

# DESIGN AND PERFORMANCE OF INFLATABLE BOATS: FLEXIBILITY AND ENVIRONMENTAL CONSIDERATIONS

P.K. Halswell

*EngD Student, University of Southampton*

Prof. P.A. Wilson

*Professor of Ship Dynamics, University of Southampton*

Dr. D.J. Taunton

*Lecturer, University of Southampton*

S. Austen

*Head of Engineering Support, RNLI*

**ABSTRACT:** This paper investigates the design and performance of inflatable boats where the structural stiffness is supplied by the inflatable tubes and jointed composite sandwich panels which allow large deformations in the hull form. Anecdotal evidence has shown that this flexibility or hydroelasticity of an inflatable boat (IB) improves its performance, especially in waves. It is hoped that this hydroelasticity can be optimised to improve aspects of the performance, including reductions to the boat motion therefore minimising the human exposure to vibrations and added resistance in waves.

This paper discusses each area of hydroelasticity found in an inflatable boat, it defines each problem, shows the current literature and possible methods of investigation. The areas of hydroelasticity include; global hydroelasticity, hydroelastic planing surfaces and hydroelastic slamming. This paper also discusses the wave and spray generation of a vessel with sponsons and relates it to the effect on boat motion and resistance. Finally this paper discusses the air and water borne noise produced by these types of vessels.

## 1 INTRODUCTION

This project is supported and partially funded by the Royal National Lifeboat Institution (RNLI). The RNLI is a charity that aims to “save lives at sea” all around the coasts of the UK and Ireland. They design, build, maintain and operate a range of vessels for almost any situation and they own the largest fleet of inflatable boats (IBs) and rigid inflatable boats (RIBs) in the UK. This paper will focus on the vessels used in littoral waters, primarily the D class inshore inflatable lifeboat known as the Inshore Boat 1 (IB1).

Compared with larger boats and ships, there is relatively little scientific understanding about the performance of RIBs and considerably less understanding of the performance of IBs. Their design is usually based on the experience of the designer or trial and error. Experiments into the performance of RIBs include; Haiping et al. (2005); Townsend et al. (2008a); Townsend et al. (2008b) and for IBs includes; Dand et al. (2008); Austen and Fogarty (2004). A computational model of a RIB has been constructed by Lewis et al. (2006).

High speed marine vehicles, such as the IB1, experience non-linear boat motion which results in

high and low frequency vibrations with large accelerations. In 2002 a European Directive (2002/44/EC) was proposed on the minimum health and safety requirements regarding the exposure of workers to physical vibrations. The exposure action value for whole-body vibration is  $0.5 \text{ ms}^{-2} \text{ r.m.s}$  (or  $9.1 \text{ ms}^{-1.75} \text{ VDV}$ ) and the exposure limit value is  $1.15 \text{ ms}^{-2} \text{ r.m.s}$  (or  $21 \text{ ms}^{-1.75} \text{ VDV}$ ). Boat motions and vibrations have been well reviewed with relation to high speed craft by Townsend (2010). Vibrations can not only cause long term injuries to the crew but it can reduce the crew's ability to perform tasks (during and after transit). Possible strategies to reduce the human exposure to boat motion have included; suspension seats, suspended decks, active and passive fins, trim tabs, interceptors, gyrostabilisers, flexible hulls and elastomer coated hulls. Townsend et al. (2008b) showed that the RNLI RIBs exceed the exposure limit value (1/3 average significant wave height = 0.4m and average wave period = 10.6s) and Dand (2004) showed that the rigid scale model of the IB1 in regular waves, with a full scale wave height of 0.55m, could be exposed to accelerations of up to 4g in the crew's position. The RNLI are currently applying for an exemption certificate,

however alongside the certificate they are also investigating methods to mitigate the human exposure to vibrations.

## 2 AIMS

Anecdotal evidence has shown that the flexibility or hydroelasticity of an IB improves its performance, especially in waves. Therefore the aim of this project is to scientifically prove how and why the hydroelasticity enhances the performance, or that hydroelasticity does not improve the performance. Then the results should be presented in the form of design guidelines for the RNLI for future designs. This project is essentially a study of hydroelasticity of highly deformable boats.

