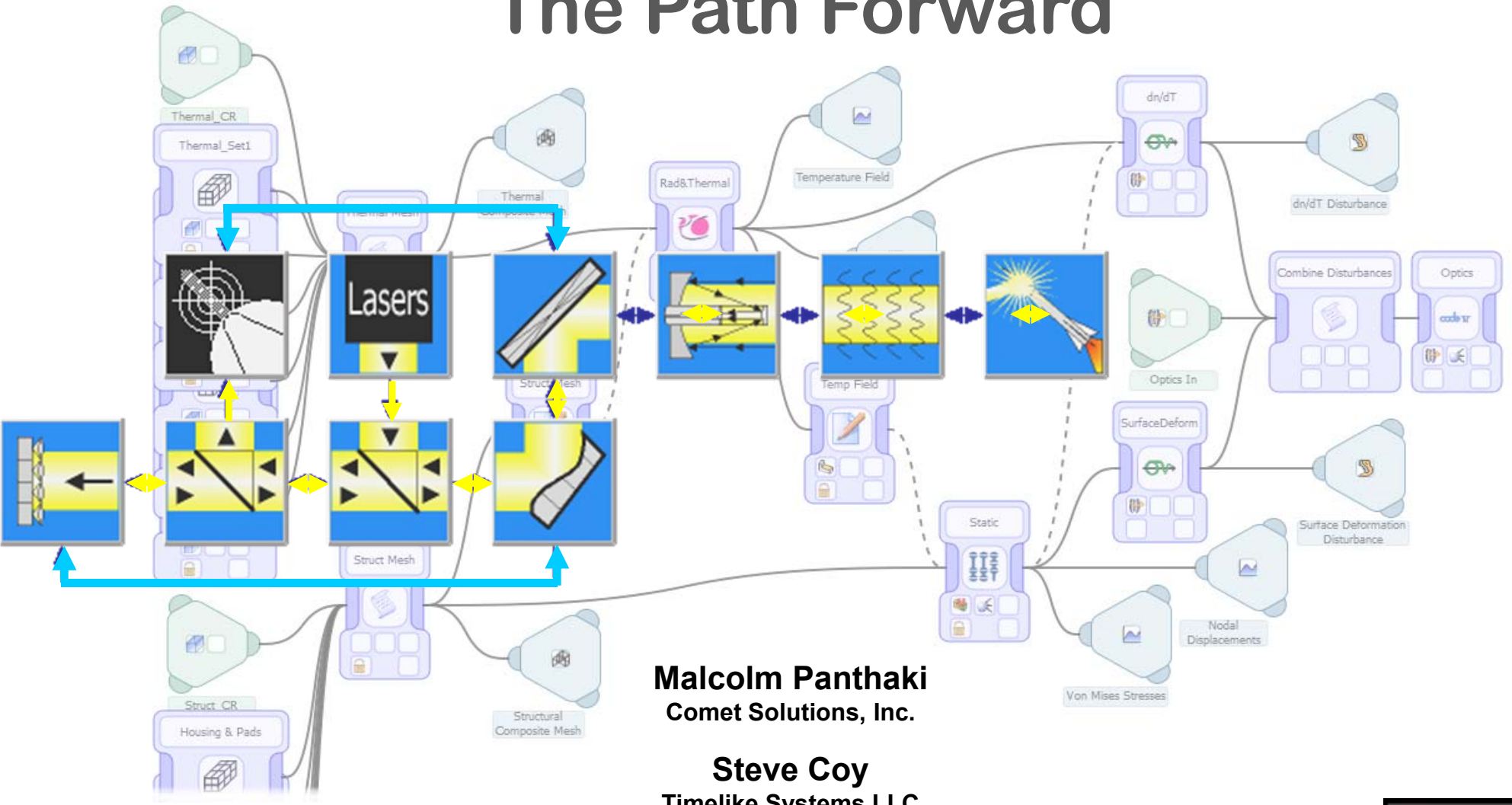
Model-Based Engineering for Laser Weapons Systems

The Path Forward



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Timelike Systems

Motivating *Effective* Systems Engg.

