RECOMMENDED CIVIL ROTORCRAFT WATER IMPACT DESIGN LIMIT ENVELOPES

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ABSTRACT

The paper describes the results of an FAA sponsored SBIR effort in which an analytical procedure for developing design limits for ditching (level 1 water impacts) and severe, but survivable water impacts(level 2 water impacts) is discussed. The design limits are presented along with the backdrop of current civil rotorcraft ditching requirements and 95th percentile water and ground accident envelopes. The analysis, utilizing program KRASH, takes into consideration acceptable occupant protection criteria such as allowable lumbar load, seat stroke, and energy absorbing seats. In addition, acceptable structure design criteria with regard to major mass items, like engine and transmission, are accounted for. Both calm sea and rough sea, as defined in ditching regulations are considered. Impact scenarios that were included in the study are: (1) airframe impact, (2) skid or float impact, (3) underside panel design pressures, (4) allowable bulkhead pressures, (5) unsymmetrical impacts, (6) nose-over potential, and (7) floor to seat accelerations. Four BH205 configurations were modeled including; (1) Maximum Gross Takeoff Weight (GTOW), Design Landing Weight (DLW), (3) auxiliary fuel tanks, and (4) amphibious (float) design.

A matrix of all conditions and configurations analyzed is provided. In all approximately 500 scenarios were analyzed. The results are presented in the form of Design Limit Envelopes (DLE), for level 1 and level 2 water impacts. The former provides a level of structural integrity that may exist in current FAR27/29 rotorcraft. The latter compares analytically developed design levels with energy absorbing seats versus current 95th percentile envelopes available from accident data.

INTRODUCTION

The Federal standards for ditching of Civil Rotorcraft are presented in References 1 and 2. There are ditching requirements stated throughout. There are specified dynamic seat test requirements and occupant/seat acceptance criteria based on ground impact tests and accident history. Figure 1 depicts both civil 95th percentile accident survivable levels and ditching envelopes. FAA sponsored research [3] has shown that levels of structural integrity during water impacts might be exceeded at different velocity profiles than impacts onto ground, wherein the latter the landing gear might afford additional energy absorption. This paper describes the outcome of the most recent FAA sponsored research [4], in which recommendations are made with regard to incorporating water impact design limits and assessing floor accelerations from such impacts with regard to seat dynamic test requirements.

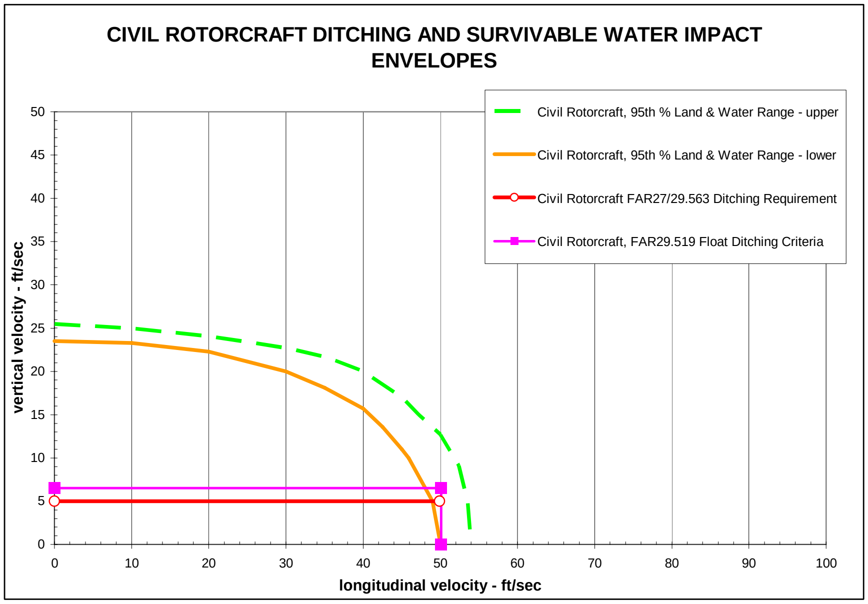


Figure 1 Civil Rotorcraft Ditching and 95th Percentile Survivable Accident Water Impact Envelopes

PROCEDURE

Previously in a FAA sponsored task [3] FAR27/29 ditching requirements were evaluated. This included an assessment of ditching compliance procedures, which were shown to under-estimate pressures and accelerations, and are lacking in the following respect;

- Scale model testing – ineffective, unrepresentative
- Similarity to existing designs – limited extrapolation
- Pressure calculations – based on static flotation
- Vertical load factors – based on stall speed, ignores sink speed
- Horizontal load factors - nonexistent

The procedure to develop design limit envelopes [4] basically consists of the following steps;

1. Establish respective ditching and water impact conditions and acceptance criteria for each
2. Perform analysis to account for variations in design as well as impact conditions
3. Obtain results in the form of water impact levels and design envelopes for each as well as determine floor and cg floor accelerations that are appropriate for each

The KRASH model used in the analysis was varied to represented several configurations such as; maximum takeoff, maximum design landing weight, auxiliary fuel tank, and float installation, is shown in figure 2. The full model size consists of **206** masses and **420** beams and can represent up **128** hydrodynamic surfaces; both primary and secondary, underside and bulkheads. The model also allowed for the representation of **8** occupant locations throughout the aircraft.