Currently hydroelasticity is used in two main ways either to calculate the stresses and strains in the structure, see Price et al. (2002) and Hirdaris and Temarel (2009), or to study its effect on boat motion, see Santos et al. (2009), Senjanovic et al. (2008) and Hirdaris and Temarel (2009). IBs have the potential to be optimized and tailored to reduce the boat motions (and hence exposure to vibrations) and to increase the boats forward speed through the correct application of hydroelasticity. If the pitch and heave motions are reduced then the added resistance in waves will be less. So the aim of the paper is to show that hydroelasticity can be used to optimise a vessel, not just study its effects. The project aims to verify this belief.

This paper will first discuss the construction of the IB1 which will show the origin of each mode of hydroelasticity. Then it will discuss each mode individually and they include; global hydroelasticity, hydroelastic planing surfaces and hydroelastic slamming. Each mode will be introduced, literature reviewed and then possible methods of investigation will be examined. The possible methods indicate how this project will proceed. To further the understanding of the performance of RIBs and IBs the wave and spray generation will be discussed. Finally the environmental noise produced by small crafts such as these RIBs and IBs will be discussed.

## 3 THE DESIGN OF IB1

It is important to understand the construction of an IB because it will demonstrate how the craft is able to deform. Figure 1 shows the main components within the IB1. The design of IBs does vary depending on their operational

requirements, component materials and construction techniques.

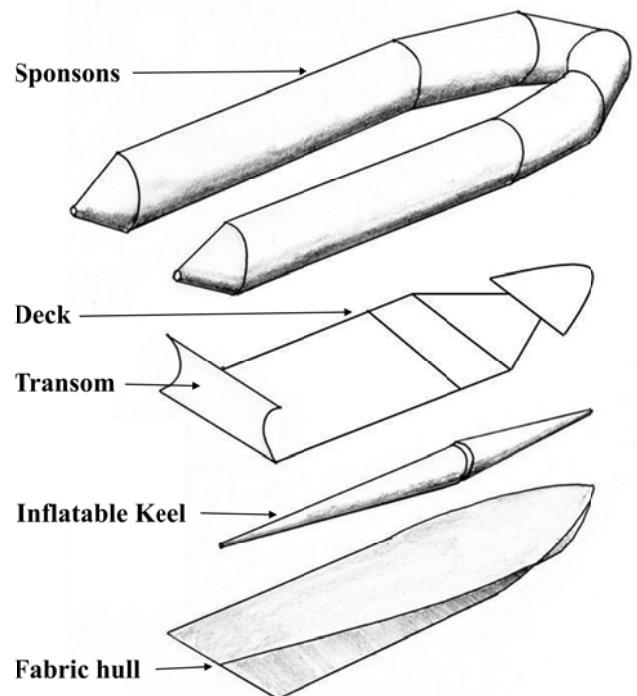


Figure 1: Main components of the IB1

1. **Sponsons** - these are the inflatable tubes that surround the boat. They are constructed from Hypalon® coated polyester and are inflated to a pressure of 206 mbar (3 psi).
2. **Deck** - this is the main structural component of the boat made from a composite sandwich panel. The deck is sectioned into four parts (plus the transom) to intentionally allow flexibility and each deck joint has its own stiffness due to the type of joint. The transom and forward deck section are bonded to the sponson but the other deck sections are slotted into place.
3. **Inflatable keel** - this is a tapered inflatable tube that is attached to the centreline of the fabric hull. It is constructed from Hypalon® coated polyester and is inflated to a pressure of 224 mbar (3.25 psi).
4. **Fabric hull** - this is a fabric sheet, constructed from two sheets of Hypalon® coated polyester, that is attached to the sponsons and transom and pulled taught over the keel.

## 4 GLOBAL HYDROELASTICITY

### 4.1 Introduction

This section is investigating the global hydroelasticity of an IB by viewing the boat as a

whole and studying the longitudinal bending and torsional twisting vibrations that exist. It has been observed that as the IB1 passes over an oblique wave that the deck bends and twists which provides a smoother ride. This could be regarded as the conventional hydroelastic response and theories such as the ones described in Bishop and Price (1979). The flexibility of the boat will affect the wave induced dynamic response of the vessel which in turn affects the boat motion.

