Fusion Engineering and Design 83 (2008) 1025–1033

Contents lists available at ScienceDirect

Fusion Engineering and Design

journal homepage: www.elsevier.com/locate/fusengdes

Computational thermo-fluid exploratory design analysis for complex ITER first wall/shield components

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ARTICLE INFO

Article history:
Available online 7 October 2008

Keywords:
ITER
Plasma facing components
First wall
Shield
Computational fluid dynamics
Neutronics
Thermal stress
Finite element method

ABSTRACT

Engineers in the ITER US Party Team used several computational fluid dynamics codes to evaluate design concepts for the ITER first wall panels and the neutron shield modules. The CFdesign code enabled them to perform design studies of modules 7 and 13 very efficiently. CFdesign provides a direct interface to the CAD program, CATIA v5. The geometry input and meshing are greatly simplified. CFdesign is a finite element code, rather than a finite volume code. Flow experiments and finite volume calculations from SC-Tetra, Fluent and CFD2000 verified the CFdesign results. Several new enhancements allow CFdesign to export temperatures, pressures and convective heat transfer coefficients to other finite element models for further analysis. For example, these loads and boundary conditions directly feed into codes such as ABAQUS to perform stress analysis. In this article, we review the use of 2- and 4-mm flow driver gaps in the shield modules and the use of 1-mm gaps along the tee-vane in the front water header to obtain a good flow distribution in both the first wall and shield modules for 7 and 13. Plasma heat flux as well as neutron heating derived from MCNP calculations is included in the first wall and shield module analyses. We reveal the non-uniformity of the convective heat transfer coefficient inside complex 3D geometries exposed to a one-sided heat flux and non-uniform volumetric heating. Most models consisted of 3–4 million tetrahedron elements. We obtained temperature and velocity distributions, as well as pressure drop information, for models of nearly exact geometry compared to the CATIA fabrication models. We also describe the coupling to thermal stress analysis in ABAQUS. The results presented provide confidence that the preliminary design of these plasma facing components will meet ITER requirements.

1. Introduction

The US ITER project team is responsible for the detailed design and fabrication of 360 first wall panels and 90 shield modules for ITER identified as modules 7, 12 and 13. During the last 2 years, researchers at Sandia National Laboratories performed a considerable amount of work on the conceptual design of these components as well as the integration of finite element (FEM) computational tools to implement a comprehensive “design by analysis” strategy shown in Fig. 1. In this strategy, FEM results from CFD, MCNP and E&M codes are used to determine the temperature, pressure and force loadings for use in the FE stress analysis code, ABAQUS [1–3]. Table 1 shows the FEA codes used, and Fig. 2 depicts the integration of these codes into a design suite by the development and use of in-house file translation routines also listed in Table 1.

In this article, we focus on the integration of fluid dynamics into this overall endeavor. A finite element CFD code, CFdesign, developed by Blue Ridge Numerics, Inc. (BRNI), provided the capabilities required for detailed analysis of large, complex 3D models. To achieve this end, BRNI provided CFdesign with several after-market enhancements at Sandia’s request. In addition, Sandia developed a number of post-processing translators to improve the interconnectivity of CFdesign with the other codes listed in Table 1. One of our translators permits the mesh, temperature and pressure loadings to be transferred into Abaqus in Abaqus input file format [4]. The CFdesign code incorporates direct geometry input from CATIA v5 CAD program used for the mechanical design of all ITER components [5]. CFdesign creates a FE model by performing meshing directly on the CAD geometry through the CATIA geometry kernel. The internal mesher only generates linear tetrahedral elements; however, CFdesign can import an external mesh of linear hexahedral

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[1] Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy’s National Nuclear Security Administration under Contract DE-AC04-94AL85000.

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doi:10.1016/j.fusengdes.2008.08.013

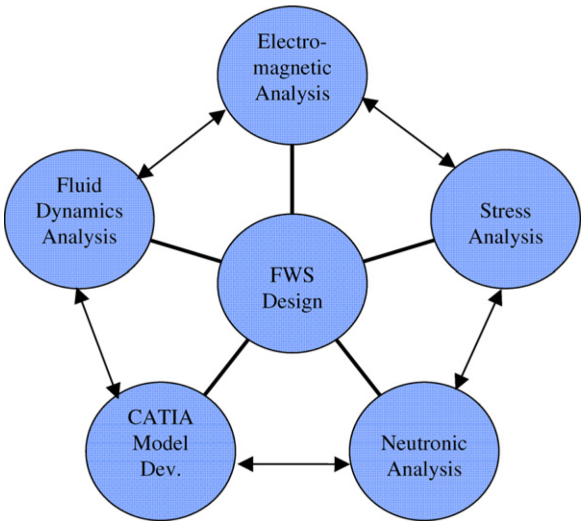

Fig. 1. "Design by analysis" exploits the power of computer-aided design/computer-aided engineering (CAD/CAE) to produce a design that satisfies all the design criteria from multiple disciplines.

