

allowables. This requires additional manufacturer data and calculations for input properties, depending on what data is forthcoming.

Aircraft size, fuselage shape, type and location of landing gears, underside panel and interior structure design factors, fuel location and attachments, and passenger layout present different modeling problems. For example, a Sea King fuselage shape and size is much different than that of the BH-205 helicopter.

It is critical for the AAIT models to have

- weight distribution data and assessing a range of appropriate configurations.
- interior layouts and three-view drawings available.
- occupant locations and representations within the structural model.
- cross-sectional views and structural data.
- underside panel pressure design data.
- fuel cell and supporting structure design factors and pressures.
- a set of criteria by which performance is evaluated. Civil aircraft should be consistent with all the 14 CFR Parts 27 and 29 aircraft.

5. ANALYSIS RESULTS.

5.1 LEVEL 1 WATER IMPACT.

Water impact analyses were performed for a series of conditions, which are noted in table 10. The following series are initially discussed:

- D1: Basic BH-205 model (9500 lb)—maximum GTOW configuration 1
- D2: Design landing weight (8000 lb)—low fuel, configuration 2
- D3: Amphibious configuration (8500 lb)—Float, configuration 3
- D4: Auxiliary fuel tank configuration (9500 lb), configuration 4
- D5: Various design and tradeoff studies
- D6: Sea-state studies

In general, the nomenclature used for file names is xD0yPz; wherein D means series Dx, y = 1, 2, 3, or 4 for 0, 25, 50, or 75 ft/sec longitudinal velocity, respectively, and z = 0, +5, or +10 degrees for pitch attitude. While some sets repeat, i.e., 6D01, there are other descriptors that distinguish the run.

The underside panel hydrodynamic surfaces, as well as extended surfaces (float, landing skid), their attached KRASH model masses, and their locations are noted in table 11.

The water impact simulations were performed in the range of the following impact conditions and parameters:

- Vertical impact velocity from 6 to 20 ft/sec
- Longitudinal impact velocities of 0, 25, 50, and 75 ft/sec
- Landing skid and/or float included
- Pitch attitude = 0, +5, +10 degrees
- Yaw and roll = 0, +15 degrees
- No LL seat (rigid seat), 12- and 14.5-g LL seat
- Calm and sea state = 4
- Panel pressure factor = 1.0 (no change in design pressure) to 2.0
- Design strength factor = 1 (no change in design strengths)
- Integration interval = 1E-5 sec
- Print interval = 1 to 2 msec
- Simulation time = between 250 msec to 1.00 second
- Aircraft impact perpendicular to wave; crest, midpoint, 1/4 from top, and trough
- Aircraft impact parallel to wave; crest

Table 10. Summary of Level 1 Water Impact Series Conditions

Set	Series	Configuration/ Conditions	Structural Model	Vertical Velocity (ft/sec)	Longitudinal Velocity (ft/sec)	Pitch Attitude (degree)	Sea State	Airframe(A) Skid(S) Float(F)	Occupant Model Rigid Seat	Occupant Model LL (g)
1D01	D1	GTOW	1	X	0	0, 5, 10	Calm	S	✓	12
1D02	D1	GTOW	1	X	25	0, 5, 10	Calm	S	✓	12
1D03	D1	GTOW	1	X	50	0, 5, 10	Calm	S	✓	12
1D04	D1	GTOW	1	X	75	0, 5, 10	Calm	S	✓	12
2D01	D2	DLW	2	X	0	0, 5, 10	Calm	S	-	12
2D02	D2	DLW	2	X	25	0, 5, 10	Calm	S	-	12
2D03	D2	DLW	2	X	50	0, 5, 10	Calm	S	-	12
3D01	D3	Amphibious	3	X	0	0, 5, 10	Calm	F	-	12
3D02	D3	GTOW	3	X	25	0, 5, 10	Calm	F	-	12
3D03	D3	GTOW	3	X	50	0, 5, 10	Calm	F	-	12
4D01	D4	Auxiliary tank	4	X	0	0, 5, 10	Calm	F	-	12
4D02	D4	GTOW	4	X	25	0, 5, 10	Calm	S	-	12
4D03	D4	GTOW	4	X	50	0, 5, 10	Calm	S	-	12
5D01-03	D5	GTOW/LG extended vs retracted	1, 3	X	0-50	0, 10	Calm	A,S,F	-	12
5D01P	D5	GTOW/panel design	1	X	0	0	Calm	A	-	12,14.5
5D01C	D5	GTOW/fuselage contour	1	X	0	0	Calm	A	✓	-
5D02F	D5	Amphibious	3	X	0, 50	0, 5, 10	Calm	F	-	12
5D02D	D5	Amphibious Drag effects	3	X	10 - 80	10	Calm	F	-	12
5D03S	D5	GTOW/ suction force	1	X	50	10	Calm	A	✓	-

Table 10. Summary of Level 1 Water Impact Series Conditions (Continued)

Set	Series	Configuration/ Conditions	Structural Model	Vertical Velocity (ft/sec)	Longitudinal Velocity (ft/sec)	Pitch Attitude (degree)	Sea State	Airframe(A) Skid(S) Float(F)	Occupant Model Rigid Seat	Occupant Model LL (g)
5D01U	D5	GTOW/ Unsymm. *	1	X	0	10	Calm	A	-	12
5D03U	D5	GTOW/ Unsymm. *	1	X	50	10	Calm	A	-	12
6D01	D6	GTOW/crest, parallel	1	X	0	0, 10	4	A	✓	-
6D02-03	D6	GTOW/crest, perpendicular	1	X	25, 50	0, 10	4	A, S	✓	-
6D01	D6	GTOW/midface, parallel	1	X	0	0, 10	4	A	✓	-
6D02-3	D6	GTOW/midface, perpendicular	1	X	25, 50	0, 10	4	A, S	✓	-
6D01	D6	GTOW/1/4 crest, parallel	1	X	0	0, 10	4	A	✓	-
6D02-3	D6	GTOW/1/4 crest, perpendicular	1	X	25, 50	0, 10	4	A, S	✓	-
6D03	D6	GTOW/crest, perpendicular	1	X	60	10	4	A	✓	-
6D03	D6	GTOW/midface, perpendicular	1	X	60	10	4	A	✓	-
6D03	D6	GTOW/trough, perpendicular	1	X	60	10	4	A	✓	-

✓ = 1 of 2 Test conditions
X = The value obtained when required conditions are satisfied (see data tables)
LG = Landing gear
Unsymm = Unsymmetrical
* Roll = Outside yaw = 10 degrees

Table 11. Hydrodynamic Surfaces and Locations

Surface Number	KRASH Mass Number	Surface Identity	FS	BL	WL
1	20	Underside	23	0	22
2	21	Underside	23	14	22
3	30	Underside	42	0	22
4	31	Underside	42	14	22
5	50	Underside	84.5	0	22
6	51	Underside	84.5	14	22
7	52	Underside	84.5	30	22
8	60	Underside	102	0	22
9	61	Underside	102	14	22
10	62	Underside	102	37.3	22
11	80	Underside	138.23	0	22
12	81	Underside	138.23	14	22
13	82	Underside	138.23	35.9	22

Table 11. Hydrodynamic Surfaces and Locations (Continued)

Surface Number	KRASH Mass Number	Surface Identity	FS	BL	WL
14	100	Underside	192	0	22
15	103	Underside	192	35	22
16	40	Underside	68.8	0	22
17	90	Underside	166.1	0	22
18	41	Underside	68.8	14	22
19	91	Underside	166.1	14	22
20	70	Underside	129	0	22
21	3	Float	67.5	50	-12
22	4	Float	134.6	50	-12
23	5	Float	201.3	50	-12
24	1	Skid	68.1	50.8	-7
25	2	Skid	166.1	50.8	-7

5.1.1 Maximum GTOW Configuration Skid Impact.

The results for the maximum GTOW configuration 1 with attached skid are provided in tables 12, 13, and 14. Table 12 data shows the impact velocity level at which failures occur at the different impact conditions. For a flat vertical impact (pitch = 0 degree and longitudinal velocity = 0 ft/sec) the vertical velocity at which underside panel failures occur is 20 ft/sec. The vertical velocity at which underside panel failures occur is lower than 20 ft/sec, where both the pitch attitude and longitudinal velocity increase. Table 12 provides both the hydrodynamic surface that failed and the time of failure occurrence. All the failures occur in time <0.200 sec after impact. All acceleration responses are based on SAE class 60 filtering.

Table 12. Underside Panel Failures—Basic Model (Maximum GTOW), Configuration 1

Scenario			1D01P0	1D02P0	1D03P0	1D01P5	1D02P5	1D03P5	1D01P10	1D02P10	1D03P10
Vertical/longitudinal velocity (ft/sec)			20/0	18/25	18/50	15/0	13/25	13/50	14/0	12/25	10/50
Pitch/roll/yaw (degree)			0/0/0	0/0/0	0/0/0	5/0/0	5/0/0	5/0/0	10/0/0	10/0/0	10/0/0
Underside panel failures			4	3	4	2	2	2	2	2	2
Panel mass (lb) Time failed (sec)			70(.073)	70(.082)	70(.009)	-	-	-	-	-	-
			81(.076)	-	81(.016)	-	-	-	-	-	-
			91(.085)	91(.087)	91(.020)	91(.112)	91(.137)	91(.141)	91(.118)	91(.141)	91(.187)
			90(.086)	90(.087)	90(.021)	90(.112)	90(.139)	90(.142)	90(.119)	90(.142)	90(.188)
Floor Response—Peak Vertical Acceleration (g)											
FS 42 BL 14	Pilot	Mass 31	60.0	38.6	34.4	18.7	14.2	13.6	14.8	8.7	7.1
FS 85 BL 30	Fwd	Mass 52	40.8	34.8	30.6	25.5	16.4	14.0	10.1	8.3	6.9
FS 102 BL 37	Mid	Mass 62	28.8	30.2	32.0	17.8	25.0	22.8	13.1	8.6	8.7
FS 139 BL 36	Aft	Mass 82	25.0	21.3	22.9	15.0	16.1	17.0	13.2	12.3	10.2

Table 12. Underside Panel Failures—Basic Model (Maximum GTOW), Configuration 1 (Continued)

Scenario			1D01P0	1D02P0	1D03P0	1D01P5	1D02P5	1D03P5	1D01P10	1D02P10	1D03P10
Vertical/longitudinal velocity (ft/sec)			20/0	18/25	18/50	15/0	13/25	13/50	14/0	12/25	10/50
Pitch/roll/yaw (degree)			0/0/0	0/0/0	0/0/0	5/0/0	5/0/0	5/0/0	10/0/0	10/0/0	10/0/0
Underside panel failures			4	3	4	2	2	2	2	2	2
Mass Response—Peak Vertical Acceleration (g)											
Transmission		Mass 7	10.2	17.2	24.4	14.5	13.9	16.2	10.7	10.8	7.6
Engine		Mass 8	16.8	13.5	16.6	13.5	13.9	13.8	11.2	15.5	10.1
Fuel – fwd		Mass 401	**33.2**	25.9	28.3	18.1	19.2	18.6	14.1	13.0	7.5
Fuel – mid		Mass 402	15.7	20.3	18.4	20.6	18.4	19.3	10.0	14.0	11.9
Fuel – aft		Mass 403	22.7	22.1	26.7	18.7	25.6	27.2	16.7	21.4	11.5
Lumbar Load (lb)											
FS 47 BL 22	Pilot	Beam 213	**2250**	**1711**	**1634**	1448	1099	1056	1098	640	510
FS 87 BL 23	Fwd	Beam 214	**1899**	**1527**	**1577**	1475	1127	1055	759	596	434
FS 117 BL 34	Mid	Beam 215	1490	**1668**	**1748**	1243	1180	1225	832	751	627
FS 139 BL 26	Aft	Beam 216	923	1249	1364	943	958	1018	794	773	602

Bold numbers exceed criteria

Table 12 shows the occupant lumbar load at each DRI-modeled occupant for each failure condition up to a longitudinal velocity of 50 ft/sec. The four floor locations that are represented by masses 31, 52, 62, and 82 are at FS 42 BL14, FS 85 BL 30, FS 102 BL 37, and FS 139 BL 36, respectively. The lumber loads are taken at the centerline of occupants that correspond to the seat floor masses, which are at FS 47 BL 22, FS 87 BL 23, FS 117 BL 34, and FS 139 BL 26.

Each seat in this set of runs was modeled as a rigid seat. At panel failure levels, some of the occupants experience lumbar loads in excess of 1500 lb. Thus, with a rigid seat, the allowable ditching condition to satisfy both panel failure and occupant lumbar load requires a lower sink speed. Using a rigid seat, the 20-ft/sec vertical impact (1D01P0) would have to reduce to less than 16 ft/sec for the lumbar load to stay within criteria. Using a 12-g LL seat, all the lumbar load results would be acceptable for the impact conditions shown in table 12.

Table 13 shows the tradeoff between sink speed, lumbar load, and seat deformation associated with a 12-g load limit. For all the rigid seat cases, the maximum deflection before reaching a lumber load of 1500 lb is < 0.45 inch.

Table 13. Tradeoff Between Sink Speed, Lumbar Load, and Seat Deformation—Maximum GTOW With Attached Skid

Scenario		1D01P0 Rigid Seat	1D02P0 Rigid Seat	1D01P0 Rigid Seat	1D01PO LL Seat 12 g
Vertical/longitudinal velocity (ft/sec)		16/0	15/25	20/0	20/0
Pitch/roll/yaw (degree)		0/0/0	0/0/0	0/0/0	0/0/0
Lumbar Load (lb)					
Pilot	Beam 213	1578	1454	2250	1206
Fwd	Beam 214	1385	1324	1899	1205
Mid	Beam 215	1465	1467	1490	1196
Aft	Beam 216	1096	1264	923	1190
Seat Deflection—Vertical (in.)					
Pilot	Beam 221	0.477	0.447	0.662	3.35
Fwd	Beam 222	0.409	0.377	0.551	1.76
Mid	Beam 223	0.394	0.39	0.386	1.31
Aft	Beam 224	0.299	0.296	0.251	0.51
Mount Deflection—Vertical (in.)					
Transmission	Beam 205	0.670	0.630	n/a	n/a
	Beam 206	0.590	0.553	n/a	n/a
Engine	Beam 207	0.094	0.122	n/a	n/a
	Beam 208	0.031	0.038	n/a	n/a
	Beam 209	0.025	0.026	n/a	n/a
	Beam 210	0.020	0.022	n/a	n/a

The comparison of 20-ft/sec vertical impacts with and without a load limit seat illustrates the following points:

- Without a LL seat, the lumbar load exceeds the 1500-lb lumbar load criteria

- The use of a 12-g LL seat increases the seat stroke, in this case to as much as 3.35 inches, but less than the allowable 5.0-inch seat stroke criteria. With a 12-g LL seat, the lumbar load reaches 1200 lb. If a 14.5-g LL seat were used, the deflection would decrease approximately 21% further and the lumbar load would increase to 1500 lb, but still within criteria. However, since underside panel failures occur at a 20-ft/sec impact, this is a mute point for this condition.

- In more severe cases of water impact wherein higher impact velocities will be considered, panel strength and seat stroke could be a factor.

For a 16-ft/sec vertical impact velocity, the floor responses (based on a SAE class 60 filter) are shown in table 14.

Table 14. Vertical Impact Results—Maximum GTOW 16 ft/sec

Mass Item	Vertical Acceleration (g)
8	13.5
401	18.8
402	15.3
403	24.4

(a)

Mass Item	Floor Vertical Acceleration (g)
31	29.2
52	25.6
62	28.9
82	20.7

(b)

Location	Lumbar Load (lb)
FS 47	1578
FS 87	1385
FS 117	1465
FS 139	1096

(c)

Unfiltered responses were obtained for the vertical 16-ft/sec impact condition and were shown to be within 10% of the filtered peaks for all engine, transmission, fuel responses, and the floor vertical responses. For the floor longitudinal response, the difference was higher (i.e., 6.9 g versus 4.5 g at FS 47 and 5.9 g versus 2.6 g at FS 102). However, these are very low level peaks. Thus, SAE class 60 data is shown throughout.

Table 15 shows the relationship between lumbar load and DRI for a couple of conditions and indicates that a DRI criteria of <15 is also satisfied if the lumbar load is <1500 lb. Thus, there is no need to show both lumbar load and DRI value for all results.

Table 15. Lumbar Load Versus DRI Value—Maximum GTOW, Configuration 1

Scenario			1D01P0 skid	1D01P0 skid	1D02P0 skid	1D02P0 skid
Vertical/longitudinal (ft/sec)			20/0	16.0	17/25	15/25
Pitch/roll/yaw (degrees)			0/0/0	0/0/0	0/0/0	0/0/0
Lumbar Load (lb)						
FS 47	Pilot	Beam 213	2250	1578	1711	1454
FS 87	Fwd	Beam 214	1899	1385	1527	1324
FS 117	Mid	Beam 215	1490	1465	1668	1467
FS 139	Side	Beam 216	923	1096	1249	1104
DRI Value						
FS 47	Pilot	Mass 212	22.2	16.3	17.7	15.3
FS 87	Fwd	Mass 222	18.0	13.4	15.1	13.0
FS 117	Mid	Mass 232	14.4	13.6	15.9	13.7
FS 139	Side	Mass 242	11.1	11.7	13.9	12.3

The major mass accelerations, as noted earlier, are generally less than 30 g. There are two transmission mounts, which are modeled to go nonlinear in the axial direction. The nonlinear curve has been shown earlier (figure 10). For more severe cases, the transmission mounts yield, but do not exceed, an average deflection of 0.63 inch.

The engine has four mounts per side as noted in section 3.2.4. The initial set of runs based the engine mount failure mode as a compressive yield. Thus, each mount is set to yield (go nonlinear) in their axial direction at a deflection of 0.06 inch. If a buckling mode failure were assumed, then the nonlinear deflection would be set between 0.030 and 0.040 inch. Buckling is expected to produce lower failure loads, however, the support mount deflection (compression) will increase. For these initial ditching conditions, the peak engine accelerations are relatively low (<12.3 g). Table 16 shows how the peak load and support deflection are affected by the mode of failure and the beam nonlinear behavior. Table 16 shows that the peak load is sensitive to a degree (<12%), but the deflection can vary substantially depending on postyield behavior. The nonlinear beam type number (NTYPE) curves are described in the KRASH user's manual and are noted in figure 13. For this series of runs, the choice of failure mode or NTYPE curve is not critical. However, for more severe impact scenarios, it could be critical because of load criteria and allowable deformation.

Table 16. Engine Mount Failure Mode and NTYPE Versus Deflection

Vertical/ Longitudinal (ft/sec)	Pitch/Roll/Yaw (degrees)	Failure Mode	NTYPE	Engine Mount—Forward Beam 207		
				Acceleration Vertical Peak (g)	Deflection (in.)	Deflection (% Length)
16/0	0/0/0	Compressive yield	5	8.94	0.117	0.59
16/0	0/0/0	Longitudinal column buckling	5	8.05	0.227	1.14
16/0	0/0/0	Longitudinal column buckling	6	8.94	0.990	4.95
16/0	0/0/0	Longitudinal column buckling	7	8.27	1.690	8.45

The fuel mass items were located at three locations. Their representative masses were attached to other structure masses by rigid beams. In reality, the fuel is contained in bladders at each location and the load is spread along the structure. As modeled, the fuel masses produce peak accelerations less than the major mass criteria of 30 g. However, the fuel mass acceleration is of relative interest and not critical because of the manner in which it is modeled.

5.1.2 All Configurations—Skid/Float Impact.

The results for the GTOW configuration, presented in section 5.1.1, are based on the airframe impacting the water on the landing skid. A comparison for the other three configurations; DLW low fuel, amphibious float, and auxiliary fuel tank, impacting on either a skid or float is provided in table 17 with regard to failure impact levels. The range of impact conditions investigated for these simulations are the same as for the basic model, except that a 12-g LL seat was used throughout these simulations.

Table 17 shows the impact velocity levels at which failures occur at different impact conditions, as well as the time and location of failure occurrence. An acceptable envelope that precludes any panel failure would be approximately 1-ft/sec vertical less than the failure levels. As with the base 9500-lb configuration, the trend is for a slightly lower vertical velocity capability as the longitudinal velocity and pitch attitude increase.

The float configuration shows added capability at pitch = 0 degree condition, based on a 10-psi float capability. The time at which the airframe strikes the water is influenced by the pitch attitude and longitudinal velocity. With a 50-ft/sec longitudinal velocity, the float configuration impacts the forward fuselage region (FS 23 to FS 68, masses 20 to 40), whereas the zero forward velocity conditions seem to drive through to the airframe at FS 166 (mass 90). The float is approximately 36 inches below the lowest airframe contact point, compared to 15 inches for the skid. This factor appears to influence the airframe response and failure pattern.

The amphibious configuration results were based on a 10-psi float design. This was chosen based on an estimate of loads that might result in failure of supporting structure, and was considered on the high end of design capability. However, for the vertical impact conditions, there were no float failures because the maximum float calculated pressure on 6.7, 3.2, and 2.8 psi for the pitch = 0, +5, and +10 degrees cases shown in table 17, respectively. The model allowed for complete penetration of the float and subsequent fuselage contact, which was why failure occurred at masses 91 and 90 (table 17).

A comparison of selected impact conditions for all four configurations is shown in table 18. The pitch = 0 degree condition for a vertical only and a combined vertical and longitudinal impact was used because it provided the higher mass responses and seat deflections. From table 18, the floor and mass item peak vertical responses and seat deflections are noted. All the mass item accelerations were less than the 30-g criteria. The acceleration results presented in table 18 are for a 12-g LL seat and may differ from the earlier rigid seat acceleration results provided in table 11. Because of underside panel failure, this was not an acceptable water impact condition.

Table 17. Underside Panel Failures—Configuration Comparisons

Scenario	2D01P0 Skid	2D03P0 Skid	2D01P5 Skid	2D03P5 Skid	2D01P10 Skid	2D03P10 Skid
Vertical/longitudinal velocity (ft/sec)	20/0	19/50	16/0	16/50	14/0	11/50
Pitch/roll/yaw (degree)	0/0/0	0/0/0	5/0/0	5/0/0	10/0/0	10/0/0
Underside panel failures	1	3	2	4	2	2
Panel mass (no.) (Time failed (sec))	70 (0.074)	70 (0.078) 90 (0.097) 91 (0.097)	91 (0.107) 90 (0.108)	91 (0.116) 90 (0.117) 81 (0.125) 70 (0.126)	91 (0.121) 90 (0.122)	91 (0.179) 90 (0.180)

(a) Configuration 2—DLW Low Fuel

Table 17. Underside Panel Failures—Configuration Comparisons (Continued)

Scenario	3D01P0 Float	3D03P0 Float	3D01P5 Float	3D03P5 Float	3D01P10 Float	3D03P10 Float
Vertical/longitudinal velocity (ft/sec)	26/0	18/50	18/0	13/50	16/0	10/50
Pitch/roll/yaw (degree)	0/0/0	0/0/0	5/0/0	5/0/0	10/0/0	10/0/0
Underside panel failures	2	3	2	5	2	9
Panel mass (no.) (Time failed (sec))	91 (0.146) 90 (0.147)	5 (0.467) 4 (0.467) 3 (0.467)	91 (0.212) 90 (0.212)	5 (0.047) 4 (0.058) 3 (0.082) 20 (0.235) 21 (0.235)	91 (0.241) 90 (0.242)	5 (0.054) 4 (0.099) 3 (0.181) 41 (0.314) 40 (0.135) to 20 (0.321)

(b) Configuration 3—Amphibious Float , 10 psi

Scenario	4D01P0 Skid	4D03P0 Skid	4D01P5 Skid	4D03P5 Skid	4D01P10 Skid	4D01P10 Skid
Vertical/longitudinal velocity (ft/sec)	20/0	18/50	16/0	13/50	14/0	11/50
Pitch/roll/yaw (degree)	0/0/0	0/0/0	5/0/0	5/0/0	10/0/0	10/0/0
Underside panel failures	4	4	2	2	2	2
Panel mass (no.) (Time failed (sec))	70 (0.073) 81 (0.076) 91 (0.085) 90 (0.086)	70 (0.082) 81 (0.086) 91 (0.095) 90 (0.096)	- - 91 (0.105) 90 (0.105)	- - 91 (0.139) 90 (0.140)	- - 91 (0.118) 90 (0.119)	- - 91 (0.162) 90 (0.163)

(c) Configuration 4—Auxiliary Fuel Tank

For the impact conditions in table 18, panel failure was noted and lumbar load exceeded 1500 lb with a rigid seat, but not with a 12-g LL seat. The deflections presented were for the 12-g LL seat to illustrate that while panel failures can exist, a seat stroke of <5 inches is achievable.

For all configurations, the lumbar load is always 1220 lb or lower, due to the 12-g LL seat. The resulting deflection generally indicates that the seat legs yield. However, the maximum deflection is 4.15 inches, which is less than the allowable 5 inches.

Previous studies [13 and 14] have shown that float systems that are active prior to impact survived water impact conditions in excess of the current ditching criteria and the civil rotorcraft 95th percentile accident upper envelope. Figure 15 and table 19 [13 and 14] show that there were 14 such events, and 10 had floats that survived without damage. An estimate of these impact conditions are shown in table 19. Two of the four floats that failed have longitudinal velocities =>50 ft/sec and three floats that survived undamaged had vertical velocities =>30 ft/sec. It may

be that a lower float design pressure is more desirable. A discussion of the effects of a lower float design pressure is discussed in section 5.1.3.2.

A comparison of capability with regard to the limit where no panel failure occurs for all four configurations is provided in table 20.

Table 18. Comparison of Mass Acceleration and Seat Deflection

Scenario			1D01P0	2D01P0	3D01P0	4D01P0
			Skid	Skid	Float	Skid
Vertical/longitudinal velocity (ft/sec)			20/0	20/0	20/0	20/0
Pitch/roll/yaw (degree)			0/0/0	0/0/0	0/0/0	0/0/0
Underside 12-g panel failure			Yes	Yes	No	Yes
LL seat lumbar load > 1500 lb			No	No	No	No
Rigid seat lumbar load > 1500 lb			Yes	Yes	Yes	Yes
Floor Response—Vertical Peak Acceleration (g)						
FS 42	Pilot	Mass 31	61.0	66.1	30.9	82.0
FS89	Fwd	Mass 52	43.5	42.5	23.3	42.4
FS129	Mid	Mass 62	28.1	32.9	39.9	26.1
FS139	Aft	Mass 82	17.1	26.7	19.4	15.1
Mass Response—Vertical Peak Acceleration (g)						
Transmission		Mass 7	12.6	27.9	20.7	12.5
Engine		Mass 8	15.6	17.5	16.3	14.4
Fuel – Fwd		Mass 401	25.6	26.7	22.4	20.7
Fuel – Mid		Mass 402	16.1		16.8	14.5
Fuel – Aft		Mass 403	17.2	29.4	20.5	17.0
Auxiliary tank		Mass 404	-	-	-	15.9
Seat Deflection—Vertical (in.)						
Pilot		Beam 221	4.1	3.45	0.92	4.15
Fwd		Beam 222	1.9	1.88	0.54	1.89
Mid		Beam 223	0.73	1.34	0.49	0.71
Aft		Beam 224	0.25	0.88	no seat	no seat

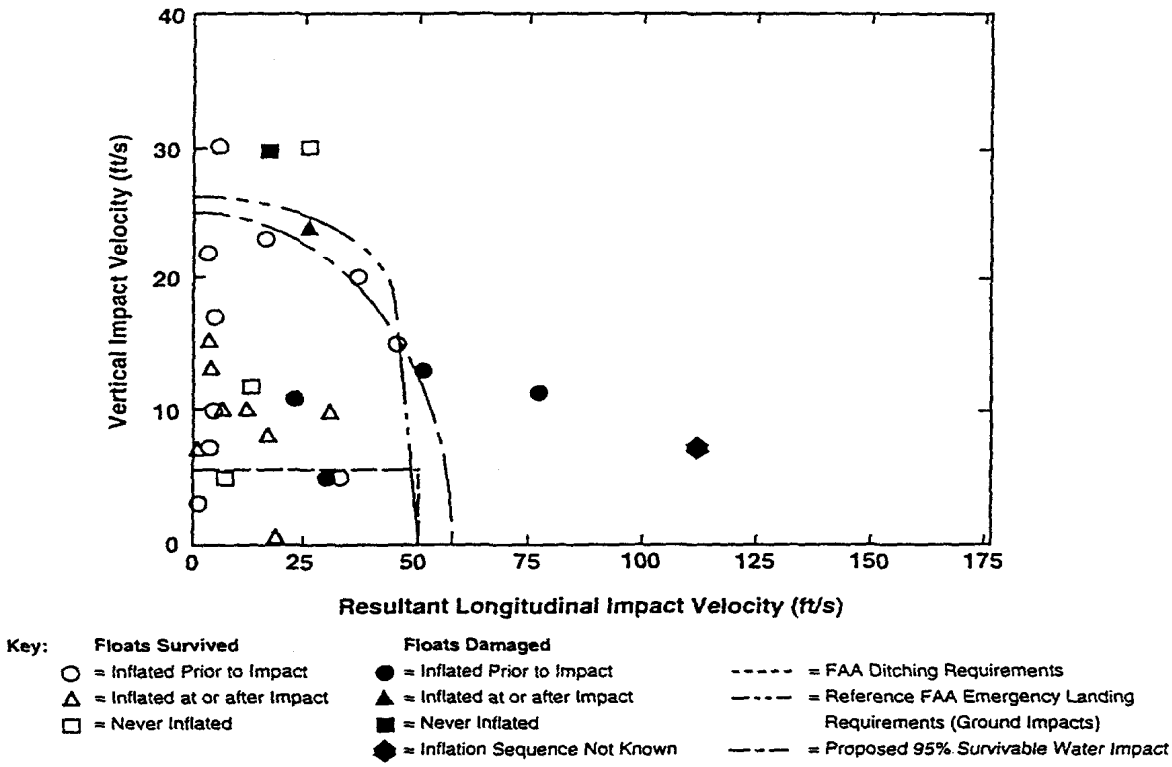


Figure 15. Rotorcraft Water Landing Envelopes—Deployable Float Impact Survivability

Table 19. Flotation System Water Impact Performance

Accident	Vertical Velocity (ft/sec)	Longitudinal Velocity (ft/sec)	Damaged Float	< Current Ditching Criteria	< Civil 95th Percentile Upper Limit
1	3	0		Yes	Yes
2	5	30		Yes	Yes
3	6	30	Yes		Yes
4	7	0			Yes
5	10	6			Yes
6	11	25	Yes		Yes
7	12	75	Yes		
8	15	45			Yes
9	15	50	Yes		
10	17	5			Yes
11	20	40			Yes
12	22	0			Yes
13	23.5	15			Yes
14	30	5			

Table 20. Comparison of Velocity Limits for all Configurations

	1D01P0	1D02P0	1D03P0	1D01P5	1D02P5	1D03P5	1D01P10	1D02P10	1D03P10
Configuration 1—Maximum GTOW	skid	skid	skid	skid	skid	skid	skid	skid	skid
Vertical/longitudinal velocity (ft/sec)	19/0	17/25	16/50	14/0	12/25	12/50	13/0	11/25	9/50
Pitch/roll/yaw (degree)	0/0/0	0/0/0	0/0/0	5/0/0	5/0/0	5/0/0	10/0/0	10/0/0	10/0/0
	2D01P0	2D02P0	2D03P0	2D01P5	2D02P5	2D03P5	2D01P10	2D02P10	2D03P10
Configuration 2—Low weight	skid	skid	skid	skid	skid	skid	skid	skid	skid
Vertical/longitudinal velocity (ft/sec)	19/0	18.5/25	18/50	16/0	15/25	11/50	13/0	11.5/25	10/50
Pitch/roll/yaw (degree)	0/0/0	0/0/0	0/0/0	5/0/0	5/0/0	5/0/0	10/0/0	10/0/0	10/0/0
	3D01P0	3D02P0	3D03P0	3D01P5	3D02P5	3D03P5	3D01P10	3D02P10	3D03P10
Configuration 3—Amphibious	float	float	float	float	float	float	float	float	float
Vertical/longitudinal velocity (ft/sec)	25/0	21/25	17/50	17/0	14.5/25	12/50	15/0	12/25	9/50
Pitch/roll/yaw (degree)	0/0/0	0/0/0	0/0/0	5/0/0	5/0/0	5/0/0	10/0/0	10/0/0	10/0/0
	4D01P0	4D02P0	4D03P0	4D01P5	4D02P5	4D03P5	4D01P10	4D02P10	4P03P10
Configuration 4—Auxilary fuel	skid	skid	skid	skid	skid	skid	skid	skid	skid
Vertical/longitudinal velocity (ft/sec)	19/0	17.5/25	16/50	15/0	13.5/25	12/50	13/0	11.5/25	10/50
Pitch/roll/yaw (degree)	0/0/0	0/0/0	0/0/0	5/0/0	5/0/0	5/0/0	10/0/0	10/0/0	10/0/0

5.1.3 Design Considerations.

The capability of 14 CFR Parts 27 and 29 aircraft to meet ditching standards in part is related to many design factors. The BH-205 is in the class of 14 CFR Parts 27 and 29 helicopters. The BH-205 has a relatively flat underside, particularly out to BL 34, and has nonretractable skid gear. There are several design configurations, as previously noted.

To evaluate design parameters, the following are considered:

- Direct impact onto the airframe and compared to an airframe with skids or floats
- The effect of underside panel and float design pressures on structural integrity
- The effect of fuselage shape on failure loads
- The influence of drag loads on aircraft pitch-over
- The influence of suction forces on aircraft behavior

5.1.3.1 Landing Gear Extended Versus Retracted.

Impact on the airframe could come about if an aircraft impacts the water with the gear retracted. The BH-205 does not offer that type of design, but other 14 CFR Parts 27 and 29 aircraft might. Table 21 compares results of impact directly on the airframe with that of initial contact with an extended gear, landing skid, or float.

Table 21. Comparison of Gear Retracted Versus Gear/Float Extended

Scenario			1D01P0		1D02P0		1D03P0		3D01P0	
			Airframe	Skid	Airframe	Skid	Airframe	Skid	Airframe	Float
Vertical/longitudinal velocity (ft/sec)			20/0	20/0	17/25	17/25	16/50	16/50	20/0	20/0
Panel failure			Yes	Yes	No	No	No	Yes	No	No
Floor Response—Vertical Peak Acceleration (g)										
FS47 BL 14	Pilot	Mass 31	42.8	60.0	34.5	34.0	32.5	34.6	59.7	30.9
FS85 BL 30	Fwd	Mass 52	37.2	42.7	28.6	32.4	27.3	32.3	38.2	23.3
FS102 BL 37	Mid	Mass 62	31.9	28.9	29.8	31.4	29.1	31.2	49.1	39.9
FS139 BL 36	Aft	Mass 82	16.8	16.0	21.0	21.9	19.3	25.4	24.8	19.4
Mass Response—Vertical Peak Acceleration (g)										
Transmission		Mass 7	13.3	12.1	21.2	20.2	20.7	18.9	25.8	16.1
Engine		Mass 8	16.1	15.7	15.6	15.4	15.5	15.6	14.2	15.0
Fuel – fwd		Mass 401	24.9	25.7	25.7	28	23.2	25.9	**30.3**	23.2
Fuel – mid		Mass 402	17.2	16.1	17.1	18.2	16.7	18.0	19.5	14.9
Fuel – aft		Mass 403	15.8	16.8	24.3	24.8	23.3	24.0	21.7	19.2
Rigid Seat—Lumbar Load (lb)										
FS 42 BL 14	Pilot	Beam 213	**2087**	**2250**	**1631**	**1711**	1498	**1595**	1204	1165
FS 85 BL 30	Fwd	Beam 214	**1821**	**1899**	**1532**	**1527**	1447	1450	1204	1114
FS 102 BL 37	Mid	Beam 215	**1779**	1490	**1632**	**1668**	**1604**	**1667**	1198	1035
FS 139 BL 36	Aft	Beam 216	1265.0	923	1255	1249	1244	1264	no seat	no seat
Seat Deflection (in.)										
Seat Type			Rigid	Rigid	Rigid	Rigid	Rigid	Rigid	12 g	12 g
FS 47 BL 22	Pilot	Beam 213	-	-	-	-	-	-	3.43	0.917
FS 87 BL 34	Fwd	Beam 214	-	-	-	-	-	-	1.88	0.541
FS 117 BL 34	Mid	Beam 215	-	-	-	-	-	-	1.46	0.487
FS 139 BL 26	Aft	Beam 216	-	-	-	-	-	-	no seat	no seat

Bold numbers exceed criteria

The BH-205 landing skids do not offer much resistance to impact, on either hard ground or water. This is reflected in the comparisons of the three cases associated with the maximum GTOW configuration in which failure or lack of failure of the underside panel is similar. The floor and mass responses vary with an active skid (gear extended) versus that of an initial impact on the airframe (no skid or gear retracted). The floor peak responses are reasonably close except possibly for the 20-ft/sec impact with skid, which produces a 60-g acceleration at FS 42, as opposed to 42 g with no skid. These two impacts are examined along with a situation where the skid physically exists, but does not participate as an active hydrodynamic lift surface. Figures 16 through 20 show a comparison of the velocity change at mass 31, the pressure at mass 31, the velocity versus pressure at mass 31, the floor acceleration at mass 31, and the floor acceleration at mass 52, respectively. The latter two figures (19 and 20) show the skid results shifted timewise to compare responses from the moment the airframe contacts the water. Also included is a comparison of the effect of a coarse integration interval in the results. The BH-205cfg1a notation refers to the BH-205 configuration 1 maximum GTOW model. The comparisons show that

- active skids and inactive skid exhibit no significant difference.
- there was a timewise shift of approximately 67 msec in peak occurrences between a skid on landing gear (LG extended) and skid off (LG retracted).
- the floor pulses were consistent, although the peak can vary between the skid on and off impacts.
- the skid is not significant in a vertical or combined velocity impact. This was evident in the S2 test in which a skid was present in a combined 28-ft/sec vertical and 39-ft/sec longitudinal impact.
- the coarse integration interval 2E-05 sec versus 1E-06 sec might affect the more sensitive responses, such as the floor accelerations, but less likely to effect velocity change or low frequency responses.