An inflatable boat has many inter-connected parameters that will affect the global vibrations which include; deck properties (material properties and thickness), deck joints (number, position and stiffness), sponson and keel properties (material properties and internal pressures), fabric hull properties (material properties and pre-tensioned stresses), mass (LCG and inertia) and construction technique. A static deflection experiment was performed by the authors and it was found that the dominant parameters to the deflection of the boat are the number, position and stiffness of the deck joints.

#### 4.2 Literature Review

There are numerical models capable of predicting the vertical motions and wave loads on a high speed craft, such as Chiu and Fujino (1988) and Santos et al. (2009), but, to our knowledge, no numerical model has yet been validated for a hydroelastic planing vessel. Plus the structural properties of inflatable fabric tubes have not been included. Santos et al. (2009) modelled a fast patrol boat which had a planing hull form but it is noted that the approach used was not suitable for planing vessels. They found large differences between the full scale measurements and the numerical model results.

Early work in the deformation of inflatable cylindrical beams started with Comer and Levy (1963) by comparing them to an Euler-Bernoulli beam. The most recent and relevant work was performed by Wielgosz et al. (2008) by using Timoshenko beam theory to account for the shear deformation. A finite element model was made using a stiffness matrix to include internal pressure. Veldman et al. (2005) highlighted the importance of using the correct modelling theory; membrane or thin-shell theory. They found better correlation using thin-shell theory even though the fabric was 60nm thick. It has not been established which theory should be used for Hypalon<sup>®</sup> coated polyester.

### 4.3 Methods of Investigation

#### 4.3.1 Experimental Methods

The conventional model scale experimental approach to this problem involves using segmented models. However, this is not applicable to the IB1 because the structure is unconventional and the deck joints allow specific flexibility.

If this problem is studied using scale models then certain scaling laws need considering. The first is the scaling of internal pressure because atmospheric pressure is the same at full and model scale. Scaling can be achieved using a combination of bellows and springs which was suggested by Stevens (1981). Scaling fabric material properties will involve altering the Poisson's ratio and the Young's modulus.

Full scale experiments on the IB1 could be performed. The main disadvantage is the uncontrollable environment. It may be possible to construct an IB with different deck properties and deck joints to study the effect of hydroelasticity on the boat motion. Another possible method is to study the effects using a spring system on each deck joint to alter its stiffness therefore allowing the parameters to be changed.

#### 4.3.2 Computational Methods

Thus we can conclude that at the present time it is not possible to accurately predict the dynamic hydroelastic motion of a planing vessel. If a method for modelling the fabric inflatable sponsons is developed, then, when a hydroelastic planing model is available the structural domain can easily be adapted for the IB1. This could be performed using a stiffness matrix similar to Wielgosz et al. (2008).

## 5 HYDROELASTIC PLANING SURFACE

### 5.1 Problem Definition

The planing surface of an IB is normally constructed from fabric which has significantly less out-of-plane bending stiffness than conventional metal or composite hulls. This will allow the planing surface to deform considerably under different loading conditions, see figure 2. The problem is to find the shape of the fabric when it is in steady-state planing and the effect of this deformation on the planing performance.

The aim is to optimise the parameters of the fabric hull to find the limitations and the effects of flexible planing surfaces. The parameters of a fabric hull are material properties and the pre-

tensioned stresses. The parameters define the out-of-plane bending stiffness of a fabric therefore as they are increased the material becomes stiffer and comparable to a conventional planing surface.