- *1960s-Present:* Focus on getting the physics right
- *Result:* Large number (100s) of highly specialized Sim Tools
- *Result:* Organizational silos formed around particular physics
- *Result:* Highly inefficient, ineffective, and error-prone simulation workflows for the design of complex systems
- *Result:* Systems engineering left in the hands of the "experts", with little or no support from the software environments
- *Result:* Ad hoc simulation data management with little reuse of either the data or processes
- **Result: 3x-5x schedule delays and cost overruns + *Failures***

Model-Based Engineering (MBE) identified by DDR&E as one of four "game-changing" technologies required to meet DoD needs for more rapid, targeted, and cost-effective systems development.

Systems 2020 Final Report

Modeling Capabilities Required for Laser Weapons R&D

- General purpose wave optics simulation
  - WaveTrain, WaveProp, ACS, OSSIM, etc.
- Scaling codes
  - SHaRE & SCALE, HELSEEM, HELCOMES
- Optical design codes: SigFit, Code V and Zemax
- Thermal and Structural finite element analysis codes
  - Nastran, Abaqus, Ansys, Thermal Desktop
- General math tools such as Excel and MATLAB
- Multi-Physics/CFD
  - GASP, COMSOL, Areté
  - Fluent, Star-CD, …

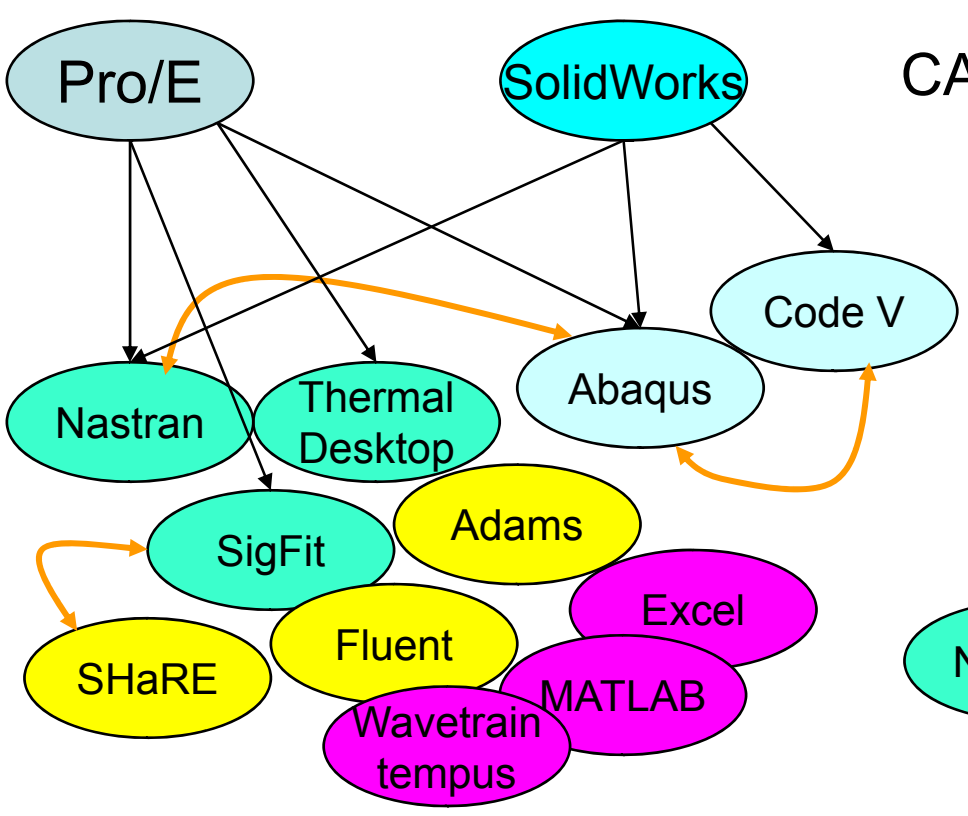
In this “risk reduction experiment” funded by AFRL, we have integrated *WaveTrain* into *Comet*, a COTS MBE framework.

Why Comet?