Figure 16 shows that the mass 31 velocity for the skid impact parallels the airframe impact but is delayed around 60 to 65 msec. If the skid impact were run longer, it most likely would show additional velocity change. Figure 17 shows that the pressure at the underside panel below mass 31 is nearly the same for both the skid and airframe impacts.

Figure 18 shows that the peak velocity and pressures, when cross-plotted, match very closely. There is a slight difference in how the peaks are reached, which is attributed to the time difference associated with the impacts.

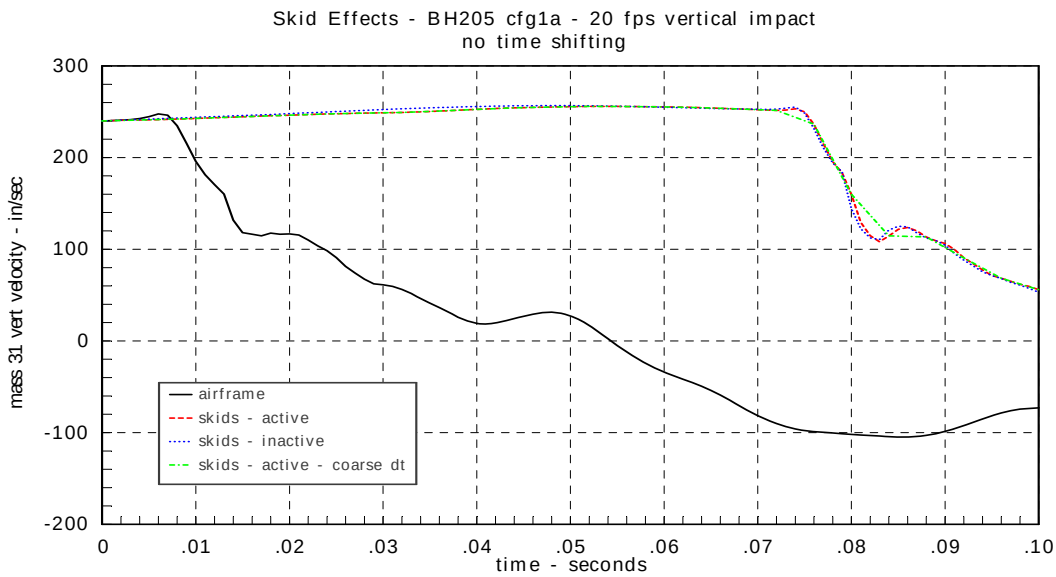


Figure 16. Mass 31 Vertical Velocity Versus Time—20-ft/sec Vertical Velocity Impact

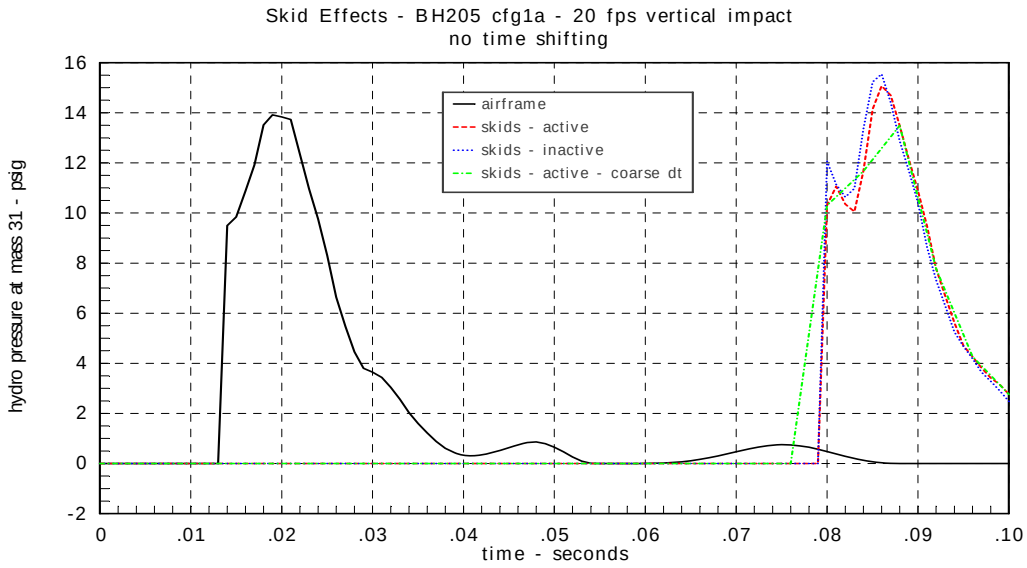


Figure 17. Mass 31 Hydronamic Pressure Versus Time—20-ft/sec Vertical Velocity Impact

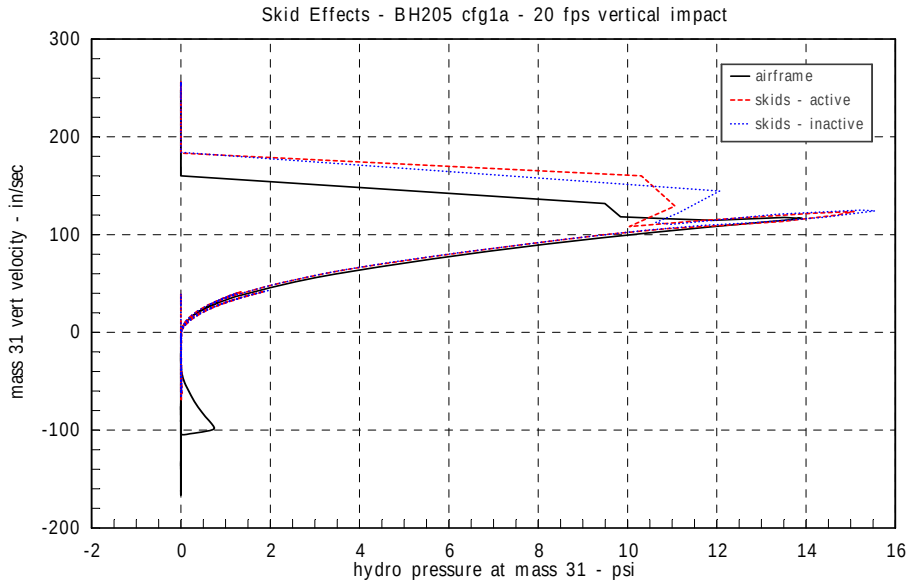


Figure 18. Fuselage Station 42 Vertical Velocity Versus Hydrodynamic Pressure—20-ft/sec Vertical Velocity Impact

Figures 19 and 20 show that the peak floor acceleration is higher for the skid impact than the airframe impact when compared for the same integration interval. This is attributed to the fact that there is a slightly higher velocity change associated with the skid impact because it has an additional free-fall distance to go before the airframe hits. The acceleration is also a more sensitive parameter than the velocity and displacement. Figure 19 shows the acceleration at FS 42 being a distinct impact. Figure 20 shows that the acceleration at FS 85 is more of a series of impacts, which track closer (skid versus airframe) in peak than at FS 42.

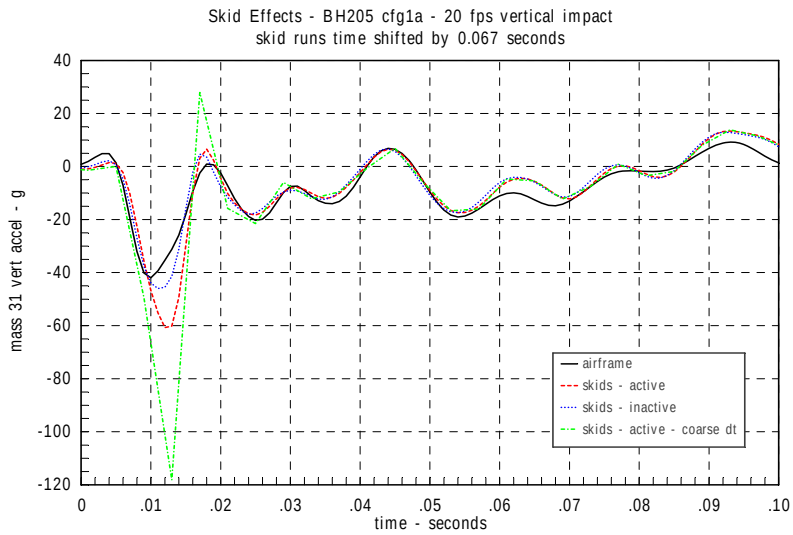


Figure 19. Fuselage Station 42 Vertical Acceleration Versus Time—20-ft/sec Vertical Velocity Impact

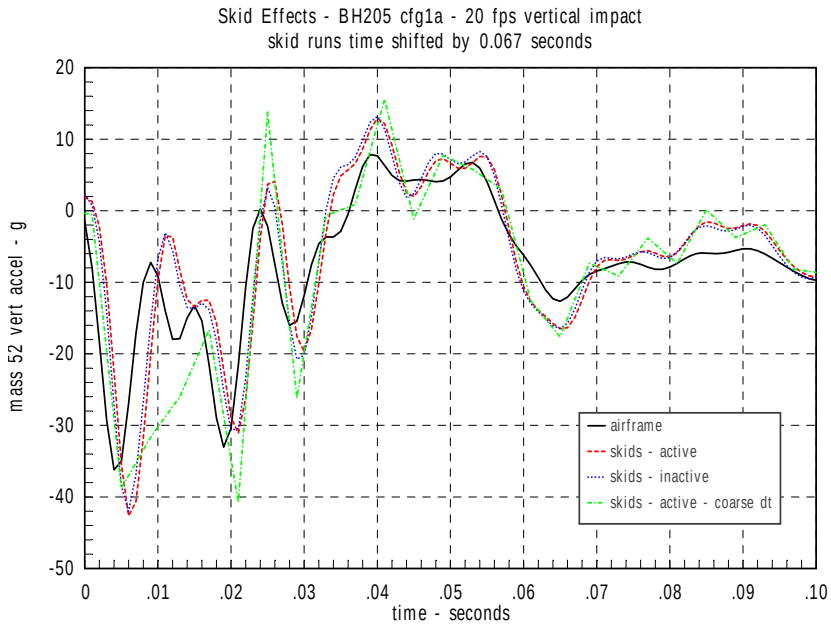


Figure 20. Fuselage Station 85 Vertical Acceleration Versus Time—20-ft/sec Vertical Velocity Impact

The GTOW configuration results (1D01P0, 1D02P0, 1D03P0) in table 21 are for a rigid seat, resulting in lumbar loads that are excessive for some of the impact conditions shown.

In table 21, the float appears to have a positive influence. As the amphibious configuration (3D01P0) airframe impact results in greater seat stroking than when the float is impacted. The peak floor acceleration and mass items accelerations are also generally higher for the airframe impact.

5.1.3.2 Design Pressures.

The maximum GTOW model was used to evaluate the influence of design pressures on failure loads and thus design limits. Included are the underside panel design pressure and the float design pressure.

Panel strength can be increased by greater panel thickness, changing the material, or changing the design concept. Based on calculations provided, [4] the panel pressure was directly related to the panel thickness. At 20 ft/sec, the mass item allowables were not exceeded. If it is assumed that either by increased thickness or other means (i.e., material), the panel pressures can be increased by 50%, then the level that panel failure will occur will increase from 20 ft/sec to 22 ft/sec. If the panel pressure capability were doubled, then the failure level is increased to 25 ft/sec. Table 22 shows this relationship for seats that have either a 12- or a 14.5-g LL seat. In addition, floor and mass item peak vertical accelerations are noted. For the regular design allowables, while the underside panels fail at 18 ft/sec, a 12-g LL seat can require a stroke of about 3.4 inches, and all the mass item vertical accelerations are less than 30 g. With a 50% increase in underside panel design allowable and a 22-ft/sec impact, the 12-g LL seat stroke still is less than 5 inches. The transmission mass and the fwd and mid fuel mass responses exceed 30 g. With a 100% increase in underside panel design and a 25 ft/sec impact, the 12-g LL seat stroke reaches 7.8 inches, the transmission vertical acceleration reaches 46 g, while fuel mass vertical acceleration exceeds 50 g. Incorporating a 14.5-g LL seat can reduce the seat stroke to less than 5 inches. However, the mass item and floor responses would not be significantly affected by the change in seat load limit. Thus, unless mass item criteria are also increased, higher panel design allowables result in greater seat deflection and higher floor and mass item responses. Both the 12- and 14.5-g LL seat produce lumbar loads less than 1500 lb, provided they do not run out of stroke.

The results presented in section 5.1.2 for the amphibious float configuration were based on a 10-psi design pressure. This may be conservative (on the high side) even though floats have survived at vertical velocity impacts of 17 through 30 ft/sec (figure 15 and table 19). There was little design data available for this particular float system. The KRASH representation of the floats as cylindrical hydrodynamic lift surfaces might underestimate the hydrodynamic forces and indicate greater capability than is appropriate, particularly at the zero longitudinal velocity impacts. Thus, additional simulations are made with the float design pressure at 3 and 5 psi. These results, noted in table 23, show that the failure levels occur at lower impact velocities with lower allowable pressures than for the comparable floats with a 10-psi design pressure, as expected. When the float fails under combined vertical and longitudinal velocities, the airframe generally impacts on the forward region anywhere from FS 23 (mass 20) to FS 68 (mass 40).

Table 22. Tradeoff Between Panel Strength, Seat g Limit, Stroke, and Peak Acceleration

Scenario			5D01P0 12-g LL Seat	5D01P0 12-g LL Seat	5D01P0 12-g LL Seat	5D01P0 12-g LL Seat
Vertical/longitudinal velocity (ft/sec)			18/0	22/0	25/0	25/0
Pitch/roll/yaw (degree)			0/0/0	0/0/0	0/0/0	0/0/0
Sea-state wave			calm	calm	calm	calm
Panel pressure factor			1	1.5	2.0	2.0
Design strength factor			1	1	1	1
Load Limit (g)			12.0	12.0	12.0	14.5
Floor Response—Vertical Peak Acceleration (g)						
FS 47 BL 14	Pilot	Mass 31	42.1	70	71.6	70.4
FS 85 BL 30	Fwd	Mass 52	36.1	44.7	59.1	57.8
FS 102 BL 37	Mid	Mass 62	32.9	41.8	55.4	56.0
FS 139 BL 36	Side seat	Mass 72	21.5	37.5	48.5	39.8
Mass Response—Vertical Peak Acceleration (g)						
Transmission		Mass 7	24.2	**36.0**	**46.0**	**45.9**
Engine		Mass 8	13.3	18.0	22.5	22.4
Fuel - Fwd Tank		Mass 401	28.1	**45.4**	**56.5**	**57.2**
Fuel - Mid Tank		Mass 402	22.4	**30.3**	**43.9**	**43.9**
Fuel - Aft Tank		Mass 403	16.4	27.9	**31.8**	**31.8**
Seat Deflection—Peak (in.)						
FS 47 BL 14	Pilot	Beam 221	3.37	4.74	**7.76**	4.72
FS 85 BL 30	Fwd	Beam 222	1.76	2.58	3.92	2.88
FS 102 BL 37	Mid	Beam 223	1.31	2.45	3.90	2.77
FS 139 BL 36	Side seat	Beam 224	1.21	1.42	2.99	1.78

Bold numbers exceed criteria

The vertical velocity-only impact tends to fail the region from FS 129 (mass 70) to FS 166 (mass 90). Table 23 compares the trend versus design pressure for both airframe and float failures. As noted in table 17, the vertical impact velocity at pitch = 0, +5, +10 degrees are 26, 18, and 16 ft/sec, respectively. They produce a float pressure of 6.7, 3.1, and 2.8 psi, respectively. Even at vertical velocity-only impacts as high as 23 ft/sec, regardless of pitch attitude, the float pressures may exceed 5 psi. This is not true for combined vertical and longitudinal velocities of 50 ft/sec. However, airframe failure has occurred at lower velocities, as noted in table 17, which violates the ditching criteria. Also, it should be noted that table 23 does not show mass item accelerations, occupant load, or seat stroke, which increase as impact velocity increases. Thus, table 17 defines the ditching limits for the 10-psi float configuration, while table 23 compares the float capability versus airframe failure vertical velocity (V_2) as a function of design pressure.

Table 23. Float Design Failure Trends

Float Pressure (psi)		10	5	3
Pitch = 0 degree	Airframe failure V_2 (ft/sec)	26	22	16
	Float failure V_2 (ft/sec)	27+	22	17
Pitch = +5 degrees	Airframe failure V_2 (ft/sec)	18	19	16
	Float failure V_2 (ft/sec)	27+	22	17
Pitch = +10 degrees	Airframe failure V_2 (ft/sec)	16	16	16
	Float failure V_2 (ft/sec)	27+	22	17

(a) Longitudinal Velocity = 0 ft/sec

Float Pressure (psi)		10	5	3
Pitch = 0 degree	Airframe failure V_2 (ft/sec)	19	17	15
	Float failure V_2 (ft/sec)	18	16	14
Pitch = +5 degrees	Airframe failure V_2 (ft/sec)	13	9	8
	Float failure V_2 (ft/sec)	13	9	8
Pitch = +10 degrees	Airframe failure V_2 (ft/sec)	10	8	7
	Float failure V_2 (ft/sec)	10	8	7

(b) Longitudinal Velocity = 50 ft/sec

5.1.3.3 Fuselage Shape.

Changing the contour of the underside fuselage can also affect the impact loads. Smaller helicopters, such as observation usage types, generally are more circular in cross-section. To evaluate this circular design concept, the BH-205 model was revised to represent the underside hydrodynamic surfaces with a radius of 50 inches versus 100 inches. The results are shown in table 24, which shows that a 22-ft/sec impact with a circular cross-section results in lower loads than the flat underside. Comparisons are made with regard to panel failure occurrence, floor peak vertical accelerations, mass item peak vertical accelerations, lumbar load, and seat stroke. Generally, the circular shape affords a 10% to 35% reduction in severity of impact, although a few responses increase between 5% to 11%. As the model was run with a rigid seat, the lumbar load, while reduced, is still above criteria. However, with 12- or 14.5-g LL seats, the lumbar load would be less than 1500 lb.

Table 24. Effect of Fuselage Contour Design on Responses

Scenario			1D01P0 Radius=100 (in.)	1D01P0 Radius=50 (in.)	Change (%)
Vertical/longitudinal (ft/sec)			20/0	20/0	
Pitch/roll/yaw (degree)			0/0/0	0/0/0	
Underside panel failure			Yes	No	
Floor Response—Vertical Peak Acceleration (g)					
FS 42 BL 14	Pilot	Mass 31	42.0	37.9	-9.8
FS 85 BL 30	Fwd	Mass 52	36.2	25.8	-28.7
FS 102 BL 37	Mid	Mass 62	31.6	33.9	7.3
FS 139 BL 36	Aft	Mass 82	16.2	17.3	6.8
Mass Response—Vertical Peak Acceleration (g)					
Transmission		Mass 7	13.3	8.7	-34.6
Engine		Mass 8	16.1	13.3	-17.4
Fuel - Fwd		Mass 401	24.9	19.9	-20.1
Fuel - Mid		Mass 402	17.2	19.1	11.0
Fuel - Aft		Mass 403	15.8	16.7	5.7
Lumbar Load (lb)					
FS 47 BL 22	Pilot	Beam 213	2147	1780	-17.1
Seat Stroke (in.)					
FS 47 BL 22	Pilot	Beam 221	0.616	0.470	-23.7

The results associated with a contour design is based on only the shape being changed and other factors such as weight distribution, underside depth, and panel design strengths remaining equal. Maximum GTOW configuration 1 was used.

5.1.3.4 Drag Effects.

The previous SBIR effort involved the analysis of several aircraft, test conditions, and accident situations. One such accident involved the Lynx helicopter. The helicopter was subjected to a high-forward velocity (172 ft/sec) and low-sink speed (6 ft/sec). The pitch attitude was approximately +3 degrees (nose-up). The helicopter, which was modeled with KRASH, pitched over during the course of the accident. Since overturns resulting from high-drag forces occur, consideration was given as to when it might occur with the BH-205. The primary configuration includes a skid, and was the test article in the SBIR S2 test. The test was conducted with a 39-ft/sec longitudinal velocity, along with 28-ft/sec vertical and +4 degree pitch. The skids have been shown, both in that test and the analysis conducted in support of the BH-205, to be ineffective both in absorbing energy and developing significant drag forces. However, the float configuration, which extends further below the fuselage and has considerably more surface area, might produce different effects. To investigate drag effects, the float configuration was run at a 13-ft/sec vertical velocity, a +5 degree pitch attitude, and forward velocity ranging from 30 to 80 ft/sec. This condition was selected because the float 5 degree pitch cases indicate failure of

the floats, as well as subsequent underside panel failures occur, when the forward velocity is greater than 30 ft/sec. At 30 ft/sec, only the floats fail. Table 25 shows these results.

Table 25. Drag Effects Versus Forward Velocity

Vertical Velocity (ft/sec)	Longitudinal Velocity (ft/sec)	Pitch Rotation (radian)	Pitch Rotation (degree)	Float Peak Drag (psi)	FS 42 Peak Longitudinal Aft Acceleration (g)	FS 42 Peak Long-Term Aft Acceleration (g)	c.g. Peak Long-Term Aft Acceleration (g)
13	30	-0.060	-3.44	5.7 - 6.7	11.6	3.0	1.68
13	40	-0.168	-9.63	9.6 - 11.9	10.1	3.5	2.50
13	50	-0.306	-17.53	14.5 - 18.3	10.7	5.5	3.32
13	60	-0.467	-26.76	20.5 - 26.1	17.5	7.5	4.58
13	70	-0.663	-37.99	27.6 - 35.3	13.2	10.0	5.68
13	80	-0.880	-50.42	35.0 - 45.9	26.1	12.5	7.10

Table 25 shows that the helicopter has rotated about 50 degrees nose-down after 0.500 sec when the forward velocity reaches 80 ft/sec. Actually, that condition was subsequently run as far as 0.70 sec, and the nose-down pitch reached 80 degrees. However, after about 0.625 sec, drag forces caused several internal bulkhead failures and resulted in model instability. The plot of the FS 42 floor and c.g. longitudinal accelerations (ax), from 50 to 80 ft/sec, are shown in figures 21 and 22, respectively. The corresponding FS 42 floor and c.g. vertical accelerations (az), from 50 to 80 ft/sec, are shown in figures 23 and 24, respectively. The pitch attitude as a function of longitudinal velocity is shown in figure 25 (mass number is shown in brackets).

There are floor short-term peak longitudinal accelerations (0.010 sec) that range between 10 and 26 g, while the corresponding long-term c.g. aft acceleration peaks range from 1.68 to 7.1 g. For the c.g. responses, the long-term duration is more like 0.250 to >0.400 second. Between approximately 0.100 and 0.220 sec, there are long-term aft accelerations ranging from 3.0 to 12.5 g that are relatively constant.

The floor short-term peak vertical accelerations (0.010 sec) range between 45 and >120 g, while the corresponding long-term c.g. peak accelerations are <10 g. For the long term c.g. vertical acceleration, the duration is 0.100 to 0.250 sec.

The long-term pulses are more indicative of pulses that the occupant will react to than the short transient peaks.

All the acceleration data is based on SAE class 60 filtering.

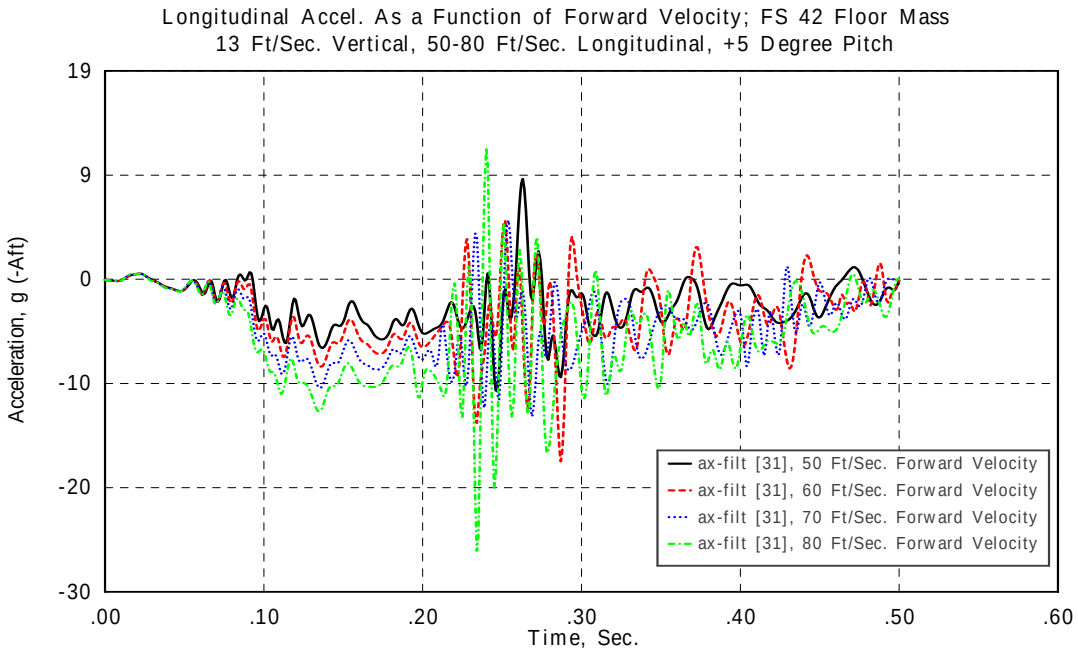


Figure 21. Floor Longitudinal Acceleration Versus Forward Velocity

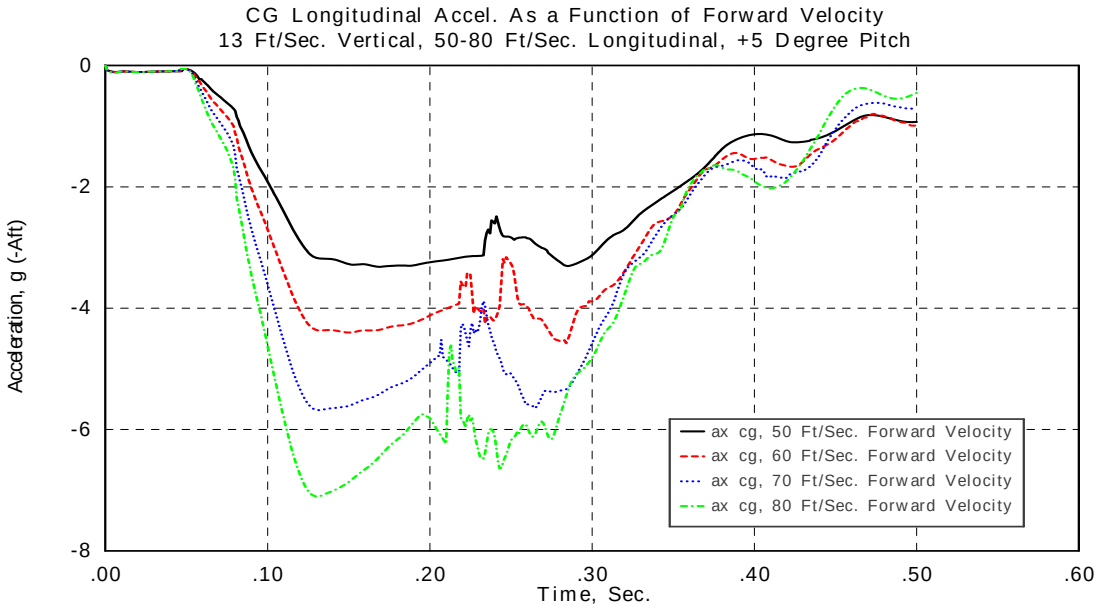


Figure 22. Center of Gravity Longitudinal Acceleration Versus Forward Velocity

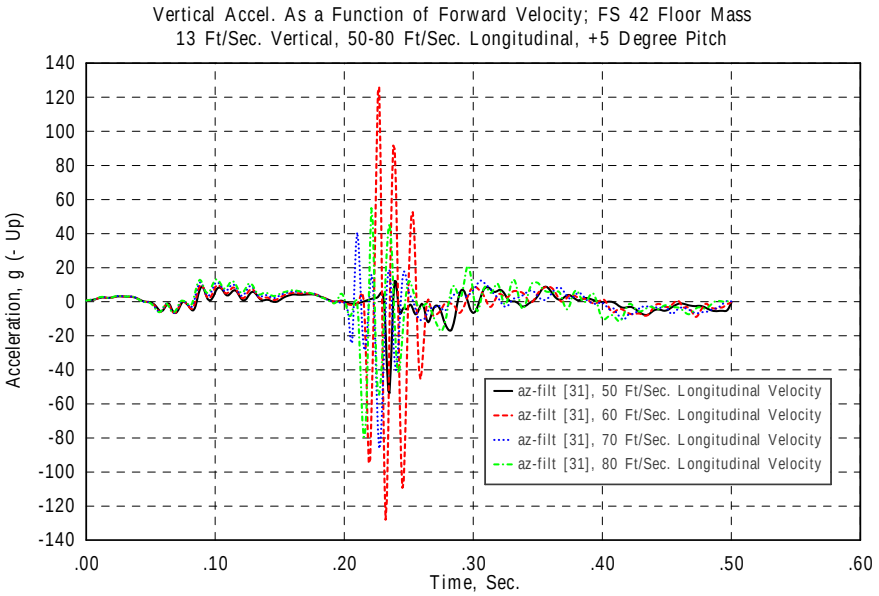


Figure 23. Floor Vertical Acceleration Versus Forward Velocity

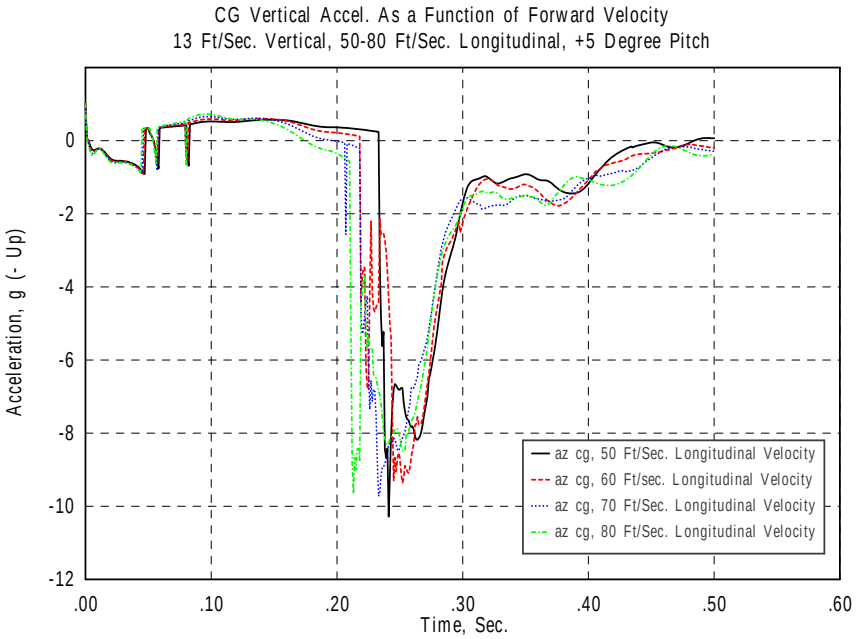


Figure 24. Center of Gravity Vertical Acceleration Versus Forward Velocity

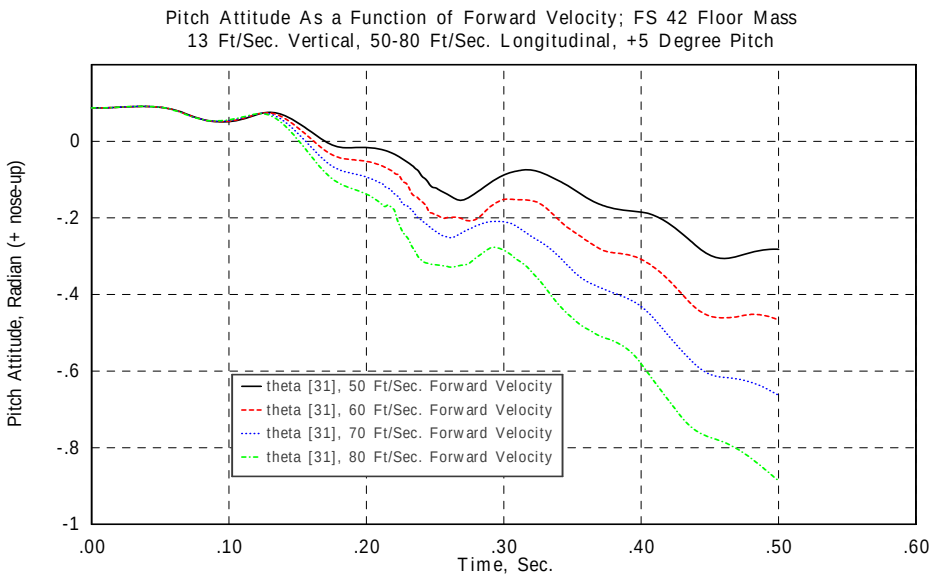


Figure 25. Pitch Attitude Versus Forward Velocity

The plots shown in figures 21 through 25 show the trend with regard to both transient pulses obtained at a selective floor station, as well as long-term pulses as would be measured at the aircraft c.g. These results illustrate that the potential for drag forces causing helicopters to nose-over is real provided there is sufficient drag forces developed on protuberances that are well below the c.g. or bulkheads that become subject to drag loads after underside panels fail. An initial pitching rate at water impact will also contribute to the pitch-over effect.

The long-term pulses may be more indicative of pulses that the occupant will react to than some of the very short-transient peaks.

5.1.3.5 Suction Force.

Suction forces tend to act aft of the c.g. and on upward contoured surfaces. The BH-205 underside is relatively flat from about FS 92 to FS 143, as shown in figure 2. Thereafter, the fuselage contours upward. Downward suction forces acting aft of the c.g., if significant, could cause the aircraft to maintain a tilt nose-up, plane and delay some pitching activity. The BH-205 KRASH model has several lifting surfaces that act aft of the c.g. To investigate the affect of potential suction effects, several underside panels were allowed to have a -10 psi pressure from the time of initiation of impact, as shown in table 26. Minus ten psi was chosen because (1) Osprey scale model tests [15] showed suction pressures of a magnitude of -3 to -10 psi and (2) -10 psi is relatively large since the design pressures in that region are usually between 17 and 58 psi.

Table 26. Suction Forces

Surface Number	KRASH Mass Number	Pressure Allowable (psi)	Surface Area (in.^{2})	Force 10 psi (lb)	FS (in.)	BL (in.)
14	100	35	1036	-10360	192	0
15	103	17	518	-5180	192	22
16	110	25	1120	-11200	211	0
18	90	41	308	-3080	166	0
20	91	58	176	-1760	166	14

Two combined vertical and longitudinal, velocity-impact conditions were run with the suction forces noted in table 26. KRASH does not compute suction forces, instead, it models suction based on input suction forces that are either surface penetration or surface time dependent. Thus, for each water impact condition, the nonsuction condition was run to determine when the surfaces that were exposed to suction forces made contact with the water, reached their peak deflections, and lost contact with the water. Thus, suction force tables were created, as noted in table 27. The impact condition is based on an airframe initial impact in lieu of a skid impact. For both failure and nonfailure conditions, suction force does not significantly change the results, but alters some dynamics. Figures 26 and 27 show a comparison of the pitch attitude for the two conditions analyzed.