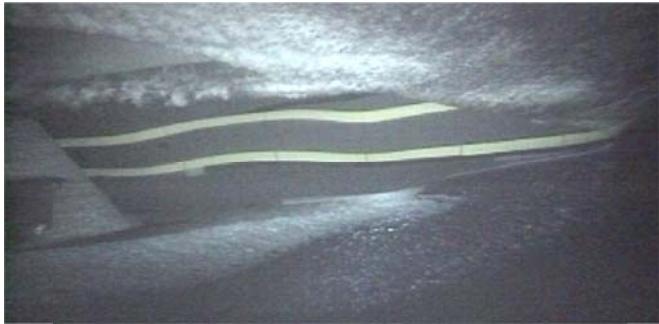


Figure 2: Hull deformation of the IB1 at 19.4 knots [Dand et al. (2008)]

Experiments by Dand (2002) and Dand (2003) were performed on the IB1 at full scale and model scale to measure the resistance, sinkage and trim. The full scale boat was flexible and the fabric hull was able to deform however the scale model was rigid. The comparison of total resistance showed that the full scale flexible boat had slightly higher resistance than the rigid scaled model. Dand et al. (2008) attributed this to the change in trim angle due to the fabric hull deforming and causing a concave camber at the aft of the hull. They also found an instability when the boat was accelerating on flat water which was described as a “pressure wave” slowly passing under the boat. It caused a “pulsing” motion primarily in pitch and heave. Whether the deformation was static or dynamic is unknown.

The first limitation is the “pulsing” motion instability found in the IB1. One hypothesis is that the reduced out-of-plane bending stiffness of the hull allowed the concave camber to form. This causes the pre-tensioned stresses in the fabric to change as the camber forms and also results in a change in the hydrodynamic forces on the hull. As the fabric stresses change, the deformation moves towards the aft. The deformation causes a change in hydrodynamics which gives the operator the feeling of this “pressure wave”. It has also been reported that as this “pressure wave” passes under the hull the sponsons can be seen to deflect which indicates high forces and fabric movement. When this deformation reaches the transom the pressure is released and the cycle begins again. This motion is only found on flat water and waves cause the cycle to be broken. So there is a limitation in the minimum out-of-plane bending stiffness of the fabric hull to ensure this instability does not occur.

Therefore the aim is to quantify the minimum out-of-plane bending stiffness to stop the dynamic motion.

Dand et al. (2008) showed that flexibility affects the resistance and trim of a planing surface. This needs to be studied further to quantify this effect and to investigate unknown consequences such as the change in sinkage.

## 5.2 Literature Review

There is no literature directly related to a membrane planing surface. However this fluid structure interaction could be compared with the aeroelasticity of a membrane aerofoil, such as sails and membrane wings. Newman (1987) noted skin friction can change the membrane tension and in an inviscid flow it is constant. A strong coupling between the frequency of the membrane oscillations and vortex shedding frequency has been shown by Song et al. (2008), Rojratsirikul et al. (2009) and Gordnier (2009). Gordnier (2009) importantly showed that the Reynold number caused the motion of the membrane aerofoil to change from a standing wave vibration to a dynamic vibration similar to travelling waves. None of the mentioned literature contains a free surface which is vital for the planing fluid forces.

## 5.3 Methods of Investigation

### 5.3.1 Experimental Methods

In an ideal world this problem could be studied using full scale tow tank tests, however, even if this was feasible it is unknown what to look for. It is unknown whether the deformation is static or dynamic. If it is static then the resultant hull shape is unknown. So to investigate this problem, one has to start at the very beginning: flat plates.

Initially the static or dynamic question needs to be answered. Different parameters and boundary conditions will cause the fabric hull’s behaviour to change from a static camber to standing waves through to dynamic travelling waves. It needs to be confirmed that the primary parameters to cause this change in behaviour are material properties and pre-tensioned stresses, other factors include speed and displacement. It is possible that the dynamic response is caused by the coupling of the different components within the IB1 and/or that there are several different types of dynamic fabric behaviour. This could be explored using a fluid jet impacting an inclined plate which is a simple analogy of a planing vessel.

Once the behaviour of a fabric planing surface is better understood then more realistic experiments can be performed. The first realistic experiments to be performed could be a fabric flat plate towed at steady state planing speed. The global shape of the fabric flat plate should be measured along with the resistance, sinkage and trim. Then a planing wedge section with a deadrise angle could be tested and taken through to complete planing hull shapes for flat water planing. Finally a series of wave experiments could be performed. Scaling laws need considering as discussed in section 4.3.1.