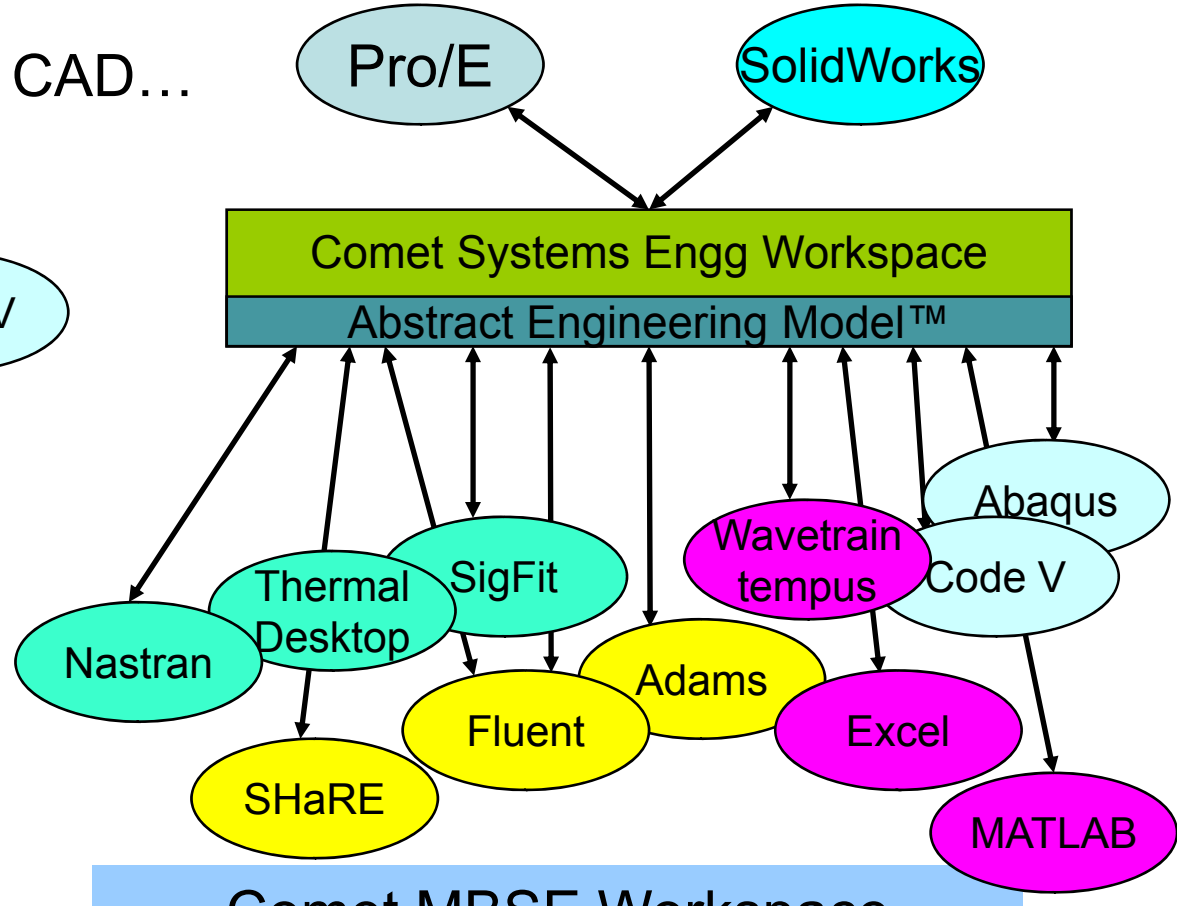
- **Comet: Process + Data, *not* Physics**
- Comet is a tool-neutral, open environment for performing integrated modeling and simulation process automation
  - Capture and easily reuse engineering IP best practices using geometry- and tool-independent templates
  - Reduce manual re-work and errors
  - Ensure that all disciplines/tools work off the same, consistent data
  - Support collaboration across the multi-disciplinary project team
  - Provide easy-to-use decision-support tools
  - Perform more robust trade studies at any desired level of fidelity
  - Maintain an audit trail of project models & results

Federated versus Unified Approaches

Integrating Tools & Data Across All Design Phases



Current Environments
(Federated Approach)