Table 27. Comparison of Failures—Suction Versus Nonsuction, Airframe Impact

Scenario			1D03P10 No Suction	5D03P10 Suction	5D03P10 Suction	1D02P5 No Suction	1D02P5 Suction	1D02P5 Suction
Vertical/longitudinal velocity (ft/sec)			10/50	10/50	10/50	12/25	12/25	12/25
Pitch (degree)			+10	+10	+10	+5	+5	+5
Suction (psi)			0	-10	-10	0	-10	-10
Underside panel failures			2	2	2	0	0	0
Panel mass (lb)			(0.010)	91 (0.011)	91 (0.110)			
(Time failed (sec))			90 (0.011)	90 (0.012)	90 (0.011)			
Suction pressure based on				Time	Penetration		Time	Penetration
				on/off (sec)	on/off (in.)		on/off (sec)	on/off (in.)
Surface 14	Mass 100	FS 192 BL 0		0.001/.100	0.001/3.5		0.020/.200	0.0001/3.5
Surface 15	Mass 103	FS 192 BL 22		0.001/.100	0.001/3.5		0.020/.200	0.0001/3.5
Surface 16	Mass 110	FS 211 BL 0		0.100/.015	0.001/2.5		0.150/.200	0.0001/1.5
Surface18	Mass 90	FS 166 BL 0		0.0001/.015	0.00001/1.0		0.0001/.170	0.0001/5.2
Surface 20	Mass 91	FS 166 BL 14		0.0001/.015	0.00001/1.0		0.0001/.170	0.0001/5.2
			Pressure (psi)					
Surface 14	Mass 100	FS 192 BL 0	19.8	13.8	14.8	3.2	-4.48	-5.0
Surface 15	Mass 103	FS 192 BL 22	0.0	0.0	0.0	0.0	-4.15	0.0
Surface 16	Mass 110	FS 211 BL 0	9.4	5.6	2.9	1.4	-4.92	-6.48
Surface 18	Mass 90	FS 166 BL 0	35.0	35.0	35.0	30.7	23.6	23.1
Surface 20	Mass 91	FS 166 BL 14	58.0	58.0	58.0	56.3	51.2	50.3

Table 27. Comparison of Failures—Suction Versus Nonsuction, Airframe Impact (Continued)

Scenario			1D03P10	5D03P10	5D03P10	1D02P5	1D02P5	1D02P5
			No Suction	Suction	Suction	No Suction	Suction	Suction
			Penetration (in.)					
Surface 14	Mass 100	FS 192 BL 0	3.24	3.60	5.35	3.5	8.55	5.35
Surface 15	Mass 103	FS 192 BL 22	0.00	0.00	0.00	0.0	3.01	0.0
Surface 16	Mass 110	FS 211 BL 0	2.23	2.60	3.65	1.5	8.29	3.65
Surface 18	Mass 90	FS 166 BL 0	0.98	1.13	6.59	5.1	8.76	6.59
Surface 20	Mass 91	FS 166 BL 14	0.89	0.93	6.59	5.1	8.77	6.59

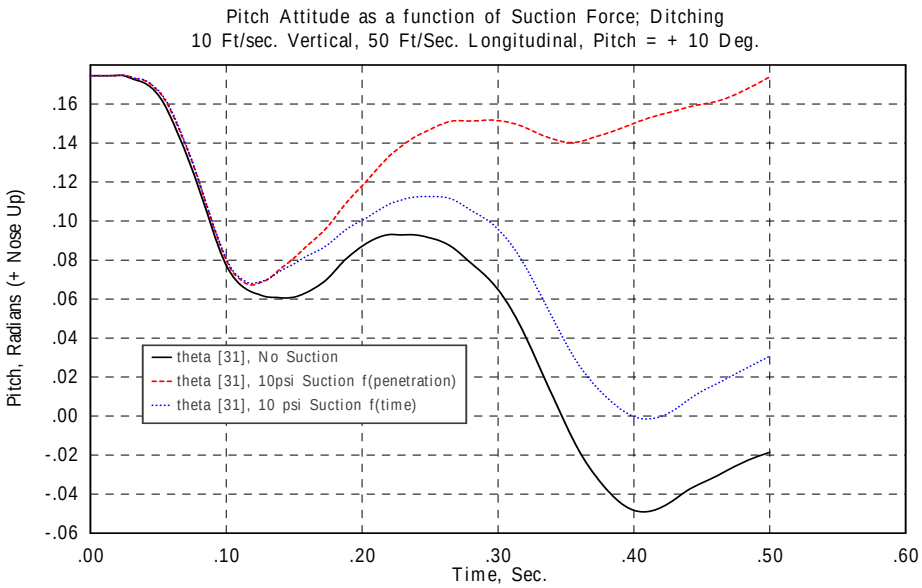


Figure 26. Aircraft Pitch Attitude Comparisons for Suction Effects—10 ft/sec Vertical, 50 ft/sec Longitudinal, +10 Degree Pitch

The plot of attitude versus time shows that for the 50-ft/sec longitudinal condition, the treatment of suction as a function of time or surface penetration results in a more nose-up pitch than the corresponding nonsuction condition. In figure 27, the plot of attitude versus time shows for the 25-ft/sec longitudinal condition that the aircraft either pitches about the same or more nose-up, depending on how the suction force is treated. The most likely scenario for how the aircraft pitches due to suction lies somewhere between the two treatments. This is because the suction force history input into KRASH program is an initial estimate. As the force acts, some of the dynamics and results change. For example, for both conditions, the peak surface deflections (table 25) are higher than the initial estimates. The time when the forces act also shifts slightly. Thus, additional intermediate changes might be necessary to balance the input estimate with the actual results. The end result appears to be that suction forces are likely to result in more planing of the aircraft, even after an initial dip in attitude. In the S2 test, (39-ft/sec longitudinal velocity), the aircraft started with a +4 degree pitch, dipped down, and then leveled off before it took on water through the open areas. However, the peak forces may have occurred before the suction forces fully acted.

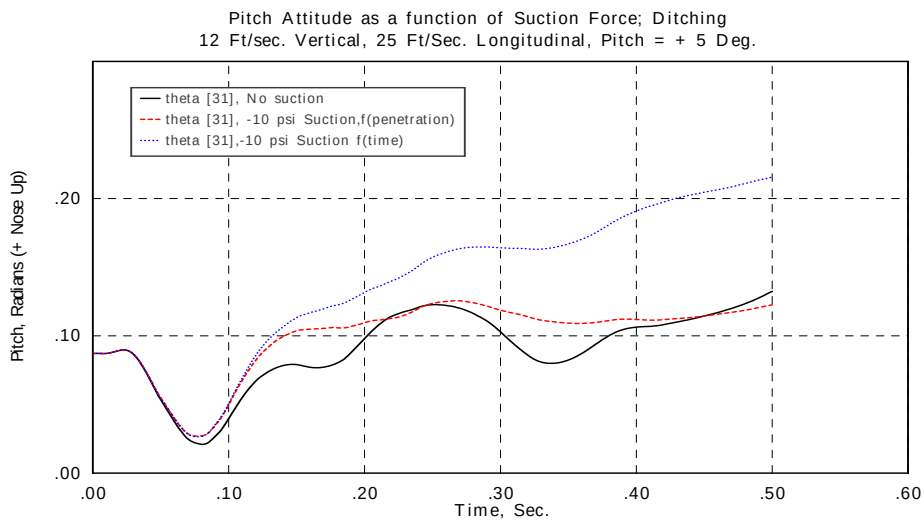


Figure 27. Aircraft Pitch Attitude Comparisons for Suction Effects—12 ft/sec Vertical, 25 ft/sec Longitudinal, +5 Degree Pitch

5.1.4 Sea State.

Title 14 CFR standards specify that a ditching into a rough sea must be taken into account. Table 28 [4] provides a set of wave profiles versus sea-state number. For a sea state = 4, the minimum wave height is 4 ft and the minimum wave velocity is 17 ft/sec.

Table 28. World Meteorological Organization Sea-State Code

Sea-State Code	Description of Sea	Significant Wave Height (meters)		Significant Wave Height (feet)		Wind Speed (knots)	
		Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
0	Calm (glassy)	0	0	0	0	0	3
1	Calm (rippled)	0	0.1	0	0.333	4	6
2	Smooth (wavelets)	0.1	0.5	0.333	1.667	7	10
3	Slight	0.5	1.25	1.667	4	11	16
4	Moderate	1.25	2.5	4	8	17	21
5	Rough	2.5	4	8	13	22	27
6	Very rough	4	6	13	20	28	47
7	High	6	9	20	30	48	55
8	Very high	9	14	30	45	56	63
9	Phenomenal	14	-	45	-	64	118

Notes:

The significant wave height is defined as the average value of the height (vertical distance between trough and crest) of the largest one-third of the waves present.

Maximum wave height is usually taken to be 1.6 times significant wave height: e.g., significant wave height of 6 meters gives maximum wave height of 9.6 meters.

Wind speeds were obtained from Appendix R of the "American Practical Navigator," by Nathaniel Bowditch, L.L. D.; published by the U.S. Naval Oceanographic Office, 1966.

Generally, in scale model testing, impacts perpendicular to and parallel to the wave are simulated. In addition, a wave length-to-height (L/H) ratio of 10 and 20 is used. Thus, several water impact simulations were used that included:

- Wave height = 4 ft, wave length = 40 ft, 0 wave velocity
- Wave height = 4 ft, wave length = 40 ft, 17-ft/sec wave velocity toward the aircraft
- Wave height = 4 ft, wave length = 80 ft, 17-ft/sec wave velocity toward the aircraft (for one condition)
- Aircraft impact perpendicular to wave; crest, midpoint, 1/4 from top, and trough
- Aircraft impact parallel to wave; crest
- Impact conditions; vertical-only, or combined vertical and longitudinal (with longitudinal velocities of 25, 50, and 60 ft/sec), pitch = 0 degree, and +10 degrees
- Water impact models; maximum GTOW configuration 1 with rigid seat, skid removed, and skid extended

The seat, whether rigid, 12-g LL, or 14.5-g LL, should not affect the underside panel failure pattern. A summary of resulting vertical and longitudinal velocities for the skid removed ditching conditions for an L/H = 10 is provided in table 29.

Landings perpendicular to the wave front resulted in panel failures at the front end of the aircraft, generally around FS 23, and occasionally closer to FS 102. By contrast, the parallel landings with waves resulted in failures around FS 155-166, which is similar to landings onto calm seas. Table 29 shows that the helicopter performed best when it landed parallel to the wave and on the crest with no wave velocity present. Operational procedures for aircraft generally state that, in a planned ditching, the speed should be reduced and that a landing should occur parallel to and on the wave crest, if at all possible. When landing perpendicular to the wave, the vertical velocity capability was reduced as much as 6 ft/sec compared to parallel crest landings for a combined vertical and longitudinal velocity impact. In general, the effect of waves appeared to reduce the velocity capability by 2 ft/sec. Vertical-only impacts appeared to be less sensitive to wave effects. In the only case run when an L/H of 20 was used (Vertical-only -0 pitch, perpendicular to wave, 1/4 below crest), the velocity capability was reduced by 2 ft/sec.

Impact conditions for brevity are also noted as x/y/z, where x = vertical velocity, y = longitudinal velocity, and z = pitch attitude.

In two sea-state impact conditions (8/50/10 perpendicular to wave face at 1/4 from the top and at the midpoint), postpanel failures resulted in hydrodynamic pressures reaching 18 psi acting on the bulkheads at FS 129 and FS 155.

Table 29. Sea-State Panel Failure Results

Scenario	Vertical/ Longitudinal (ft/sec)	Pitch/Roll/Yaw (degree)	Sea State				
			Wave Height (in.)	Wave Length (in.)	Wave Velocity (ft/sec)	Wave Orientation	Impact Location
6D01P0	20/0	0/0/0	48	480	0	Parallel	Crest
6D02P0	19/25	0/0/0	48	480	0	Parallel	Crest
6D03P0	18/50	0/0/0	48	480	0	Parallel	Crest
6D01P10	17/0	10/0/0	48	480	0	Parallel	Crest
6D02P10	15/25	10/0/0	48	480	0	Parallel	Crest
6D03P10	12/50	10/0/0	48	480	0	Parallel	Crest
6D01P0	19/0	0/0/0	48	480	-27	Parallel	Crest
6D02P0	17/25	0/0/0	48	480	-27	Parallel	Crest
6D03P0	16/50	0/0/0	48	480	-27	Parallel	Crest
6D01P10	16/0	10/0/0	48	480	-27	Parallel	Crest
6D02P10L	14/25	10/0/0	48	480	-27	Parallel	Crest
6D03P10	10/50	10/0/0	48	480	-27	Parallel	Crest
6D01P0	19/0	0/0/0	48	480	0	Perpendicular	Crest
6D02P0	14/25	0/0/0	48	480	0	Perpendicular	Crest
6D03P0	10/50	0/0/0	48	480	0	Perpendicular	Crest
6D01P10	18/0	10/0/0	48	480	0	Perpendicular	Crest
6D02P10	13/25	10/0/0	48	480	0	Perpendicular	Crest
6D03P10	6/50	10/0/0	48	480	0	Perpendicular	Crest
6D01P0	18/0	0/0/0	48	480	-27	Perpendicular	Crest
6D02P0	13/25	0/0/0	48	480	-27	Perpendicular	Crest
6D03P0	6/50	0/0/0	48	480	-27	Perpendicular	Crest
6D01P10	18/0	10/0/0	48	480	-27	Perpendicular	Crest
6D02P10	13/25	10/0/0	48	480	-27	Perpendicular	Crest
6D03P10	6/50	10/0/0	48	480	-27	Perpendicular	Crest
6D01P0 1/4 Crest	18/0	0/0/0	48	480	-27	Perpendicular	1/4 Below Crest
6D02P0 1/4 Crest	14/25	0/0/0	48	480	-27	Perpendicular	1/4 Below Crest
6D03P0 1/4 Crest	10/50	0/0/0	48	480	-27	Perpendicular	1/4 Below Crest
6D01P10 1/4 Crest	18/0	10/0/0	48	480	-27	Perpendicular	1/4 Below Crest
6D02P10 1/4 Crest	14/25	10/0/0	48	480	-27	Perpendicular	1/4 Below Crest
6D03P10 1/4 Crest	8/50	10/0/0	48	480	-27	Perpendicular	1/4 Below Crest
6D01P0 Mid	18/0	0/0/0	48	480	-27	Perpendicular	Midface
6D02P0 Mid	14/25	0/0/0	48	480	-27	Perpendicular	Midface
6D03P0 Mid	10/50	0/0/0	48	480	-27	Perpendicular	Midface
6D01P10 Mid	18/0	10/0/0	48	480	-27	Perpendicular	Midface
6D02P10 Mid	14/25	10/0/0	48	480	-27	Perpendicular	Midface
6D03P10 Mid	8/50	10/0/0	48	480	-27	Perpendicular	Midface

A sea-state skid (landing gear) extended analysis was performed at the same water impact level as conditions noted in table 29. These included the following three +10 degree ditching conditions:

- Landing parallel to the wave and on the crest at a 10/50/10 condition
- Landing perpendicular to the wave and on the crest at a 6/50/10 condition
- Landing perpendicular into the face of the wave at wave mid-height at a 8/50/10 condition

At these conditions, the results were similar to the landing gear retracted results within 1-ft/sec vertical velocity. A fourth condition, landing perpendicular into the face of the wave at its mid-height, with a longitudinal velocity-only (no vertical velocity) impact with a +10 degree pitch, was also analyzed. For this condition, no panel failure was experienced until after the longitudinal velocity reaches 65 ft/sec.

Additional sea-state analyses were performed for several select perpendiculars to the wave water impact conditions, such as:

- 8/50/10 crest, 1/4 from crest, mid-face, and trough
- 5/60/10 crest, 1/4 from crest, mid-face, and trough

These sea-state conditions were analyzed primarily to determine the magnitude of the interior bulkhead pressure that would develop at failure. The results of these conditions are provided in table 30 where it shows that at the 5/60/10 water impact conditions, bulkhead pressures are generally greater than 20 psi and can exceed the criteria of 23 psi.

Several simulations were also performed for the float configuration to ascertain the effect of impacting waves: three perpendicular impacts with an L/H ratio of 20 (at a wave trough, at the mid-face, and at a top quarter below the crest) with the latter being the most severe. The results showed that at both vertical-only and combined-velocity water impacts there was no significant reduction in velocity capability versus calm sea. Generally, it is expected that the L/H factor will increase the severity of the impact since it effectively acts to increase the pitch attitude.

Table 30. Sea-State Bulkhead Panel Pressure Results

		6D03P10	6D03P10	6D03P10	6D03P10	6D04P10	6D04P10	6D04P10	6D04P10
Scenario		Skid	Skid	Skid	Skid	Skid	Skid	Skid	Skid
Vertical/longitudinal velocity (ft/sec)		8/50	8/50	8/50	8/50	6/60	6/60	6/60	6/60
Pitch/roll/yaw (degree)		10/0/0	10/0/0	10/0/0	10/0/0	10/0/0	10/0/0	10/0/0	10/0/0
Sea state	Wave height (in.)	48	48	48	48	48	48	48	48
	Wave length (in.)	480	480	480	480	480	480	480	480
	Wave velocity (ft/sec)	-27	-27	-27	-27	-27	-27	-27	-27
	Wave orientation	Perpendicular	Perpendicular	Perpendicular	Perpendicular	Perpendicular	Perpendicular	Perpendicular	Perpendicular
	Impact location	Midface	1/4 Below Crest	Trough	Crest	Midface	1/4 Below Crest	Trough	Crest
Panel failures—mass no.		70,71	70,71	40,41	21,20	70	61,70,71	51,61	71,72
		80.81	80.81	70-72	70,71	80.81	80.81	70	-
		90,91	90,91	80.81	-	90,91	90,91	80.81	-
			61,72	90,91	-	-	-	90,91	-
Time frame (sec)		0.083 - 0.108	0.088 - 0.172	0.468 - 0.500	0.072 - 0.105	0.083 - 0.108	0.092 - 0.195	0.468 - 0.498	0.105 - 0.106
Maximum Bulkhead Pressures (psi)									
FS 23	Mass 20,21	-	-	-	19.2	-	-	-	-
FS 68	Mass 40,41	-	-	18.9	-	-	-	-	-
FS 92	Mass 50-52	-	-	-	-	-	-	**24.4**	-
FS 102	Mass 60-62	16.5	-	-	-	-	**24.9**	**25.9**	-
FS 129	Mass 70-72	16.9	17.5	17.2	18.5	-	**25.6**	20.5	**26.6**
FS 155	Mass 80-82	19.0	17.6	19.7	-	**25.3**	**25.3**	**24.1**	-
FS 166	Mass 90,91	18.8	17.9	16.5	-	**25.2**	**27.6**	22.3	-
FS 178	Mass 100	-	-	-	-	-	-	-	-
FS 211	Mass 103	-	-	-	-	-	-	-	-

Bold numbers exceed criteria

Sea-state analysis is sensitive to not only wave characteristics and impact scenarios, but also to the relationship between aircraft size and wave definition. While several relationships were investigated, this analysis by no means explores the full spectrum of sea-state considerations.

5.1.5 Unsymmetrical Water Impact.

To assess the effect that roll and yaw have on the water impact results, the three airframe pitch = +10 degree cases (1D01P10, 1D02P10, and 1D03P10) were run with roll and yaw = +10 degrees each. A comparison of the failure sequence is noted in table 31 where it shows, as anticipated, the impact is unsymmetrical. KRASH renumbers the opposite side masses and beams by adding 500 to the numbering scheme. Thus, mass 590 RHS = mass 90 LHS. The time sequence varies somewhat, but the impact velocity profile, based on underside panel failure, is such that the envelope of vertical versus longitudinal velocity is similar for symmetrical versus unsymmetrical impact.

Table 31. Symmetrical Versus Unsymmetrical Panel Failure Results, Airframe Impact

Scenario	1D01P10 Symmetrical	5D01P10 Unsymmetrical	1D02P10 Symmetrical	5D02P10 Unsymmetrical	1D03P10 Symmetrical	5D03P10 Unsymmetrical
Vertical/longitudinal velocity (ft/sec)	14/0	14/0	12/25	12/25	10/50	10/50
Pitch/roll/yaw (degree)	10/0/0	10/10/10	10/0/0	10/10/10	10/0/0	10/10/10
Underside panel failures - Panel mass (no.) (failed at Time (sec))	none	591 (0.0038)	91 (0.0063)	591 (0.0041)	91 (0.0099)	591 (0.0143)
			90 (0.0071)	603 (0.0225)	90 (0.0108)	

A symmetrical impact will not result in lateral forces and accelerations for masses that are on the centerline; i.e., engine, transmission, midfuel tank. However, it can produce lateral forces and accelerations for off-centerline masses. Nonuniformity in the lateral distribution of the vertical impact or weight distribution will induce roll acceleration. Likewise, drag load nonuniformity or weight distribution will induce yaw acceleration. Roll and yaw will lead to lateral accelerations. Thus, the floor masses and forward fuel and aft fuel masses located off-centerline can produce lateral accelerations in a symmetrical impact.

Table 32 shows floor accelerations for both symmetrical and unsymmetrical impacts for three different impact scenarios. Table 32 shows that the unsymmetrical impacts affect the responses, however, the maximum floor responses are very small, regardless. The maximum vertical peak acceleration is 13.5 g, the maximum lateral peak acceleration is 4 g, and the maximum longitudinal peak acceleration is 6.7 g.

Table 32. Symmetrical Versus Unsymmetrical Water Impact, Floor Responses

Scenario			1D01P10 Symmetrical	5D01P10 Unsymmetrical	1D02P10 Symmetrical	5D02P10 Unsymmetrical	1D03P10 Symmetrical	5D03P10 Unsymmetrical
Vertical/longitudinal velocity (ft/sec)			14/0	14/0	12/25	12/25	10/50	10/50
Pitch/roll/yaw (degree)			10/0/0	10/10/10	10/0/0	10/10/10	10/0/0	10/10/10
			Response—Longitudinal Peak (g)					
FS 42 BL 14	Fwd Floor Facing Seat RHS	Mass 31	3.30	2.13	4.7	5.30	2.70	2.54
		Mass 531	3.30	2.51	4.7	3.67	2.70	2.70
FS 85 BL 30	Aft Facing Seat RHS	Mass 52	2.60	2.41	3.0	4.60	1.90	1.86
		Mass 552	2.60	2.32	3.0	4.04	1.90	1.88
FS 102 BL 37	Fwd Facing Seat RHS	Mass 62	2.50	2.59	3.1	5.00	2.50	2.51
		Mass 562	2.50	2.47	3.1	6.72	2.50	1.87
FS 139 BL 36	Side Facing Seat RHS	Mass 82	2.00	2.16	4.4	4.04	1.61	2.48
		Mass 582	2.00	2.02	4.4	6.10	1.61	1.86

Table 32. Symmetrical Versus Unsymmetrical Water Impact, Floor Responses (Continued)

Scenario			1D01P10 Symmetrical	5D01P10 Unsymmetrical	1D02P10 Symmetrical	5D02P10 Unsymmetrical	1D03P10 Symmetrical	5D03P10 Unsymmetrical
Vertical/longitudinal velocity (ft/sec)			14/0	14/0	12/25	12/25	10/50	10/50
Pitch/roll/yaw (degree)			10/0/0	10/10/10	10/0/0	10/10/10	10/0/0	10/10/10
			Floor Response—Lateral Peak (g)					
FS 42 BL 14	Fwd Facing Seat RHS	Mass 31	0.36	2.31	3.3	3.25	1.60	1.4
		Mass 531	0.40	2.62	3.3	2.82	1.60	1.6
FS 85 BL 30	Aft Facing Seat RHS	Mass 52	1.23	2.31	2.2	2.21	1.60	1.5
		Mass 552	1.20	2.83	2.2	1.92	1.60	1.6
FS 102 BL 37	Fwd Facing Seat RHS	Mass 62	2.20	2.37	3.0	2.96	2.20	1.6
		Mass 562	2.20	2.51	3.0	4.01	2.20	2.2
FS 139 BL 36	Side Facing Seat RHS	Mass 82	2.50	2.86	2.9	2.88	1.80	1.8
		Mass 582	2.50	2.16	2.9	2.07	1.80	1.4
			Floor Response—Vertical Peak (g)					
FS 42 BL 14	Fwd Facing Seat RHS	Mass 31	13.50	13.1	9.6	9.62	6.50	6.49
		Mass 531	13.50	9.72	9.6	9.12	6.50	5.81
FS 85 BL 30	Aft Facing Seat RHS	Mass 52	7.30	6.69	9.3	7.74	6.10	6.06
		Mass 552	7.30	9.52	9.3	9.31	6.10	5.21
FS 102 BL 37	Fwd Facing Seat RHS	Mass 62	11.00	7.47	14.7	9.39	5.70	5.41
		Mass 562	11.00	12.4	14.7	14.47	5.70	5.68
FS 139 BL 36	Side Facing Seat RHS	Mass 82	10.80	9.27	14.3	11.5	7.50	5.90
		Mass 582	10.80	10.80	14.3	14.4	7.50	7.50

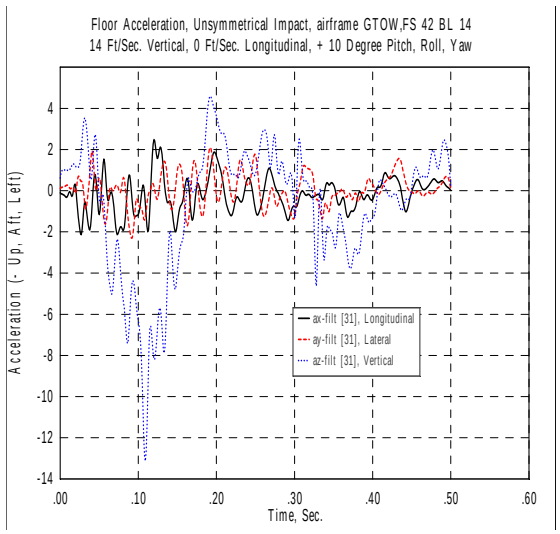
Table 33 provides mass item results for symmetrical versus unsymmetrical impacts. The unsymmetrical impact introduces lateral accelerations for the transmission, engine, and center fuel mass, but they do not exceed 4 g. However, the ditching with a combined 12-ft/sec vertical and 25-ft/sec longitudinal velocity, does result in an aft fuel lateral acceleration of 18 g lateral (in excess of criteria) and 14 g longitudinal on the RHS. These increases result in higher responses than the other two symmetrical and unsymmetrical comparisons.

Table 33. Symmetrical Versus Unsymmetrical Water Impact, Mass Item Responses

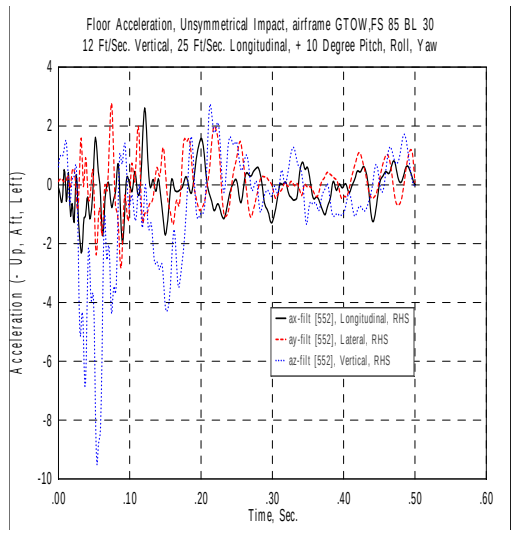
Scenario		1D01P10 Symmetrical	5D01P10 Unsymmetrical	1D02P10 Symmetrical	5D02P10 Unsymmetrical	1D03P10 Symmetrical	5D03P10 Unsymmetrical
Vertical/longitudinal velocity (ft/sec)		14/0	14/0	12/25	12/25	10/50	10/50
Pitch/roll/yaw (degree)		10/0/0	10/10/10	10/0/0	10/10/10	10/0/0	10/10/10
		Response—Longitudinal Peak Acceleration (g)					
Transmission	Mass 7	4.67	5.19	6.13	8.59	7.73	5.45
Engine	Mass 8	6.72	6.73	8.91	5.74	7.88	5.42
Fuel – Fwd – LHS	Mass 401	3.20	2.85	3.69	4.14	3.14	2.52
Fuel – Fwd – RHS	Mass 901	3.20	3.25	3.69	7.03	3.14	2.66
Fuel – Mid	Mass 402	4.83	3.11	4.34	3.51	5.13	3.85
Fuel – Aft - LHS	Mass 403	4.04	4.15	4.74	6.22	5.16	2.90
Fuel – Aft - RHS	Mass 903	5.38	5.38	4.74	14.00	5.16	3.01
		Response—Lateral Peak Acceleration (g)					
Transmission	Mass 7	0.00	3.94	0.00	3.94	0.00	3.46
Engine	Mass 8	0.00	4.32	0.00	3.77	0.00	3.21
Fuel – Fwd – LHS	Mass 401	4.23	3.56	4.56	5.07	2.65	3.21
Fuel – Fwd – RHS	Mass 901	4.23	2.73	4.56	3.91	2.65	3.04
Fuel – Mid	Mass 402	0.00	3.86	0.00	3.95	0.00	2.60
Fuel – Aft LHS	Mass 403	5.38	4.99	8.34	4.56	8.28	2.70
Fuel – Aft RHS	Mass 903	5.38	4.37	8.34	**18.00**	8.28	4.10
		Response—Vertical Peak Acceleration(g)					
Transmission	Mass 7	7.96	8.03	9.35	13.50	9.40	10.40
Engine	Mass 8	16.10	16.30	13.90	13.70	12.50	7.60
Fuel – Fwd – LHS	Mass 401	12.50	10.70	14.90	10.60	10.80	6.40
Fuel – Fwd – RHS	Mass 901	12.50	9.28	14.90	12.90	10.80	6.52
Fuel – Mid	Mass 402	14.10	15.50	12.70	16.60	12.70	7.04
Fuel – Aft - LHS	Mass 403	13.00	10.70	15.50	12.10	15.90	6.93
Fuel – Aft - RHS	Mass 903	13.00	13.40	15.50	18.50	15.90	8.30

Bold numbers exceed criteria

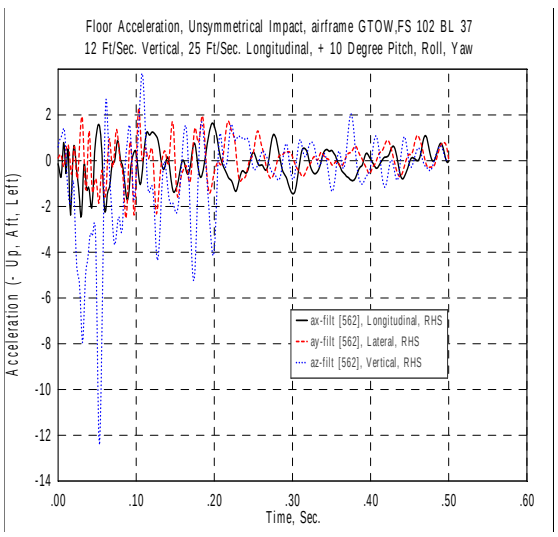
Figure 28 shows the peak vertical, lateral, and longitudinal acceleration floor pulses for the unsymmetrical water impact conditions. Figure 28(a) shows the forward seat at FS 42 LHS, figure 28(b) at FS 85 RHS, figure 28(c) at 102 RHS, and figure 28(d) at 139 RHS. The FS 139 seat is a sideward-facing seat.



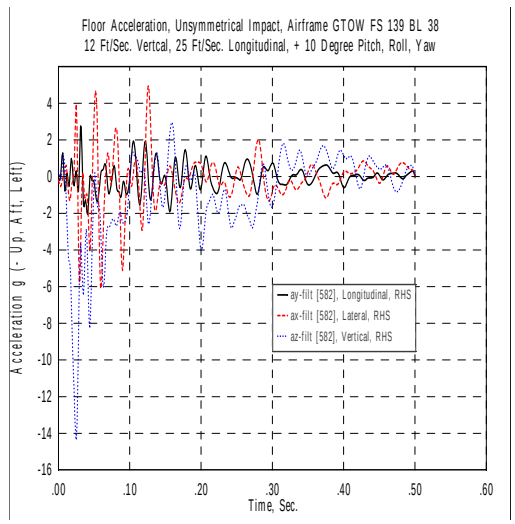
(a) FS 42 LHS



(b) FS 85 RHS



(c) FS 102 RHS



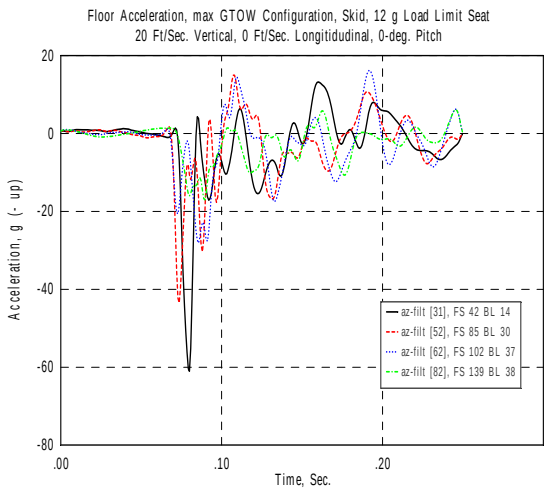
(d) FS 139 RHS

Figure 28. Longitudinal, Lateral, and Vertical Floor Accelerations, Unsymmetrical Water Impact

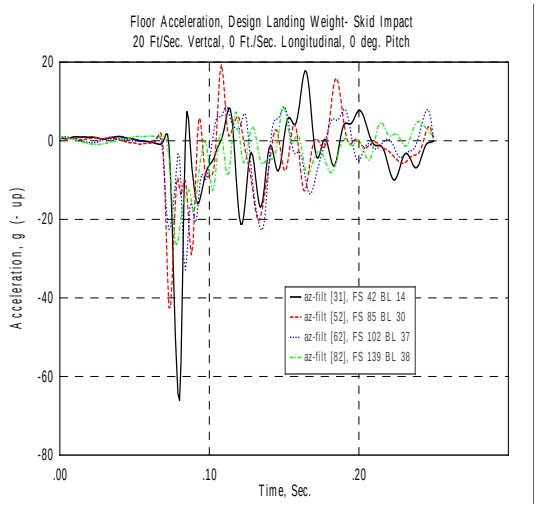
The acceleration plots in figure 28 are presented using a SAE class 60 (100 Hz) filter.

5.1.6 Floor and Mass Item Accelerations.

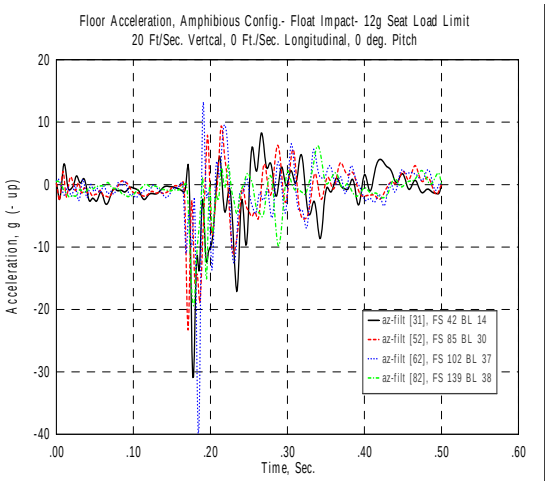
All acceleration plots are based on the use of a SAE class 60 (100 Hz) filter. Figure 29 provides floor vertical acceleration responses of the four test configurations.



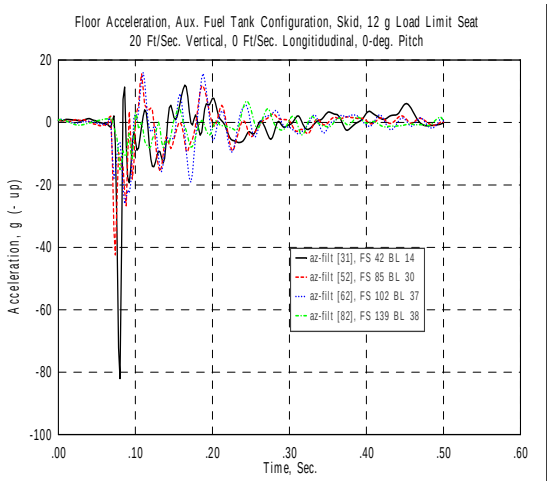
(a) Configuration 1: Maximum GTOW



(b) Configuration 2: DLW Low Fuel



(c) Configuration 3: Amphibious/float



(d) Configuration 4: Auxiliary Fuel Tank

Figure 29. Floor Vertical Acceleration—All Configurations, 20-ft/sec Vertical Impact on Skid/Float

The results are based on a 20-ft/sec vertical, 0-ft/sec longitudinal, and 0 degree pitch water impact into calm seas and with active skid or float. Each configuration has 12-g LL seats. The acceleration results are based on the SAE class 60 (100 Hz) filter. This impact condition represents a severe ditching condition wherein underpanel failure occurs. An impact initially on the skid delays the occurrence of the peak floor response for about 80 msec for configurations 1, 2, and 4. For configuration 3, the delay is about 150 msec as a result of both the added distance the float extends from the airframe, as well as the action of the float. The highest peak acceleration is at FS 42 near the forward seat (FS 47 BL 14) where the pilot and copilot seats are located. The floor accelerations at this location range from approximately 32-82 g for all the configurations. The next highest response, approximately 42 g, occurs at the floor located at FS

85 BL 30. This is a set of five aft-facing occupants. At the third row of forward-facing seats (FS 102 BL 37), the peak acceleration is 40 g or less. For the side-facing seats at FS 139 BL 38, the peak acceleration is 25 g or less. The floor responses have short duration rise times (0.0005 to 0.0075 sec) and durations (0.010 to 0.015 sec) associated with the primary pulse.

Figure 30 depicts the velocity change that occurs at the floor locations for a 20-ft/sec initial vertical velocity for maximum GTOW configuration 1. In actuality, with a slight rotational velocity increase and a rebound, the total velocity change approaches 25 ft/sec at FS 42 and about 20 ft/sec at the other locations. Similarly, for a 15-ft/sec impact, the total velocity change can increase by about 4 to 5 ft/sec.

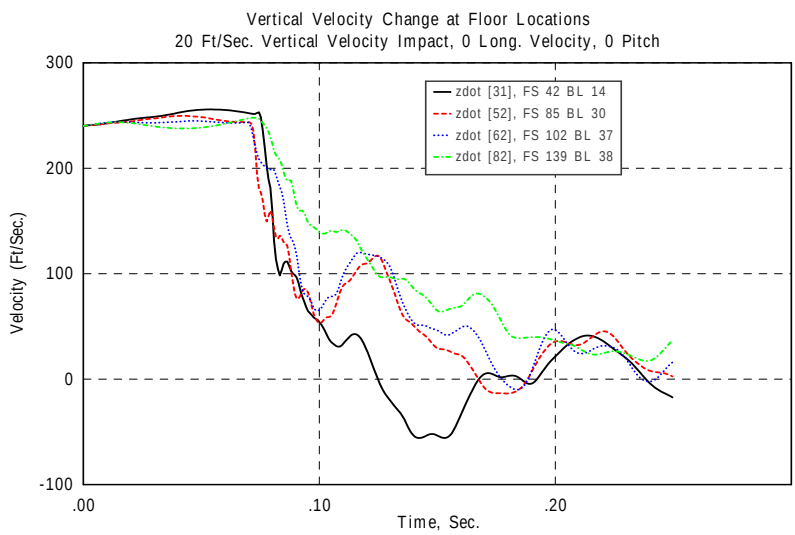


Figure 30. Velocity Change at Floor Locations—20-ft/sec Impact

The results for a 20-ft/sec vertical impact directly onto the airframe (skids retracted) for the maximum GTOW configuration 1 is shown in figure 31. A floor peak vertical acceleration of about 42 g results versus 60 g with the skid on.

