A 10-minute Introduction to Eilmer

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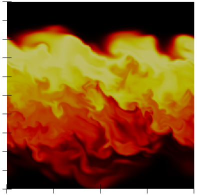
About Me

- BE in Mech/Space Engineering, UQ (2010-2013),
- PhD in Hypersonics, UQ (2014-2019)
- Postdoctoral Research Fellow, UQ (2020-Present)

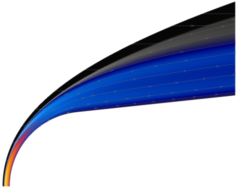
Things I do:

- The Gasdynamic Toolkit (github.com/gdtk-uq/gdtk)
- ceq: A lightweight Equilibrium Chemistry Calculator (github.com/uqngibbo/ceq)
- Simulations:

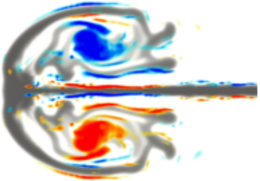
Supersonic Combustion



High Temperature Flows



Compressible Turbulence



Eilmer: An open-source hypersonic multi-physics solver

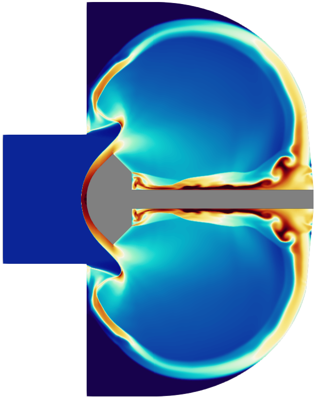
Eilmer is our high-speed flow research simulation code

- Developed at UQ by Rowan Gollan, Peter Jacobs, Kyle Damm, and me!
- Used for re-entry flows, combustion research, compressible flow physics

Features:

- Free and open-source
- Parallel scaling to thousands of cores
- Build your own grids or read them in
- Extensively validated against hypersonic experiments

Website: `gdtk.uqcloud.net`
Paper: `doi.org/10.1016/j.cpc.2022.108551`

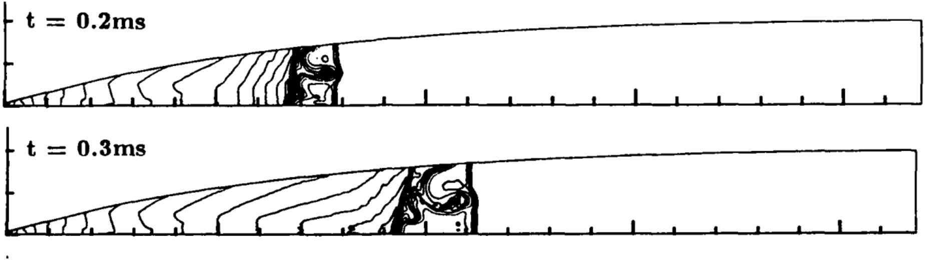


Hayabusa Aeroshell scale model in X2, by Peter Jacobs

Eilmer: A quick history

Some parts of the code go back a long way:

- CNS4u: Single block Navier-Stokes integrator by PJ for ICASE (1991)
- MBCNS: Multi-block version, C and custom command script (1996)
- Elmer: Hybrid code using C and Python (2004)
- Elmer 2: Back to plain C (2005)
- Eilmer 3: Massive expansion of codebase, switch to C++ (2008)



Eilmer: The Current Code

June 2015: Eilmer 3 starts to become unmanageably large and problematically old

- Peter Jacobs and Rowan begin porting key routines to D

The D programming language:

- D is a high-level compiled language designed to be a modernised improvement on C++
- Familiar C-like syntax, greatly improved compiler technology
- Resdesigned high level features: Macros, templates, objects, etc.

Eilmer: The Current Code

July 2021: the v4.0.0 tag is commited, our first official release

- Eilmer (previously Eilmer 4) has most of the old capabilities and plenty of new ones
- Grids: Structured (Built-in/GridPro) and unstructured (built-in/Pointwise/SU2)
- Thermochemistry: Cutting edge multi-temperature and chemical kinetics models
- Turbulence: RANS and LES capability
- Time Advancement: Multi-step explicit modes, point-implicit, Jacobian-Free Newton-Krylov

Towards an Eilmer Four Point Zero Release

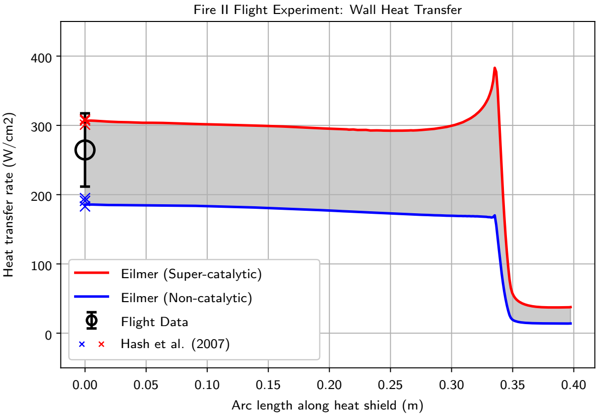
Rowan Gollan, Peter Jacobs, Kyle Damm, Nicholas Gibbons, Daryl Bond