Comet MBSE Workspace
(Unified Data Model Approach)

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“Intelligent” Templates & Abstract Models

Simulation Templates

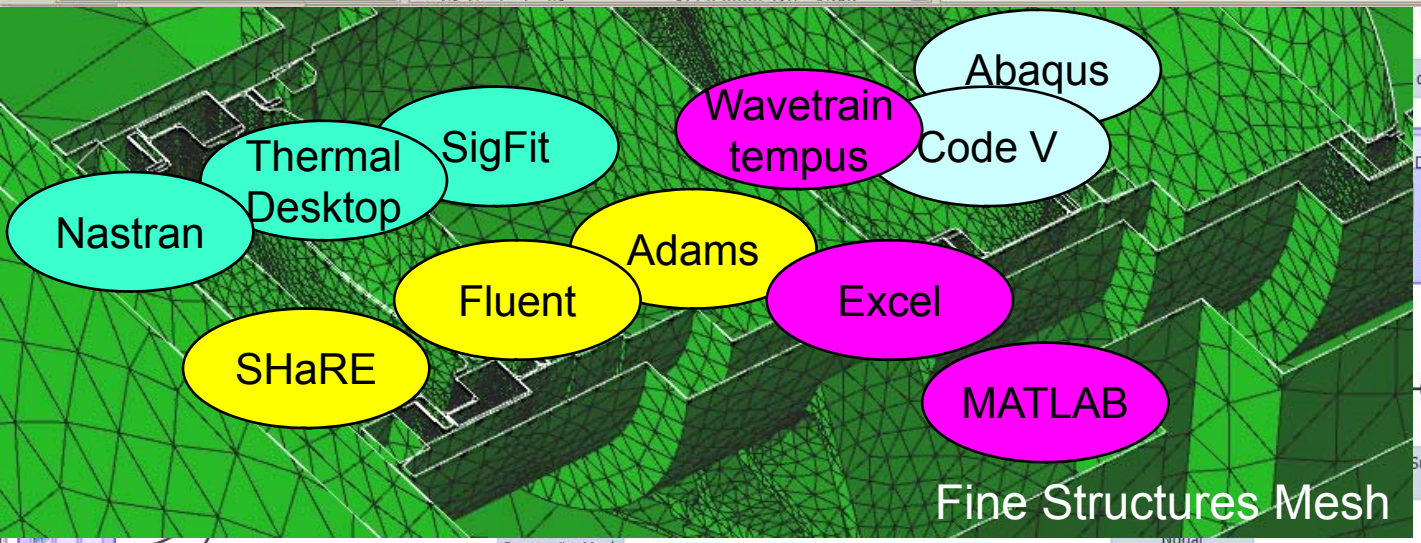
Project Dashboard

Constant	Value
L13-L16:Mass Budget	1.0000 kg

Variable	Value
Contactor06	75.0000 W/m^2*K
Contactor07	75.0000 W/m^2*K
Contactor08	75.0000 W/m^2*K
Contactor09	75.0000 W/m^2*K
Contactor10	75.0000 W/m^2*K
Contactor11	75.0000 W/m^2*K
Heater_L13	1.4600 W
Heater_L16	1.4600 W
Heater_Off	41.1000 degC
Heater_On	40.9000 degC
InitialTemperature	20.0000 degC
Load:L13_PerPad	7.2000 lbf
Load:L14_PerPad	7.0000 lbf
Load:L15_PerPad	3.2000 lbf
Load:L16_PerPad	9.9000 lbf
OBA_Temperature_Bottom	14.0000 degC
OBA_Temperature_Sides	13.0000 degC
OBA_Temperature_Top	14.0000 degC

Requirement	Value
L13-L16:Total Mass	1.0653 kg
Structural:Lenses:L13:Max Displacement	4.964072e-03 mm
Thermal:Temp:L13:Max	36.5390 degC