The membrane deformation needs to be measured both accurately for displacement and sampling frequency. Jenkins and Korde (2006) reviewed the experimental membrane vibration literature and discussed the use of laser vibrometers. Arbos-Torrent et al. (2011) used photogrammetry to measure the deflection of an oscillating aerofoil at 1200 frames per second.

### 5.3.2 Computational Methods

This problem could be tackled computationally but this will require extensive computational time and power and is highly complex. It may be possible to use a similar approach as the 2D computational models discussed in section 6.3 and 6.4.2. However these models will still need experimental validation and verification.

## 6 HYDROELASTIC SLAMMING

### 6.1 Problem Definition

The problem addressed within this section is regarding the effect of hydroelasticity on the loads and accelerations of a 2D wedge vertically impacting a free surface. An IB has three main flexible components in the vertical direction which are the fabric hull, the inflatable sponsons and the inflatable keel, see figure 3. In reality these three components act together and will affect the response of each other, however, for an initial investigation each can be studied individually.

The aim is to find the optimum parameters to minimise the vertical accelerations which will change the boat motion in terms of pitch and heave. The parameters for the hull are fabric material properties and pre-tensioned stresses and the parameters for the inflatable keel and sponsons are material properties and internal pressure. The other important variables are impact velocity, deadrise angle and inertia. A simple hull wedge impact was investigated by Townsend et al. (2010)

to study the possible methods for reducing the vertical acceleration on high speed crafts. The hull stiffness was reduce from 69GPa (aluminium) to 6.9GPa to investigate the effect of intentionally reducing the hull stiffness. It was found to have minimal effect on the acceleration but it is anticipated that the fabric will have a significantly lower equivalent stiffness which will amplify the effect.

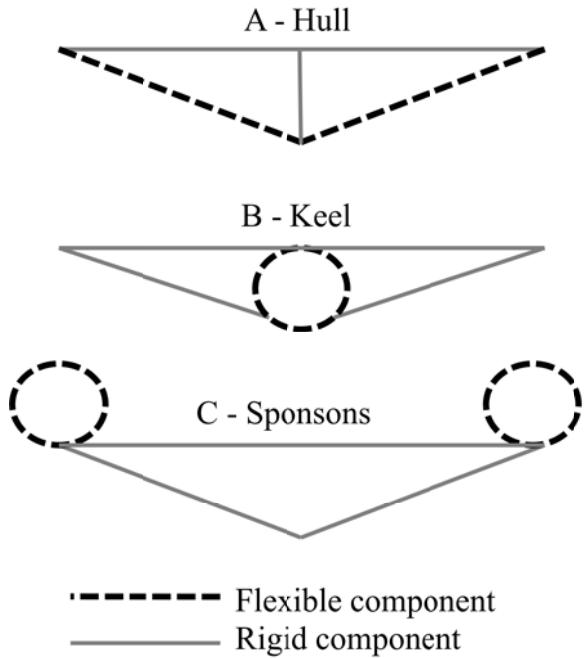


Figure 3: The flexible components within a vertically impacting IB

It has been proposed but not validated by many authors including Natzijl (1998) and Pike (2003) that sponsons absorb energy during slamming motions. Townsend (2008) did investigate this concept but the internal pressure reduction was shown to have no effect. It is worth noting that the Atlantic 85 investigated by Townsend (2008) had a hull shape so that the sponsons rarely came into contact with the water which is not the case for the IB1. The experiment proposed for the wedge sections with sponsons will answer this question and allow an investigation into the effect of material properties and internal pressure. Other variables that will affect the amount of energy absorbed by the sponsons include; sponson diameter, sponson overhang and sponson attachment.

### 6.2 Literature Review

Faltinsen et al. (2004) provides a good review of this problem and discusses the challenges within it. Here is a list of particular effects that may

require consideration; gravity, viscosity, air cushions, air pockets, air to bubble generation, water compressibility, air compressibility, flow separation and membrane behaviour.