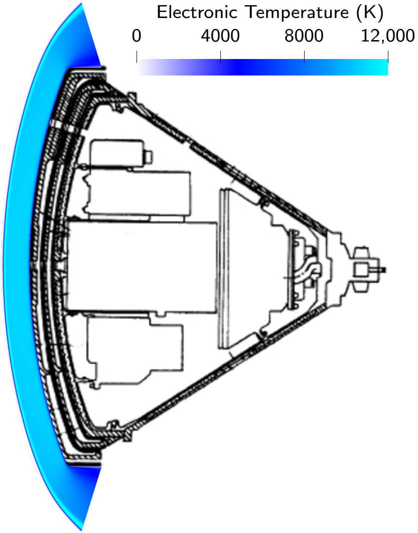
21 January 2021

Things we do with Eilmer: Re-entry Flows

Project FIRE, Flight 2 (May 1965) Validation Exercise:

- Subscale (≈ 1 m) Apollo capsule model at 11 km/s, 71 km altitude
- 2-Temperature, 11 species air reactions by Kim and Jo, (2021)
- Surface chemistry is uncertain, but good match to 1965 flight data

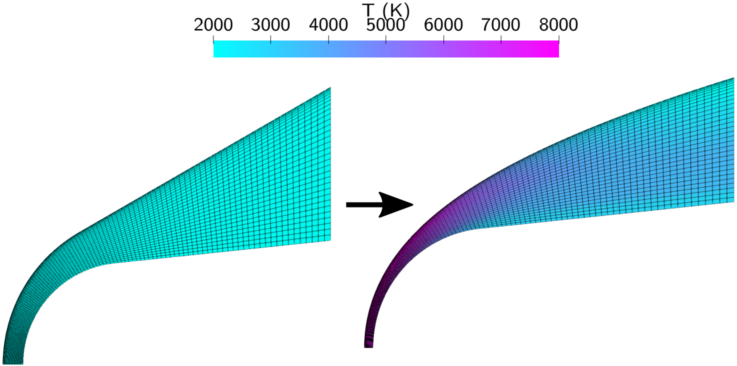




Things we do with Eilmer: Re-entry Flows

Blunt body simulations require a grid to be VERY carefully tailored

- We use automatic shock-fitting to generate initial grids
- Subsequent simulations are static and resolve heat transfer/viscous diffusion etc.



Things we do with Eilmer: Aero Optimisation

Kyle Damm's PhD thesis: Adjoint-based optimsation using CFD

- Adjoint method can compute the gradients of an objective function in one simulation
- CFD solves unstructured grids generated parametrically
- This example shows a simple wedge, parameterised with a 10-point Bezier curve

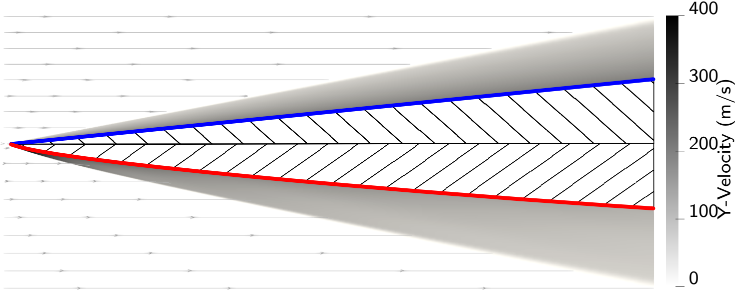
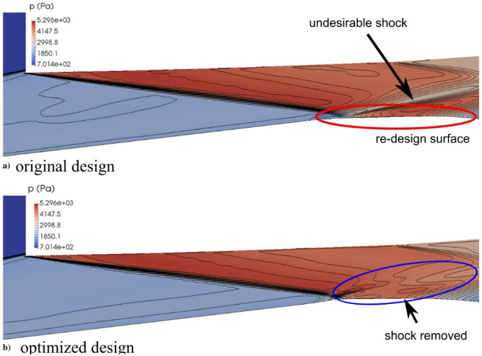
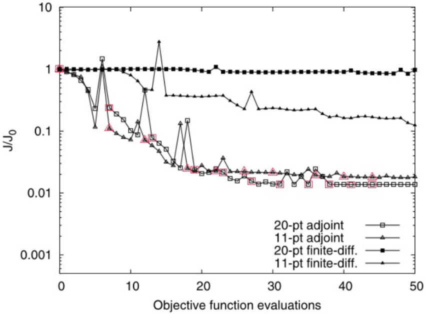


Figure 1: Before (blue) and after (red) axisymmetric wedge subjected to optimisation for minimum wave drag.