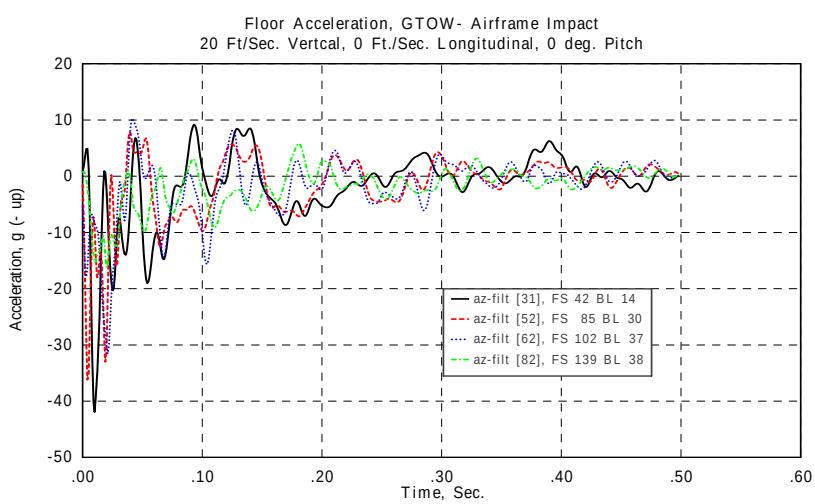


Figure 31. Floor Vertical Acceleration—20-ft/sec Vertical Impact on Airframe

With a 16-ft/sec vertical velocity accompanied by a 50-ft/sec longitudinal velocity, figure 33 shows the peak acceleration is about 34 g or less at the floor locations. The accompanying fore-aft peak accelerations are less than 7 g and oscillatory, as can be observed in figure 34. Since the seats at FS 139 BL 38 are sideward facing, the fore-aft floor pulse acted as a sideward pulse to the seat.

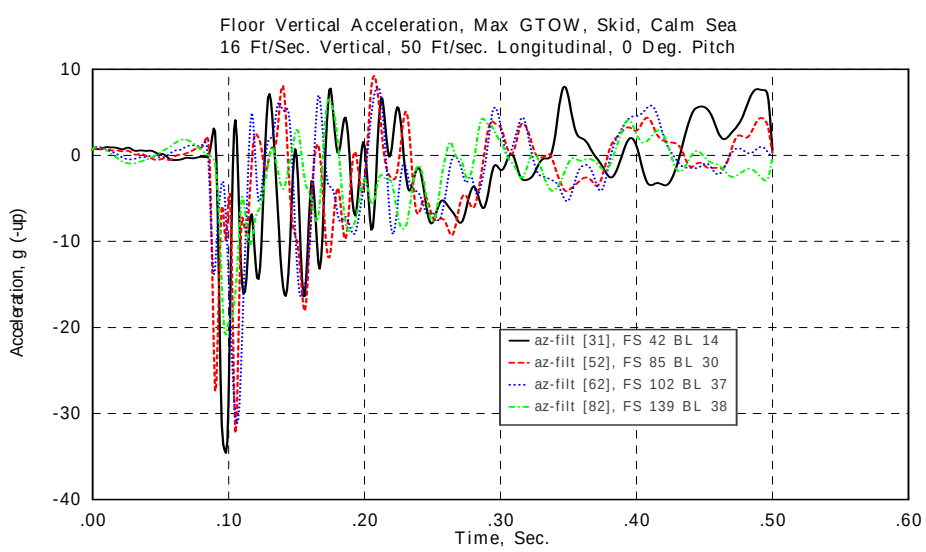


Figure 32. Floor Vertical Acceleration—16-ft/sec Vertical, 50-ft/sec Longitudinal Impact on Skid

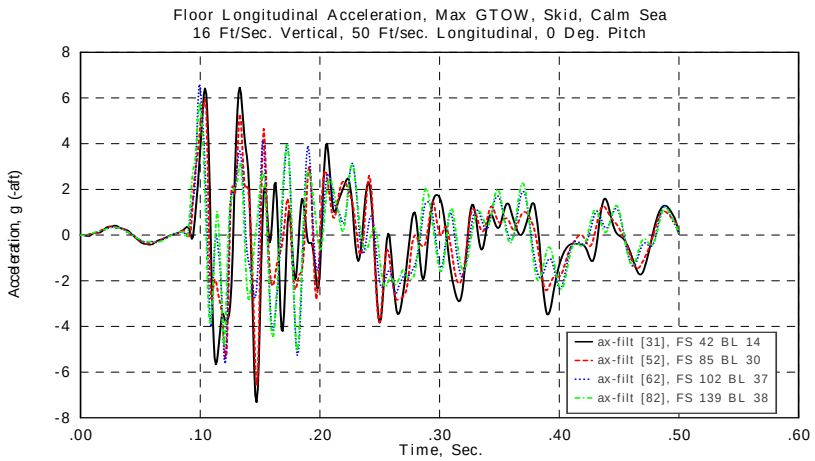


Figure 33. Floor Longitudinal Acceleration—16-ft/sec Vertical, 50-ft/sec Longitudinal Impact on Skid

The floor vertical acceleration for configuration 1 with active skids for the condition in which the lumbar load does not exceed 1500 lb with a rigid seat, is shown in figure 34.

For a flat 15-ft/sec vertical velocity water impact, figure 35 shows that the floor peak acceleration is less than 30 g at several locations. The characteristic pulses are similar to those shown in figures 30 through 33.

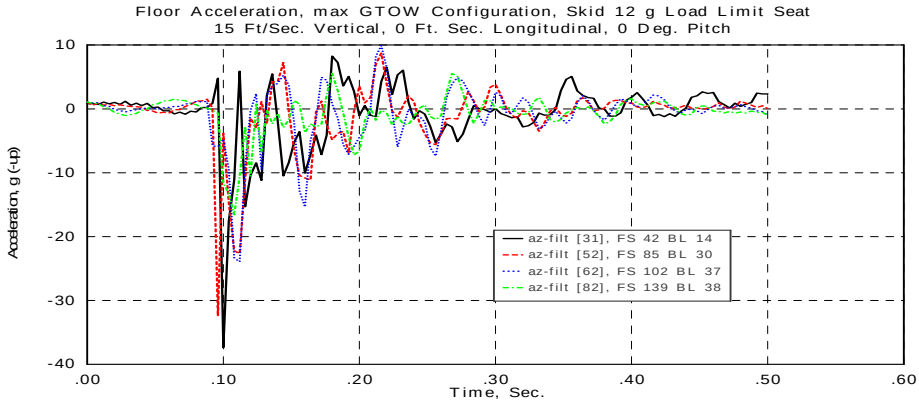


Figure 34. Floor Vertical Acceleration—15-ft/sec Vertical Impact on Skid

The mass item vertical accelerations for the flat 20-ft/sec water impact are shown in figures 35 (transmission), 36 (engine), and 37 (fuel), respectively. The forward fuel cell shows the highest response among the three fuselage fuel cells. Included in figure 37 are the forward fuel cell and auxiliary fuel cell responses. No fuel cell responses are provided for configuration 2 because there is only a nominal 40.4 lb total available. The results presented in figures 35 through 37 correspond with the floor responses provided in figures 29(a) through 29(d). From these figures, it can be observed that no peak exceeds about 28 g.

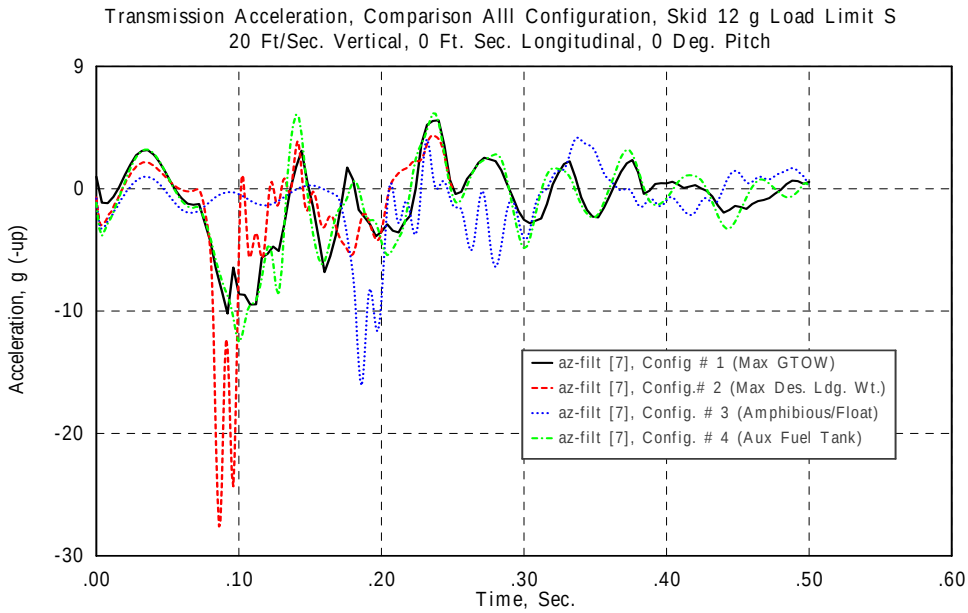


Figure 35. Transmission Vertical Acceleration—20-ft/sec Vertical Impact on Skid/Float, all Configurations

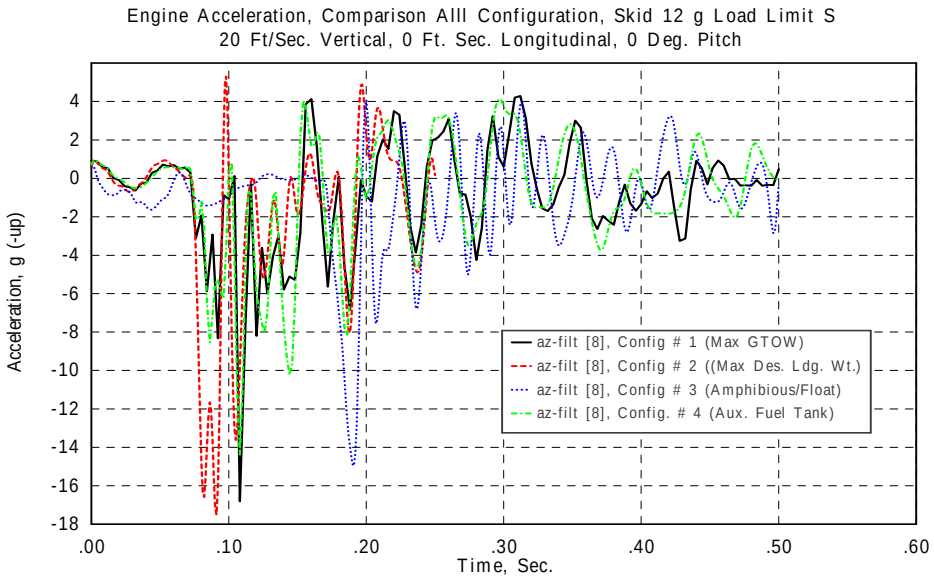


Figure 36. Engine Vertical Acceleration—20-ft/sec Vertical Impact on Skid/Float, all Configurations

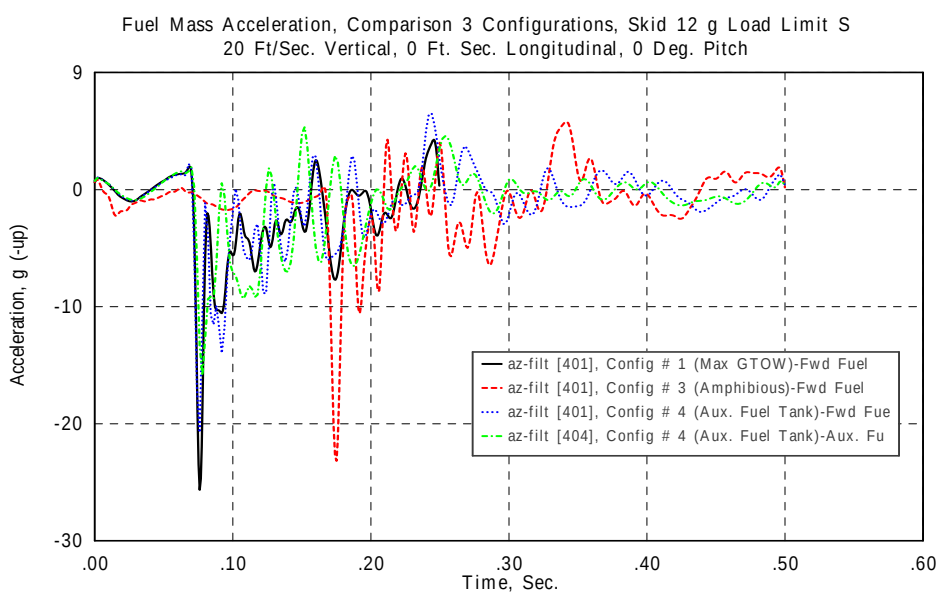


Figure 37. Fuel Mass Vertical Acceleration—20-ft/sec Vertical Impact on Skid/Float, Three Configurations

At the 15-ft/sec vertical velocity water impact, the mass item peak acceleration responses and floor pulses decrease. Figure 38 shows the fuel peaks decrease to less than 20 g versus about 26 g at 20 ft/sec. Figure 39 shows that the transmission and engine peaks are 15 and 12 g, respectively, at a 15-ft/sec vertical impact.

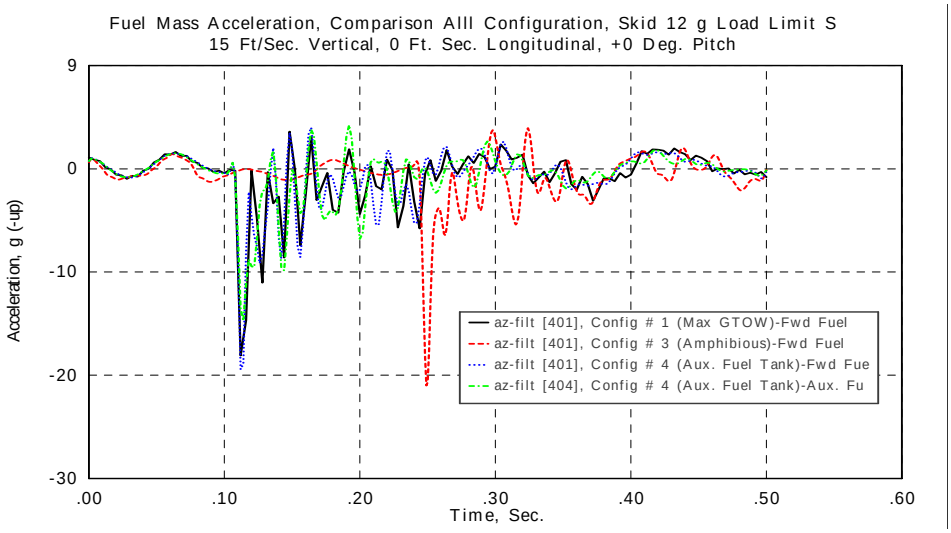


Figure 38. Fuel Mass Vertical Acceleration—15-ft/sec Vertical Impact on Skid/Float, Three Configurations

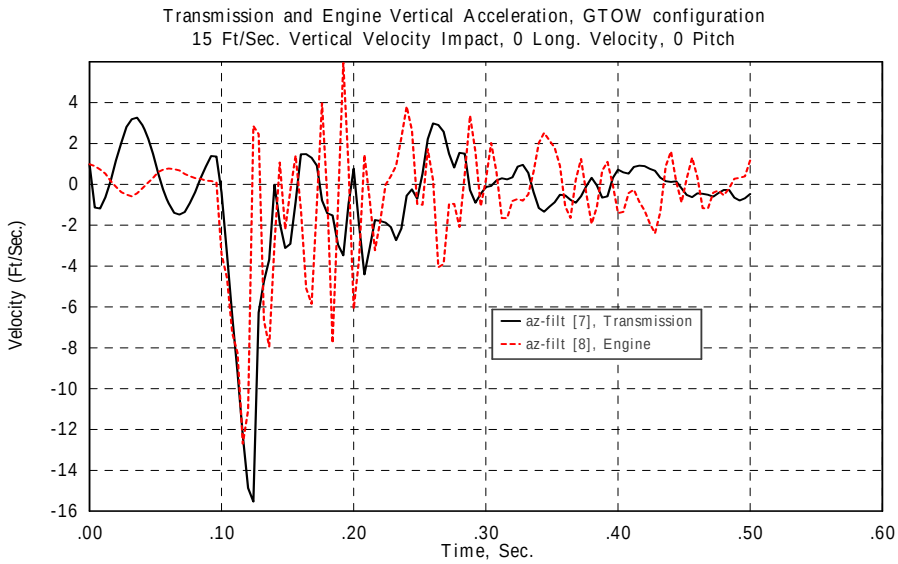


Figure 39. Transmission and Engine Vertical Acceleration—15-ft/sec Vertical Impact on Skid, GTOW

Referencing table 29, the sea-state analysis results indicate that the failure envelope is dependent on aircraft orientation to the wave, wave velocity, and impact location. A water impact with the aircraft impacting perpendicular to the wave, off the crest, and moving opposite the aircraft is considered more severe than landing parallel to or perpendicular to a wave crest.

Several plots for a water impact are presented for the following conditions:

- Sea state = 4
- Perpendicular to a 4-ft high, 40-ft long wave moving at a velocity of 27 ft/sec opposite to the aircraft
- Impacting at the midpoint of the face of the wave
- Aircraft water impact with 8-ft/sec vertical velocity, 50-ft/sec longitudinal velocity, and +10 degree pitch
- Aircraft water impact with 18-ft/sec vertical velocity, 0-ft/sec longitudinal velocity and 0 degree pitch
- Underside panel failure occurs

Figure 40 shows floor peak vertical accelerations less than 30.5 g for the combined (8-ft/sec vertical and 50-ft/sec longitudinal) velocity water impact. The corresponding transmission, engine, and fuel peak vertical accelerations are 13.8, 13.0, and 25.2 g (mass 401), respectively. Similarly, figure 42 shows floor peak longitudinal accelerations less than 7.2 g. The corresponding transmission, engine, and fuel peak vertical accelerations are 13.0, 11.7, and 10.5 g, (mass 403), respectively.

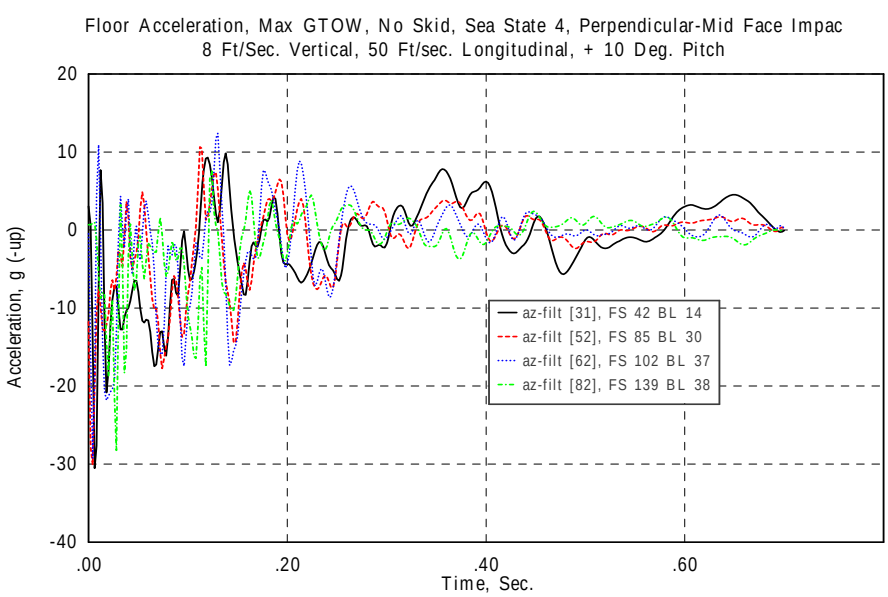


Figure 40. Floor Vertical Acceleration—8-ft/sec Vertical, 50-ft/sec Longitudinal, +10 Degree Pitch Impact on Airframe, GTOW

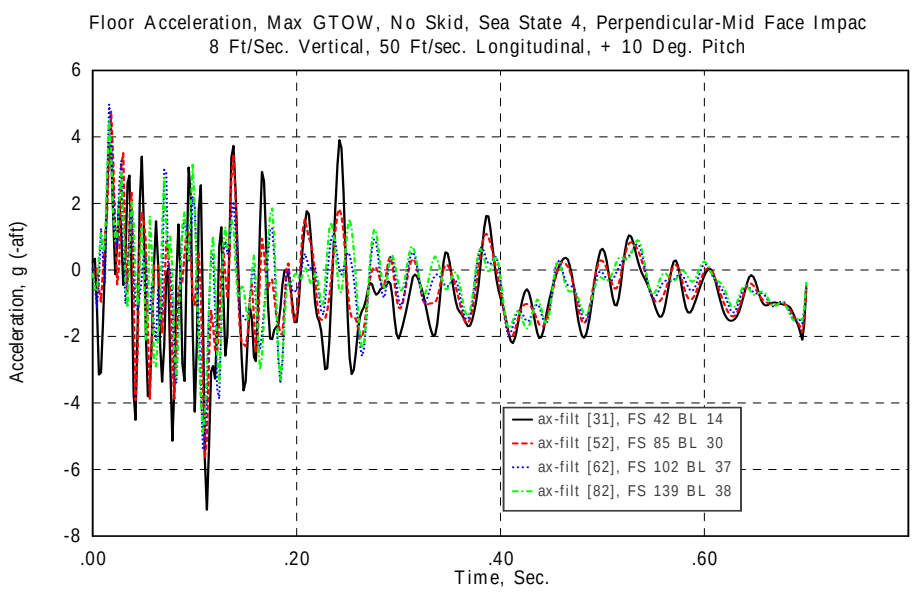


Figure 41. Floor Longitudinal Acceleration—8-ft/sec Vertical, 50-ft/sec Longitudinal, +10 Degree Pitch Impact on Airframe, GTOW

For the 18-ft/sec vertical velocity water impact (case 6D01P10, table 29), the corresponding peak accelerations for the vertical and longitudinal responses are:

- Floor (FS 47 BL 14); 37.8 g (4.1 g)
- Floor (FS 85 BL 30); 29.4 g (4.2 g)
- Floor (FS 102 BL 37); 25.5 g (3.9 g)
- Floor (FS 139 BL 38); 17.2 g (3.9 g)
- Transmission; 16.4 g (10.4 g)
- Engine; 10.5 g (9.6 g)
- Fuel (mass 401); 16.2 g (3.0 g)
- Fuel (mass 402); 14.2 g (7.2 g)
- Fuel (mass 403); 14.1 g (6.9 g)

5.2 LEVEL 2 WATER IMPACT.

The following nomenclature used for the water impact series is as follows:

- Basic BH-205 model (9500 lb)—maximum GTOW configuration 1
- Design landing weight (8000 lb)—low fuel, configuration 2
- Amphibious configuration (8500 lb)—Float, configuration 3
- Auxiliary fuel tank configuration (9500 lb), configuration 4

Water impact analysis was performed for a series of conditions that are noted in table 34.

Table 34. Summary of Level 2 Water Impact Series Conditions

Set	Series	Configurations/ Conditions	Structural Model	Vertical Velocity (ft/sec)	Combined Velocity (ft/sec)	Pitch (degree)	Skids/Float Active Extended	Airframe Impact Retracted	Occupant Model LL Seat (g)
0W01	S1	GTOW	1	26	-	0	✓	-	12
0W02	S2	GTOW	1	28	39	4	✓	-	12
0W01	S1	DLW	2	26	-	0	✓	-	12
0W02	S2	DLW	2	28	39	4	✓	-	12
0W01	S1	Amphibious	3	26	-	0	✓	-	12
0W02	S2	Amphibious	3	28	39	4	✓	-	12
0W01	S1	Auxiliary fuel tank	4	26	-	0	✓	-	12
0W02	S2	Auxiliary fuel tank	4	28	39	4	✓	-	12
0W01	S1	GTOW	1	26	-	0	-	✓	12
0W02	S2	GTOW	1	28	39	4	-	✓	12
0W01	S1	DLW	2	26	-	0	-	✓	12
0W02	S2	DLW	2	28	39	4	-	✓	12
0W01	S1	Amphibious	3	26		0	-	✓	12
0W02	S2	Amphibious	3	28	39	4	-	✓	12
0W01	S1	Auxiliary fuel tank	4	26	-	0	-	✓	12
0W02	S2	Auxiliary fuel tank	4	28	39	4	-	✓	12
1W01	W1	GTOW	1	X	-	0, 5, 10	-	✓	12, 14.5
1W02	W1	GTOW	1	X	39	0, 5, 10	-	✓	12, 14.5
1W03	W1	GTOW	1	X	50	0, 5, 10	-	✓	12, 14.5
2W01	W2	GTOW	1	X	-	0, 5, 10	✓	-	12, 14.5
2W02	W2	GTOW	1	X	39	0, 5, 10	✓	-	12, 14.5
2W03	W2	GTOW	1	X	50	0, 5, 10	✓	-	12, 14.5
3W01	W3	GTOW/95th %, upper limit	1	12.7 to 26	0 to 50	0,5,10	✓	-	14.5
3W02	W3	GTOW/95th %, upper limit	1,2,3,4	26	0	0, 5	✓	-	14.5
3W03	W3	GTOW/95th %, upper limit	1,2,3,4	20	50	0, 5	✓	-	14.5
3W04	W3	GTOW/95th %, lower limit	1	20 to 23.5	0 to 30	5, 10	✓	-	14.5
6W01	W5	GTOW Unsymmetrical(1)	1	12.7 to 26	0 to 50	10	✓	✓	14.5
6W02	W6	GTOW Bulkhead design	1	14 to 28	39 to 60	5,10	✓	-	14.5

(1) Roll, yaw = +10 degrees
✓ = Test condition
X = The value obtained when required conditions are satisfied (see data tables 39, 40, 41, and 42)

The underside panel hydrodynamic surfaces, as well as extended surfaces (float, landing skid), their attached KRASH model masses, and their locations are previously noted in table 11.

Initially, a series of water impacts were run at the S1 impact condition of 26-ft/sec vertical velocity and 0-degree pitch and initial impact to the airframe. The S2 impact condition was

28-ft/sec vertical, 39-ft/sec longitudinal, +4-degree nose-up pitch, and an initial impact to the skids. These runs were made with a 12-g or a 14.5-g LL seat. All water impacts were conducted for calm sea and a load limit seat. The full range of all the water impact conditions and criteria are as follows:

- Vertical impact velocity from 15 to 30 ft/sec
- Longitudinal impact velocity from 0 to 50 ft/sec
- Pitch attitude = 0 to +10 degrees
- Yaw and roll = +10 degrees max
- LL seat =12 g or 14.5 g
- Panel pressure factor = 1
- Design strength factor = 1
- Integration interval = 1E-5 sec
- Print interval = 100 to 200 msec
- Simulation time; < 250 msec

5.2.1 BH-205 Analysis Results for the S1 and S2 Impact Conditions.

A set of results for all four configurations for both the S1 and S2 impact conditions (IC) is provided in tables 35 through 38. Table 35 shows the peak vertical accelerations, table 36 shows the peak longitudinal accelerations, table 37 shows the seat/occupant responses, and table 38 shows the peak hydrodynamic lift surface pressures. All results presented are based on the initial impact on the airframe.

For the S1 impact condition:

- Tables 35 and 36 show that the transmission mass vertical accelerations are less than 22 g and the longitudinal accelerations are less than 20 g. The engine mass vertical accelerations are less than 30 g, except for configuration 2, and the longitudinal accelerations are less than 12 g for all configurations. The fuel mass vertical accelerations are less than 32 g, and the longitudinal accelerations are less than 14 g. The seat-based floor peak accelerations range from 22 to 109 g vertical and from 5 to 12 g longitudinal. All accelerations are based on a SAE class 60 filter.

- It can be observed from table 37 that the copilot seat vertical deflection exceeds the 5-inch stroke criteria (5.9 to 6.0 inches) for all the configurations with a 12-g LL seat, except for the float configuration.

- As shown in table 38, a significant number of underside panels fail for all configurations.

If a 14.5-g LL seat is used, the seat peak deflections for the 26-ft/sec vertical velocity impact for all configurations would most likely reduce to less than 5 inches from the current 6 inches, while still maintaining a lumbar load less than 1500 lb.

Table 35. Vertical Acceleration Results, S1 and S2 Impacts on Airframe

						S1 IC				S2 IC			
						Peak Upward Vertical Acceleration (g)				Peak Upward Vertical Acceleration (g)			
						Configuration Number				Configuration Number			
Mass	Description	Weight	FS	BL	WL	1a	2a	3a	4a	1a	2a	3a	4a
7	Trans	589	138.25	0	82.24	21.62	21.42	20.45	21.19	24.37	22.52	23.57	23.14
8	Engine	629	186.83	0	79.17	27.58	32.64*	24.43	29.54	34.61*	46.03	38.42	32.66
9	Hub & Rotor	743	133.05	0	141.74	22.72	24.21	20.51	22.24	27.11	26.58	24.67	24.23
200	Tail Rotor	31	479.4	0	137.56	16.54	22.44	17.58	17.95	32.64	36.07	33.71	36.94
301	Baggage	0 – 400	243 – 283	4	44.75	24.50	24.42	22.73	27.40	33.58	55.04	36.51	40.12
401	Fwd Fuel	0 – 583	129.8	25.1	10.9 – 15.5	31.52*	30.33	31.38	29.64*	33.62	34.44	53.34	52.52*
402	Ctr Fuel	0 – 434	166.5	0	23 – 35.5	29.33	-	23.14	28.44	32.92	-	36.99	44.32
403	Aft Fuel	0 – 418	172	27	23 – 35.5	20.97	20.10	20.35	23.45	30.71	57.23*	30.53	32.30
404	Aux Fuel	0 – 1170	145.66	24.5	26.5 – 37	-	-	-	16.32	-	-	-	25.94
31	Copilot	28.37	42	14	22	109.35**	109.09**	103.50**	109.30**	88.34	107.54**	157.60**	98.97**
52	Fwd pax	26.94	84.5	30	22	62.80	64.13	65.54	64.81	91.74**	84.07	100.54	91.57
72	Mid pax	26.15	129	36.25	22	39.71	48.13	43.64	44.50	63.72	60.39	65.43	72.63
82	Aft pax	17.96	138.25	35.89	22	22.57	36.82	29.06	26.59	59.86	57.51	56.86	60.91

*Max vertical acceleration (nonfloor)
**Max vertical acceleration (floor)

Table 36. Longitudinal Acceleration Results, S1 and S2 Impacts on Airframe

						S1 IC				S2 IC			
						Peak Longitudinal Acceleration (g)				Peak Longitudinal Acceleration (g)			
						Configuration Number				Configuration Number			
Mass	Description	Weight	FS	BL	WL	1a	2a	3a	4a	1a	2a	3a	4a
7	Transmission	589	138.25	0	82.24	9.89	14.44	13.54	20.11	32.68	24.80	35.22	26.55
8	Engine	629	186.83	0	79.17	9.18	11.12	11.02	8.29	13.98	13.69	15.00	14.28
9	Hub and Rotor	743	133.05	0	141.74	5.23	5.23	5.63	5.86	13.20	13.37	12.05	13.85
200	Tail Rotor	31	479.4	0	137.56	52.07*	50.08*	43.36*	54.48*	58.60*	56.72	59.19*	54.90*
301	Baggage	0 – 400	243 – 283	4	44.75	8.13	10.38	10.85	12.82	23.57	35.16	25.62	31.88
401	Fwd Fuel	0 – 583	129.8	25.1	10.9 – 15.5	5.01	13.89	5.15	6.16	15.59	58.05*	24.21	14.36
402	Ctr Fuel	0 – 434	166.5	0	23 – 35.5	9.34	-	7.41	8.87	23.59	-	20.26	18.52
403	Aft Fuel	0 – 418	172	27	23 – 35.5	7.40	4.92	8.72	13.74	26.78	16.23	25.77	21.63
404	Aux Fuel	0 – 1170	145.66	24.5	26.5 – 37	-	-	-	8.69	-	-	-	29.60
31	Copilot	28.37	42	14	22	11.26**	7.33**	9.79**	12.01**	20.78	17.67	27.59	15.82
52	Fwd pax	26.94	84.5	30	22	4.69	6.39	9.31	9.66	18.05	22.52**	29.33**	21.07
72	Mid pax	26.15	129	36.25	22	5.54	6.04	4.82	7.64	23.26**	16.61	23.19	21.39**
82	Aft pax	17.96	138.25	35.89	22	5.52	6.06	4.36	7.24	21.37	16.22	22.27	20.81

*Max vertical acceleration (nonfloor)
**Max vertical acceleration (floor)

Table 37. Occupant/Seat Results, S1 and S2 Impacts on Airframe

Mass	Location	Peak DRI							
		S1 IC				S2 IC			
		Configuration Number				Configuration Number			
		1a	2a	3a	4a	1a	2a	3a	4a
212	Copilot	15.49*	15.48*	15.50*	15.51*	13.31	12.75	12.34	13.27
222	Fwd pass	14.81	14.87	15.03	14.85	13.45	13.53	13.50*	13.46
232	Mid pass	15.03	15.30	15.19	14.86	13.49	12.66	13.38	13.47*
242	Aft pass	15.09	15.18	-	-	14.12*	13.83*	-	-

*Max DRI

(a) Peak Occupant DRIs

Beam	Location	Peak Lumbar Load (psi)							
		S1 IC				S2 IC			
		Configuration Number				Configuration Number			
		1a	2a	3a	4a	1a	2a	3a	4a
213	Copilot	1206*	1207*	1208*	1207*	1259*	1231*	1256*	1280*
214	Fwd pass	1202	1203	1205	1203	1138	1137	1065	1142
215	Mid pass	1109	1195	1182	1191	1193	1127	1183	1194
216	Aft pass	1119	1133	-	-	1015	976	-	-

*Max lumbar load

(b) Peak Occupant Lumbar Loads

Beam	Location	Peak Seat Vertical Deflection (in.)							
		S1 IC				S2 IC			
		Configuration Number				Configuration Number			
		1a	2a	3a	4a	1a	2a	3a	4a
219	Copilot	6.011*	5.896*	5.981*	6.029*	5.306*	4.576*	4.319*	5.026*
220	Fwd pass	2.845	2.780	2.408	2.817	3.163	2.733	2.232	2.930
221	Mid pass	1.407	1.608	1.447	1.327	2.854	3.386	2.636	2.831
222	Aft pass	0.877	1.172			1.013	1.002	-	-

*Max lumbar load

(c) Peak Occupant Vertical Deflection

Table 38. Underside Panel Pressure Results, S1 and S2 Impacts on Airframe

Surf No.	Mass No.	FS	BL	WL	Failure Pressure (psi)	Peak Hydropressure (psi)							
						S1 IC				S2 IC			
						Configuration Number				Configuration Number			
						1a	2a	3a	4a	1a	2a	3a	4a
1	20	23	0	22	25.0	15.7	15.7	15.1	15.9	51.0	48.2	31.6	42.5
2	21	23	14	22	42.0	31.6	31.5	29.2	31.5	42.0	42.0	42.0	42.0
3	30	42	0	22	30.0	14.3	14.3	12.6	14.3	30.0	31.8	31.7	30.0
4	31	42	14	22	40.0	30.0	30.0	27.9	30.1	40.0	40.0	40.0	40.0
17	40	68.84	0	22	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0
19	41	68.84	14	22	58.0	58.0*	58.0*	58.0*	58.0*	58.0	58.0	58.0	58.0
5	50	84.5	0	22	40.0	27.6	27.5	24.0	26.8	40.0	40.0	40.0	40.0
6	51	84.5	14	22	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
7	52	84.5	30	22	45.0	16.8	16.4	16.9	16.5	45.0	45.0	45.0	45.0
8	60	102	0	22	35.0	34.7	34.6	34.0	34.4	36.0	35.0	35.6	37.6
9	61	102	14	22	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0	35.0
10	62	102	37.32	22	64.0	16.1	12.9	14.2	15.6	64.0	64.0	64.0	64.0
21	70	129	0	22	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0
11	80	138.25	0	22	35.0	35.0	35.0	35.0	35.0	60.4	51.4	57.4	60.3
12	81	138.25	14	22	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0	40.0
13	82	138.25	35.89	22	66.0	39.9	35.1	33.2	38.7	66.0*	66.0*	66.0*	66.0*
18	90	166.06	0	22	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0	41.0
20	91	166.06	14	22	58.0	58.0*	58.0*	58.0*	58.0*	58.0	58.0	58.0	58.0
14	100	192	0	22	35.0	32.9	27.2	28.3	32.7	57.2	52.6	55.0	58.5
15	103	192	35.12	22	17.0	15.5	14.2	15.9	17.0	17.0	17.0	17.0	17.0
16	110	211	0	22	25.0	19.8	16.7	17.7	20.0	25.0	25.0	25.0	25.0

*Max peak hydropressure

The results for all four configurations for the S2 water impact skid/float extended condition are also noted in tables 35 through 38. For the S2 impact condition, tables 35 through 38 indicate that

- the transmission mass vertical acceleration is below 25 g for all configurations.
- the engine mass vertical acceleration exceeds 30 g for all configurations.
- the fuel mass vertical accelerations can also exceed 26 g and can reach 57 g.
- the seat-based floor peak vertical accelerations range from 57 to 157 g.
- peak copilot seat vertical deflections range from 4.3 to 5.3 inches.
- the longitudinal accelerations for the transmission mass ranges from 25 to 35 g.
- the longitudinal accelerations for the engine mass is <15 g.

- the floor mass longitudinal accelerations range from 16- to 29-g peak.
- the fuel mass longitudinal accelerations generally range from 15 to 30 g, with one peak reaching 58 g at the forward fuel mass for configuration 2.
- the pressure results show failures at all locations for all configurations.

The S1 and S2 results provide a frame of reference for subsequent BH-205 water impact analyses.

5.2.2 Water Impact on Airframe—12- and 14.5-g LL Seats.

A series of simulations were made using the maximum GTOW configuration initially impacting the airframe to determine the combination of vertical and longitudinal impact velocities associated with pitch attitudes of 0, +5, and +10 degrees. For each combination, a determination was made to provide seat stroke and acceleration responses within criteria guidelines.

