Advancing high-order mesh generation with *NekMesh*

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1 Outline

High-order methods are now becoming increasingly popular in the academic and industrial communities due to their attractive numerical and computational properties. This has lead to the development of software such as *Nektar*++, a spectral/hp element framework designed to simplify the task of writing solvers to capitalise on this emerging technology. However before the advantages of these methods can be truly realised, a major barrier must be overcome: developing algorithms for the generation of curved boundary-layer meshes around complex three-dimensional bodies. This is a significant obstacle for the popularity of these methods, since these geometries are crucial in both industrial and academic applications. The purpose of this project is to finalise a number of developments in this area and support the release of an in-house high-order mesh generation, *NekMesh*, which can be more widely used by both other PRISM partners and the wider academic community.

2 Project objectives

The key challenge of generating curved meshes for complex three-dimensional bodies lies striking a balance between a coarseness of the elements, so that the mesh is suitable for a high-order discretisation, whilst accommodating the curvature of the geometry near the boundary, so that the resulting mesh is valid and can be used in a solver. During my time at Imperial I have been involved in a number of projects that lie in this area, with both the collaborators named above and in supervising various postgraduate projects. These interactions have lead to the gradual creation of a mesh generation program, *NekMesh*, which encapsulates the entire high-order mesh generation process: from interfacing to a CAD engine, surface meshing through a curvature-based refinement strategy, through to boundary layer and volume meshing. By interfacing with a number of different input and output formats, *NekMesh* represents an evolution in the current level of high-order mesh generation capability. This software therefore has the potential to greatly ease the burden of the generation procedure, thereby increasing the usability of high-order methods.

However, before *NekMesh* can be made available, a number of small but important tasks need to be completed to finalise its release and wider dissemination. The purpose of this project is to finalise a number of these 'loose ends' in the following areas:

- **Finalising algorithmic developments:** One of the most recent developments is the creation of a novel variational framework for mesh optimisation, which performs the key step of correcting invalid elements in the mesh after the curvature of the boundary has been applied. A proof-of-concept of this technique has been implemented and recently presented as a conference proceeding. This project will complete this work for more complex hybrid meshes of more than one element type and look towards additional implementations on different hardware types through the use of the Kokkos library.

- **Package generation:** Until now, *NekMesh* has remained fairly firmly embedded within the *Nektar*++ framework. One of the goals of this project is to improve the package generation procedure inside Nektar++ so that a separate *NekMesh* package can be created and disseminated amongst the wider academic and industrial communities. It is also anticipated that this will improve the ability of other *Nektar*++ solvers and utilities to be disseminated in a similar fashion.

3 Alignment with PRISM strategy

- **Retention and development of key staff:** I am one of the senior developers of the *Nektar*++ framework and am currently involved in supervising a number of developments in this area. One of the aims of this project is, together with an EU Horizon 2020 project on which I am a work package coordinator, to provide a bridge in funding between my current position and my appointment as a lecturer at the University of Exeter, due to start in March 2017. Alongside the tasks set out in this document, this bridge funding will allow me time to further develop or conclude these additional projects which are of significance to the development of the *Nektar*++ framework.

- **Supporting long-term research:** *Nektar*++ and furthering the use of advanced finite element methods for various application areas both form a key part of my plans for future academic work and my new position at Exeter. This project will

therefore allow me to establish firm collaborations with the members of the PRISM group as I transition to my new role.

- **Collaboration with other PRISM members:** In addition to *Nektar++*, PyFR is another PRISM code being developed by Dr. Peter Vincent and is also based around high-order technology. Mesh generation has already been identified as a significant bottleneck for problems being investigated by this code. We are therefore working with the PyFR team to test meshes being generated by *NekMesh* for use in various PyFR test cases.

4 Brief workplan

- Develop a comprehensive set of example geometries in order to showcase the capabilities of the generator software.
- Finalise the work on the variational optimisation technique and use the geometries above to demonstrate its capabilities for journal publications.
- Improve package management for *Nektar++* to support the creation of standalone packages for *NekMesh*. In particular, significant development of the underlying CMake build system will be made to simplify package creation across major architectures.
- Create a website to support community engagement and on which to publish the *NekMesh* package.
- Write and submit a journal publication, targetted in *Comp. Phys. Comm.*, to both advertise *NekMesh* and show academic accomplishments of the overall project.