Gravity can normally be neglected in this problem, see Faltinsen et al. (2004). Viscosity is also commonly neglected but this could affect flow separation when there is not a sharp corner which will be discussed later, see Faltinsen et al. (2004). Air cushions and the compressibility of air were initially ignored but Bereznitski (2001) showed the importance of including them. Air pockets can occur when the structure is very flexible and can excessively deform vertically past the corner of the wedge, as shown in figure 4. Faltinsen et al. (2004) noted that the breakdown of air cushions into bubbles requires better understanding and the effect of this is unknown. The time scale of water compressibility is, typically, significantly smaller than the time scale of the local structural response so it can be assumed incompressible, see Faltinsen et al. (2004). However, the time scale of the fabric deformation has not currently been identified so the assumption needs validation. Flow separation is another consideration and this can be described when there is a hard chine but Faltinsen (2005) stated the round bilge flow separation is difficult to handle and here viscosity may need to be included. Finally the membrane behaviour is significantly different from that of conventional solids with nonlinear behaviour due to the interaction of the weave and weft, see Lewis (2003).

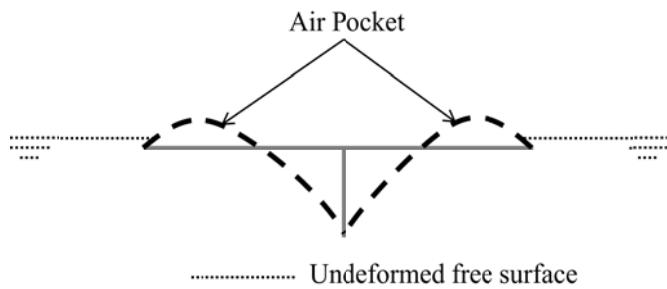


Figure 4: Air pocket formation

Faltinsen (1997) divided this problem into two time scales. The initial time scale is the structural inertia phases where the large hydrodynamic forces lead to large accelerations of a small structural mass. This phase is very short compared to the second time scale. The second scale is the free vibrations phase which is the highest wetted natural period of the structure. The behaviour is

the free elastic vibrations of the structure with the initial conditions obtained from the first phase. The maximum stresses occur in the free vibration phase.

Faltinsen (1999) discusses the importance of hydroelasticity as a ratio between the first period of natural vibration of the wet beam and the duration of the impact. It is quantified in terms of nondimensionalised parameters. Bereznitski (2001) uses the same ratio except it is the natural vibrations of the dry beam. Bereznitski (2001) says that if the ratio is greater than two then hydroelasticity does not play a significant role. Increasing either the material properties or pretensioned stresses in the fabric will alter the period of vibration therefore affecting the importance of hydroelasticity.

$$\text{Ratio} = \frac{\text{Duration of Impact}}{\text{Period of Vibration}}$$

### 6.3 Critique of Modelling Methods

The problem of water entry of 2D bodies started in a purely hydrodynamical sense for rigid body with the work of Wagner and Von Karman in the 1920s and 1930s. This work was advanced by many researches but it was not until the work of Kvalsøld et al. (1995) who considered the local hydroelastic effects within this problem.

Kvalsøld in 1994 theoretically studied the slamming-induced local stresses in a wetdeck of a multihull vessel for a doctor of engineering thesis and jointly published the results in Kvalsøld and Faltinsen (1995). The structure was modelled using a 2D Timoshenko beam and the fluid was modelled using Wagner theory and assumed it to be incompressible and irrotational, plus air entrapment and cavitation was not included. This solution was complex and Faltinsen (1997) simplified this solution. Experimental results from Faltinsen et al. (1997) and Kvalsøld et al (1995) agreed well with both theoretical solutions. Faltinsen (1999) used the numerical solution of Kvalsøld and Faltinsen (1995) to study the water entry of a wedge including the forward speed of the vessel by solving the coupled non-linear equations by a Runge-Kutta 4th order scheme. Korobkin et al., (2006) demonstrated that it is possible to directly couple finite element method for the structural domain with Wagner theory for the fluid domain. The results were compared with a modal method using a beam model and the results showed very good correlation.

Lu et al., (2000) used boundary element methods (BEM) for the fluid and finite element method (FEM) for the structure. The non-linear free surface boundary condition is satisfied and the jet is properly treated. Good agreement was found with the results of Zhao and Faltinsen (1993).