Table 39 compares the airframe water impact responses for several impacts for the maximum GTOW configuration and a 12-g LL seat. All seat lumbar loads are <1500 lb. Noted in bold are responses that are in excess of 5-inch stroke or 30-g mass item criteria established earlier. The seat stroke in one case is marginally above 5 inches. Only one transmission vertical response is above 30 g. In most instances, the mass response criteria dictates criticality. The transmission longitudinal response is most critical at the 50-ft/sec longitudinal impacts. The engine longitudinal response is most critical at the 39-ft/sec longitudinal impact.

Table 40 compares the airframe water impact responses using the maximum GTOW configuration for 12- and 14.5-g LL seats.

The 14.5-g LL seat reduces the seat stroke as expected while still maintaining the lumbar load below 1500 lb. The load limit level does not influence the floor and mass item accelerations to any significant degree.

Table 39. Summary of Airframe Water Impact Responses—12-g LL Seat, Maximum GTOW Configuration 1

Scenario			1W01P0	1W01P5	1W01P10	1W02P0	1W02P5	1W02P10	1W03P0	1W03P5	1W03P10
Vertical/longitudinal (ft/sec)			23/0	24/0	24/0	19/39	19/39	20/39	19/50	19/50	19/50
Pitch/roll/yaw (degree)			0/0/0	5/0/0	10/0/0	0/0/0	5/0/0	10/0/0	0/0/0	5/0/0	10/0/0
Seat Stroke (in.)											
Pilot			**5.15**	4.73	4.14	4.14	4.41	4.87	4.95	5.00	4.04
Floor Response—Vertical Peak (g)											
FS 42	Pilot	Mass 31	61.5	45.5	30.0	43.0	43.0	35.2	42.9	40.5	34.2
FS 89	Fwd	Mass 52	36.1	44.3	38.1	33.6	37.7	38.2	34.4	35.8	40.4
FS 129	Mid	Mass 62	39.6	41.3	36.1	28.1	47.1	51.5	29.3	43.6	40.4
FS 139	Side	Mass 82	22.2	18.1	20.5	18.6	32.4	37.6	12.2	33.1	30.9
Mass Response—Vertical Peak (g)											
Transmission		Mass 7	18.1	15.9	12.3	14.4	10.4	16.0	15.2	**33.1**	18.3
Engine		Mass 8	21.3	**35.4**	26.3	16.1	**33.8**	24.9	18.4	**30.6**	24.2
Fuel Mass	Fwd	Mass 401	24.9	23.3	20.3	26.0	24.1	17.5	26.1	29.8	19.9
	Mid	Mass 402	19.3	26.6	**32.2**	18.9	23.8	**46.2**	23.4	20.7	**44.6**
	Aft	Mass 403	18.3	13.9	22.1	15.8	17.6	21.9	17.1	20.4	21.3
Floor Response—Longitudinal Peak (g)											
FS 47 BL 14	Pilot	Mass 31	11.9	6.2	8.2	7.5	16.1	13.0	9.4	16.0	17.7
FS 85 BL 30	Fwd	Mass 52	6.1	6.2	5.5	4.9	7.9	11.0	7.2	12.8	15.4
FS 102 BL 37	Mid	Mass 62	5.7	4.5	7.8	5.3	13.6	17.0	6.00	14.6	17.5
FS 139 BL 36	Side	Mass 82	4.7	7.1	7.6	4.7	15.5	16.6	6.2	14.0	17.4
Mass Response—Longitudinal Peak (g)											
Transmission		Mass 7	7.7	9.7	12.8	9.2	11.8	18.6	14.7	19.7	22.6
Engine		Mass 8	10.0	16.7	13.3	10.4	13.6	22.6	10.9	15.1	20.0
Fuel Mass	Fwd	Mass 401	6.5	6.4	8.5	5.9	18.7	13.5	6.6	17.6	13.7
	Mid	Mass 402	8.7	7.2	11.6	6.8	13.9	15.4	7.5	9.8	12.5
	Aft	Mass 403	6.8	17.4	13.7	6.2	24.0	23.3	8.5	22.7	26.1

Bold numbers exceed criteria

Table 40 suggests that with an initial water impact on the airframe, a 14.5-g LL seat has an additional margin before the seat stroke criteria is exceeded. However, as noted in table 39, mass item criteria is exceeded in all but three of the impact scenarios; 23/0/0, 19/39/0, and 19/50/0.

Table 41 shows the results for the 14.5-g LL seat at various vertical and longitudinal velocities. The seat deflection for two of these cases still prevail and determines the critical criteria and not the mass responses.

Table 40. Comparison of Airframe Water Impacts With 12- and 14.5-g LL Seats, Maximum GTOW Configuration 1

Scenario			1W01P0	1W01P5	1W01P10	1W01P0	1W01P5	1W01P10
Load limit seat (g)			12	12	12	14.5	14.5	14.5
Impact On			Airframe	Airframe	Airframe	Airframe	Airframe	Airframe
Vertical/longitudinal velocity (ft/sec)			23/0	24/0	24/0	23/0	24/0	24/0
Pitch/roll/yaw (degree)			0/0/0	5/0/0	10/0/0	0/0/0	5/0/0	10/0/0
			Seat Stroke Acceleration (in.)					
Pilot			**5.15**	4.73	4.14	3.03	2.38	1.38
			Mass Response—Vertical Peak Acceleration (g)					
Transmission		Mass 7	18.1	15.9	12.3	17.8	15.6	12.2
Engine		Mass 8	21.3	**35.4**	26.3	21.1	**35.4**	26.3
Fuel mass	Fwd	Mass 401	24.9	23.3	20.3	24.6	23.3	20.3
	Mid	Mass 402	19.3	26.6	**32.2**	19.1	20.5	**32.2**
	Aft	Mass 403	18.3	13.9	22.1	16.0	14.2	22.1
			Floor Response—Longitudinal Peak Acceleration (g)					
FS 42	Pilot	Mass 31	61.5	45.5	30.0	60.2	45.2	31.0
FS 89	Fwd	Mass 52	36.1	44.3	38.1	35.9	46.1	37.4
FS 129	Mid	Mass 62	39.6	41.3	36.1	39.3	40.0	35.4
FS 139	Side	Mass 82	22.2	18.1	20.5	22.0	18.1	19.2

Bold numbers exceed criteria.

Table 41. Limits for the 14.5-g LL Seat Based on Initial Airframe Water Impact

Scenario			1W01P0	1W02P0	1W03P0
Load limit seat (g)			14.5	14.5	14.5
Vertical/longitudinal velocity (ft/sec)			23/0	23/39	22/50
Pitch/roll/yaw (degree)			0/0/0	0/0/0	0/0/0
Seat Stroke (in.)					
Pilot			3.03	**5.28**	**5.00**
Mass Response—Vertical Peak Acceleration (g)					
Transmission		Mass 7	17.8	20.1	28.1
Engine		Mass 8	21.1	28.1	23.8
Fuel mass	Fwd	Mass 401	24.6	27.9	22.1
	Mid	Mass 402	19.1	20.7	24.4
	Aft	Mass 403	16.0	18.8	19.6

Bold numbers exceed criteria

5.2.3 Water Impact on Skids—12- and 14.5-g LL Seats.

A series of simulations were made using the GTOW configuration initially impacting on the skids to determine the combination of vertical and longitudinal impact velocities associated with pitch attitudes of 0, +5, and +10 degrees. For each combination, a determination was made to provide seat stroke and acceleration responses within criteria guidelines.

Table 42 compares the skid water impact responses for the maximum GTOW configuration and a 12-g LL seat. Noted in bold are responses that are in excess of 5-inch stroke or 30-g mass item criteria established earlier. The mass item and floor peak responses are provided for three impact levels.

- Vertical velocity = 23 to 24 ft/sec, longitudinal velocity = 0 ft/sec, pitch = 0, +5, and +10 degrees
- Vertical velocity = 19 to 20 ft/sec, longitudinal velocity = 39 ft/sec, pitch = 0, +5, and +10 degrees
- Vertical velocity = 19 ft/sec, longitudinal velocity = 50 ft/sec, pitch = 0, +5, and +10 degrees

Table 42. Summary of Skid Water Impact Responses—12-g LL Seat, Maximum GTOW Configuration 1

Scenario			1W01P0	1W01P5	1W01P10	1W02P0	1W02P5	1W02P10	1W03P0	1W03P5	1W03P10
Vertical/longitudinal velocity (ft/sec)			23/0	24/0	24/0	19/39	19/39	20/39	19/50	19/50	19/50
Pitch/roll/yaw (degree)			0/0/0	5/0/0	10/0/0	0/0/0	5/0/0	10/0/0	0/0/0	5/0/0	10/0/0
Seat Stroke (in.)											
Pilot			**6.11**	**5.60**	4.01	4.77	1.79	0.76	**5.44**	1.68	1.13
Floor Response—Vertical Peak Acceleration (g)											
FS42	Pilot	Mass 31	80.0	46.4	36.9	49.1	35.4	21.2	51.9	35.3	28.2
FS89	Fwd	Mass 52	43.2	42.9	33.5	38.2	32.7	23.0	37.4	34.5	25.7
FS129	Mid	Mass 62	34.3	41.3	41.4	27.5	36.5	29.2	27.0	37.7	31.4
FS139	Side	Mass 82	21.1	17.5	20.3	17.1	22.2	25.8	15.5	22.8	21.6
Mass Response—Vertical Peak Acceleration (g)											
Transmission		Mass 7	19.7	19.0	13.3	15.3	24.0	20.8	21.9	25.6	28.0
Engine		Mass 8	20.1	**34.2**	26.9	17.1	14.1	23.8	20.4	15.7	20.4
Fuel Mass	Fwd	Mass 401	24.1	24.5	18.6	24.9	28.1	24.1	23.9	29.4	28.3
	Mid	Mass 402	19.6	14.9	**35.3**	17.7	**30.6**	**31.9**	25.6	**31.4**	**30.1**
	Aft	Mass 403	15.7	17.1	22.4	18.4	22.4	24.7	20.9	23.4	24.0
Floor Response—Longitudinal Peak Acceleration (g)											
FS 47 BL 14	Pilot	Mass 31	6.3	5.9	8.5	5.4	9.2	11.1	8.2	12.6	14.3
FS 85 BL 30	Fwd	Mass 52	5.2	6.0	6.1	4.8	7.1	11.0	7.0	6.0	7.8
FS 102 BL 37	Mid	Mass 62	5.5	6.7	8.4	4.8	8.9	13.0	6.10	7.1	9.4
FS 139 BL 36	Side	Mass 82	5.6	6.4	8.8	4.6	10.6	12.7	7.2	8.7	8.8

Bold numbers exceed criteria

Table 42. Summary of Skid Water Impact Responses—12-g LL Seat, Maximum GTOW Configuration 1 (Continued)

Scenario			1W01P0	1W01P5	1W01P10	1W02P0	1W02P5	1W02P10	1W03P0	1W03P5	1W03P10
Vertical/longitudinal velocity (ft/sec)			23/0	24/0	24/0	19/39	19/39	20/39	19/50	19/50	19/50
Pitch/roll/yaw (degree)			0/0/0	5/0/0	10/0/0	0/0/0	5/0/0	10/0/0	0/0/0	5/0/0	10/0/0
Mass Response—Longitudinal Peak Acceleration (g) (Continued)											
Transmission		Mass 7	8.2	13.1	13.6	9.1	19.8	17.6	12.0	8.2	15.5
Engine		Mass 8	9.4	10.4	13.2	9.2	13.6	24.2	11.1	12.4	12.7
Fuel Mass	Fwd	Mass 401	6.9	7.3	9.8	5.2	8.0	15.4	7.2	8.2	9.7
	Mid	Mass 402	5.4	10.4	13.4	5.3	10.0	11.7	7.3	9.0	9.0
	Aft	Mass 403	5.4	12.7	12.4	4.4	11.1	14.9	6.9	9.8	14.1

Bold numbers exceed criteria

At these levels, the seat vertical deflection does exceed the allowable 5 inches for several scenarios, particularly with the zero pitch and higher-impact velocities. In section 5.1.3.1 table 21, the skid impact was shown to have some increased floor acceleration levels due to increased velocity. Reviewing c.g., floor mass 31, and seat parameters, the following was noted:

- The initial impact time delay associated with the skid is obvious in all acceleration, displacement, and rotation plots.
- The c.g. distances and velocity changes are correct.
- The mass 31 rotation and velocity change characteristics are the same, except for the time difference.
- The seat leg force is the same, except for the time difference.
- The seat deflection is delayed, but is higher for the skid as noted.
- Using a SAE class 60 filter, the c.g. and mass accelerations reflect about a 25% difference for the airframe versus the skid peak acceleration with all other characteristics the same. Compared to the mean, this is a spread of ±14.3%. Unlike the velocities and deflections, the mass accelerations are filter sensitive. When an SAE class 30 filter is used, the difference is 13.2% for the airframe versus skid peak acceleration and ±7% spread compared to the mean.

Thus, this may be a model discrepancy since the skid should not appreciably alter the impact. There is no transmission and only one engine response that exceeds the 30-g criteria. Five cases show a fuel mass vertical acceleration > 30 g, with only one being higher than the criteria by 17%.

A comparison of the skid versus airframe for the skid with a 12-g LL seat and a 14.5-g LL seat was also made for several impact scenarios and showed that the load limit level did not affect the floor and mass item acceleration levels.

The three other configurations were not run for comparison of potential envelopes for 12- and 14.5-g LL seats for the following reasons:

- Airframe impact results for the S1 and S2 impact conditions presented in section 5.2.2 showed similar seat stroke and occupant load results, panel failures, and acceleration responses for all four configurations. While some acceleration levels varied, they are not sufficient to require a detailed investigation, particularly since no transmission failure occurred.

- Skid and float participation results for the 12-g LL seat presented in section 5.2.1 showed very similar results for configurations 1, 2, and 4 with regard to vertical impact consequences concerning panel pressure failure, acceleration responses, and seat responses. Configuration 3 appeared to afford more protection (less panel pressures exceeded) because of the float and thus resulted in a lower seat stroke. However, for the combined impact scenario, DLW low fuel configuration 2 displayed a different failure pattern than the others and resulted in a much greater pilot/copilot seat stroke than the other configurations.

- Selected impacts associated with the civil rotorcraft 95th percentile ranges were investigated for all four configurations and are discussed in section 5.2.5.

5.2.4 Civil Rotorcraft Accident Upper 95th Percentile Range.

The civil rotorcraft 95th percentile lower and upper land and water range curves are depicted in figure 2 and are approximated as shown in table 43. The analysis for the impact conditions associated with an upper-range curve was performed for the maximum GTOW configuration 1; an active skid impact; a 14.5-g LL seat; and pitch attitudes of 0, +5, and +10 degrees. Results including seat stroke, floor peak vertical acceleration, and mass peak vertical acceleration are shown in tables 44, 45, and 46.

Table 43. Civil Rotorcraft 95th Percentile Data Points

95th	Upper	95th	Lower
Longitudinal Velocity (ft/sec)	Vertical Velocity (ft/sec)	Longitudinal Velocity (ft/sec)	Vertical Velocity (ft/sec)
0.0	26.0	0.0	23.5
10.0	25.0	10.0	23.3
20.0	24.1	20.0	22.3
30.0	22.7	30.0	20.0
40.0	20.0	40.0	15.7
50.0	12.7	45.0	11.0
52.4	9.0	50.0	0.0
55.0	0.0	-	-

Table 44. Summary of Responses—Civil Rotorcraft Upper 95th Percentile Range, Pitch = 0 Degree, Maximum GTOW Configuration 1

Scenario			3W01P0	3W02P0	3W03P0	3W04P0	3W05P0	3W06P0
Vertical/longitudinal velocity (ft/sec)			26/0	25/10	24.1/20	22.7/30	20/40	12.7/50
Pitch/roll/yaw (degree)			0/0/0	0/0/0	0/0/0	0/0/0	0/0/0	0/0/0
Maximum seat stroke (in.)			4.77	4.64	**6.00**	**5.13**	3.37	0.37
			Floor Response—Vertical Peak Acceleration (g)					
FS 42 BL 14	Pilot	Mass 31	104.0	108.0	89.0	76.2	51.9	25.9
FS 85 BL 30	Fwd	Mass 52	60.7	56	46.1	40.2	41.7	21.8
FS 102 BL 37	Mid	Mass 62	39.1	48.8	43.0	37.6	28.3	21.2
FS 139 BL 38	Aft	Mass 82	25.3	22.8	25.2	23.9	16.3	13.9
			Mass Response—Vertical Peak Acceleration (g)					
Transmission		Mass 7	23.3	24.1	25.9	25.8	20.7	15.3
Engine		Mass 8	26.7	25.3	24.8	24.0	20.7	9.9
Fuel Mass - Fwd		Mass 401	**30.4**	28.3	27.7	25.3	23.9	15.1
Fuel Mass - Mid		Mass 402	29.1	28.2	23.9	21.9	25.2	11.,5
Fuel Mass - Aft		Mass 403	26.3	25.0	25.0	20.2	21.5	11.9

Bold numbers exceed criteria

Table 45. Summary of Responses—Civil Rotorcraft Upper 95th Percentile Range, Pitch = +5 Degrees, Maximum GTOW Configuration 1

Scenario			3W01P5	3W02P5	3W03P5	3W04P5	3W05P5	3W06P5
Vertical/longitudinal velocity (ft/sec)			26/0	25/10	24.1/20	22.7/30	20/40	12.7/50
Maximum seat stroke (in.)			4.35	4.81	4.97	3.73	1.23	0.23
			Floor Response—Vertical Peak Acceleration (g)					
FS 42 BL 14	Pilot	Mass 31	59.5	57.0	53.4	39.0	38.2	13.2
FS 85 BL 30	Fwd	Mass 52	58.4	57	49.0	43.8	29.4	12.7
FS 102 BL 37	Mid	Mass 62	57.7	51	45.5	49.6	44.1	18.5
FS 139 BL 38	Aft	Mass 82	22.3	22.8	33.2	37.7	24.1	15.5
			Mass Response—Vertical Peak Acceleration (g)					
Transmission		Mass 7	24.8	27.5	19.7	10.8	19.8	13.6
Engine		Mass 8	**34.5**	**40.5**	**34.1**	**35.2**	14.8	13.8
Fuel Mass - Fwd		Mass 401	30.0	28.5	28.8	28.4	26.0	16.8
Fuel Mass - Mid		Mass 402	14.2	18.6	25.6	25.2	31.6	19.4
Fuel Mass - Aft		Mass 403	18.4	18.7	19.9	15.2	23.8	19.1

Bold numbers exceed criteria

Table 46. Summary of Responses—Civil Rotorcraft Upper 95th Percentile Range, Pitch = +10 Degrees, Maximum GTOW Configuration 1

Run			3W01P10	3W02P10	3W03P10	3W04P10	3W05P10	3W06P10
Vertical/longitudinal velocity (ft/sec)			26/0	25/10	24.1/20	22.7/30	20/40	12.7/50
Maximum seat stroke (in.)			1.89	2.60	3.70	2.20	0.66(3)	0.22(4)
			Floor Response—Vertical Peak Acceleration (g)					
FS 42 BL 14	Pilot	Mass 31	62.2	60.1	42.6	37.0	20.9	9.6
FS 85 BL 30	Fwd	Mass 52	28.6	78	41.7	50.0	29.4	8.4
FS 102 BL 37	Mid	Mass 62	43.2	44.7	52.4	54.1	28.7	9.2
FS 139 BL 38	Aft	Mass 82	15.5	12.3	36.4	26.6	25.3	11.2
			Mass Response—Vertical Peak Acceleration (g)					
Transmission		Mass 7	19.2	21.7	15.5	15.6	20.8	14.9
Engine		Mass 8	**38.4**	**34.6**	**28.9**	28.7	23.0	14.1
Fuel Mass - Fwd		Mass 401	18.9	18	25.8	22.8	24.1	14.1
Fuel Mass - Mid		Mass 402	**46.1**	**46.1**	**47.4**	**53.5**	**32.1**	15.2
Fuel Mass - Aft		Mass 403	29.5	28.0	23.8	25.6	24.8	15.4

Bold numbers exceed criteria

For the most part, the BH-205 exhibits the ability to meet the civil rotorcraft 95th percentile upper profile with a few exceptions, as noted below:

- Seat stroke >5 inches at 24.1/20/0 and 22.7/30/0 impact conditions
- Forward mass fuel vertical acceleration >30 g (30.4 g) at 26/0/0 condition
- Engine vertical acceleration >30 g at several pitch = +5 and +10 degrees impact conditions
- Center fuel mass vertical acceleration >30 g at all pitch = +10 degrees, except at 12.7/50/10 condition

Table 47 shows the results of all the civil rotorcraft 95th percentile lower profile for the +5 and +10 degree attitudes. Previous data for the vertical-only and pitch = 0 attitude impacts at or above the lower curve velocities showed no exceedance of criteria. For the data shown in table 47, all seat stroke, transmission, and engine responses (except one) are within criteria. The 20/30/5 condition shows the center fuel mass to be 1% in excess of 30 g. The center fuel mass acceleration exceeds the 30-g criteria for the 23.5/0/10, 23.3/10/10, and 22.3/20 conditions by about 20%.

Table 48 shows a comparison of vertical responses for all four configurations at the civil upper 95th percentile for 26/0/0 and 20/40/5 impact conditions. All four configurations exhibit seat deflections below 5 inches with the 14.5-g seat. The results from tables 44 through 47 were also based on a 14.5-g seat. With the exception of a few excessive mass item vertical accelerations (one of which is >10% above the 30-g criteria), all four configurations are within criteria for these two conditions.

Table 47. Summary of Responses—Civil Rotorcraft Lower 95th Percentile Range, Pitch = +5 and +10 Degrees, Maximum GTOW Configuration 1

Scenario			3W01P5	3W02P5	3W03P5	3W04P5	3W01P10	3W02P10	3W01P10	3W02P10
Vertical/longitudinal velocity (ft/sec)			23.5/0	23.3/10	22.3/20	20/30	23.5/0	23.3/10	22.3/20	20/30
Pitch/roll/yaw (degree)			5/0/0	5/0/0	5/0/0	5/0/0	10/0/0	10/0/0	10/0/0	10/0/0
Maximum seat stroke (in.)			2.53	3.15	2.04	1.26	1.29	1.85	0.81	0.58(3)
Floor Response—Vertical Peak Acceleration (g)										
FS 42 BL 14	Pilot	Mass 31	43.6	47.9	39.0	39.1	34.6	31.9	30.5	21.1
FS 85 BL 30	Fwd	Mass 52	43.8	48.8	42.2	29.3	33.8	33.5	40.8	23.5
FS 102 BL 37	Mid	Mass 62	37.2	40.9	45.5	40.4	40.8	43.4	36.6	29.7
FS 139 BL 38	Aft	Mass 82	16.9	20.1	26.4	23.9	19.7	21.7	20.1	24.6
Mass Response—Vertical Peak Acceleration (g)										
Transmission		Mass 7	26.4	20.9	22.1	27.2	14.9	14.1	19.3	21.7
Engine		Mass 8	19.7	**34.8**	19.5	15.1	26.4	27.4	20.7	22.8
Fuel Mass - Fwd		Mass 401	23.1	25.0	24.7	24.8	18.8	19.9	18.1	23.4
Fuel Mass - Mid		Mass 402	27.6	19.6	29.9	**30.3**	**35.4**	**35.8**	**35.2**	29.6
Fuel Mass - Aft		Mass 403	21.1	14.7	22.7	23.2	20.4	21.2	22.6	23.6

Bold numbers exceed criteria

Table 48. Summary of Responses—Civil Rotorcraft Upper 95th Percentile Range, Pitch = +0 and +5 Degrees, all Configurations

Scenario			3W01P0 Config 1	3W02P0 Config 2	3W03P0 Config 3	3W04P0 Config 4	3W0P5 Config 1	3W0P5 Config 2	3W0P5 Config 3	3W0P5 Config 4
Vertical/longitudinal velocity (ft/sec)			26/0	26/0	26/0	26/0	20/40	20/40	20/40	20/40
Pitch/roll/yaw (degree)			10/0/0	10/0/0	10/0/0	10/0/0	5/0/0	5/0/0	5/0/0	5/0/0
Maximum seat stroke (in.)			4.77	4.45	1.21	4.77	1.23	2.00	1.06	1.14
Floor Response—Vertical Peak Acceleration (g)										
FS 42 BL 14	Pilot	Mass 31	104.6	91.6	46.4	105.5	38.2	44.5	60.4	37.5
FS 85 BL 30	Fwd	Mass 52	60.7	58.0	41.6	60.7	29.4	30.7	65.2	31.0
FS 102 BL 37	Mid	Mass 62	39.1	47.9	35.7	43.7	44.1	25.7	55.8	35.8
FS 139 BL 38	Aft	Mass 82	25.5	36.6	31.5	32.3	24.1	26.7	32.6	38.3
Mass Response—Vertical Peak Acceleration (g)										
Transmission		Mass 7	23.3	24.7	27.8	22.8	19.8	23.5	14.7	21.3
Engine		Mass 8	26.7	**31.7**	14.4	28.1	14.8	22.5	6.7	21.9
Fuel Mass - Fwd		Mass 401	**30.4**	NA	**37.1**	27.8	26.0	NA	27.3	23.1
Fuel Mass - Mid		Mass 402	29.1	NA	23.0	28.3	**31.6**	NA	14.3	24.9
Fuel Mass - Aft		Mass 403	26.3	Na	20.3	26.3	23.8	NA	13.5	19.5
Auxiliary		Mass 404	NA	NA	NA	15.1	NA	NA	NA	19.6

Bold numbers exceed criteria

5.2.5 Design Allowables—Panel Underside and Bulkhead Pressures.

The ditching design allowable study showed that thickness and design changes that allow increased panel pressure allowables can result in improved (higher) impact velocity. However,

for ditching, this occurs because the governing criteria was underside panel failure and seat stroke <5 inches with a rigid seat. The ditching results also showed that, at acceptable ditching levels, the mass item criteria was not a factor. If ditching improvements can be implemented, mass item criteria will be a factor. In addition, if improvements can increase ditching capability, the 12- and 14.5-g LL seats are needed.

For severe but survivable water impacts, panel underside pressures are allowed, 12- and 14.5-g LL seat requirements are necessary, and excessive interior (secondary) panel pressures govern the criteria. While improved designs could show that higher velocity impacts might be achievable by virtue of delaying panel failures, one can anticipate higher seat strokes and mass item responses at these higher impact velocities.

For ditching, the pressure acting on the interior bulkheads is not a factor because the no underside panel failure criteria preclude hydrodynamic forces from acting on the interior bulkheads. However, for the more severe water impact scenarios, underside panel failures are permissible. Thus, the bulkheads are prone to interior hydrodynamic forces under some conditions. Table 49 shows what these bulkhead pressures can be for a series of impact conditions. Included in table 49 are bulkhead pressures from analysis of the

- S2 UH-1H configuration subjected to the S2 28/39/4 impact condition.
- BH-205 maximum GTOW configuration 1 subjected to the S2 28/39/4 impact condition.
- BH-205 maximum GTOW configuration 1 subjected to a civil rotorcraft 95th percentile upper level limits; 20/40/5.
- BH-205 maximum GTOW configuration 1 subjected to several upper level severe water impact scenarios; 23/39/5, 23/39/10, 20/50/5, and 20/50/10.
- BH-205 maximum GTOW configuration 1 subjected to severe water impact scenarios; 14/60/5 and 14/60/10.
- BH-205 maximum GTOW configuration 1 ditching perpendicular into the face of a sea-state wave of 4 ft at its midpoint; 8/50/10.

The results show that

- the S2 configuration analysis produced bulkhead pressures lower than corresponding pressures than the maximum GTOW configuration, except at FS 92, when compared at the S2 impact levels.
- the +5 degree pitch produced the higher bulkhead pressures when compared to the +10 degree pitch impacts.
- the floor longitudinal accelerations were generally less than 20 g aft at all the water impact levels, except for a couple of responses that reach about 23 g.

- the bulkhead pressures (17 to 18 psi) that the sea-state ditching failure condition produced were in the range of bulkhead pressures (17 to 21 psi) that resulted from the 20/50/10 water impact.

- if the initial bulkhead criteria of 20 psi held, then the 14/60/5 condition exceeded it and the 20/50/5 condition was marginal.

- the bulkhead pressure increased as longitudinal velocity increased.

Table 49. Bulkhead Pressures

Scenario			S2 Model Calm	6W02P4 Calm	6W02P4 Calm	6W02P4 Calm	6W03P5 Calm	6W04P5 Calm	6W02P10 Calm	6W03P10 Calm	6W04P10 Calm	6D03P10 Wave
Vertical/longitudinal velocity (ft/sec)			28/39	28/39	23/39	20/40	20/50	14/60	23/39	20/50	14/60/10	8/50
Pitch/roll/yaw (degree)			4/0/0	4/0/0	5/0/0	5/0/0	5/0/0	5/0/0	10/0/0	10/0/0	10/0/0	10/0/0
Underside panel failures			17	17	13	9	9	2	11	11	2	2
Underside panel failure surfaces no.			5, 7-21	5-16 18,20 21-23	8, 9 11-16 18, 20-23	8, 9 11,12 18, 20-23	8, 9 11, 12 18, 20-23	18, 20	8, 9 11-16 18, 20, 21	8, 9 11-16 18, 20, 21	18, 20	17,18 10, 21
			Maximum Bulkhead Pressure (psi)									
FS 68			0.0	0.0	0.0	0.0	0.0		0.0	0.0		
FS 92			15.1	12.0	0.0	0.0	0.0		0.0	0.0		
FS 102			10.0	12.0	15.5	14.9	**21.4**		9.7	13.4		
FS 129			10.2	10.1	11.0	11.4	16.8		7.8	14.5		18.2
FS 155			10.3	10.2	10.6	11.9	18.7		9.1	14.7		18.1
FS 166			10.2	11.5	10.3	12.5	18.8	**25.7**	8.4	14.4	**23**	18.0
FS 178			9.7	10.3	10.6	0.0	0.0		9.2	14.8		
FS 211			9.2	10.0	9.9	0.0	0.0		9.0	14.7		
			Floor Response—Longitudinal Peak Acceleration (g)									
FS 42 BL 14	Pilot	Mass 31	NA	20.8	16.9	11.1	12.0	7.3	19.8	14.3	5.0	10.1
FS 85 BL 30	Fwd	Mass 52	20.9	18.4	8.9	6.2	6.5	4.7	18.1	14.0	3.8	8.3
FS 102 BL 37	Mid	Mass 62	23.4	20.0	10	7.9	8.7	6.3	18.6	17.0	3.2	7.5
FS 139 BL 36	Aft	Mass 82	18.7	22.9	9	10.4	10.7	5.5	18.6	18.2	3.4	6.6
			Mass Response—Longitudinal Peak Acceleration (g)									
Transmission		Mass 7	24.5	**30.4**	15.1	16.3	18.2	8.0	27.4	7.0	8.7	8.2
Engine		Mass 8	27.1	19.4	13.2	14.3	15.4	6.8	15.4	8.0	10.9	10.4

Bold numbers exceed criteria

In the modeling, the bulkhead pressure can only occur if a lift surface that it is attached to fails. There can be independent surfaces that are exposed to hydrodynamic forces as a result of the longitudinal velocity component of the impact. These surfaces would be representative of unpressurized regions or protuberances that project below the floor. However, no such surfaces were considered in the analytical model.

The table 49 results, combined with results from tables 39 and 40 and 44 through 47, will be discussed with regard to water impact acceptable design limits in section 6.2.

5.2.6 Unsymmetrical Impacts.

Table 50 shows mass item accelerations for several symmetrical and unsymmetrical impacts. Impact conditions 26/0, 20/40, and 12.7/50 are representative of the civil rotorcraft 95th percentile accident upper envelope. The 20/50 impact condition represents a more severe scenario. As with the ditching unsymmetrical analysis discussed in section 5.1.6, the unsymmetrical impact introduces transmission, engine, and midfuel lateral accelerations that are not present in a symmetrical impact. The highest lateral accelerations introduced by an unsymmetrical impact are 12.8 g for the transmission, 6.0 g for the engine, and 8.4 g for the midfuel. The 20/50 impact has several fuel mass lateral accelerations >15 g criteria. One RHS fuel mass lateral acceleration is >15 g for a 95th percentile scenario (20/40). Several vertical accelerations exceed the 30-g criteria for both symmetric and unsymmetrical impacts.

Table 51 shows floor accelerations for several symmetrical and unsymmetrical impacts. In addition to comparing symmetrical and unsymmetrical impacts at 26/0, 20/40, and 20/50, the symmetrical responses for the 12.7/50 and a 14/60 are also shown. The latter impact condition is representative of a high longitudinal velocity impact in which drag surface pressure exceeds its allowable criteria. Since both the 12.7/50 and 14/60 symmetrical impacts indicate extremely low floor peak accelerations in all directions, there appeared no need for running their unsymmetrical counterparts. For the floor accelerations of the other three scenarios, the results show that some unsymmetrical impact peak accelerations can increase when compared to the symmetrical impacts, while others decrease when compared on a point to point basis. The highest floor peak lateral acceleration is 17.8 g for the side-facing seat and a 20/50 impact. The longitudinal acceleration (13.4 g) in an unsymmetrical impact for that side-facing seat at FS 139 and the 20/50 impact condition is very close to the highest longitudinal pulse in table 51. The KRASH floor longitudinal and lateral floor accelerations at FS 139 are actually lateral and longitudinal pulses, respectively, for seat testing purposes. The highest combination of lateral and longitudinal peak accelerations for the 95th percentile scenarios is 16.2 g lateral and 10.4 g longitudinal for the same seat, or 12.7 g lateral and 12.1 g longitudinal for the seat at FS 102.