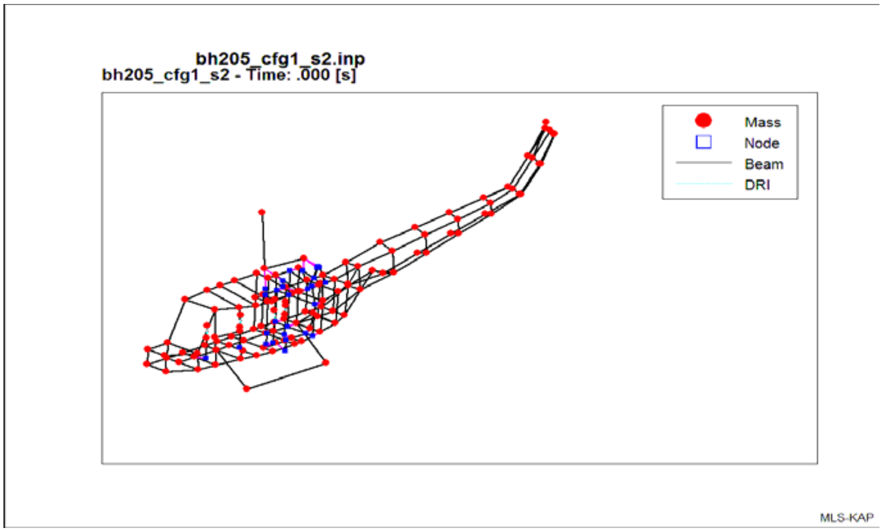


Figure 2 BH205 KRASH Model

The first step in the process established two impact levels designated level 1 and level 2. A level 1 impact is representative of extended range ditching, while a level 2 impact is associated with lower and upper limit survivable envelopes noted in figure 1. For both impact levels; acceptable mass item (engine, transmission, fuel tank) acceleration criteria, occupant protection limits (seat stroke, lumbar load, HIC, restraint loads), and design pressures (underside panel, bulkhead), were utilized to establish design limit levels.

The second step in the process included analyzing variations in design levels and conditions and included the effects of; panel strength, seat limit load, float design, fuselage shape, suction forces, impact symmetry, protuberances and their effect on aircraft behavior.

The third step was to characterize the results in the form of Design Limit Envelopes (ENV), survivable limit envelopes and seat dynamic test impact conditions. The BH205 rotorcraft modeled included forward, aft and side facing seats an array of potential test conditions is available.

RESULTS

A series of Design sensitivity analyses were performed [4], which included the effects of:

- aircraft orientation to the sea state
- protrusions on rotorcraft nose-over potential

- suction force on aircraft behavior
- panel strength on floor and mass item accelerations
- panel strength on occupant forces and seat stroke requirements
- unsymmetrical impacts
- extended vs. retracted landing gears

Samples of the relationship of response parameters as a function of longitudinal velocity for protrusions and the response of floor and occupant in relation to panel design strength and sink speed are illustrated in figures 3 and 4, respectively.

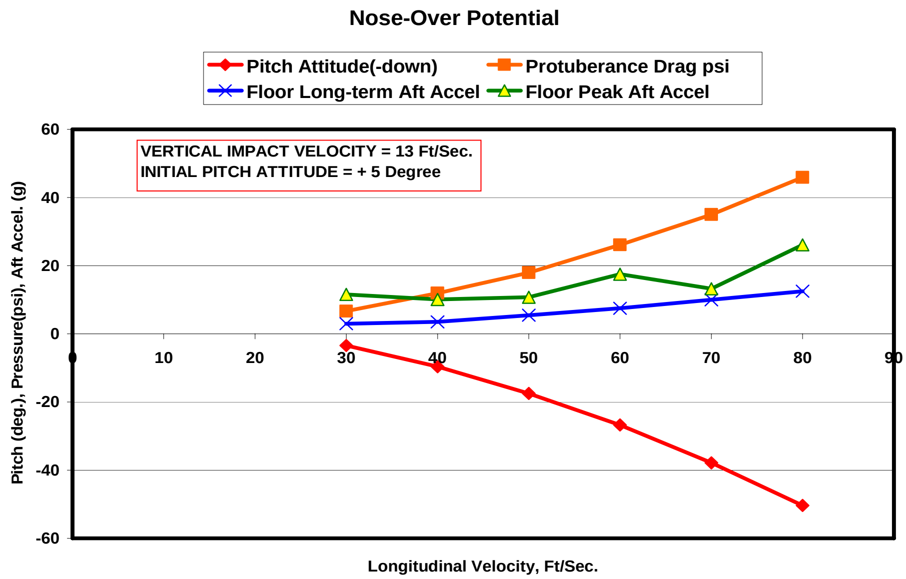


Figure 3 Nose –over Parameters as a Function of Longitudinal Velocity for a Vertical Impact of 13 ft/sec. and + 5 Degree Pitch

