Institution: University of East Anglia

Unit of Assessment: 10 – Mathematical Sciences

Title of case study:

Safety on the Sea

1. Summary of the impact

The safe operation of ships is a high priority task in order to protect the ship, the personnel, the cargo and the wider environment. Research undertaken by Professor Alexander Korobkin in the School of Mathematics at UEA has led to a methodology for the rational and reliable assessment of the structural integrity and thus safety of ships and their cargos in severe sea conditions. Central to this impact is a set of mathematical models, the conditions of their use, and the links between them, which were designed to improve the quality of shipping and enhance the safety of ships. The models, together with the methodology of their use, are utilised by the ship certification industry bringing benefits through recognised quality assurance systems and certification.

2. Underpinning research

The underpinning research for this impact is concerned with mathematical modelling of fluid-structure interaction. The research was primarily undertaken by **Professor Alexander Korobkin** at UEA. The research was further developed with the support of the EU funded project TULCS, which had considerable industrial involvement.

The idea of the underpinning research is to identify the most typical situations of violent interaction between a structure and a liquid and then simplify in order to describe the interaction with idealised geometries and including only the most important physical parameters [1]. The structural response and stresses are described by a finite-element model of the structure, in which simplified models of the hydrodynamic loads are used instead of fully nonlinear models of the hydrodynamics. In view of all the assumptions and uncertainties in the estimation of such situations and actual sea conditions, the semi-analytical models of hydrodynamic loads devised by Korobkin provide a more reliable and practical alternative to more complex and extremely computationally expensive Computational Fluid Dynamics (CFD) models. There is little advantage in using the complex models, when the conditions of interaction are only known with large uncertainty. Korobkin and colleagues have shown that the structural response is rather insensitive to details of the flow and pressure distribution [4] and only global characteristics are important [5]. Risk assessment is based on the stress distribution in the structure, with the hydrodynamic forces being indicators of high stresses. Korobkin's simplified models of hydrodynamics, which were developed with the aim of understanding the fluid-structure interaction in critical conditions, have been found to be of practical use once they are combined with CFD analysis. This combined local-global modelling benefits from the accuracy of CFD far from the violent parts of the flow and the flexibility of semi-analytical models in the violent zones, where the CFD codes are not so accurate. The combination of approaches gives more reliable predictions of safety levels.

The models developed during this research were designed for use both together with CFD and also on their own at the pre-design stage [4, 5]. The models were designed to be simple enough to be used by industry, bringing not only numbers but also understanding to designers and certification bodies. The simplified models are flexible in the sense that they include a physical effect only where it is needed and neglect it elsewhere. Korobkin's work provided a significant improvement over existing models. In particular, the Modified Logvinovich Model (MLM) which he developed, [1], is a very accurate and efficient way of predicting loads on a solid body during slamming impact onto water. The model is based on the results of collaborative research published in [2, 3].

In addition, Korobkin was involved in developing a research methodology for the SLOSHEL consortium (includes *Bureau Veritas*, *MARIN*, the *Lloyd*'s *Register*, and many other companies) as a subcontractor of *Bureau Veritas*. This consortium is interested in the sloshing of Liquefied Natural Gas in tanks, in particular focussing on the hydroelasticity of the tank walls during violent sloshing.

The work is based on papers [1-5]. The methodology for SLOSHEL work is outlined in [6].

UEA personnel
Lead academic: Prof Alexander Korobkin (2007 to date)
PhD Student: Alessandro Iafrati (UEA 2009)

3. References to the research

(UEA authors in bold)

[1] **Korobkin A.A.** (2011) Semi-analytical approach in generalised Wagner model, *Proceedings of the 26th International Workshop on Water Waves and Floating Bodies, Athens, Greece*, 85-88 Available from: http://www.iwwwfb.org/Abstracts/iwwwfb26/iwwwfb26_22.pdf

[2] Iafrati A. and **Korobkin A.A.** (2008) Hydrodynamic loads during early stage of flat plate impact onto water surface, *Physics of Fluids*, **20**, 082104 doi:10.1063/1.2970776

[3] Iafrati A. and **Korobkin A.A.** (2011) Asymptotic estimates of hydrodynamic loads in the early stage of water entry of a circular disk, *Journal of Engineering Mathematics*, **69**, 199-224 doi:10.1007/s10665-010-9411-y

[4] Ten I., Malenica S. and **Korobkin A.** (2011) Semi-analytical models of hydroelastic sloshing impact in tanks of liquefied natural gas vessels, *Philosophical Transactions of the Royal Society A*, **369** (1947), 2920-2941 doi:10.1098/rsta.2011.0112

[5] Khabakhpasheva T.I., **Korobkin A. A.** and Malenica S. (2013) Fluid impact onto a corrugated panel with trapped gas cavity, *Applied Ocean Research*, **39**, 97-112 doi:10.1016/j.apor.2012.10.005