Table 50. Symmetrical Versus Unsymmetrical Mass Item Responses

Scenario		3W01P10 Symmetrical	6W01P10 Unsymmetrical	3W05P10 Symmetrical	6W05P10 Unsymmetrical	1W03P10 Symmetrical	6W03P10 Unsymmetrical	3W06P10 Symmetrical	6W06P10 Unsymmetrical
Vertical/longitudinal velocity (ft/sec)		26/0	26/0	20/40	20/40	20/50	20/50	12.7/50	12.7/50
Pitch/roll/yaw (degree)		10/0/0	10/10/10	10/0/0	10/10/10	10/0/0	10/10/10	10/0/0	10/10/10
Mass Response—Longitudinal Peak Acceleration (g)									
Transmission	Mass 7	21.6	11.5	17.0	13.3	25.0	17.6	6.9	5.61
Engine	Mass 8	13.9	13.3	15.2	19.2	24.7	18.6	8.6	7.34
Fwd fuel - LHS	Mass 401	7.0	9.4	13.7	12.5	12.8	12.1	2.8	3.32
Fwd fuel - RHS	Mass 901	7.0	7.7	13.7	10.7	12.8	13.0	2.8	6.43
Midfuel	Mass 402	9.9	7.2	9.2	12.2	15.4	9.0	4.5	2.94
Aft fuel – LHS	Mass 403	20.3	18.3	12.3	17.0	18.7	22.4	4.7	6.13
Aft fuel - RHS	Mass 903	20.3	16.5	12.3	21.1	18.7	18.1	4.7	5.86
Mass Response—Lateral Peak Acceleration (g)									
Transmission	Mass 7	0.0	7.0	0.0	11.4	0.0	12.8	0.0	2.74
Engine	Mass 8	0.0	6.0	0.0	2.9	0.0	4.7	0.0	2.34
Fwd fuel - LHS	Mass 401	9.5	11.1	19.5	10.2	**21.1**	**15.2**	3.2	5.2
Fwd fuel - RHS	Mass 901	9.5	11.6	19.5	**20.2**	**21.1**	**21.2**	3.2	3.99
Midfuel	Mass 402	0.0	6.2	0.0	8.4	0.0	6.1	0.0	2.32
Aft fuel - LHS	Mass 403	16.4	19.0	7.5	12.8	**22.4**	**15.3**	9.4	4.43
Aft fuel - RHS	Mass 903	16.4	18.6	7.5	11.7	**22.4**	**17.6**	9.4	7.67
Mass Response—Vertical Peak Acceleration (g)									
Transmission	Mass 7	19.2	14.6	20.8	25.7	18.2	26.7	14.9	9.9
Engine	Mass 8	**38.4**	**38.3**	23.0	24.0	24.1	18.6	14.1	10.4
Fwd fuel - LHS	Mass 401	18.9	16.0	24.1	17.9	25.0	21.3	14.1	9.8
Fwd fuel - RHS	Mass 901	18.9	20.9	24.1	**36.2**	25.0	23.0	14.1	13.3
Midfuel	Mass 402	**46.7**	27.7	**32.1**	25.8	**40.4**	24.8	15.2	17.3
Aft fuel – LHS	Mass 403	29.5	23.4	24.8	22.7	24.2	18.3	15.4	15.2
Aft fuel - RHS	Mass 903	29.5	23.2	24.8	19.7	24.2	26.5	15.4	14.9

Bold numbers exceed criteria

Table 51. Symmetrical Versus Unsymmetrical Floor Responses

Scenario			3W01P10 Symmetrical	6W01P10 Unsymmetrical	3W05P10 Symmetrical	6W05P10 Unsymmetrical	1W03P10 Symmetrical	6W03P10 Unsymmetrical	6W06P10 Symmetrical	6W06P10 Symmetrical
Vertical/Longitudinal velocity (ft/sec)			26/10	26/10	20/40	20/40	20/50	20/50	12.7/50	14/60
Pitch/Roll/Yaw (degree)			10/0/0	10/10/10	10/0/0	10/10/10	10/0/0	10/10/10	10/0/0	10/0/0
Floor Response—Longitudinal Peak Acceleration (g)										
FS 42 BL 14	Fwd	Mass 31	8.7	9.5	13.1	10.8	13.1	12.8	3.60	5.01
	RHS	Mass 531	8.7	11.4	13.1	11.8	13.1	10.4	3.60	5.01
FS 85 BL 30	Aft	Mass 52	7.7	9.9	9.33	10.0	14.9	12.9	3.15	3.78
	RHS	Mass 552	7.7	10.7	9.33	9.1	14.9	10.6	3.15	3.78
FS 102 BL 37	Fwd	Mass 62	12.9	10.5	11.4	9.92	17.6	12.7	2.86	3.23
	RHS	Mass 562	12.9	7.9	11.4	12.1	17.6	13.5	2.86	3.23
FS 139 BL 38	Side	Mass 82	10.5	10.2	11.0	9.31	17.4	13.4	1.99	3.35
	RHS	Mass 582	10.5	6.0	11.0	10.4	17.4	11.5	1.99	3.35
Floor Response—Lateral Peak Acceleration(g)										
FS 42 BL 14	Fwd	Mass 31	3.1	9.8	2.59	11.5	3.3	9.8	0.79	0.82
	RHS	Mass 531	3.1	10.3	2.59	9.7	3.3	7.9	0.79	0.82
FS 85 BL 30	Aft	Mass 52	4.9	9.5	3.02	9.69	4.8	4.7	1.88	2.06
	RHS	Mass 552	4.9	11.3	3.02	6.43	4.8	6.7	1.88	2.06
FS 102 BL 37	Fwd	Mass 62	7.5	10.2	5.81	7.18	10.2	10.0	3.01	3.27
	RHS	Mass 562	7.5	10.4	5.81	12.7	10.2	12.9	3.01	3.27
FS 139 BL 38	Side	Mass 82	5.7	8.3	9.22	7.52	11.0	17.8	2.74	2.81
	RHS	Mass 582	5.68	9.03	9.22	16.2	11.0	17.3	2.74	2.81
Floor Response—Vertical Peak Acceleration (g)										
FS 42 BL 14	Fwd	Mass 31	62.2	31.0	20.9	21.3	24.8	20.0	9.58	10.8
	RHS	Mass 531	62.2	32.9	20.9	17.0	24.8	19.7	9.58	10.8
FS 85 BL 30	Aft	Mass 52	78.6	33.4	29.4	30.9	32.1	33.5	8.44	9.4
	RHS	Mass 552	78.6	47.3	29.4	19.0	32.1	21.0	8.44	9.4
FS 102 BL 37	Fwd	Mass 62	43.2	65.4	28.7	23.8	46.8	25.8	9.21	13.1
	RHS	Mass 562	43.2	37.3	28.7	24.8	46.8	21.8	9.21	13.1
FS 139 BL 38	Side	Mass 82	15.5	27.6	25.3	22.3	37.8	26.2	11.2	13.4
	RHS	Mass 582	15.5	40.4	25.3	43.4	37.8	43.7	11.2	13.4

Additionally, an unsymmetrical impact was analyzed for a combined vertical-lateral impact. The impact conditions that are representative of a previous UH-1H helicopter ground impact test for which an earlier KRASH version simulation was performed [11], are:

- 23-ft/sec vertical velocity
- 16.7-ft/sec lateral velocity (left)
- -1 degree pitch
- +10 degree roll
- +26.4 degree/sec roll (left)

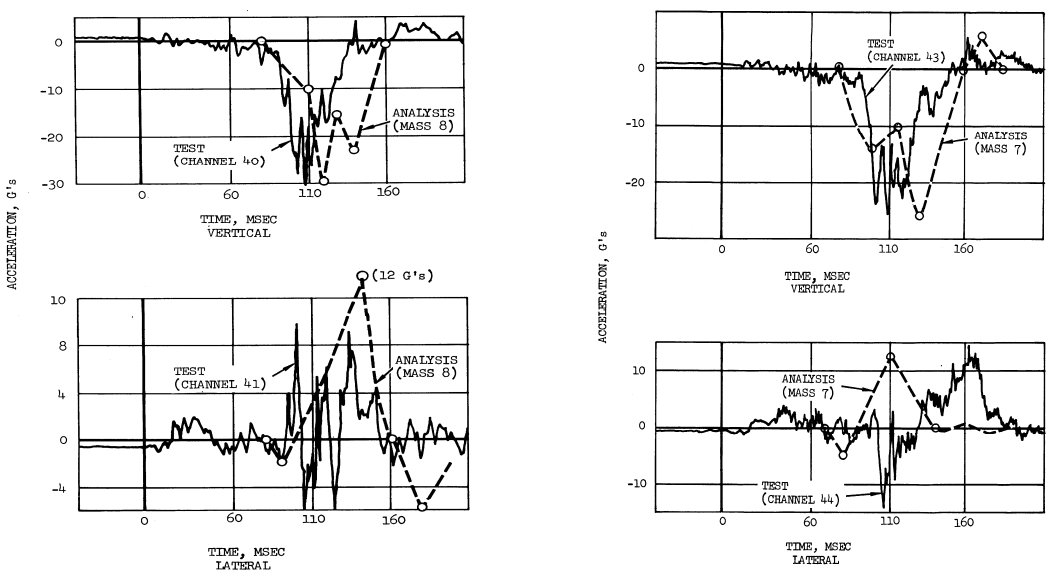
The engine and transmission results in table 52 show that the water impact analysis provided lower engine and transmission responses. The ground impact simulation showed good correlation. While the KRASH filtering characteristics used in the ground impact simulation [11] are different than the current SAE class filtering used in the water impact analysis, the results in table 52 indicate that the major mass items are not very sensitive to the filtering levels used in both instances. The ground impact analysis/test used a 50-Hz low-pass filter, whereas

the water impact analysis/test uses an SAE class 60 filter (100 Hz cutoff). Also, the models are different in size since the ground impact model is only 31 masses and 37 beams.

Table 52. Ground Versus Water Impact, Unsymmetrical Impact

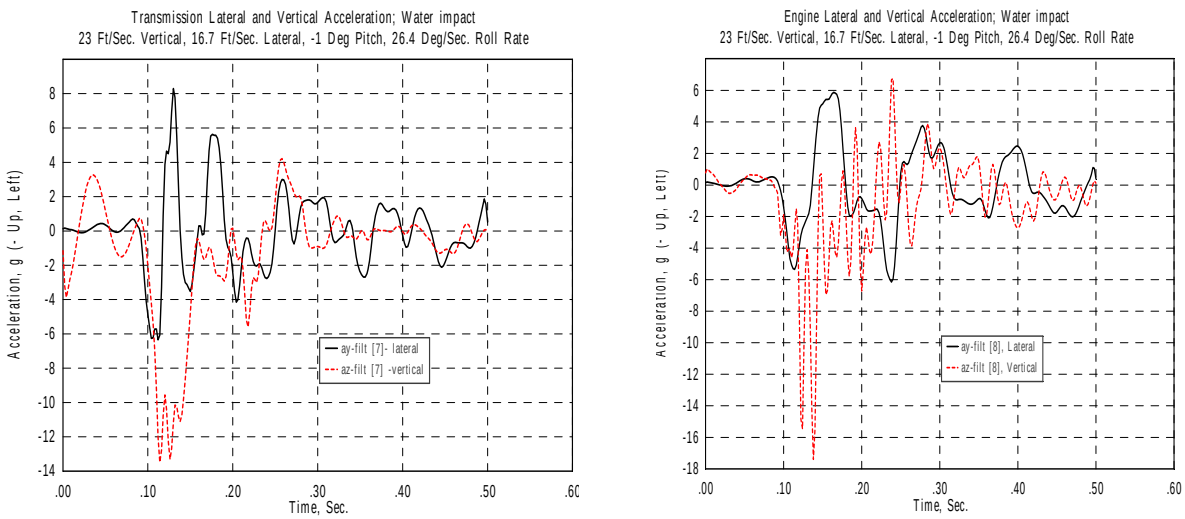
Mass	Direction	Peak Acceleration (g)			
		Ground Impact		Water Impact	
		Test Unfiltered	Analysis Filtered	Analysis Unfiltered	Analysis Filtered
Transmission	vertical	-30.0	-30.0	-14.7	-13.8
Transmission	lateral	9.0	12.0	8.0	8.2
Transmission	longitudinal	-6.0	-6.0	-8.0	-6.0
Engine	vertical	-25.0	-26.0	-18.6	-17.2
Engine	lateral	12.0	11.0	9.0	6.0
Engine	longitudinal	-12.0	-5.0	-7.6	-6.0

Figure 42 shows the ground impact test and analysis results. Figure 43 shows the corresponding transmission and engine lateral and vertical accelerations, respectively. The durations of the vertical pulses appear to be between 0.050 and 0.080 sec. The ground impact results are slightly shorter (0.050 sec) for the water impact. The lateral pulses are of shorter duration for the ground impact results (0.050 sec) and more oscillatory for the water impact.



(a) Transmission (b) Engine

Figure 42. Mass Item Accelerations—Ground Impact



(a) Transmission (b) Engine

Figure 43. Mass Item Accelerations—Water Impact

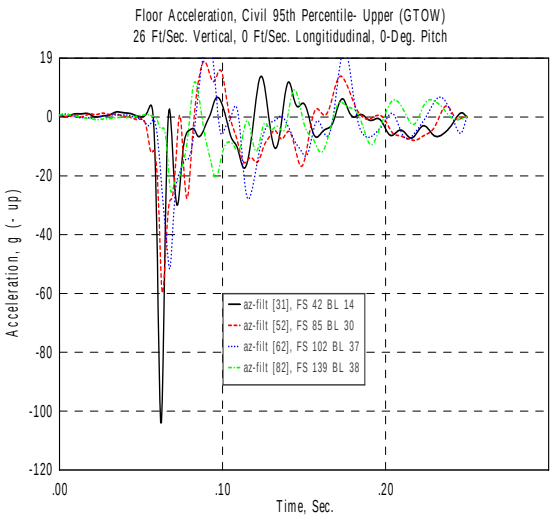
Figure 43 shows the engine and transmission acceleration time histories for the water impact condition are similar to the ground impact condition for figure 42. The SAE class 60 filter results are shown. Table 52 shows that the unfiltered results do not significantly alter the vertical peaks.

5.2.7 Floor and Mass Item Accelerations.

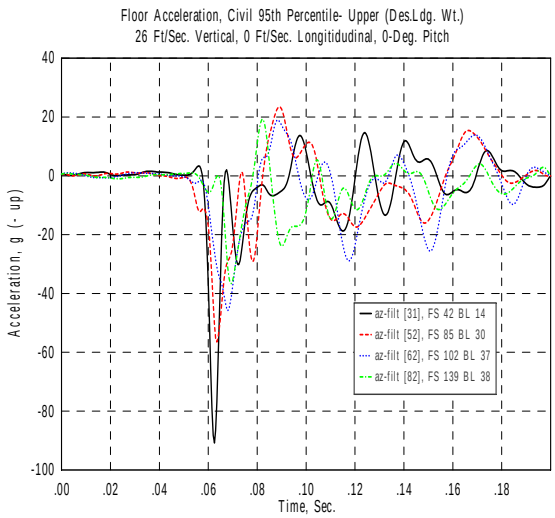
All acceleration plots are obtained using an SAE class 60 (100-Hz) filter. Figures 44 and 45 show floor acceleration plots for:

- Basic BH-205 model (9500 lb)—maximum GTOW configuration 1
- Design landing weight (8000 lb)—low fuel, configuration 2
- Amphibious configuration (8500 lb)—Float, configuration 3
- Auxiliary fuel tank configuration (9500 lb), configuration 4

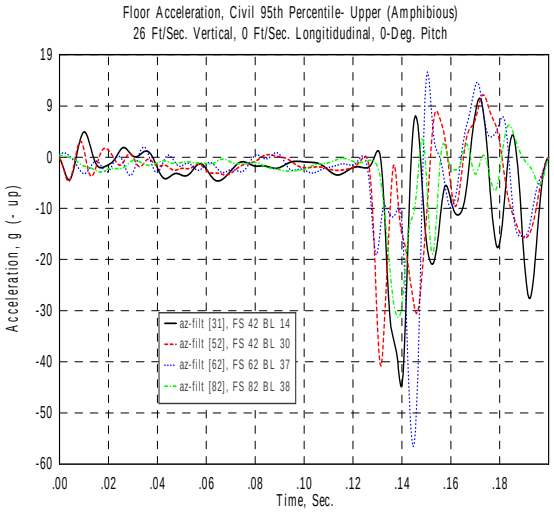
Figure 44 is for the 26/0/0 impact condition and figure 45 is for the 20/40/5 impact condition. Both impact points are on the civil rotorcraft 95th percentile upper accident velocity curve.



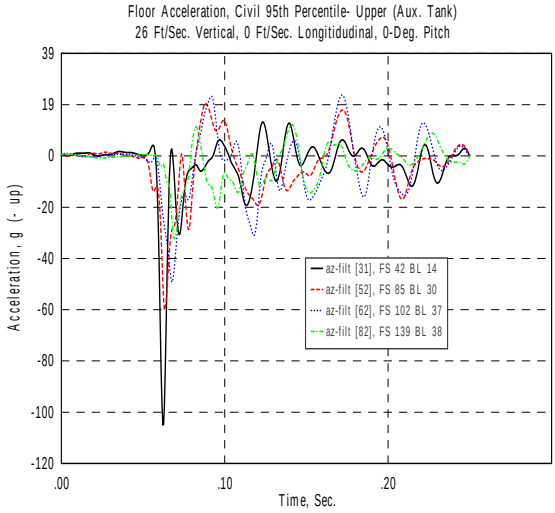
(a) Configuration 1



(b) Configuration 2

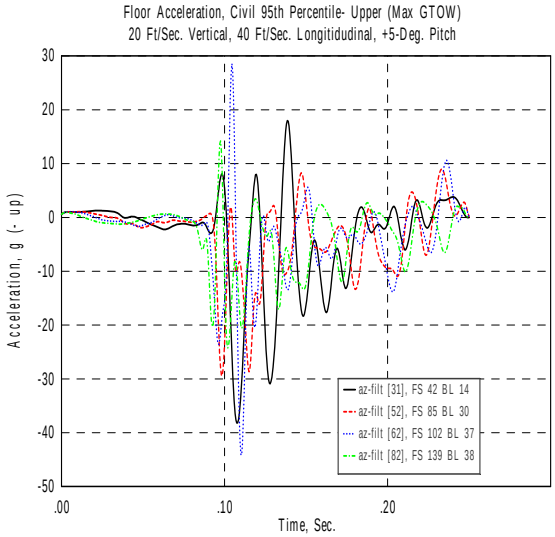


(c) Configuration 3

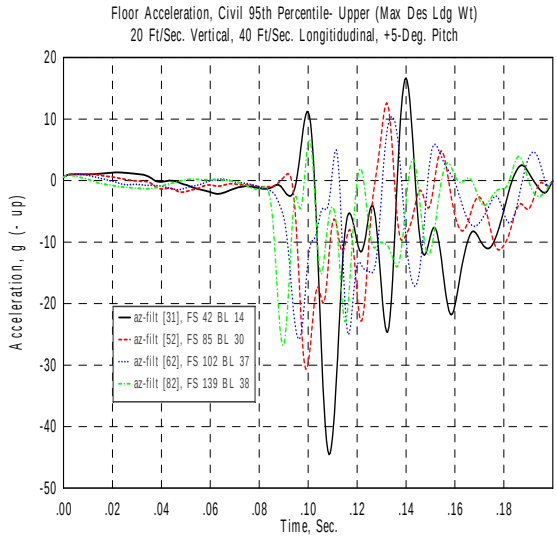


(d) Configuration 4

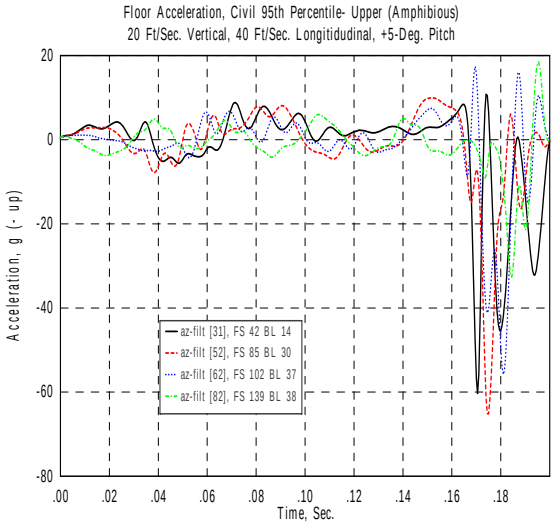
Figure 44. Floor Vertical Accelerations—All Configurations, 26 ft/sec Vertical, 0 ft/sec Longitudinal, 0 Degree Pitch



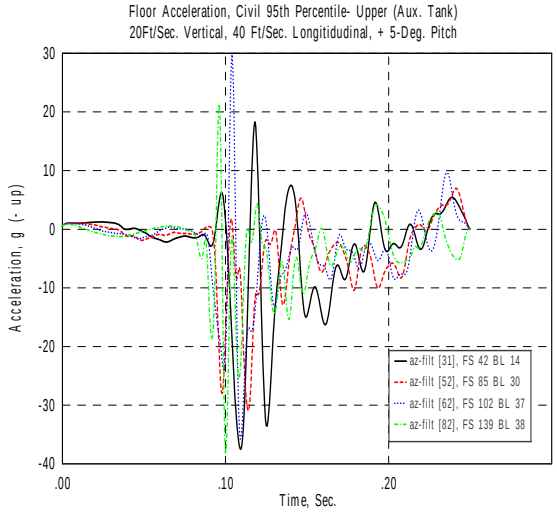
(a) Configuration 1



(b) Configuration 2



(c) Configuration 3



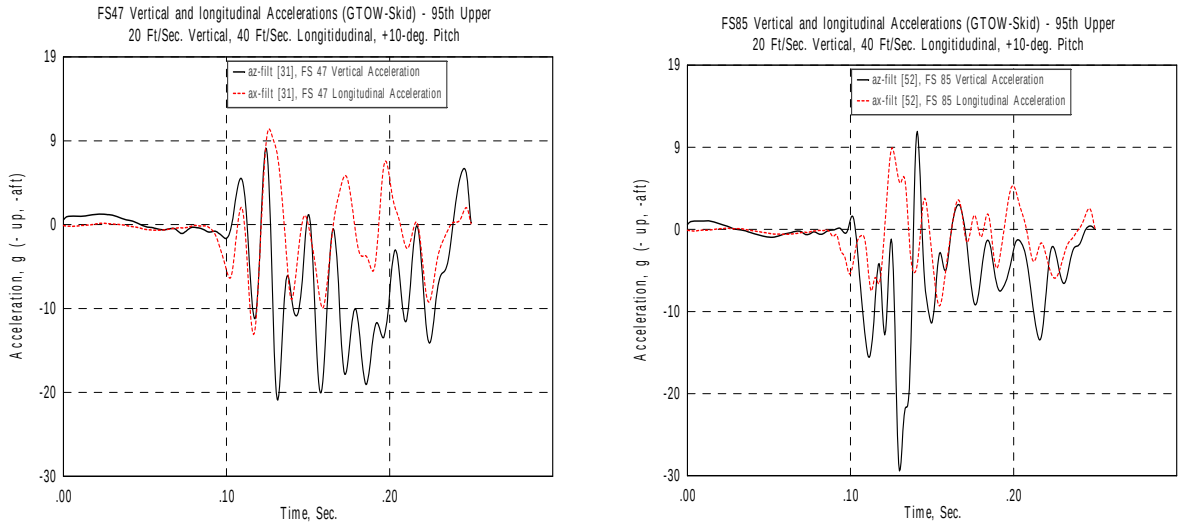
(d) Configuration 4

Figure 45. Floor Vertical Accelerations—All Configurations, 20 ft/sec Vertical, 40 ft/sec Longitudinal, +5 Degree Pitch

The data for these configurations was taken from table 48. For this impact condition, one engine (configuration 2) and two forward fuel mass peak accelerations (configurations 1 and 3) exceed the 30-g criteria. Only the midfuel, mass acceleration for configuration 1 exceeds the 30-g criteria.

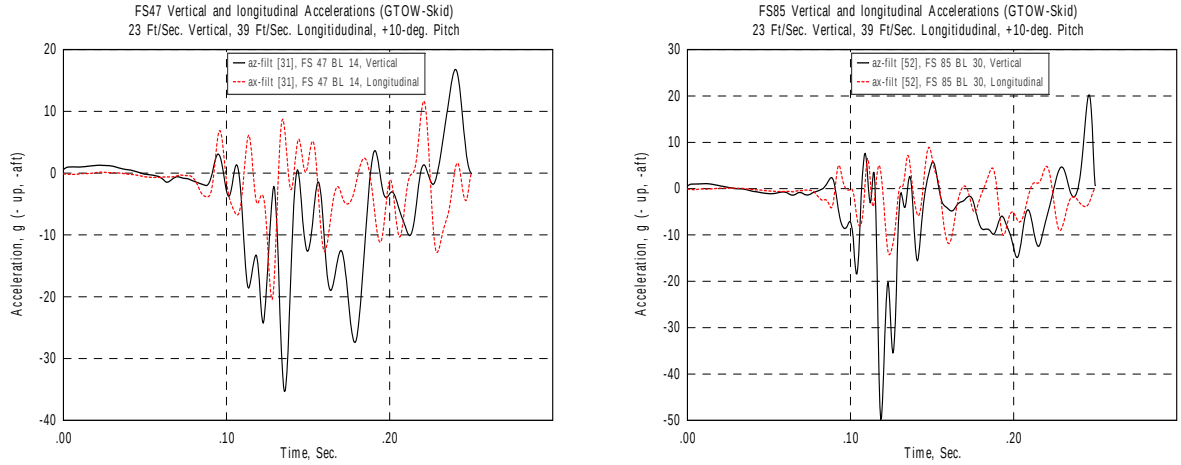
The combined floor vertical and longitudinal acceleration time histories at two locations (FS42-47 and FS 85) is shown in figure 46 for the 20/40/10 impact condition and figure 47 for the 23/39/10 impact condition, respectively. The latter was a more severe impact compared to

the civil rotorcraft 95th upper limit at 20/40/10. The +10 degree pitch condition was chosen because it produces more significant longitudinal pulses.



(a) FS 42-47 (b) FS 85

Figure 46. Floor Responses at FS 47 and FS 85—GTOW Configuration, 20-ft/sec Vertical Velocity, 40-ft/sec Longitudinal Velocity, +10 Degree Pitch



(a) FS 42-47 (b) FS 85

Figure 47. Floor Responses at FS 47 and FS 85—GTOW Configuration, 23-ft/sec Vertical Velocity, 39-ft/sec Longitudinal Velocity, +10 Degree Pitch

The BH-205 seats at FS 85 are aft facing so that the floor aft longitudinal pulse that normally produces a forward seat test pulse is reversed. Similarly, the longitudinal pulse acting on the sideward-facing seat at FS 139 actually produces a side pulse for test purposes. Figure 48 shows the floor response at FS 139 for the 20/40/10 impact.

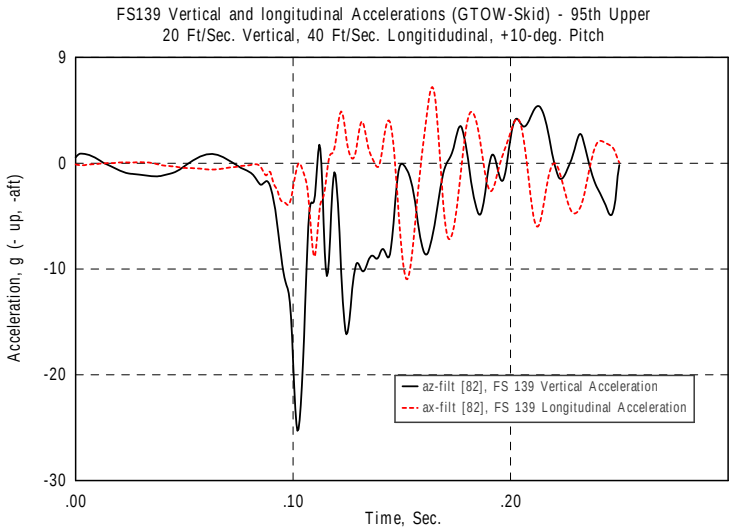
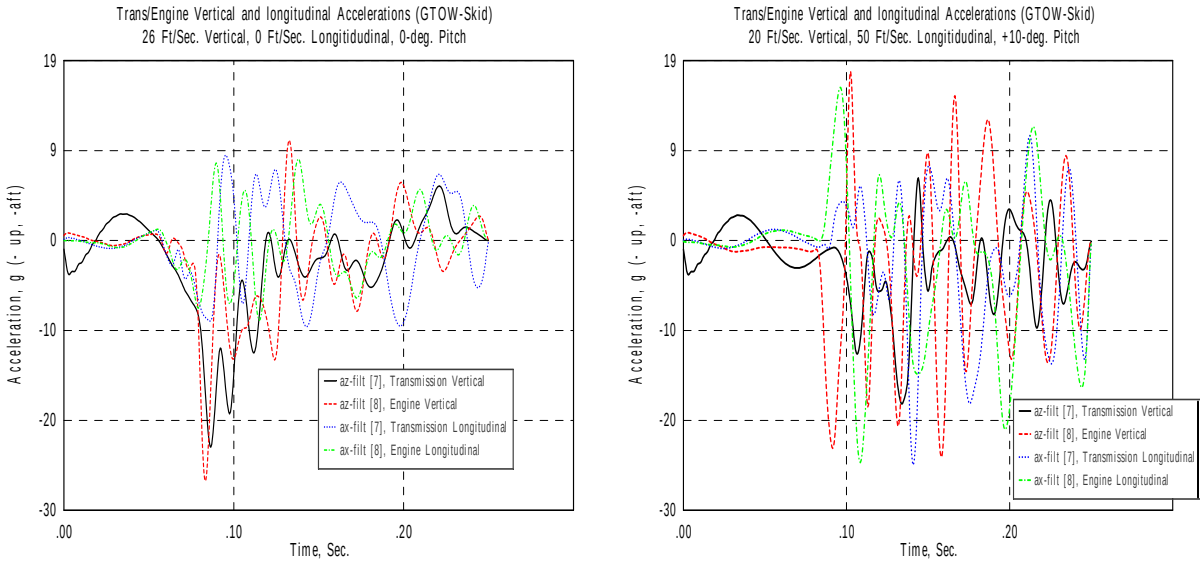


Figure 48. Floor Responses at FS 139—GTOW Configuration, 20-ft/sec Vertical Velocity, 40-ft/sec Longitudinal Velocity, +10 Degree Pitch

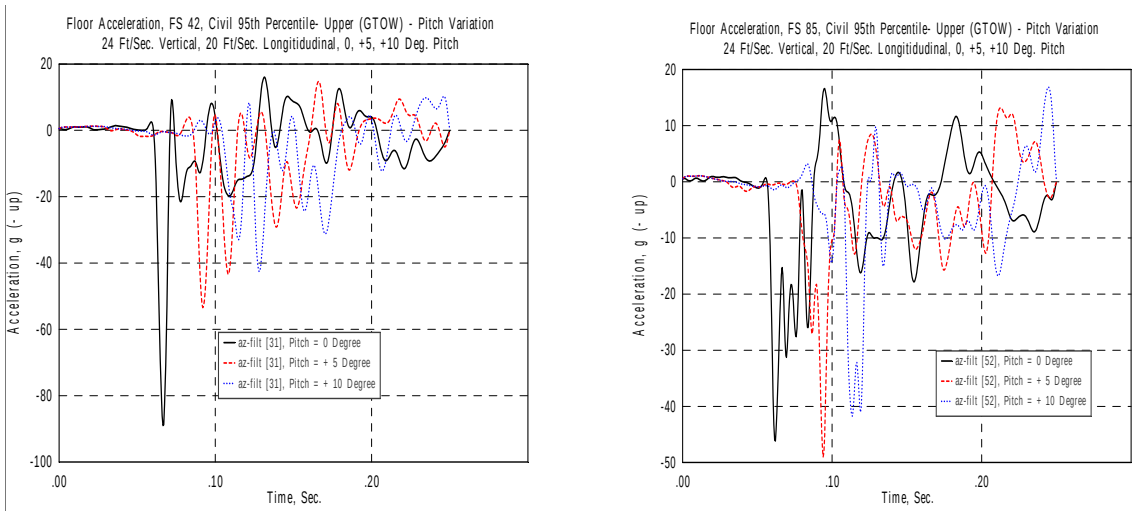
Figure 49 depicts the transmission and engine vertical accelerations for both a vertical velocity impact and a combined vertical and longitudinal impact.



(a) 26/0/0 Vertical Impact (b) Combined 20/50/10 Impact

Figure 49. Transmission and Engine Accelerations—GTOW Configuration, Vertical and Combined Vertical and Longitudinal Impacts

Figure 50 depicts the floor responses at two locations as a function of pitch attitude for the 95th percentile upper limit impact point at a 24-ft/sec vertical and 20-ft/sec longitudinal impact. From this plot, it can be observed that the peaks occur later as the initial impact pitch attitude increases.



(a) FS 42 (b) FS 85

Figure 50. Floor Acceleration at FS 42 and FS 85—Maximum GTOW Configuration, 24-ft/sec Vertical Velocity, and 20-ft/sec Longitudinal Velocity

6. DESIGN LIMIT ENVELOPES, TRENDS, AND TRADEOFFS.

6.1 LEVEL 1 WATER IMPACT.

Ditching is considered a controlled event because the pilot or copilot has the opportunity to control and position the aircraft in light of the pending ditching scenario. Level 1 water impacts, as defined in the introduction, are based on maintaining structural integrity in the form of a protective shell.

The results from section 5.1 are compiled and presented in the form of water impact DLE, fuselage responses, and tradeoffs with regard to criteria and impact levels.

Figure 51 shows the DLEs for a maximum GTOW configuration 1 in calm sea with skid extended and for pitch = 0, +5, and +10 degrees and based on no panel failure criteria. The use of load limit seats does increase the capability until after panel failure occurs.

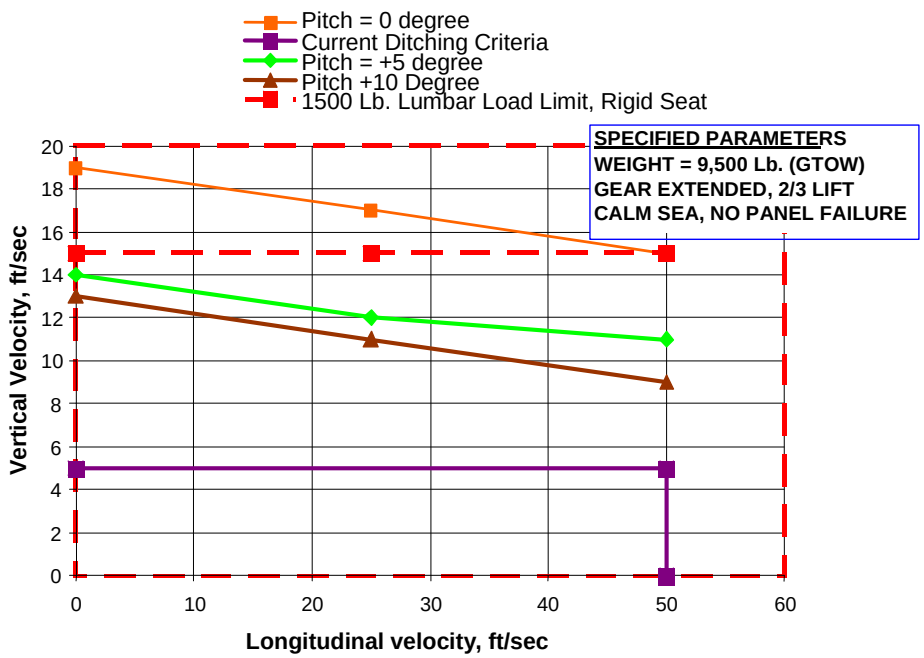


Figure 51. Water Impact DLE for Calm Sea Scenario—GTOW Configuration

Also shown in figure 51 is the limit of vertical velocity for a rigid seat in which the lumbar load for a 50th percentile occupant is equal to or less than 1500 lb. Figure 51 is based on data from table 12.

Table 17 shows the failure limit of the DLW low fuel configuration 2 and the auxiliary fuel tank configuration 4 is similar to that of table 12 of the maximum GTOW configuration 1. The float configuration 3 results shown in table 17 may add up to an additional 2-ft/sec capability at some impacts with pitch attitudes of 0 and +5 degrees. Of interest is that the float ditching standard from 14 CFR 29.519 for hull type aircraft, water-based and amphibian, is a vertical descent velocity of 6.5 ft/sec, which is 1.5 ft/sec greater than the 5.0-ft/sec requirement of 14 CFR 29.563 structural ditching provisions. From a design consideration that involves maximum occupancy, it would appear that the DLEs are based on configurations 1 and 2 for nonamphibious configurations and that the amphibious configuration might be 2 ft/sec higher.

Table 21 shows that the BH-205 skids provide marginally different responses and occupant loads when compared with an impact directly onto the airframe for all three configurations. Thus, the envelopes shown in figure 52 can be considered for landing gear extended or retracted.

Figure 52 depicts a set of DLE for water impact into a sea state = 4. Included are pitch = 0 and +10 degree impact attitudes and landing either parallel to and on a wave crests, as well as a landing perpendicular to and into a wave at its midpoint. The result of a water impact into a rough sea is dependent on many factors including wave length to height, aircraft size relative to wave, aircraft orientation relative to the wave, impact location onto the wave, aircraft speed, wave speed, and aircraft attitude. To develop a DLE for each and every potential consideration is not practical. Thus, select scenarios of landings parallel and perpendicular to a wave are presented in figure 52.

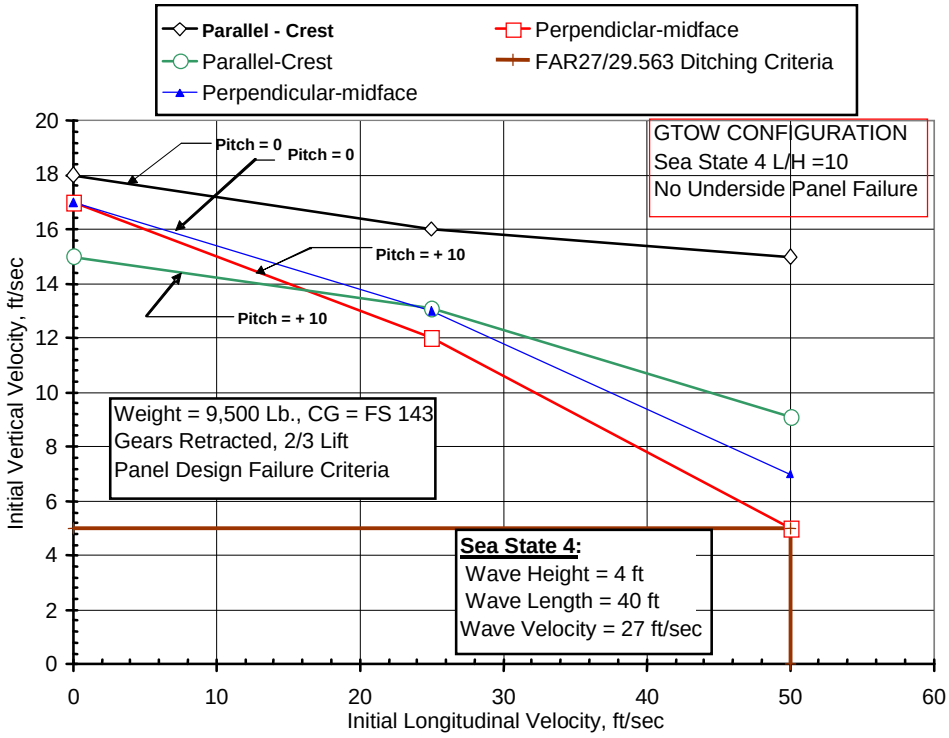


Figure 52. Water Impact DLEs for Sea-State Scenario—GTOW Configuration 1

Figure 52 illustrates how a ditching DLE takes into consideration a specified sea state (4) as a function of pitch attitude and aircraft orientation to the wave. Below a 16-ft/sec vertical velocity, the curves are appropriate for rigid seats. Above 16 ft/sec, a load limit seat is required to keep the lumbar load below 1500 lb. If the underside panels do not fail, the capability with a load limit seat, which maintains the lumbar load below 1500 lb, can be extended to about 20-ft/sec vertical velocity.

Figure 53 is a composite of all the results, creating a minimum standard DLE that encompasses all the criteria and impact scenarios. Figure 53 is based on a rigid or load-limited seat. However, the use of a load limit seat would not alter the ditching DLE in figure 53 because panel underside failure, pitch attitude, and sea state are the governing criteria. The DLE takes the lower limit of capability when a sea state is applied and a pitch attitude up to +10 degrees is considered. At a pitch attitude of 0 degree, the curve would be higher.

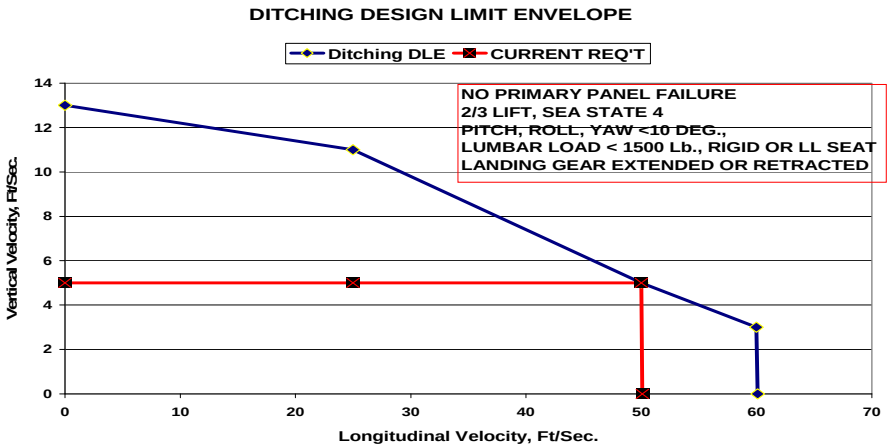


Figure 53. Water Impact DLE Compared to Versus Current 14 CFR 27 and 29.563 Standard

The DLE shown in figure 53 is applicable to the maximum GTOW or the maximum DLW configuration. The float configuration has about a 2 ft/sec added capability.