Bereznitski (2001) published an important paper on the role of hydroelasticity in the 2D slamming problem and uses four methods for solving the problem. The first is a Wagner's solution where the body is rigid and this can be compared to the work of Faltinsen (1997) where the body is elastic. Bereznitski also used a self developed code plus two commercial codes called MSC Dytran and LS-DYNA. Bereznitski commented that the most suitable methods were either MSC Dytran or LS-DYNA because they can both deal with the coupled hydroelastic interaction and include modelling of air cushions. It is worth noting MSC Dytran and LS-DYNA are quite similar and the equations for the state of water and air are the same, see Bereznitski (2001). LS-DYNA has been used to study this problem by Bereznitski (2001), Le Sourne et al. (2003), Stenius (2006) and Stenius et al. (2007). Stenius et al. (2007) used finite element analysis based on multi-material arbitrary Lagrangian-Eulerian formulation and a penalty contact algorithm and the hydrodynamic loads correlated well with experimental results.

## 6.4 Methods of Investigation

### 6.4.1 Experimental Methods

This problem could be investigated using experimental scale drop tests, however, the scaling laws need to be carefully considered. The scaling of internal pressure will involve the use of a bellow and spring combination, see Stevens (1981). Scaling fabric material properties will involve altering the Poisson's ratio and the Young's modulus. The scaling of jet and spray formation is not clear because of the effect of surface tension influencing the jet break down into spray droplets. This involves changing the Webber number of the fluid, see Savitsky et al. 2010. Another scaling issue is the air cushion and the Euler number needs to be the same for model and full scale tests, see Faltinsen et al. (2004).

The scaling laws show that it would be advantageous to perform this experiment at full scale. However, scale models could have the advantage that a smaller test model could be forced into the water at a constant velocity and kept vertical.

This project intends to use full scale drop test to study this problem. Full scale models can be constructed which will allow the various parameters (material properties, pre-tensioned stresses and internal pressure) and variables (deadrise and impact velocity) to be altered. The accelerations could be measured using a number of devices including; accelerometers, laser or optical devices, sonic transducers and inertia measurement units (IMU). The measurement device will require a sampling frequency of at least 500 Hz, see Faltinsen et al. (1997). The shape of the elastic component also needs to be measured and this presents a few issues. It would be undesirable to use a contact measurement device as this will affect the response of the elastic component. Therefore laser or optical devices would be ideal.

### 6.4.2 Computational Methods

The first computational method that could be used to model this problem is using membrane theory coupled with Wagner theory in a similar manner to Kvalsvoid and Faltinsen (1995); Korobkin et al. (2006). BEM and FEM could be coupled to solve this problem such as Lu et al. (2000) and ANSYS. The best method would probably involve using LS-DYNA to explicitly couple the problem. LS-DYNA has been used and validated in the past plus most of the considerations can be included.

## 7 WAVE WASH AND SPRAY GENERATION

### 7.1 Problem Definition

As a vessel increases in speed, beyond the hump speed, the main resistance component changes from wave resistance to spray resistance, see Payne (1988). The mechanisms for wave and spray generation are understood for planing vessels with hard chines, see Savitsky and Morabito (2010). However, the IB1 and most IBs do not have chines and the mechanisms for generation are not well understood. Therefore the problem is to study the wave and spray generation around a vessel with interacting sponsons with speeds from zero to planing and above.

This work aims to minimise the wave and spray generation of a craft with interacting sponsons. This has the potential to improve top speed and acceleration of the craft. Plus it has the capability to reduce the environmental damage from wave wash, however, this may have an adverse effect on the boat motion. The problem can be viewed in 2D transverse slices which allow the effect of the

sponsors on the added mass to be investigated; or the problem can be viewed longitudinally studying the effect of sponsons on the resistance of the craft.

This work is linked with the hydroelastic slamming of a 2D section with sponson however this section studies the effect of sponsons on the hydrodynamics rather than hydroelasticity, i.e. this section wishes to define the fluid flow around a sponson.

## 7.2 Literature Review

Dand (2003) performed resistance experiments on the IB1 at full and model scale. No measurements of the wave or spray generation were made but figure 5 shows that the spray is attached to the sponsons until it detaches to form spray sheets. This indicates that surface tension and the coanda effect need to be considered.