[6] Malenica S., **Korobkin A.A.**, Ten I., Gazzola T., Mravak Z., De-Lauzon J. and Scolan Y.M. (2009) Combined semi-analytical and finite element approach for hydro structure interactions during sloshing impacts - SlosHel Project *Proceedings of the 19th International Offshore and Polar Engineering Conference, Osaka, Japan, ISOPE*, **3**, 143-152 Available from: www.veristar.com/content/static/veristarinfo/images/4139.1.ISOPE2009-MALENICA.pdf

Key Research Funding and Industrial Partners

FP7: "Tools for Ultra Large Container Ships (TULCS)" (2009-2012)
Industrial partners: *Bureau Veritas* (France), *MARIN* (Netherlands), *CMA-CGM* (France), *Odense Steel Shipyard* (Denmark), *CEHIPAR* (Spain), *INSEAN*, *SIREHNA* (France), *WIKKI* (UK) and *HYDROCEAN* (France).
Total budget £2.75M – UEA budget £120K

Royal Society International Joint Project: "Free-surface separation from a body which starts to move suddenly" (2009-2011)
Budget: £12,000

International Centre for Mathematical Sciences award for the workshop on "Mathematical challenges and modeling of hydroelasticity" Edinburgh, June 2010
Budget: £21,000

4. Details of the impact

By developing mathematical models of high-speed liquid impacts in a wide variety of violent-flow applications, the research described above has impact in the area of risk assessment for shipping. The adopted approach to research ensures that there are clearly identified routes to exploitation for the mathematical modelling developed within UEA and that the research has a positive impact on industry.

Risk Assessment for Shipping

The importance of being able to assess the risk of wave-inflicted damage to large ships was motivated by the findings of the official report into the loss of the huge container ship *MSC Napoli* in the English Channel on 18th January 2007. This large (62,000 tons) and fairly modern (built 1991) ship was lost due to excessive wave bending moments experienced by the ship in heavy seas.

Korobkin's research is utilised by service companies specialising in quality, health & safety and environment management for ships and shipping. These companies are also responsible for the certification (underwriting / insuring) of every ship for every route and cargo. In the UK this is *Lloyd's Register*, and in France it is *Bureau Veritas*. At any one time more than 10000 ships are classed (underwritten / insured) by *Bureau Veritas* and all are subject to periodical class and statutory surveys.

In order to successfully certify a ship, the companies need to be able to assess all risk factors. Within this overall risk assessment, our research is utilised to understand the effect of, and risks associated with, differing sea conditions. The tools and methodologies developed at UEA have been used to improve the guidelines used by *Bureau Veritas* for the assessment of hydro-elastic interactions in severe sea conditions. In addition, our research has improved the industrial computational tools for safety and risk estimates.

The importance of the UEA research is clear from the supporting letter from *Bureau Veritas* which states:

> "The results of the cooperation showed to be very useful to our company and the tools and methodologies which were developed, are used on a daily basis in practice."
>
> "... our Guidelines for assessment of hydro-elastic interactions during impacts were updated thanks to the knowledge developed with these cooperations. Due to the extreme complexity of the physical modelling cooperation with Prof. Korobkin is still continuing and even increasing in the recent years".

(corroborating source [A])

Industrial Recognition

The contribution to this field by Korobkin is internationally recognised by the Society of Naval Architects and Marine Engineers. In 2009, he was awarded the prestigious Weinblum Memorial Lectureship, the highest award in ship hydrodynamics, with the following citation:

> "In recognition of the many outstanding contributions to the field of ship hydrodynamics which you have made in the course of a very successful career in education and scientific research, it is our privilege to invite you to present the 32nd Weinblum Memorial Lecture. The Lectureship was established to honour individuals who exemplify the spirit and ideals of Georg P. Weinblum. The lecturer is chosen annually by a selection committee consisting of the Director of the Institute fur Schiffbau der Universitat Hamburg, the Chairman of the Fachausschuss Schiffshydrodynamik der Schiffbautechnischen Gesellschaft, the Chairman of the Journal of Ship Research Committee and the Analytical Ship Wave Relations Panel of the Society of Naval Architects and Marine Engineers."

(corroborating source [B])

Korobkin is only the fourth academic from the UK to be awarded this Lectureship (G.E. Gadd, National Physical Laboratory, in 1982; F. Ursell, University of Manchester, in 1985; E. Taylor, University of Oxford, in 2005).

5. Sources to corroborate the impact

[A] Letter from the Head of Hydro Structure Section, Deputy Director, Research Department - Marine Division, *Bureau Veritas* - letter held on file at UEA.

[B] Citation letter for the Weinblum Memorial Lectureship - letter held on file at UEA.