A DLE set could be created that takes into account improved design, load limit seats, and mass item acceleration criteria that would be higher than that shown in figure 53. For example, figure 54 depicts the tradeoff between increased underside panel strength, occupant lumbar load (<1500 lb), and a 5-inch seat stroke criteria.

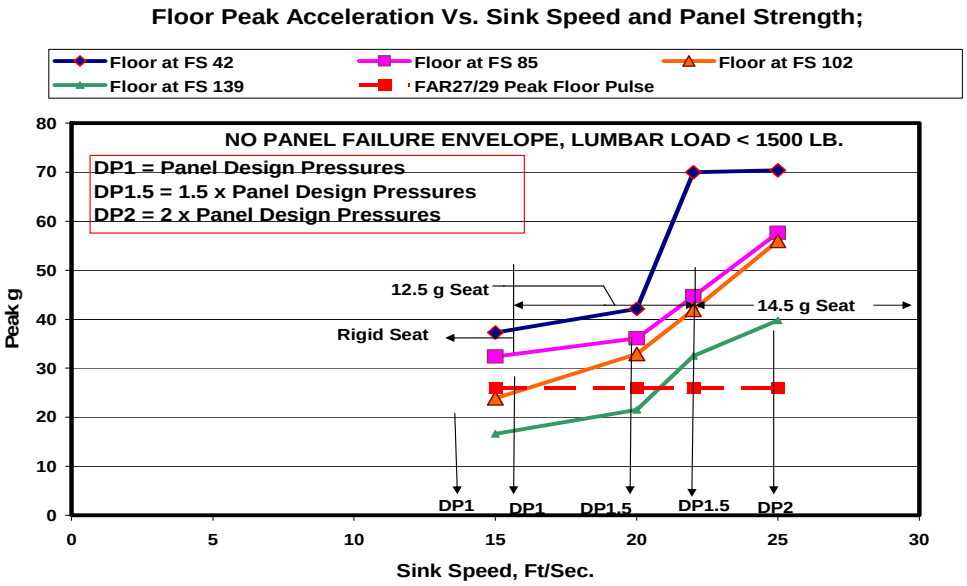


Figure 54. Floor Peak Vertical Acceleration Versus Sink Speed and Panel Strength

From figure 54, it can be observed that

- below 15.5 ft/sec, a rigid seat provides adequate protection (lumbar load below 1500 lb). The panel strength is the current design and is depicted as DP1.

- a 12-g LL seat provides adequate lumbar load protection, within the 5-inch stroke requirement, up to about 20-ft/sec for the current design, but the underside panel failure prevails.

- a 50 % increase in panel strength, denoted as 1.5 DP1, requires a 12-g LL seat above the 15.5-ft/sec sink speedup until the sink speed reaches 22 ft/sec.

- increasing the panel strength to twice the current strength (DP2) requires a 14.5-g LL seat for a 25-ft/sec impact velocity.

- the load limit level limitations are based on maintaining seat stroke below 5 inches (lumbar load below 1500 lb).

The relationship between material properties and panel thickness versus panel strength or design pressure is provided in reference 4. The equations show the relationships exist between the various parameters. The increase in floor accelerations as strength increases is consistently higher, except at the floor at FS 42, where it appears that the peak response flattens out at the DP2 configuration. Of interest is that the current seat dynamic test peak vertical acceleration of 26 g is noted. However, a more rigorous comparison would include rise time and pulse duration.

While the structure can be potentially strengthened and the occupant seat load can be limited to tolerable lumbar loads, the increased strength also increases floor and mass item peak acceleration responses. From figure 55 it is observed that, at current underside panel design capability, the transmission, engine, and fuel mass are all below the 30-g vertical acceleration criteria with the DLE shown in figure 53. These mass items would appear to still be below 30 g even at sink speed just below 20 ft/sec. However, as the panel strength increases in excess of 20 ft/sec, the 30-g limit is exceeded. Thus, to be consistent with occupant protection from excessive lumbar load or seat stroke, the mass item criteria would have to increase to 40 g or more if panel strength were increased.

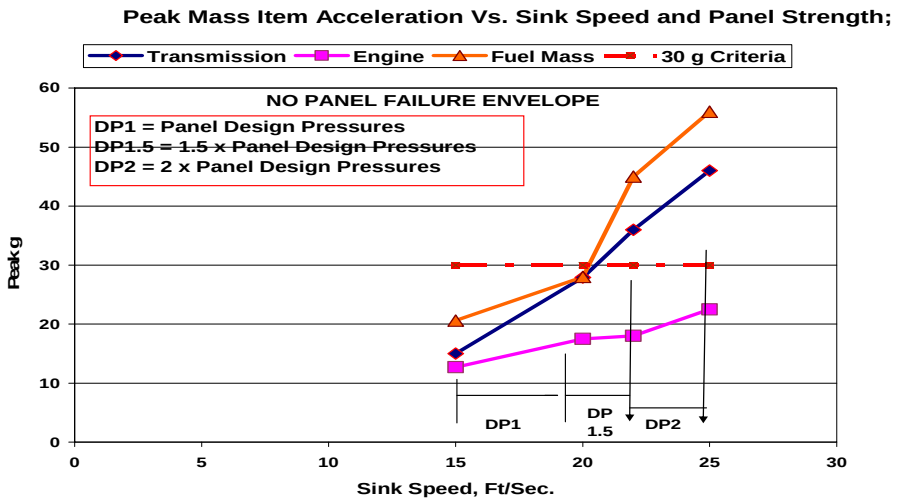


Figure 55. Mass Item Peak Vertical Acceleration Versus Sink Speed and Panel Strength

In addition to trends associated with increased strength noted in figures 54 and 55, the analysis results show that other trends can be observed. Figure 56 shows that the nose-over potential increases as longitudinal velocity increases if there is a protuberance present. The drag pressure, floor peak aft acceleration, and long-term aft acceleration all increase as the longitudinal velocity increases. Thus, a 5-ft/sec vertical, 160-ft/sec longitudinal velocity, +3 degree nose-up attitude accident condition that nosed-over, which is discussed in section 5.1.3.4, is very realistic.

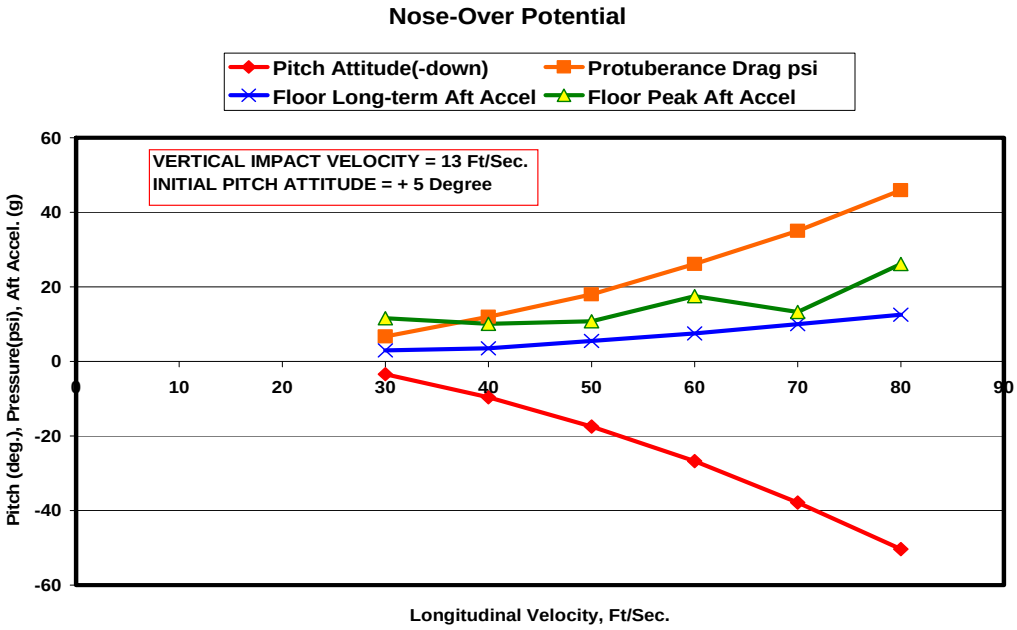


Figure 56. Nose-Over Potential Versus Longitudinal Velocity

The float design can influence the capability of the amphibious configuration with regard to the potential DLE. Figure 57 shows a plot of vertical velocity versus float design pressure for different pitch attitudes and a specified longitudinal velocity of 50 ft/sec. As anticipated, the capability reduces as the design pressure decreases. A similar trend holds for a different forward velocity, i.e., 0 ft/sec.

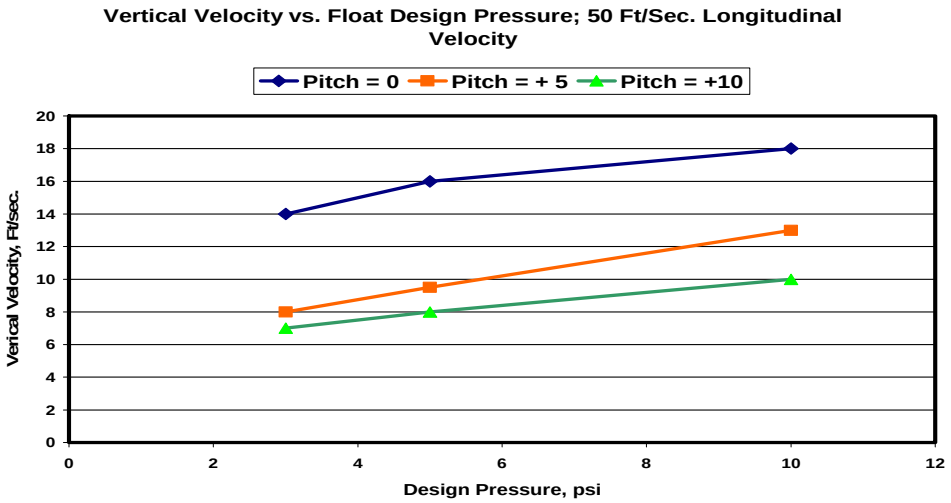


Figure 57. Vertical Velocity Capability Versus Float Design Pressure

Figure 58 shows a series of water impact DLEs for an amphibian configuration as a function of float design pressure and compared to the current 14 CFR 29.519 ditching standard for amphibious designs.

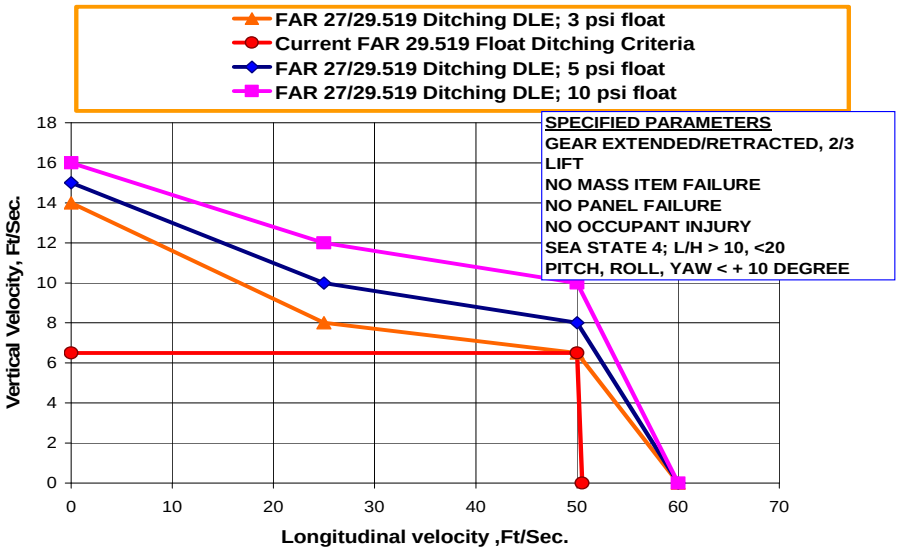


Figure 58. Water Impact DLEs for Amphibian Configuration Versus Float Design Pressure and 14 CFR 29.519 Standard

6.2 LEVEL 2 WATER IMPACT.

The results from section 5.2 are compiled and presented in the form of DLEs, fuselage responses, and tradeoffs with regard to criteria and impact levels. The mass acceleration data from tables 44 through 46 are plotted in figures 59 through 61.

Figures 59, 60, and 61 show the mass item vertical response trends for the range of pitch = 0, +5, and +10 degrees for the civil rotorcraft 95th percentile upper accident curve at the following envelope points: 26/0, 20/40, and 12.7/50, respectively. For each point, the use of a 14.5-g LL seat results in a seat stroke within the 5-inch criteria.

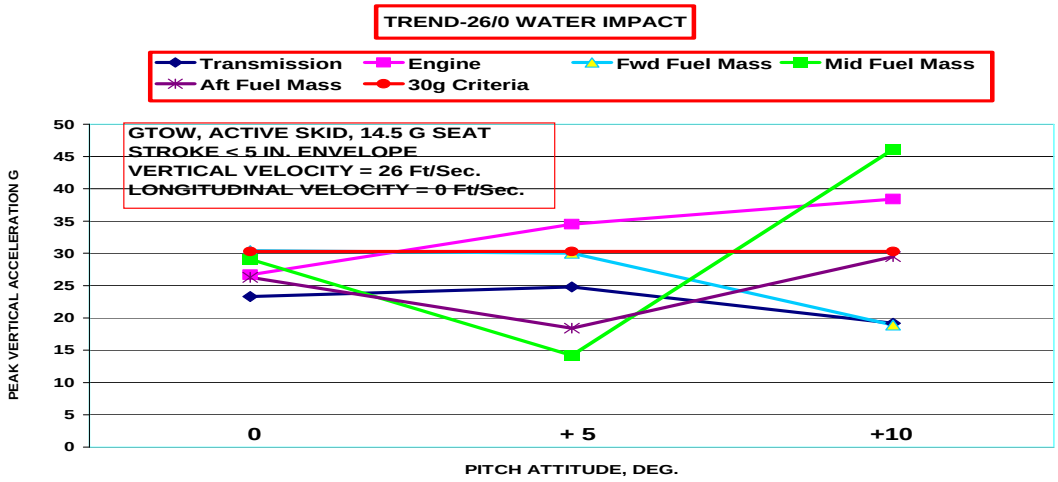


Figure 59. Mass Item Vertical Acceleration Trends—Civil Rotorcraft 95th Percentile Upper Limit, 26/0 Impact Condition

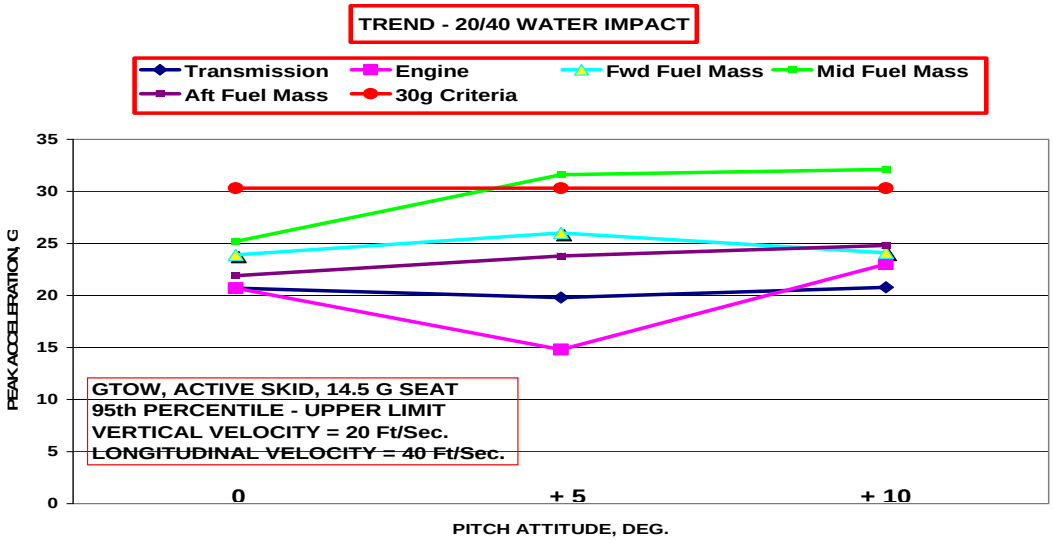


Figure 60. Mass Item Vertical Acceleration Trends—Civil Rotorcraft 95th Percentile Upper Limit, 20/40 Impact Condition

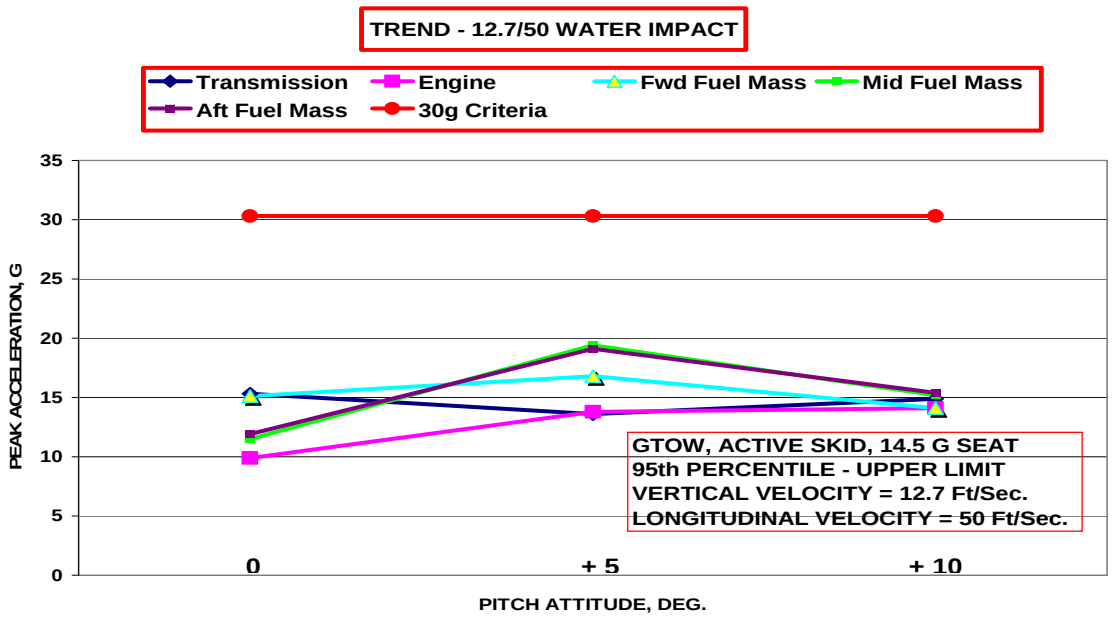


Figure 61. Mass Item Vertical Acceleration Trends—Civil Rotorcraft 95th Percentile Upper Limit, 12.7/50 Impact Condition

From figures 59, 60, and 61, it can be observed that

- the transmission response generally trends relatively flat as pitch attitude increases, but all below 30 g. Transmission peak trends lower as vertical velocity decreases.

- the engine response shows an inconsistent relationship with pitch attitude as the vertical velocity decreases. At the 20/40 velocity condition, the engine peak response is lower at +5 degree than at 0 and +10 degree pitch. At 26/0, the engine peak is >30 g for pitch = +2.5 degrees (extrapolated).

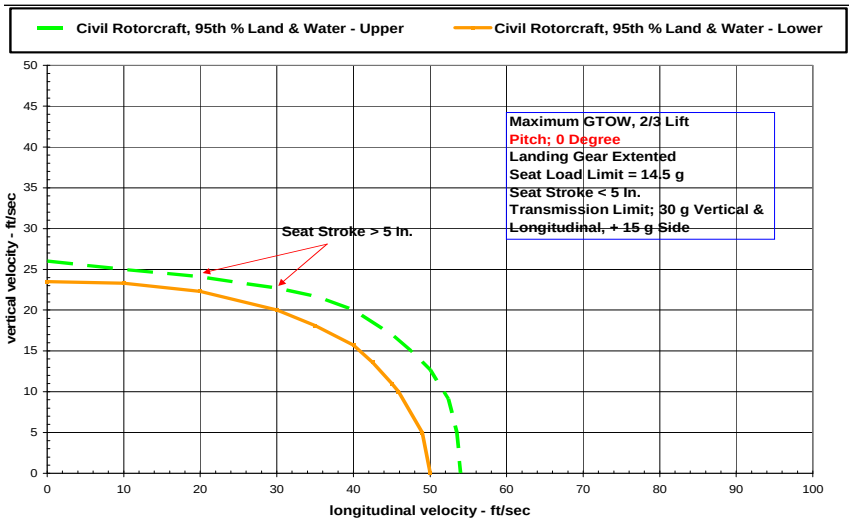
- the forward fuel response is marginally at or above 30 g for the 26/0 impact condition with pitch equal to or less than +5 degrees. The forward fuel mass trends slightly up from 0 to +5 degree pitch and slightly down at +10 degree pitch.

- the midfuel response trends are inconsistent in that a minimum g is reached at +5 degree pitch for the 26/0 condition, but that trend is reversed at the 12.7/50 impact condition. The acceleration is >30 g for the 26/0 impact condition when pitch = +10 degrees, and at the 20/40 condition when pitch is = +5 degrees.

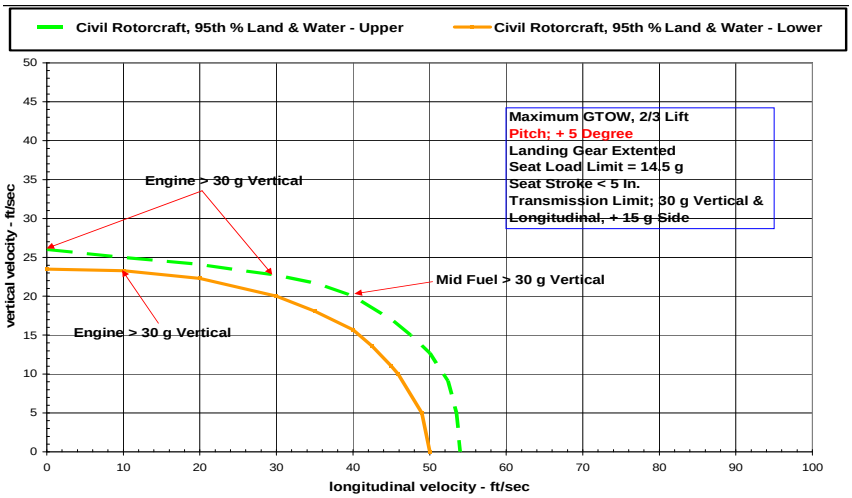
- the aft fuel responses are all below 30 g. The trend is similar to the midfuel mass response as the velocity combination changes.

- several impact scenario trends; 25/20, 24.1/20, and 22/30, are not plotted. The mass item responses are provided in tables 44, 45, and 46.

It is difficult to decipher why the trends sometimes shift. The trough in the peak response at a +5 degree pitch noted in a few instances might be similar to that noted in scale model test results in which optimum pitch attitude is somewhere around +6 to +8 degrees, although the tests range from 0 to +12 degrees. The different impact velocity combinations along with changing pitch attitudes most likely effect each of the five masses noted by virtue of where they are located, and the sequence with regard to how the fuselage impacts the water and the underside panels fail. Figure 62 provides an assessment of a DLE set based on the upper and lower limits of the civil rotorcraft 95th percentile accident profiles for pitch attitudes of 0, +5, and +10 degrees. For each pitch condition, the exceedance of 30 g vertical is noted.

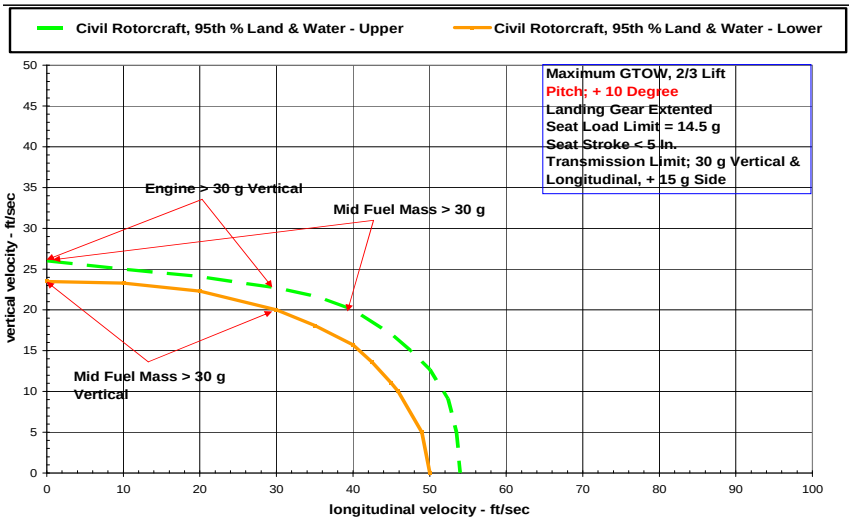


(a) 0 Degree Pitch



(b) +5 Degree Pitch

Figure 62. Water Impact DLEs for Civil Rotorcraft 95th Percentile Limits; 0, +5, +10 Degree Pitch



(c) +10 Degree Pitch

Figure 62. Water Impact DLEs for Civil Rotorcraft 95th Percentile Limits; 0, + 5, +10 Degree Pitch (Continued)

Figure 63 provides a potential water impact DLEs or revised 95th percentile lower and upper envelopes curves based on the limits of the landing gear extended and retracted impacts and within the framework of 12- and 14.5-g LL seats. The current civil rotorcraft lower and upper limit survivable envelopes, based on accident data, are also shown. The minimum curve is based on an LG extended impact and a 12-g seat. The upper curve is based on an LG retracted and a 14.5-g LL seat. Both curves limit seat stroke to 5 inches and provide lumbar load < 1500 lb. The outer limit, at a longitudinal velocity of 60 ft/sec, is based on the interior bulkheads experiencing less than 23 psi of pressure acting normal to their surface and acting over the entire surface after the underside panels fail. Locally, a pressure could exceed 23 psi. Both the existing 95th percentile envelopes and those provided by analysis of the BH-205 allow for underside panel failure. The data from tables 40 through 42 indicate that, with a pitch attitude of +5-degrees or less, the following exceedance of criteria occurs:

- Upper limit; engine >30 g vertical at 26/0/5 and at 22/40
- Upper limit; midfuel mass vertical acceleration exceeds 30 g at 20/50
- Lower limit; no exceedance of mass criteria; except midfuel at the 19/39 impact velocity condition

At a pitch of +10 degrees, fuel and engine vertical accelerations can approach or exceed 40 g.

Since the water impact DLEs are being compared to current accident data representative of civil rotorcraft 95th percentile survivable envelope, they can be treated as such.

The significance of the seat load limit level (12 or 14.5 g) affects the seat stroke since both result in lumbar load <1500 lb until the seat bottoms out.

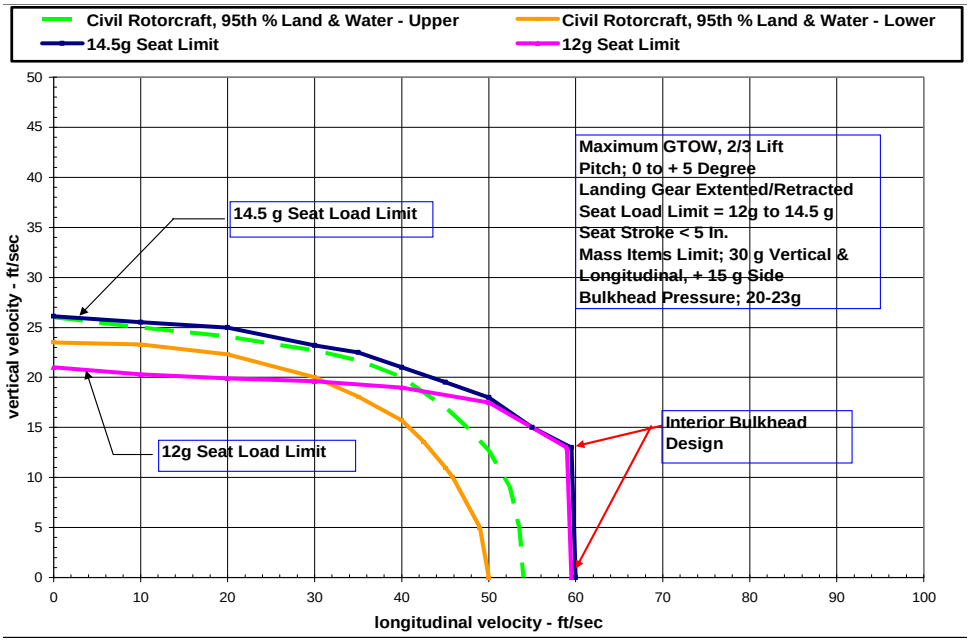


Figure 63. Water Impact DLEs for 12- and 14.5-g LL Seats Versus Civil Rotorcraft 95th Percentile Limits

A summary of DLEs and design criteria development is represented in table 53.

Table 53. Summary of DLEs and Design Criteria Development

Considerations	Ditching	Water Impact
Configurations modeled	Maximum GTOW DLW Low Fuel Amphibious/Float Auxiliary Fuel Tank	Maximum GTOW DLW Low Fuel Amphibious/Float Auxiliary Fuel Tank S1, S2 Test Article
Design envelope	14 CFR Parts 27 and 29	Civil 95th percentile-upper Civil 95th percentile-lower
Vertical velocity (ft/sec)	0 to 25	10 to 28
Longitudinal velocity (ft/sec)	0 to 80	0 to 60
Pitch attitude (degree)	0, 5, 10	0, 4, 5, 10
Roll, yaw (degree)	10, 10	10, 10
Sea state	Calm, sea state 4	Calm, no
Landing gear position	Retracted, extended	Retracted, extended
Rigid seat	Yes	No
Load limit seat g	12, 14.5	12, 14.5

Table 53. Summary of DLEs and Design Criteria Development (Continued)

Considerations	Ditching	Water Impact
Drag effects (pitch-over)	Yes	No
Float design considerations (psi)	3, 5, 10	10
Panel design strength tradeoff (psi)	Current- 2X current	No
Suction (psi)	-10	No
Seat stroke limit (in.)	5	5
Lumbar load limit (lb)	1500	1500
Underside panel failure (psi)	Design	Design
Interior bulkhead failure (psi)	Design	Design
HIC	1000	1000
Restraint belt load (lb)	1750-2000	1750-2000
Mass item restraint – vertical/longitudinal/side (g) engine transmission fuel	30/30/15	30/30/15

7. SEAT TEST PULSES AND SEAT OCCUPANT RESTRAINT LOADS.

7.1 FLOOR PULSES/SEAT DYNAMIC TEST REQUIREMENTS.

The current 14 CFR Parts 27 and 29 regulations [9 and 10] Seat Dynamic Test Standards are the same and are defined in their respective 14 CFR 27.562 and 29.562. Along with the seat test pulse definitions are the criteria for acceptance with regard to HIC value and restraint loads. The KRASH structural models used in the aforementioned analysis allow for simple representations of the occupant, which is more appropriate for vertical loading than longitudinal loading. The acceptance of the DLEs discussed in sections 6.1 and 6.2 are independent of the floor pulses experienced during ditching and water impact, which may or may not yield pulses that exceed seat dynamic test requirements and acceptance criteria. However, in an attempt to expand the evaluation of the analysis results, an unvalidated KRASH type model of the seat occupant with restraints was used and is described in section 6.4, along with its limitations. This model is referred to as KRASH-SOMR or SOMR, which stands for seat occupant model with restraints.

Figure 64 depicts the vertical acceleration response at FS 42 BL 14 for 16-, 20-, and 26-ft/sec water impacts. The 16- and 20-ft/sec acceleration responses are from the ditching analysis provided in section 5.1. For uniformity, all SOMR results are based on the use of a 14.5-g LL seat and are compared to KRASH model results using a 14.5-g LL seat as well. The 26-ft/sec condition represents an upper limit on the ability of a 14.5-g LL seat to protect the occupant against excessive spinal loads (lumbar load < 1500 lb) while maintaining a seat stroke at or below 5 inches. All these results are based on using a simplified seat occupant DRI model within the structural model of the aircraft. This simplified model does not address occupant restraint loads.

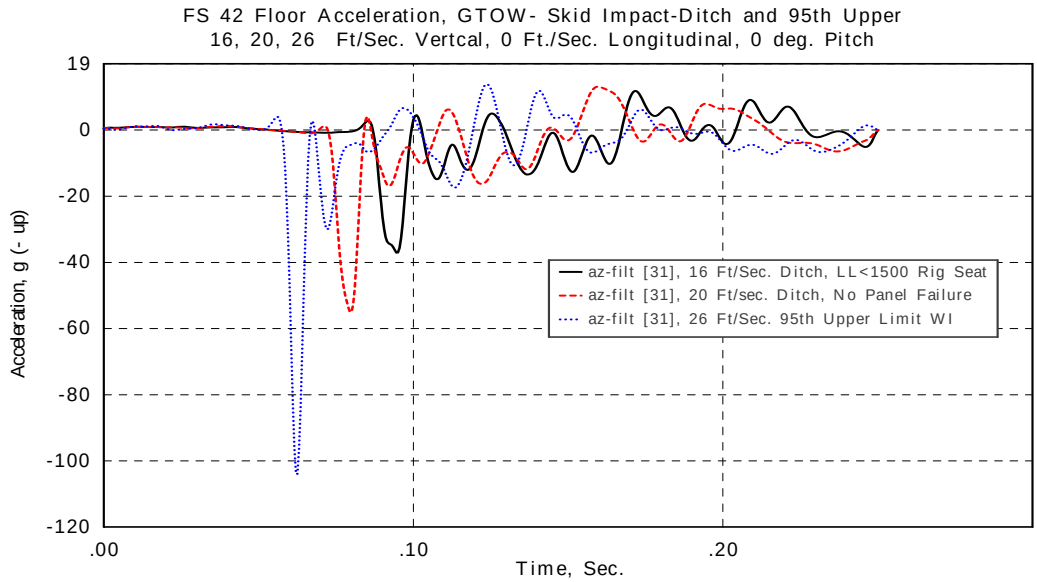


Figure 64. Fuselage Station 42 Floor Vertical Acceleration—16-, 20-, and 26-ft/sec Vertical Velocity

Figure 65 depicts how these three accelerations are depicted in KRASH-SOMR as input accelerations at four seat leg attachments to the floor.

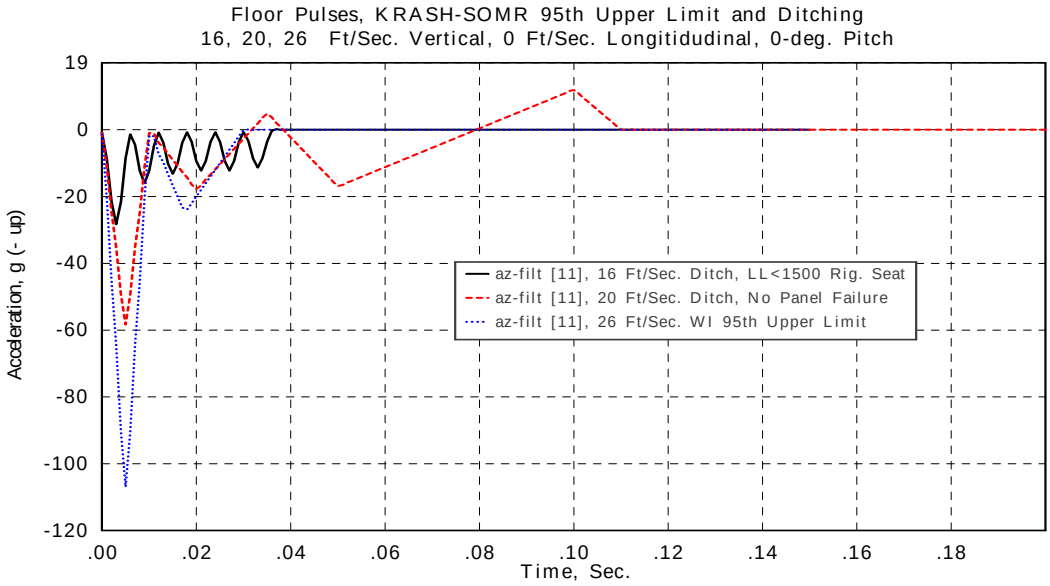


Figure 65. Fuselage Station 42 Idealized Floor Vertical Acceleration Pulses for SOMR Analysis

Figure 66 depicts a simultaneous floor vertical and longitudinal acceleration time history. These responses are obtained for what is considered both a severe but acceptable water impact, and also represent a data point on the civil rotorcraft 95th percentile upper limit. These accelerations are approximated for input to SOMR, as shown in figure 67.