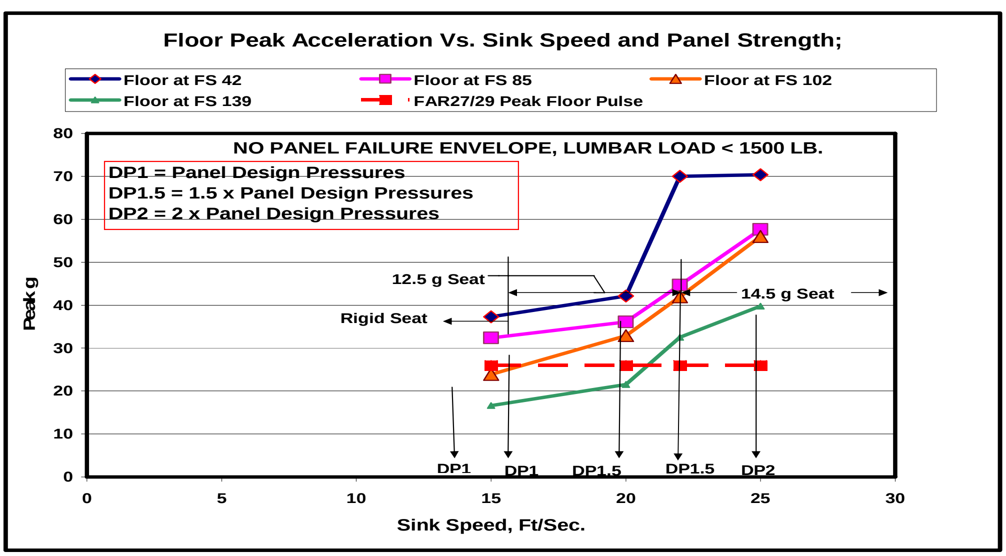


Figure 4 Floor Peak Vertical Acceleration vs. Sink Speed, and Panel Strength

Table 1 indicates the scope of the FAA sponsored research [4] with regard to configurations analyzed, conditions considered, structure integrity levels and occupant tolerance criteria considered. There were two levels of water impact that were established, in addition to the ditching levels that are described in the regulations and depicted in figure 1. Level 1 water impacts are relatively low energy impacts which preclude failure of the underside surface. Level 2 impacts are high energy impacts that are akin to the 95th percentile severe but survivable impacts that are often referred to

TABLE 1 DLE DEVELOPMENT AND DESIGN CRITERIA CONSIDERATIONS

CONSIDERATIONS		LEVEL 1 WATER IMPACT	LEVEL 2 WATER IMPACT
Configurations Modeled		GTOW Max Design Landing Amphibious/Float Auxiliary Fuel Tank	GTOW Max Design Landing Amphibious/Float Auxiliary Fuel Tank S1, S2 Test Article
Design Envelope		FAR27/FAR29	Civil 95th Percentile -Upr Civil 95th Percentile-Lwr
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
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
Criteria			
Seat Stroke limit	In.	5	5
Lumbar Load Limit	Lb.	1500	1500
Underside Panel Failure	psi	Design	Design
Interior Bulkhead Failure	psi	Design	Design
Head Injury	HIC	1000	1000
Restraint Belt Load	Lb.	1750-2000	1750-2000
Mass Item Restraint	g	30/30/15 <1>	30/30/15 <1>
Engine			
Transmission			
Fuel			
<1> Vertical/Longitudinal/ Side			

Taking into consideration the various configurations, impact conditions, and design tradeoffs the results were formulated in the form of design limit envelopes and floor seat pulses. These results are now recommended for consideration for FAR27/29 rotorcraft requirements and associated seat dynamic test considerations.

For example, it is recognized that for certification purposes that ditching is defined as 5 ft/sec. sink and up to 50 ft/sec. longitudinal velocity and a sea state = 4. However, there is no reason that if current rotorcraft have greater capability that a new DLE can not be incorporated to ensure the integrity of future aircraft. To that end the DLE in figure 5 is recommended as a supplement to the FAR 27/29,573 structural ditching provisions".

The basis for the curve shown in figure 5 is that the lower limit is associated with the numerous water impact scenarios[4], including calm sea or seat state of 4, pitch roll and yaw of + 10 degrees or less, gears retracted or extended. The overriding criteria are that no underside panels fail no major mass items, fail, and no occupant injury; spinal or head occurs. The DLE shown in figure 5 is applicable to rigid seat or load limit seats, because at the levels shown there is little likelihood that load limit seats are required.

For guidance it is recommended that the 95th percentile survivable accident envelope be revised as noted in Figure 6. Effectively this expands the survivability envelope to higher longitudinal velocity range, primarily because it takes into account the interior bulkhead structural integrity levels. Figure 6, like that shown in figure 5, is based on a set of criteria which includes (1) major mass item and fuel failure criteria, (2) Occupant spinal and head injury acceptance levels, (3) seat stroke limitations, and (4) aircraft weight, velocity profiles and attitudes