Table 1
Analysis codes and translators

Code name	Discipline	File formats	Sandia translators
CFdesign, v9.0	CFD, TH	unv, fld, CATx	Unv2Abq
SC/Tetra, v4.0		sat	
CFD2000, v5.2		iges	
Fluent, v6.2		sat	
Opera 3-d, v11.1	E&M	unv	Unv2Abq, Forces2Abq, Unv2CFdesign
Abaqus, v6.2	TS, M	inp	Abq2FV
FieldView, v11.2	Visualization	fld	FV2Abq, FV2Unv
Catia, v5.1 R16	CAD	CATpart, CATproduct	

elements as an IDEAS universal (unv) file. The user must input the boundary and initial conditions, as well as material properties, in the CFdesign GUI to complete the model. By using the 64-bit version of CFdesign, we are able to perform analyses on very large models with many millions (3–8 million) of elements with no memory limitations. Results from standard CFD benchmark problems and from flow experiments provided comparisons between CFdesign and finite volume codes such as Fluent, SC/Tetra and CFD2000.

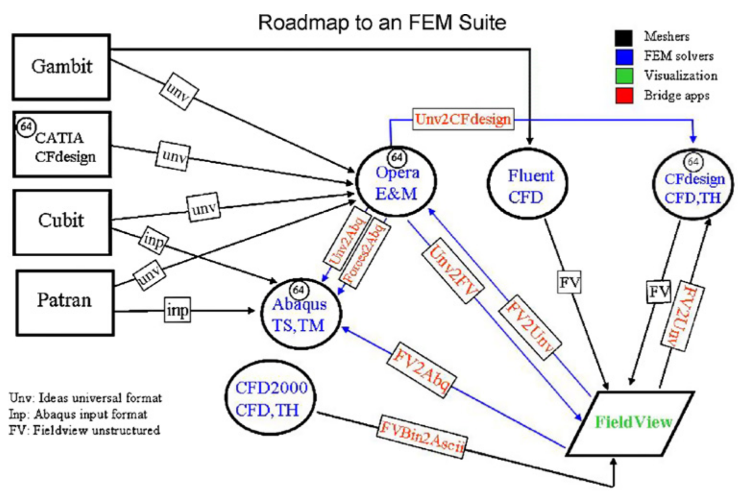

Fig. 2. Bridging routines can create an FEM suite from a dissimilar set of "best" in-house FE codes.

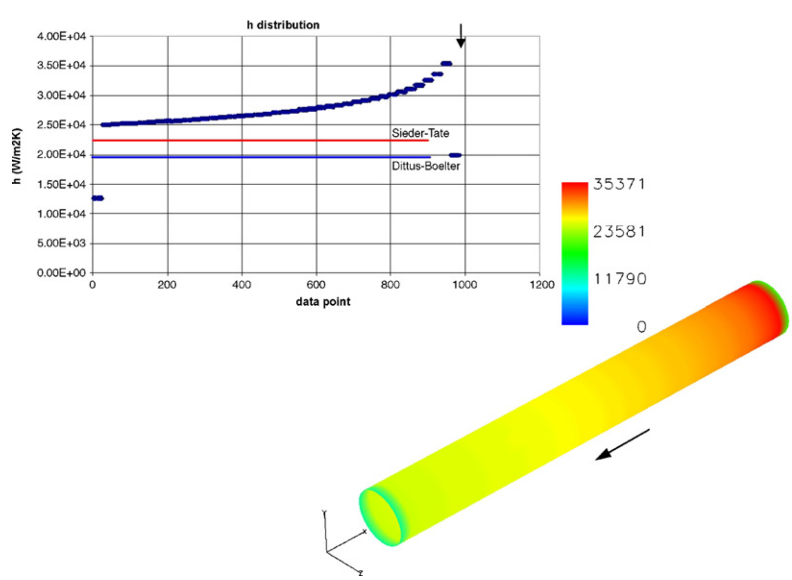

Fig. 3. A comparison of CFdesign computed convective heat transfer coefficients with those from classical correlations for sub-cooled forced convection show good agreement for fully developed conditions.