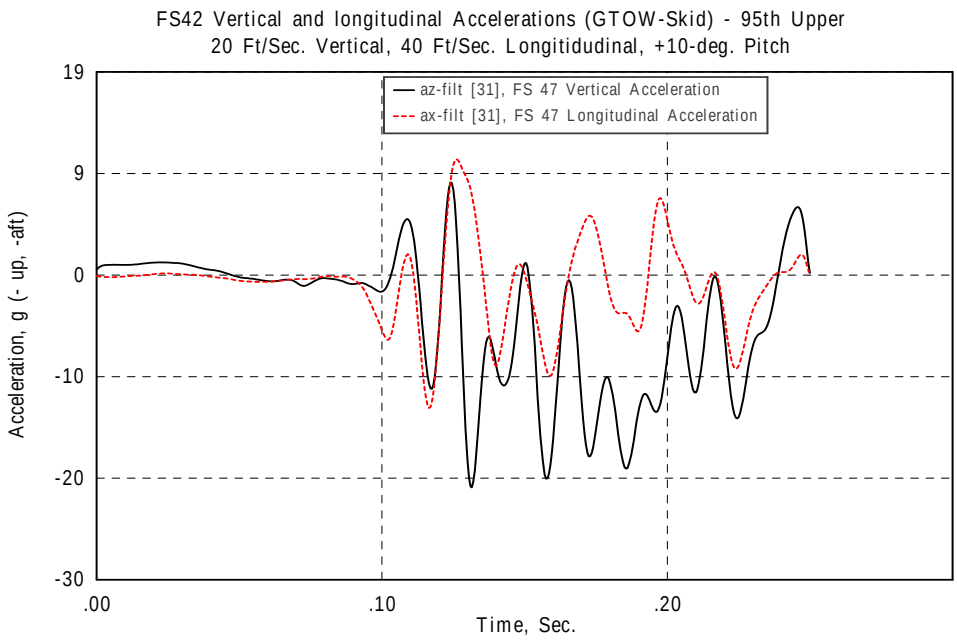


Figure 66. Fuselage Station 42 Floor Accelerations—20-ft/sec Vertical Velocity, 40-ft/sec Longitudinal Velocity, +10 Degree Pitch

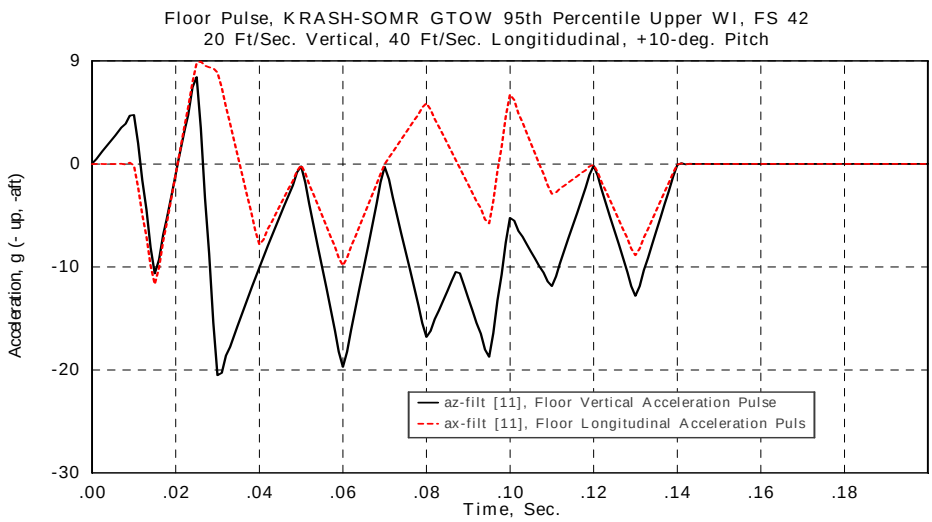


Figure 67. Idealized Floor Accelerations for SOMR Analysis—20-ft/sec Vertical Velocity, 40-ft/sec Longitudinal Velocity, +10 Degree Pitch

A plot of the 14 CFR 27 and 29.562 seat dynamic test acceleration levels is shown in figure 68. The vertical and longitudinal components of the combined velocity test are noted for the 30-ft/sec 30 degree seat test, whereas the longitudinal seat test pulse is defined as the 42-ft/sec velocity impact.

The vertical impact floor accelerations obtained from the analysis are shown in figure 69. These accelerations have been idealized as triangular pulses. The 16- and 20-ft/sec pulses are for level 1 water impact conditions. The 26-ft/sec pulse represents a civil rotorcraft 95th percentile upper limit level 2 water impact. Also shown is the current 14 CFR 27 and 29.562 seat dynamic test vertical component.

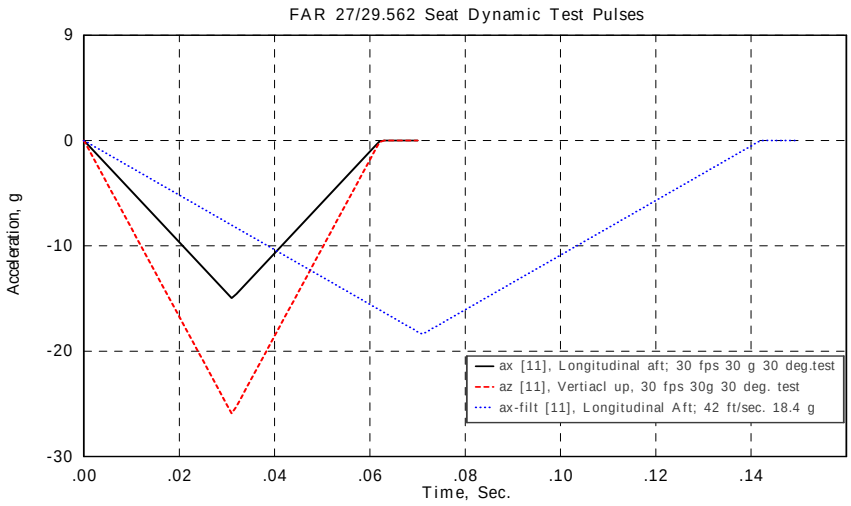


Figure 68. Current 14 CFR Parts 27 and 29 Dynamic Test Accelerations

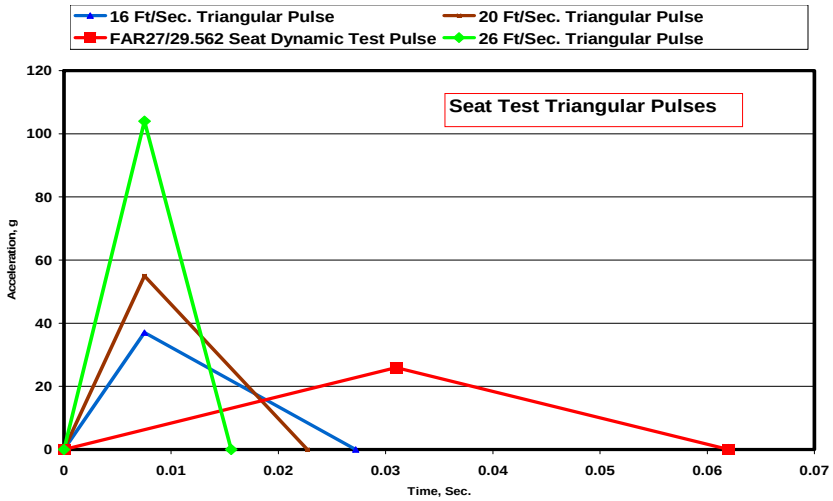


Figure 69. Comparison of Vertical Accelerations

Accelerations associated with high-longitudinal water impact conditions are shown in figures 70 through 72. It is difficult to obtain longitudinal pulses at the respective floor locations that tend to have durations at or near the 14 CFR Parts 27 and 29 seat test specification unless the c.g. acceleration is used. This acceleration, while longer in duration, is usually lower in magnitude.

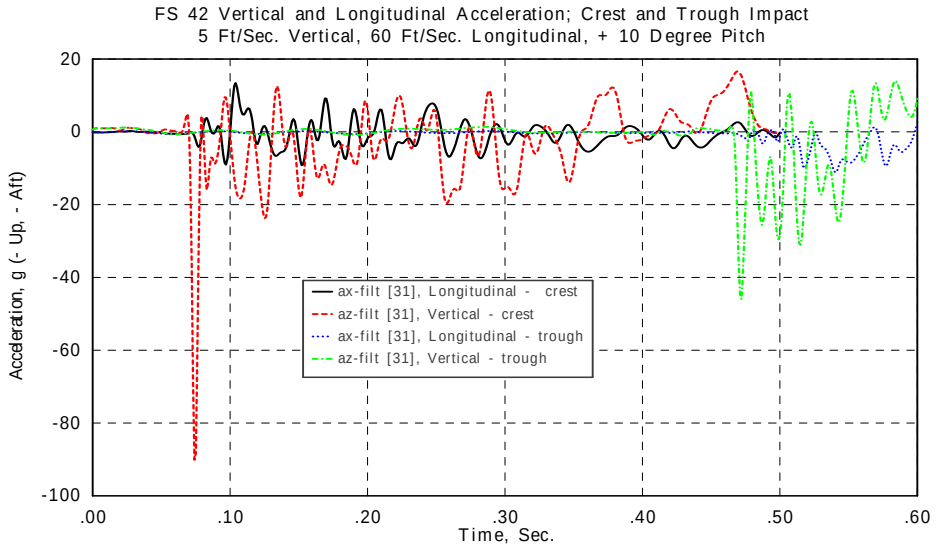


Figure 70. Floor Accelerations—Water Impact Into a Wave

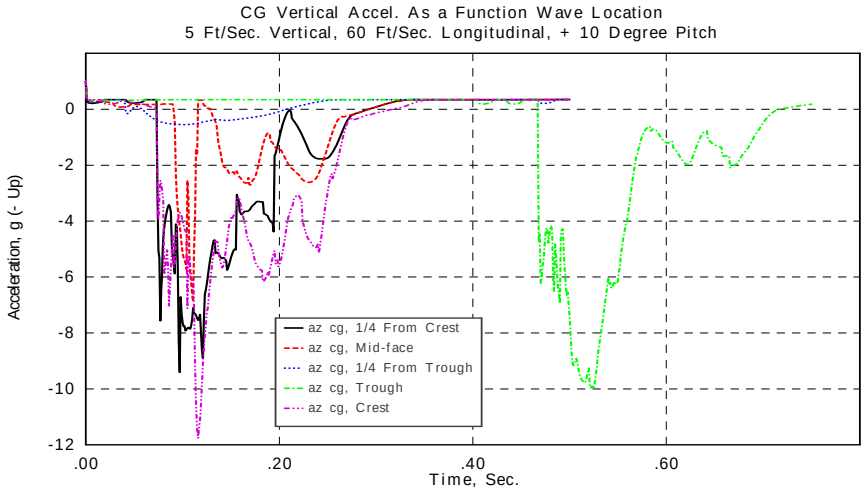


Figure 71. Center of Gravity Vertical Accelerations—Water Impact Into a Wave

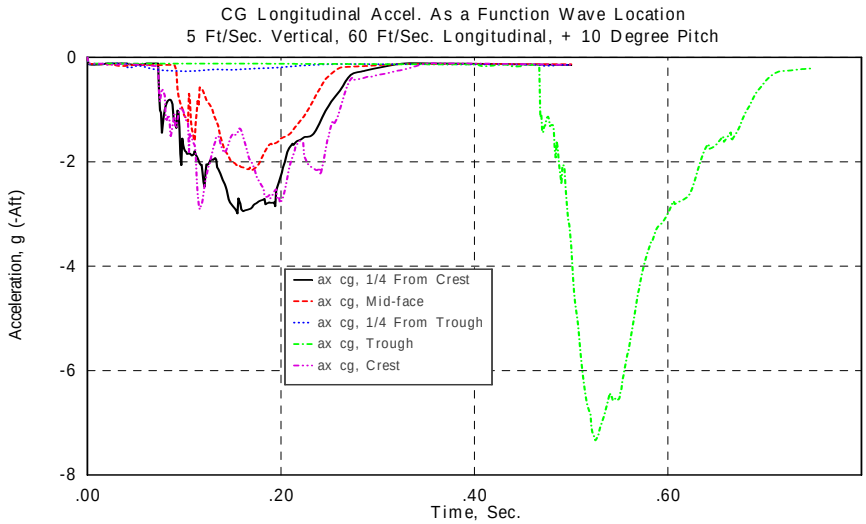


Figure 72. Center of Gravity Longitudinal Accelerations—Water Impact Into a Wave

Figure 71 shows the floor accelerations for a water impact into waves at different orientations. Figures 72 and 73 show the c.g. vertical and longitudinal accelerations as a function of the wave orientation.

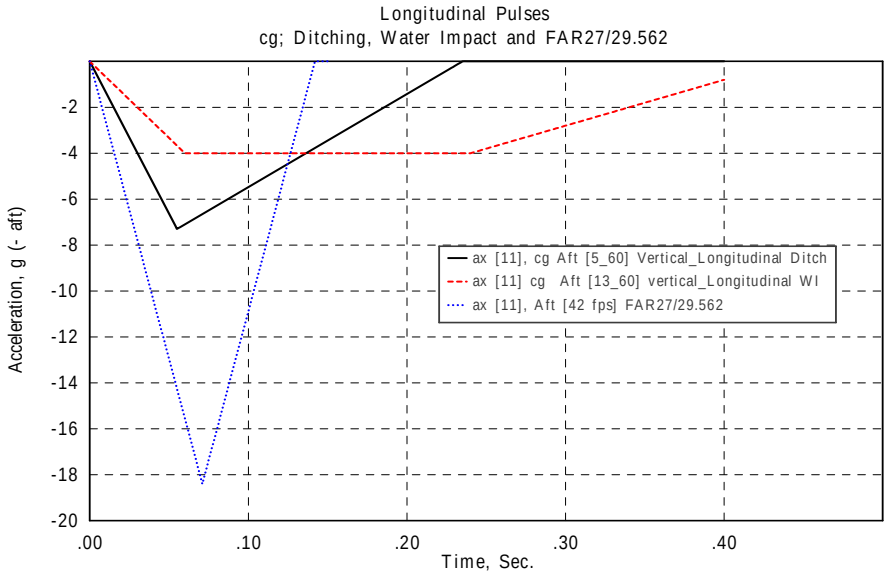


Figure 73. Center of Gravity and 14 CFR Parts and 27 and 29.562 Longitudinal Seat Test Pulses

In section 5.1.3.4, figures 21 through 24 illustrate how the vertical and longitudinal floor and c.g. accelerations vary as a function of longitudinal impact velocity. In these cases, the longitudinal impact velocity varies from 50 to 80 ft/sec. The vertical velocity for each case is 13 ft/sec vertical and the pitch attitude is +5 degrees.

The long duration longitudinal c.g. pulses from figures 72 and 24 are shown in figure 73, along with the corresponding 14 CFR Parts 27 and 29 seat longitudinal test dynamic pulse.

7.2 PRELIMINARY ASSESSMENT OF HEAD INJURY POTENTIAL AND RESTRAINT BELT LOADS.

The KRASH-SOMR model expands on the three mass occupant DRI models that are generally used within the structural models. In the BH-205, the pilot and copilot seats at FS 47 have upper torso and lap belt restraints. All other occupants are restrained by lap belts. SOMR allows for head injury and restraint system loads to be determined at the pilot location. The expanded seat occupant model allows for either a stiff or deformable surface to be impacted by the occupant head.

At all locations, floor acceleration time histories are available for either input into the SOMR model or into a specialized seat occupant program. Since some seats are rear facing or side facing, this could allow for addressing the appropriate floor acceleration directions.

The following output data is available when SOMR is used:

- HIC and SI values, impact surface penetration
- Restraint belt/harness loads and deflections
- Lumbar load, DRI, and seat stroke
- Occupant and seat forces and motion
- Floor accelerations in all directions that drive the seat occupant restraint system

The following criteria are applicable:

- Lumbar load <1500 lb [9 and 10]
- Seat stroke <5 inches
- DRI <18
- HIC, SI <1000 [7 and 8]
- Individual upper torso straps tension load <1750 lb [7 and 8]
- Dual upper torso strap tension load <2000 lb [7 and 8]

The expanded KRASH pilot/copilot seat occupant restraint system SOMR model is shown in figure 74.

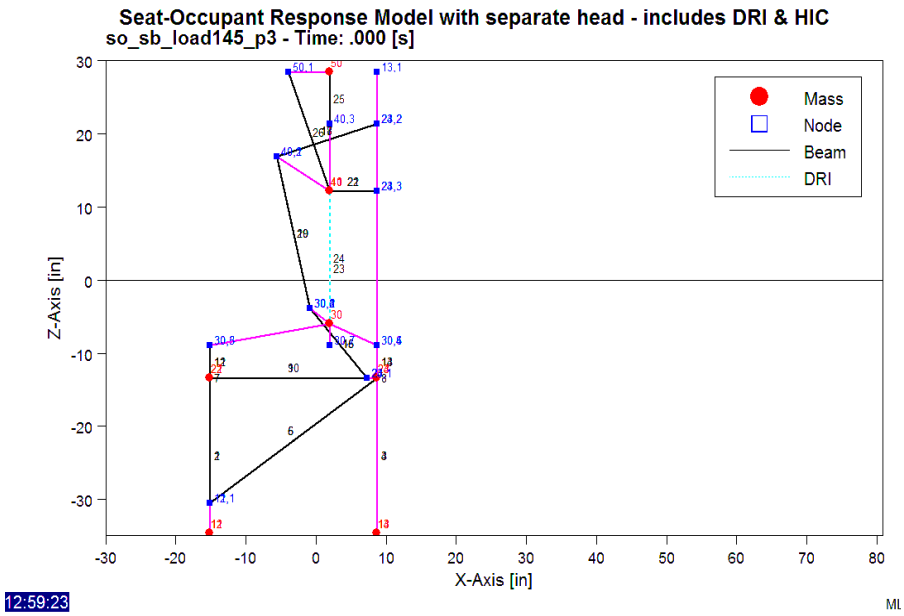


Figure 74. Expanded Seat Occupant Restraint (KRASH-SOMR) Model

The KRASH-SOMR model depicted in figure 74 is excited at four floor points with six directional accelerations at each point and consists of:

- 13 masses
- 26 mass less node points
- 36 beams (1 pinned, 11 unsymmetrical, and 4 nonlinear beams)

The mass, beam, and node point representations are noted in table 54.

The restraint stiffnesses were obtained from representative lap and shoulder harness data. Figure 75 [6] shows webbing load versus elongation properties. Knowing the length of each belt allowed for the determination of the belt stiffness. Belt failure loads are around 6000 to 8000 lb, which is substantially higher than the allowable criteria of 1750 to 2000 lb.

Table 54. Seat Occupant Model With Restraints Model Description

Mass	Description	Beam	Description	Node	Description
11	Floor left forward	1	Seat vertical left front	11-1	Diagonal side brace attachment fwd
12	Floor right forward	2	Seat vertical right front	12-1	Diagonal side brace attachment fwd
13	Floor left aft	3	Seat vertical left aft	13-1	Shoulder harness seat attachment
14	Floor right aft	4	Seat vertical right aft	13-2	Head impact reference point
21	Seat pan left forward	5	Seat base diagonal left side	13-3	Upper torso back rest point
22	Seat pan right forward	6	Seat base diagonal right side	14-1	Shoulder harness seat attachment
23	Seat pan left aft	7	Seat pan lateral forward	21-1	Seat pan node-fwd LHS
24	Seat pan right aft	8	Seat pan lateral aft	22-1	Seat node-fwd RHS
30	Lower torso	9	Seat pan fore-aft left side	23-1	Seat pan node-aft LHS
40	Upper torso	10	Seat pan fore-aft right side	24-1	Seat pan node-aft RHS
41	DRI	11	Seat cushion left forward	30-1	Lower torso hip point - LHS
50	Head	12	Seat cushion right forward	30-2	Lower torso hip point - RHS
		13	Seat cushion left aft	30-3	Lower torso attach point fwd – LHS
		14	Seat cushion right aft	30-4	Lower torso attach point fwd – RHS
		15	Lap belt aft	30-5	Lower torso attach point fwd - LHS
		16	Lap belt right	30-6	Lower torso attach point aft - RHS
		17	Shoulder harness left	30-7	Lower torso hip point - center
		18	Shoulder harness right	40-1	Upper torso belt attach point - LHS
		19	Shoulder to lap belt left	40-2	Upper torso belt attach point - RHS
		20	Shoulder to lap belt right	40-3	Lower neck
		21	Upper torso backrest	50-1	Forehead
		22	Lumbar spine		
		23	DRI		
		24	Neck		

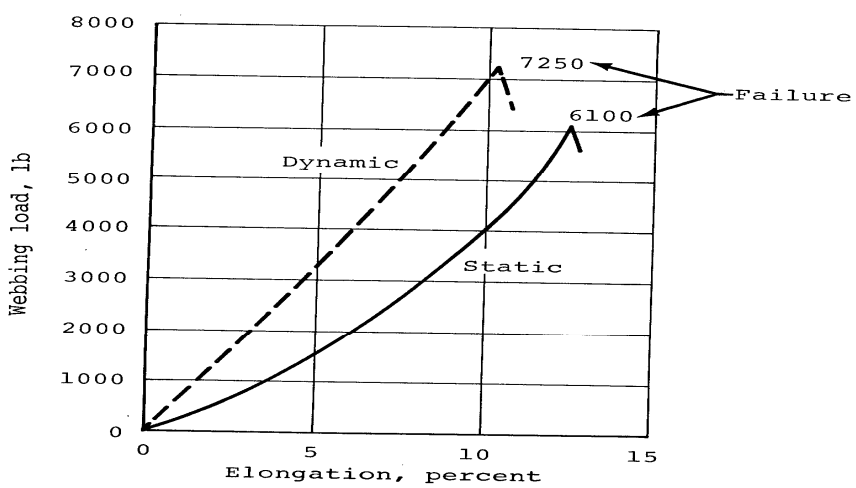


Figure 75. Restraint Belt Webbing Load Versus Elongation

The belts are tension-only beams that have the following stiffnesses:

- Lap belt = 1700 lb/in.
- Shoulder harness = 1400 lb/in.
- Shoulder to lap belt = 543 lb/in.

An additional beam is included in the model to represent the connection or attachment of the occupant and the seat. This element has tension-only properties and is intended to act like friction between the occupant and seat to minimize or reduce unwarranted occupant motion, such as submarining.

The SOMR model has several limitations with regard to accurately modeling occupant motion that is restrained, which are:

- The occupant is represented by three masses: lower torso, upper torso, and head.

- The belts cannot slide over the contour of the occupant's body because there are no body segments. This means attachment points may be compromised and belt loads and extensions may be distorted.

- There is no element that can describe the occupant sliding across the seat. This means that occupant motion might pitch backward (rotate and submarine) unless a restraining force is available.

Table 55 shows results for the vertical accelerations for vertical velocity impacts obtained from SOMR, as well as those obtained from the BH-205 structural model results.

From table 55 it can be observed that the structural model produced somewhat higher deflections, lumbar loads, and DRI values than SOMR driven by the floor pulse. The SOMR results show load and deflection associated with each side. Thus, the total lap belt and harness load is double. Even so, these loads are less than 2000 lb each and do not peak at the same time. The maximum of all belts acting simultaneously the corresponding peaks would be 1824, 1716 and 1800 lb, respectively, for the 16-, 20-, and 26-ft/sec conditions. For the vertical impacts, the HIC = 0. The lumbar loads and DRI values are such that spinal injury criterion is satisfied.

Table 56 shows results for the combined accelerations for combined vertical and longitudinal velocity impacts obtained from SOMR, as well as those obtained from the BH-205 structural model results.

Table 55. Seat Occupant Model With Restraints and BH-205 Analysis Results; Floor Vertical Pulse

Scenario	Skid Model Impact	SOMR Detailed 16/0 Pulse	Skid Model Impact	SOMR Detailed 20/0 Pulse	Skid Model Impact	SOMR Detailed 26/0 Pulse
Vertical/longitudinal velocity (ft/sec)	16/0	16/0	20/0	20/0	26/0	26/0
Floor pulse		Vertical		Vertical		Vertical
Simulation time (sec)		0.160		0.100		0.080
Floor vertical acceleration peak (g)	37.1	37.1	60.0	60.0	110.0	110.0
Floor longitudinal acceleration peak (g)	0	0	0	0	0	0.0
Floor pulse rise time (sec)	0.0085	0.0085	0.0005	0.005	0.005	0.005
Floor pulse duration (sec)	0.080	0.080	0.100	0.100	0.030	0.030
Floor vertical velocity change (ft/sec)	18.0	22.5	21.3	24.7	27.4	25.0
Floor longitudinal velocity change (ft/sec)	0	0	0	0	0	0.0
Floor pulse type	Irregular	Irregular	Irregular	Irregular	Irregular	Irregular
Seat Deflection (in.) - 14.5-g LL seat	0.93	0.04-0.10	2.32	0.28-0.93	4.77	3.5-4.5
DRI	16.6	11.7	18.1	16.0	18.6	17.9
Lumbar load (lb)	1402	973	1420	1390	1455	1270
Seat leg, total load (lb)	2511	2116	2171	2520	2278	2520
Restraint/side load (lb)	NA		NA		NA	
Lap belt load (lb)		912		858		709
Shoulder harness load (lb)		170		0		762
Lap shoulder load (lb)		161		300		424
Restraint/side deflection (in.)	NA		NA		NA	
Lap belt deflection (in.)		0.10		0.48		0.45
Shoulder harness deflection (in.) <1>		0.50		2.44		2.60
Lap-shoulder deflection (in.)		0.12		0.53		0.35
Head injury	<2>		<2>		<2>	
HIC		0		0		0
Severity index		0		0		0
Allowable forward motion (in.)		2.0		2.0		2.0
Maximum forward motion (in.)		0		0		0

<1> 2-inch dead band
<2> Not modeled

Table 56. Analysis Results of SOMR and BH-205 Floor; Combined Vertical and Longitudinal Pulse

Scenario	Skid Model Impact	SOMR Detailed 20/40 Pulse	SOMR 14 CFR 27/29 25.62
Vertical/longitudinal velocity (ft/sec)	20/40		26/15
Floor pulse	+10	0	0
Simulation time (sec)	0.140	0.120	0.070
Floor vertical acceleration peak g	21	21	26
Floor longitudinal acceleration peak g	13	13	15
Floor pulse rise time (sec)	0.005	0.005	0.031
Floor pulse duration (sec)	0.140	0.140	0.062
Floor vertical velocity change (ft/sec)	21.6	21.1	21.2
Floor longitudinal velocity change (ft/sec)	9.6	16.7	17.6
Floor pulse type	Irregular	Irregular	Symmetrical Triangular
Seat deflection (in.) - 14.5-g LL seat	0.34	0.050-.130	0.050-0.102
DRI	15.3	13.0	9.2
Lumbar load (lb)	1077	1007	911
Seat leg, total load (lb)	2173	2530	2520
Restraint/side load (lb)	NA		
Lap belt load (lb)		850	1430
Shoulder harness load (lb)		660	1379
Lap-shoulder load (lb)		420	886
Restraint/side deflection (in.)	NA		
Lap belt deflection (in.)		0.49	0.81
Shoulder harness deflection (in.) <1>		2.53	2.90
Lap-shoulder deflection (in.)		0.62	0.62
Head injury	<2>		
HIC		806	806
SI		990	990
Allowable forward motion (in.)		2.0	2.0
Maximum forward motion (in.)		2.13	2.13

<1> 2-inch dead band
<2> Not modeled

The pulse from the 20/40/10 condition was chosen because the 10 degree pitch provided the highest longitudinal acceleration. A comparison of the 20/40 impacts with 0, +5, and +10 degree pitch results are shown in table 57.

Table 57. Comparison of the 20/40 Impacts With 0, +5, and +10 Degree Pitch Results

Pitch attitude	Peak Vertical Acceleration (g)	Peak Longitudinal Acceleration (g)
0	51.9	8.4
+5	38.2	10.3
+10	20.9	13.1

The 20/40 KRASH floor pulse was represented in SOMR as an approximate duplication of the actual time history, which is referred to in table 56 as detailed. This is an irregular pulse, which is unlikely to be reproduced in a laboratory seat dynamic test. In addition to the 20/40 impact pulse, a 14 CFR 27.562 pulse was analyzed with SOMR. The velocity changes referred to in table 56 represent values obtained from the SOMR analysis and not the estimated velocity change anticipated from the pulse characteristics. The maximum spinal measurements, DRI and lumbar load, are all within acceptable criteria, as are the HIC and SI values. For the representative 20/40 impact-produced pulse, the lap belt and harness loads are less than 2000 lb. However, for the idealized 20/40 floor pulse and the simulated 14 CFR 27 and 29.562 test pulse, the lap belt and shoulder harness each would exceed 2000 lb.

The simulation times associated with the SOMR results are different for each analysis and are based on an evaluation of the time frame for which the motion of the occupant is considered acceptable. This evaluation is made on the basis of a review of the animation of the respective results using MLS-KAP software.

Presumably, current seat designs have passed 14 CFR 27 and 29.562 dynamic seat test requirements within the acceptable restraint belt, spinal injury, and HIC. Thus, the fact that the SOMR results show restraint loads that are greater than the allowable for the 14 CFR 27 and 29.562 pulse suggests that the SOMR model does not represent a current acceptable seat design or that it is yielding conservative restraint loads.

The 14 CFR 27 and 29.562, 30-ft/sec combined seat dynamic test pulse was also analyzed with SOMR for the same model as the other pulses were. The results for that condition showed the following:

- DRI = 19.7
- Lumbar load = 1378 lb
- Seat deflection = 2.1–3.2 inches
- Total lap belt = 732 lb
- Total shoulder harness load = 2826 lb
- Total shoulder-lap load = 0 lb
- HIC = 1088

- SI = 1337
- Head motion = 3.36 inches
- Allowable head strike distance = 3.36 inches

The HIC and SI values obtained are for the 14 CFR 27 and 29.562 30-ft/sec pulse, are based on an optimum head strike distance where the head strike velocity is at its highest value and a rigid head contact surface. A lesser distance would result in lower values (i.e., at 2.8 inches, HIC = 910 and SI = 740) and a head strike distance greater than 3.36 inches would preclude any head strike for the configuration modeled. A head surface capable of absorbing more energy would also reduce the SIC and HIC values.

Table 58 depicts results from analyzing the two c.g. pulses; ditching into a wave (figures 72 and 73) and impacting at a high forward velocity (figures 22 and 24). These pulses are idealized as either a triangular or trapezoidal shaped pulse to obtain occupant and restraint system loads. Also shown are KRASH/SOMR results for the 14 CFR Parts 27 and 29 seat dynamic test longitudinal direction pulse. None of the result present potential occupant injury, except possibly the 1200 lb/side lap belt load for the 14 CFR 27.562 pulse.

Table 58. Longitudinal Pulse Results of KRASH/SOMR

Scenario	Longitudinal Pulse c.g. Sea State	Longitudinal Pulse c.g. Calm Sea	Longitudinal Pulse 14 CFR 27.562
Vertical velocity (ft/sec)	5	13	0
Longitudinal velocity (ft/sec)	60	60	42
Resultant velocity (ft/sec)	60.2	67.3	42
Vertical acceleration peak (g)	10	4.5	0
Longitudinal acceleration peak (g)	7.3	9.0	18.4
Resultant peak (g)	12.4	10.1	18.4
Pulse rise time (sec)	0.040	0.060	0.071
Pulse duration (sec)	0.235	0.440	0.142
Pulse Type	Unsymmetrical Triangle	Trapezoid	Symmetrical Triangular
DRI	< 1	< 1	< 1
Lumbar load (lb)	902	1008	200
Lap belt/side load (lb)	428	500	1200
Shoulder harness/side load (lb) <1>	625.0	100	800
Shoulder-lap/side load (lb)	125.0	0	216
HIC	189	51	589
SI	232	42	725
Allowable head motion (in.)	2.8	2.0	5.0
Maximum head motion (in.)	3.38	2.24	5.76

<1> 3-inch dead band

The head injury potential as measured by the HIC and SI are well below 1000 for both the 5- and 13-ft/sec vertical velocity conditions. The head movement relative to a strike point is no more than 3.4 inches. The 14 CFR Parts 27 and 29 pulse produces a SIC = 725 and HIC = 589 based on a 5-inch head strike distance. While the head can move as much as 5.76 inches relative to the strike point, the peak head velocity occurs at 5.0 inches. Any distance greater than 5.76 inches would preclude a head strike for this configuration. Since the BH-205 head strike distance is greater than 6 inches, no HIC or SI value should occur.

The restraint loads for the BH-205 analyses show total lap, harness, and harness-lap belt loads of 856, 1250, and 250 lb, respectively, for the 5-ft/sec condition. No total load exceeds 2000 lb. For the 13-ft/sec condition, no total belt load exceeds 1000 lb. For the 14 CFR Parts 27 and 29 pulse, the total lap belt load is 2400 lb, the total shoulder harness load is 1600 lb, and the total shoulder-lap load is 432 lb. These loads exceed the 14 CFR Parts 27 and 29 allowable 2000 lb for restraint loads.

Several items to consider in evaluating KRASH/SOMR results are:

- The occupant c.g. in the SOMR model, unlike the simple occupant models, is not aligned with the seat c.g.
- SOMR has to approximate belt attachment locations both on the structure and occupant, and belts can neither slide along the occupant nor follow the contour of the body.
- SOMR is a generic seat model and its geometry, size, and restraint properties can be different than BH-205 seats or other 14 CFR Parts 27 and 29 rotorcraft seats.
- Restraint attachment mechanisms and locations are critical in analyzing seat design.
- SOMR is an unvalidated model.

The SOMR restraint results indicate that

- the vertical pulse results, which are acceptable, indicate that the ditching DLE would most likely not deter current seats from being acceptable.
- the water impact scenario, which includes the 26/0, 20/40, and 13/60 impact conditions, would not likely produce floor pulses that current seats cannot pass.

However, the BH-205 pulses that were analyzed represent a small sample of the entire spectrum of floor pulses available from the myriad of ditching and water impact scenarios analyzed.

While SOMR allows for a preliminary assessment of the head injury and restraint loads, the use of specialized seat occupant restraint system models representative of current designs is advocated. To that end, there are numerous floor pulses available from the BH-205 analyses. Also, consideration must be given to defining pulses, such as triangular or ramped, that can be reproduced in seat dynamic laboratory tests. The structural model analysis often provides nonuniformly shaped pulses that are difficult to reproduce in a test and must be idealized.

8. CONCLUSIONS.

The results of the effort described herein show that:

- A water impact design landing envelopes (DLE) of vertical velocity versus longitudinal velocity is presented for a condition that precludes underside panel failure, and for a particular set of parameters, such as:

  - Aircraft configuration or weight/center of gravity (c.g.)
  - Landing gear position
  - Pitch, roll, and/or yaw attitude
  - Sea state
  - Specified level of seat load limit and allowable seat stroke

  The levels associated with the DLEs are above the current Title 14 Code of Federal Regulations (CFR) Parts 27 and 29.563 ditching standards.

- The amphibious configuration has shown slightly greater capability than the maximum gross takeoff weight or design landing weight low fuel configurations. Thus, a ditching DLE for amphibious operations should be about 2 ft/sec greater and equal or higher than existing 14 CFR 29.519 standards.

- Parametric studies are shown to alter the DLE if acceptance criteria is changed.

- For level 2 water impacts, the DLE is also considered a vertical velocity versus longitudinal velocity envelope but with an acceptance of underside failure, as long as other criteria is met. The parameters of interest are similar to the level 1 water impact parameters, with the exception that underside panel failure is permitted, only calm sea is considered, and that the seat load limit is a minimum of 12 acceleration of gravity (g) and a maximum of 14.5 g.

- The outer limit water impact DLE can be considered a 95th percentile civil rotorcraft curve to which 14 CFR Parts 27 and 29 rotorcraft must adhere to based on specified acceptance criteria, such as:

  - Aircraft configuration or weight/c.g.
  - Landing gear position
  - Pitch, roll, and/or yaw attitude
  - Sea state
  - Specified level of seat load limit and allowable seat stroke
  - Structural limits
  - Underside panel and interior surface pressure limits

- Seat dynamic test floor pulses from water impact differ from ground impact seat test floor pulses, but still must adhere to 14 CFR 27 and 29.562 seat dynamic test acceptance criteria with regard to spinal injury loads, head injury loads, and restraint system loads.

- Floor pulses within the developed water impact level 1 and level 2 DLEs are preliminarily shown likely not to produce lumbar loads, restraint loads, and head injury criteria levels greater than acceptance criteria of 1500, 2000 and 1000 lb, respectively. However, the consequences of these pulses should be evaluated with validated seat occupant restraint system models and tests.

- The 95th percentile survivability design limit envelope is based on potential forward or midfuel responses in exceedance of the 30-g up-down criteria. However, the fuel mass acting as a uniform pressure would produce pressures less than the fuel cell backup structure crash design criteria. However, since the KRASH model may not distribute the loads to all the structure that may be able to react to it, additional detail analysis could prove beneficial.

9. REFERENCES.

1. Wittlin, Gil and Gamon, Max, "S1 Test Report; Test Preparation, Performance, and Analysis" Dynamic Response Inc., DRI-9902, February 2000.

2. Wittlin, Gil and Gamon, Max, "S2 Test Report; Test Preparation, Performance, and Analysis," Dynamic Response Inc., DRI-2000-1, March 2000.

3. Wittlin, Gil and Gamon, Max, "SBIR Contract N68335-98-C-0035 Final Report," Dynamic Response Inc., DRI 2000-3, October 2000.

4. Wittlin, Gil and Gamon, Max, "Task 2.3; Evaluation of FAR27/29 Water Impact Standards," Dynamic Response Inc., DRI-2000-2, July 2000.

5. BH-205A-1 Flight Manual and Supplements, 1969.

6. BH-204/205A-1 Installation Kit 204-706-053-057, Amphibious Landing Gear, 1969.

7. BH-204/205A-1 Installation Kit 204-706-044-045, Auxiliary Fuel System, 1969.

8. U.S. Crash Survival Design Guide, December 1989.

9. Title 14 Code of Federal Regulations, Part 27, Airworthiness Standards: Normal Category Rotorcraft, Revised January 1998.

10. Title 14 Code of Federal Regulations, Part 29, Airworthiness Standards: Transport Category Rotorcraft, Revised January 1998.

11. Wittlin, Gil and Gamon, Max, USAAMRDL 72-72A, “Experimental Program for the Development of Improved Helicopter Structural Crashworthiness Analytical and Design Techniques,” May 1973.

12. Wittlin, Gil and Gamon, Max, “The Investigation, Evaluation, and Application of Techniques for Correlating Rotorcraft Full-Scale Water Impact Tests Versus Analyses,” FAA report DOT/FAA/AR-04/5, June 2004.

13. Chen, Charles, Muller, Mark, and Fogarty, K.M., “Rotorcraft Ditchings and Water-Related Impacts That Occurred From 1982 to 1989-Phase I,” FAA report DOT/FAA/CT-92/13, October 1993.

14. Muller, Mark and Bark, Lindley, “Rotorcraft Ditchings and Water-Related Impacts That Occurred From 1982 to 1989-Phase II,” FAA report DOT/FAA/CT-92/14, October 1993.

15. Broodsmith, M.F. and Williams, D.L., Report No. EEL/ED/445, Issue A, “Model Ditching Tests on the V-22 Osprey Aircraft, Bell-Boeing Contract Number N00019-85-C-0145,” March 1987.