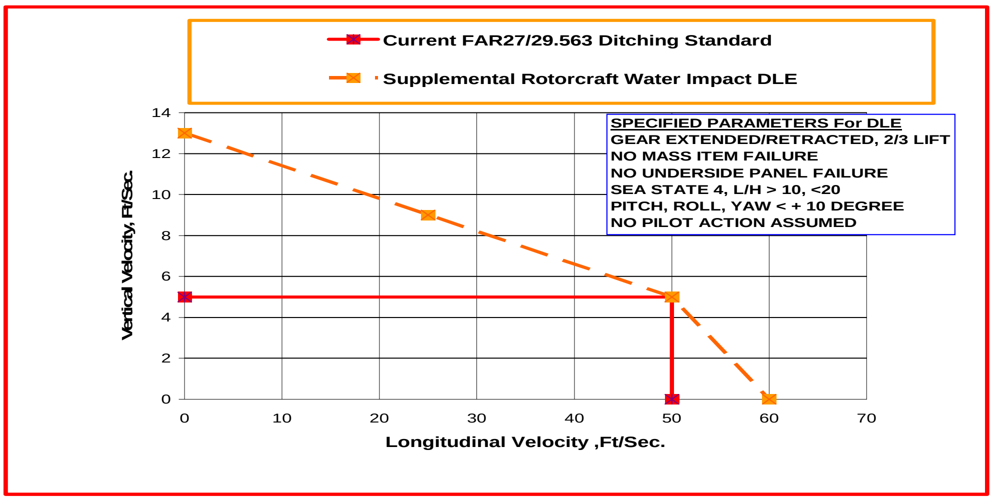


Figure 5 FAR 27/29.563 Water Impact Level 1 DLE for GTOW Configuration

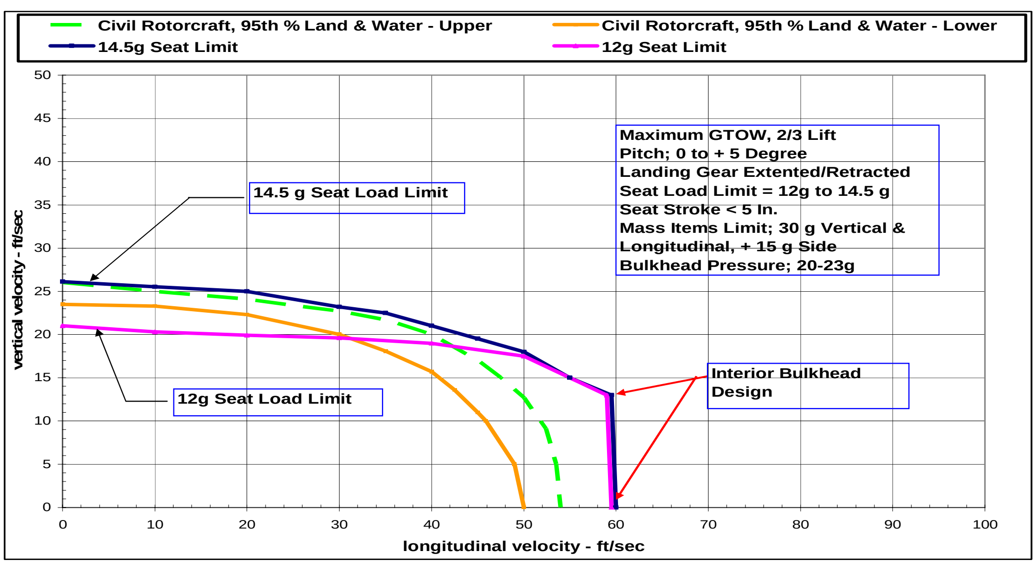


Figure 6 Water Impact Level 2 DLE vs. Civil Rotorcraft 95th Percentile Limits

In addition to Level 1 and Level 2 envelopes as noted in figures 5 and 6, there are numerous floor and cg acceleration pulses for both short term transient and long duration, in the form of acceleration vs. time, are available [4]. These pulses are for vertical, longitudinal, and lateral directions and are compared to current seat dynamic test requirements and could affect or influence FAR 27.562 and FAR 29.562 seat dynamic test requirements. The following discussion provides some of these pulses and notes why they should be evaluated and considered. One might have to ascertain with test and/or analysis the following with regard to these pulses:

- Whether exceedance of FAR 27/29.562 spinal injury criteria (1500 lb.), restraint load criteria (2000 lb.), and HIC (1000) occurs
- A development of equivalent floor pulses that can be reproduced in laboratory tests
- Whether supplements to current FAR 27/29.562 seat dynamic test conditions are warranted

The floor accelerations obtained via analysis or measured during tests are generally irregular time histories. Several of these pulses have been idealized as triangular in shape. As one can observe the water impact peak accelerations can exceed 100 g, albeit with a short duration (.015 seconds). It is desirable to ascertain whether such pulses, when compared to the current FAR 27/29.562 requirements, will result in exceedance of spinal injury and restraint load acceptance levels. The vertical component of the FAR27/29.562 combined vertical - longitudinal acceleration pulse is also shown in figure 7.

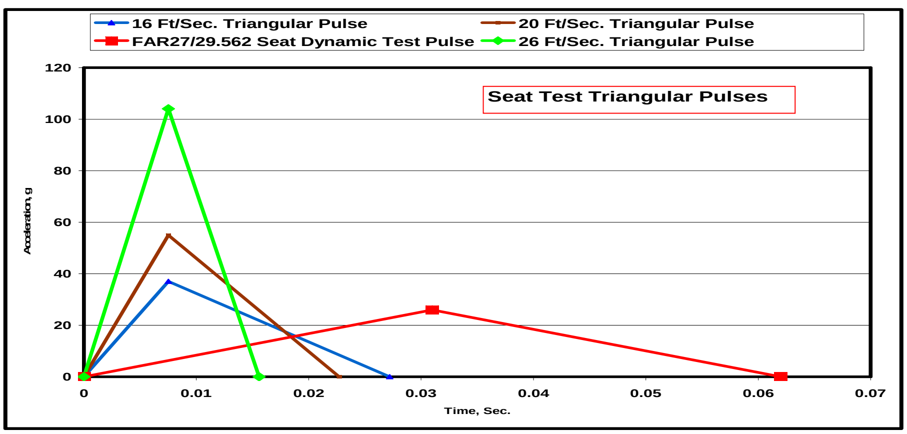


Figure 7 Comparison of Idealized Water Impact Floor Vertical Pulses With Current FAR27/29 Seat Dynamic Test Requirements

Several floor acceleration time histories compiled from combined vertical-longitudinal impacts, and thus producing simultaneous vertical and longitudinal pulses, are noted in Figures 8 -11. Some of the pulses are transient in that they exist for short periods of time, such as < 100 msec, as noted in figures 8 and 9. Others are relatively long term in that they can occur over 400 msec. or longer, as noted in figure 10.