Figure 5: Spray generation of the IB1 at 19.4 knots [Dand (2003)]

An investigation into the boat motions of RIBs and specifically the RNLI Atlantic 85 were investigated by Townsend et al. (2008a). It was found that the sponsons were rarely in contact with the water while planing, resulting in the sponsons having minimal effect on the high speed performance. Therefore the sponsons of conventional RIBs have negligible effect on the wave or spray generation but this is clearly not the case for the IB1.

## 7.3 Methods of Investigation

This could be investigated through full or scale model towing tank tests. Clearly, if scale models are used then the scaling laws need considering and this was discussed in section 6.4.1. The wave can be measured using a wave probe however the spray is less conventional and at present the ITTC do not have any recommended procedures for measuring the spray or accounting for the model

scale. The location of the spray sheet separation from the sponsons also needs to be measured.

Another possible method is through 2D drop tests such as the one discussed in section 6; Hydroelastic Slamming. This will exclude the forward motion but could be compared to strip theory.

## 8 ENVIRONMENTAL NOISE

Environmental noise is an issue due to the increase in concern for the environment and the unknown effects of noise upon the wildlife. In 2003 the European Directive 2003/44/EC was introduced to regulate the noise emissions from recreational craft. The maximum sound pressure level allowed is defined by the engine size and can be seen in table 1. There are currently International Standards on measuring the air borne noise produced by small recreational crafts. Small craft — Airborne sound emitted by powered recreational craft: Part 1 - Pass-by measurement procedures (ISO 14509-1:2008); Part 2 - Sound assessment using reference craft (ISO 14509-2:2006); Part 3 - Sound assessment using calculation and measurement procedures (ISO 14509-3:2009). The aim is to measure the air borne noise produced by the IB1 using the international standards, analyse the data and to publish the results. The SoundBoat project, part of ISO 14509-3:2009, found methods for predicting the hull noise produced by a rigid hull. It would be interesting to study the effect of flexible hulls on the noise generation.

Single Engine Power (kW)	Maximum Sound Pressure Level (dB)
$P > 10$	67
$10 > P > 40$	72
$P > 40$	75

Table 1: Maximum sound pressure levels

There are currently no regulations regarding the water borne noise of a small craft such as the IB1. The aim is to measure the water borne noise using ISO 14509 as a benchmark and altering as necessary for under water effects. A spectrum analysis can be performed to divide the noise into hull and propulsion noise. The results will then be published to aid future research.

It is intended that publishing the results will help future research in this area. Marine biologists will therefore know the frequencies and amplitudes of the noises that are being produced and find out which ones are harming wildlife. It will also assist acoustician, such as the SoundBoat project, in

predicting the noises produced by various types of craft.

## 9 CONCLUSIONS

This paper initially showed the construction of an IB and this indicated the areas of flexibility within the design of the IB1. These areas of flexibility show where hydroelasticity should be considered during the design of IBs. The optimisation of hydroelasticity could lead to improvements in boat motion (reduced human exposure to vibrations), boat forward speed/acceleration and added resistance in waves.

This paper discussed the global hydroelasticity within an IB and showed that it may be possible to alter current theories to include inflatable tubes and deck joints. These theories can then be used to optimise the global hydroelasticity.

Then the paper considers the complex problem of hydroelastic planing surfaces. It appears that at the current time computational models are not accurate enough to indicate the differences between rigid and hydroelastic planing surfaces. This paper outlines possible methods for experimentally investigating this problem.

Hydroelastic slamming was reviewed in this paper showing the different modes of flexibility. Each mode could be studied computationally or experimentally to find its effect on vertical accelerations. One mode will validate whether sponsons absorb impact energy during a slamming motion and to quantify the effect.

Wave and spray generation of a vessel with interacting sponsons was explored and this could be investigated as part of the hydroelastic slamming experiments. Finally the air borne noise regulations and standards that apply to crafts of this size and type are discussed. Also the novel area of water borne noise is discussed.

## 10 ACKNOWLEDGMENTS

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