Things we do with Eilmer: Aero Optimisation

- We hook into DAKOTA to actually process the sensisitives and move the points
- For non-trivial examples, adjoint makes a huge difference
- P2 Inlet optimsation published in Damm et al. (2020), AIAA (10.2514/1.J058913)

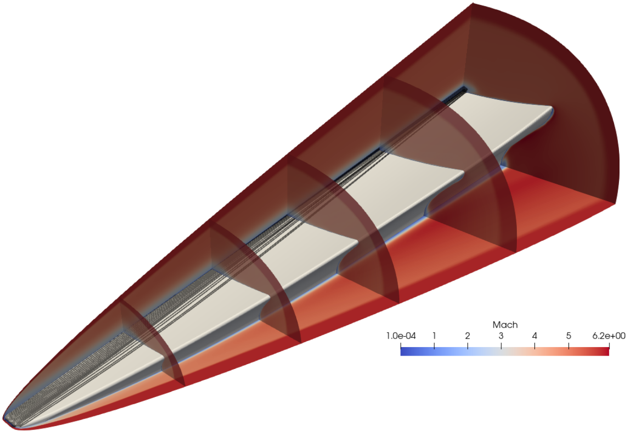




Things we do with Eilmer: Big 3D Flows

Recent progress in the steady-state solver has given us the ability to start doing some big CFD

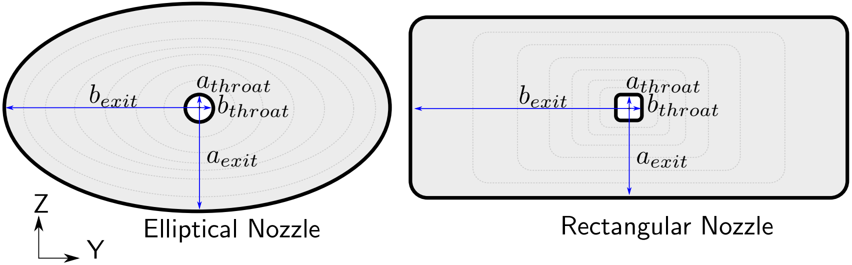
- Supersonic combustion experiments
- Flight experiments (e.g. BoLT-II)
- Shape-transitioning nozzles and inlets



Shape Transitioning Nozzle for Gasdynamic Laser Project

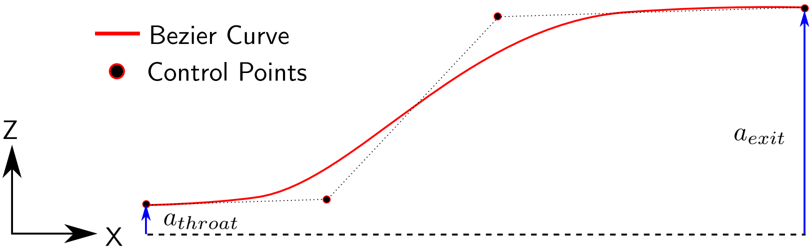
Requirements:

- High area ratio to enhance thermal nonequilibrium
- Circular throat for attachment to TADFA shock tunnel
- Rectangular exit section to accomodate mirrors for lasing



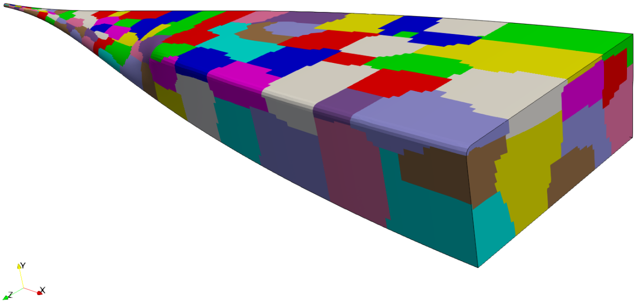
Shape Transitioning Nozzle for Gasdynamic Laser Project

- Growth in Z and Y controlled by Bezier curves with different parameters
- Figure below shows growth of a as x increases, with a similar curve for b
- Both ellipse and rectangular shape use the same initial and final a and b
- Shapes are blended with a hyperbolic tangent function



Shape Transitioning Nozzle for Gasdynamic Laser Project

Nominal Nozzle Shape	
Length	250mm
Throat	2mm
Exit	70mm x 30mm
Area Ratio	≈ 660



Shape Transitioning Nozzle for Gasdynamic Laser Project

Nominal Flow Conditions	
Gas Comp.	100% CO
Stag. Pressure	20 MPa
Stag. Temperature	3000 K
Exit Mach Number	9.7
Exit Temperature	157 K
Exit Vib. Temperature	2047 K