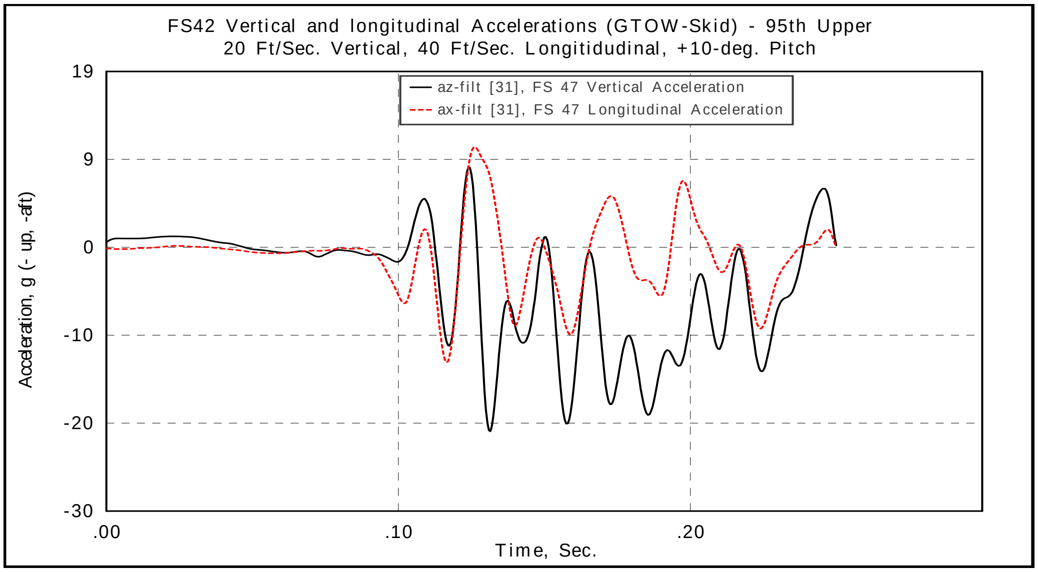


Figure 8 Water Impact Floor Pulses; 20 Ft/Sec Vertical and 40 Ft/Sec Longitudinal Velocities; Calm Sea

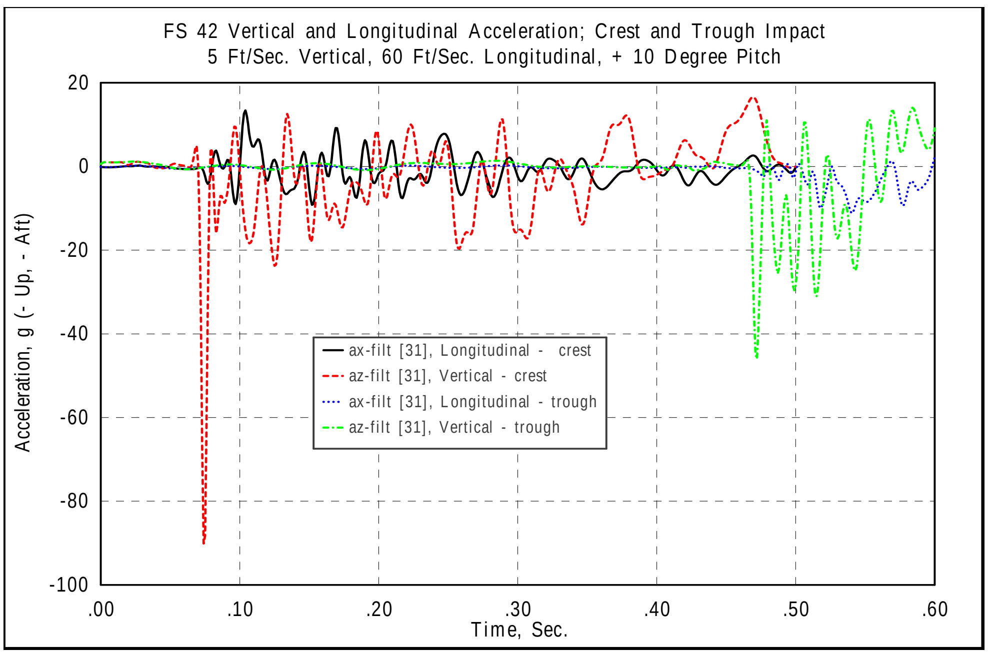
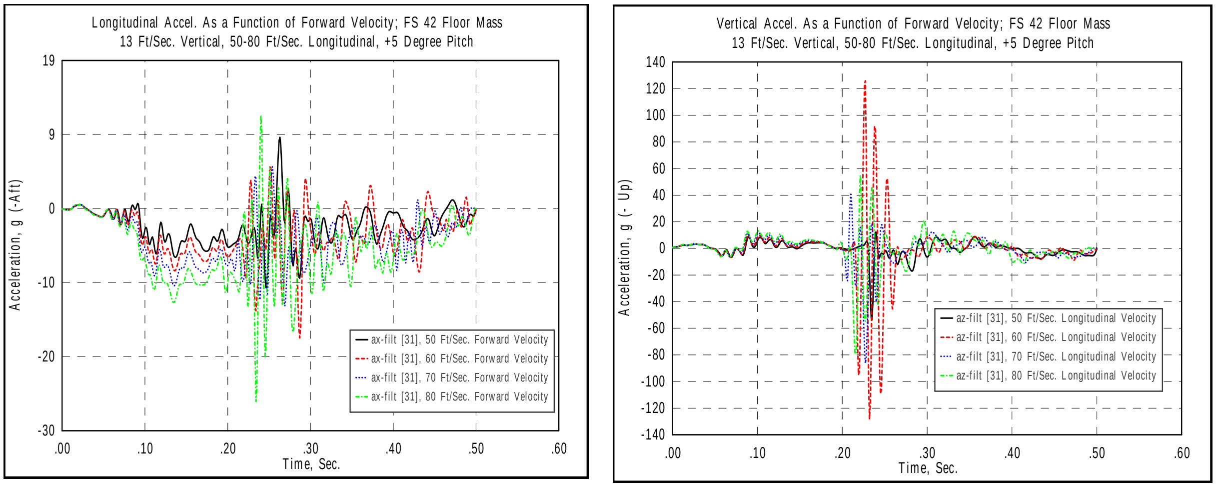


Figure 9 Water Impact Floor Pulses; 5 Ft/Sec Vertical and 60 Ft/Sec Longitudinal; Sea State

Figure 10 shows a relatively long term longitudinal floor acceleration combined with what would be considered short term transient vertical floor acceleration.

The vertical and longitudinal components of the FAR27/29.562 combined vertical - longitudinal dynamic test, as well as the peak acceleration pulse for the longitudinal dynamic test, are shown in figure 11.



Longitudinal Acceleration Vertical Acceleration

Figure 10 Floor Accelerations Vs. Forward Velocity; 13 Ft/Sec Vertical, 50-80 Ft/Sec Longitudinal Water Impact

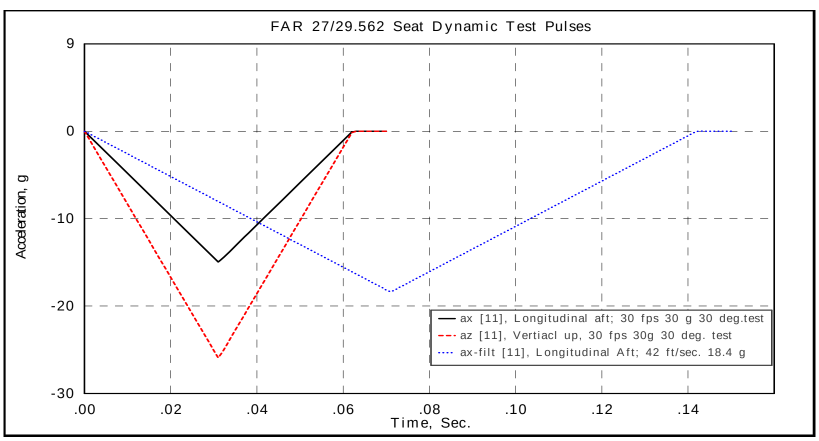
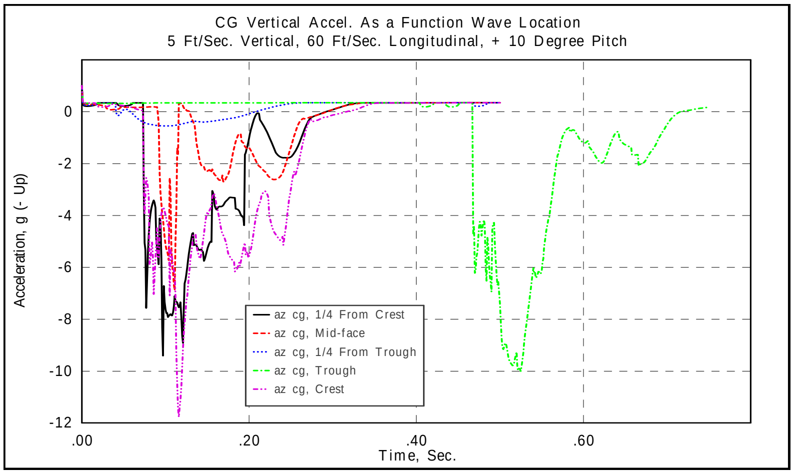


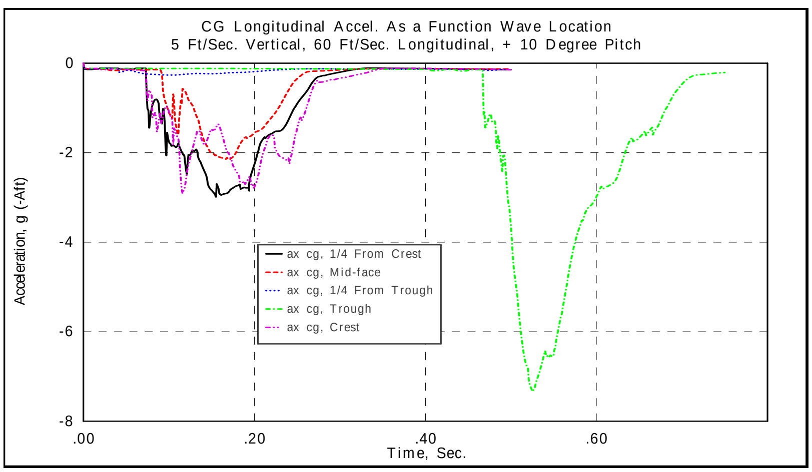
FIGURE 11 FAR27/29.562 SEAT DYNAMIC TEST ACCELERATIONS

The difficulties associated with the floor acceleration time-histories, such as those noted in figures 8-10, are 1) to reproduce an equivalent simultaneous vertical and longitudinal acceleration that results in the same occupant and seat response as the irregular time history, and 2) develop, if necessary, a laboratory reproducible pulse similar to those produced in figure 11, and 3) determine if the actual pulse will result in either occupant injury or deterioration of seat performance.

Often the effect of a long duration floor acceleration is depicted by cg responses as opposed to a local floor response. Figures 12a and 12b depict such long duration cg responses.



(a) VERTICAL



(b) LONGITUDINAL

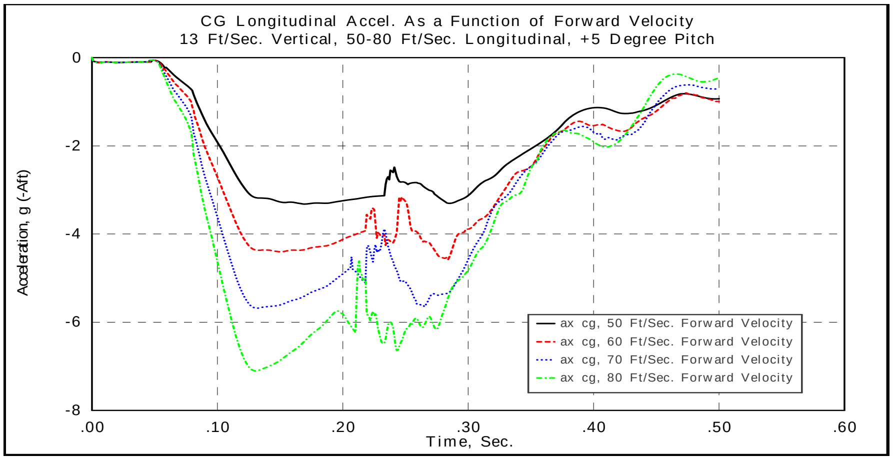
FIGURE 12 CG ACCELERATIONS; WATER IMPACT INTO A WAVE; 5 FT/SEC VERTICAL and 60 FT/SEC LONGITUDINAL

The cg accelerations shown in figure 12 can be characterized as triangular with:

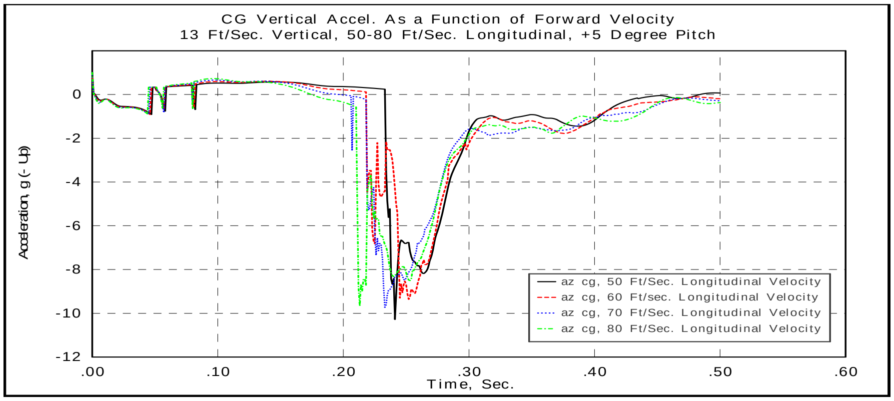
- Vertical; peak = 10 g, velocity change = 23 -37 ft/sec., rise time = 0.040 sec., duration = 0.150 - 0.235 sec.
- Longitudinal; peak = 7.3 g, velocity change = 17-28 ft/sec., rise time = 0.040 sec., duration = 0.150 - 0.235 sec.
- Resultant Acceleration = 12.4 g; Resultant Velocity = 28 – 45 ft/sec.

Triangular pulses are easily reproducible in a laboratory test. At first glance a resultant 12.4 g and average 36 ft/sec. velocity change is less severe than the FAR27/29.562 seat dynamic test requirement of 30 g and 30 ft/sec velocity.

Additionally other combined vertical-longitudinal long duration cg pulses such as those noted in figure 13 are candidates for further evaluation.



(a) LONGITUDINAL



(b) VERTICAL

Figure 13 CG Acceleration vs. Longitudinal Velocity; 13 Ft/Sec Vertical Water Impact

The cg acceleration shown in figure 13, indicate that the peak responses are not simultaneous and that they can be characterized as:

- Longitudinal; peak = 5 g, velocity change = 55 ft/sec., rise time = 0.060 sec., duration = 0.440 sec., <u>trapezoid</u>
- Vertical; peak = 9.0 g, velocity change = 14.5 ft/sec., rise time = 0.060 sec., duration = 0.100 sec.; <u>triangular-trapezoid</u>
- Resultant Acceleration = 10.3 g; Resultant velocity = 57 ft/sec. for simultaneous pulses

The cg acceleration noted above is probably not of concern because the combined vertical –longitudinal seat acceleration in FAR 27/29.562 is closer to 26 g vertical and 15 g longitudinal, and at a resultant velocity change of 30 ft/sec..

Another consideration is that water impacts combined with seat orientation can produce floor accelerations that are potentially detrimental to the occupant in the lateral direction. Water impact transient and long duration cg floor accelerations that are depicted in figure 14 affect sideward facing seats in FAR27/29 rotorcraft.

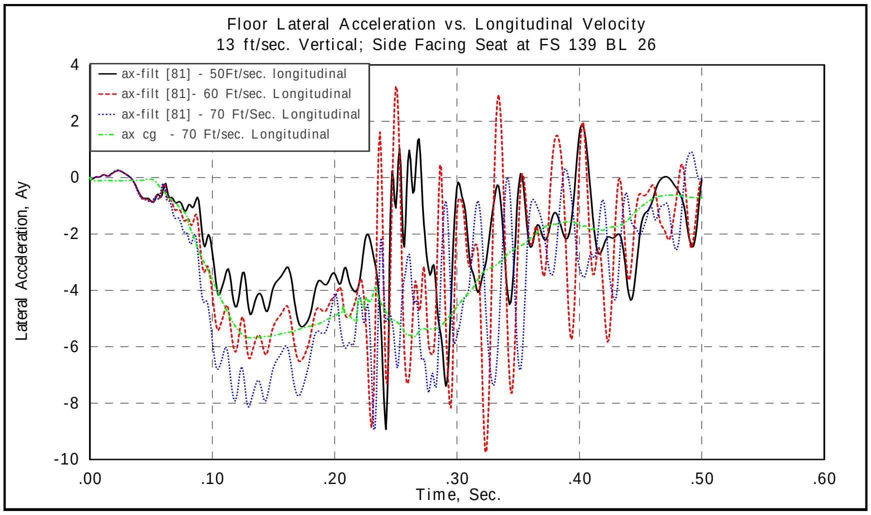


Figure 14 Floor and CG Lateral Acceleration; 13 Ft/Sec Vertical and 50-70 Ft/Sec Longitudinal Velocities

The floor accelerations presented in figure 14 are based on responses for the side facing seats exposed to longitudinal forces. The pulses shown in figure 14 indicate that that the peak responses can be characterized as:

- Floor lateral peak = 4 to 8 g, velocity change = 21-42 ft/sec., rise time = 0.050 sec., duration = 0.220 -0.250 .sec., trapezoid
- Cg lateral peak = 5.6 g, velocity change = 56 ft/sec., rise time = 0.050 sec., duration = 0.450 sec.; triangular-trapezoid

The FAR27/29 rotorcraft configuration contained seats that face sideward and aft, as is probably the situation in other FAR27/29 rotorcrafts. Thus, floor and cg longitudinal pulses can affect both aft facing and side-facing seats. Aft facing seats may not be a problem because of human tolerance forces in that direction are generally greater than for forward facing seats. However, the longitudinal pulses presented in figures 8-14 may impact the FAR 27/29.562 seat dynamic test requirements, since the water impact floor pulse can exceed 4 g's with comparable velocity changes (42 ft/sec) to that specified in 27/29.563 where the lateral component in the 18.4 g peak longitudinal direction test is about 3.2 g.

Floor short duration peak longitudinal accelerations have been shown by the analyses presented in this research to be in the range of 10 g-25 g. CG long duration peak longitudinal accelerations and thus lateral accelerations for side facing seats have been shown by program KRASH analysis to be in the range of 4 g-8 g with velocity changes in the 42 ft/sec to 56 ft/sec. range

CONCLUSION

Analysis of a current rotorcraft encompassing several weight configurations and a series of 500 impact scenarios and design considerations, has shown that there are potential Design Limit Envelopes that are applicable FAR27/29 regulations with regard to water impact. In particular there;

- Is a Design Limit Envelope that to maintain a current level of structural integrity exceeds the current ditching envelope
- Is a 95th percentile survivable envelope that extends the current rotorcraft 95th percentile survivable water impact envelope based on previous accident data
- Side facing seats can be exposed to lateral floor accelerations that exceed current FAR 27/29.562 seat dynamic test levels that are designed for a combined vertical-longitudinal impact or a predominantly longitudinal velocity impact.
- Irregularly shaped floor pulse that are developed during water impacts have to be evaluated with regard to how they impact the current seat dynamic testing requirement. These floor pulses have characteristics that need be evaluated with regard to shape, magnitude, duration and reproducibility in a test environment.

All of the above are recommended to be considered for their impact on certification of future civil rotorcraft as well as with regard to how they can be incorporated into advisory material.

REFERENCES

1. FAR 27 Airworthiness Standards: Normal Category Rotorcraft, Revised January 1998

2. FAR 29 Airworthiness Standards; Transport Category Rotorcraft, Revised January 1998

3. “Evaluation of FAR 27/29 Water impact Standards”, DRI Report 2000-2, June 2000

4. “The Development of Ditching and Water Impact Design Limit Curves For Civil Rotorcraft”, Dynamic Response Inc., FAA Technical Center Report DOT/FAA/AR-07/8, dated May 2007