Metric	Value
Extracted Time	Scalar (ContainedEntity (
L13-L16: Total Mass	1.0653 kg
Structural:Lenses:L13:Max Displacement	4.964072e-03 mm
Structural:Lenses:L13:Max Von Mises Stress	7.429000e+06 Pa
Structural:Lenses:L13:Min Displacement	1.462581e-03 mm
Structural:Lenses:L14:Max Displacement	3.058609e-03 mm
Structural:Lenses:L14:Max Von Mises Stress	6.321000e+05 Pa
Structural:Lenses:L14:Min Displacement	2.374102e-03 mm
Structural:Lenses:L15:Max Displacement	5.430060e-03 mm
Structural:Lenses:L15:Max Von Mises Stress	6.053000e+06 Pa
Structural:Lenses:L15:Min Displacement	3.013111e-03 mm
Structural:Lenses:L16:Max Displacement	4.915143e-03 mm
Structural:Lenses:L16:Max Von Mises Stress	4.952000e+06 Pa
Structural:Lenses:L16:Min Displacement	3.969294e-03 mm
Thermal:IncTemp:L13:Max	scalar (FieldMaximum (
Thermal:IncTemp:L14:Max	scalar (FieldMaximum (
Thermal:IncTemp:L15:Max	scalar (FieldMaximum (
Thermal:IncTemp:L16:Max	scalar (FieldMaximum (



omponent)

Lens-13 (CAD, optics…)
D) for thermal
D) for structural
optics with CODE V
nent) with WaveTrain
s-13 (CAD)

matic Design
ormed Using
Practices

Comet External Adaptors Coverage

3-D CAD	Native Geometry	Pro/E (WF3, WF4)
	Bi-Directionally	Solidworks (2009 SP3.0,2010 SP4.0)
	Associative	NX (6.0)
		SpaceClaim Engineer
	Translated In	CATIA V4 (4.1.9 - 4.2.4)
		CATIA V5 (R2-R19)
		IGES (upto 5.3)
		Autodesk Inventor (6-2009)
		STEP (AP203, AP214)
Physics	Multi-Body Dynamics	MD Adams (2010)
	Optics	CODE V (9.70, 9.80)
		SigFit (2008R1, 2009R1)
		WaveTrain/Tempus (under dev)
	Structures	Abaqus/Standard (6.7-1, 6.10-1)
		Ansys (10.0, 11.0)
		MD Nastran (2010.1)
		NX Nastran
	Thermal	Thermal Desktop (5.2, 5.3,5.4)
	Fluids	Fluent
Calculators	Spreadsheet	MS Excel (2003, 2010)
	Math-Based	MATLAB (R2007a, R2010)
Embedded	FE Meshing	Simmetrix GeomSim Suite
Toolkits	CAD/CAE Visualization	VTK
	Web-based Viewing	*Vcollab*
Ext Services	DOE/Optimization	Isight, ModeFrontier, ModelCenter
	Robust Design	Ontonix OntoSpace
	Vertical Apps	EASA
Specialty/	Circuit Simulation	Proprietary code @ Sandia Nat. Labs
In-House	Electromagnetics	Proprietary code @ Sandia Nat. Labs
	Weapons Analysis	Proprietary inhouse codes

COTS Adaptors- Supplied and Maintained by Comet

Planned for future releases

Comet templates called in background “batch mode”

Developed in the past; Not currently maintained

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Customers & Applications

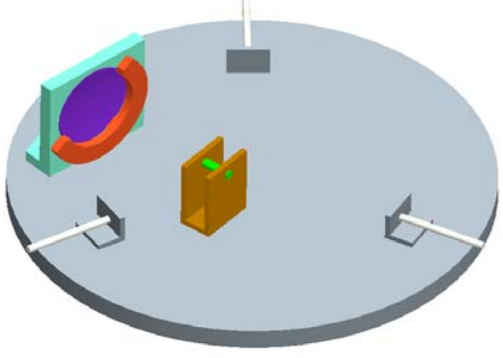
	Industry	Physics Domains	Application of Comet in Product Design/Development
THE AEROSPACE CORPORATION	Aero & Defense	CAD/Structural/ Thermal/Optical	Classified satellite with Sandia Labs; Mid-wave Spectrometer Project
MIT Lincoln Laboratory	Aero & Defense	CAD/Structural/ Thermal/Optical	Classified military satellite program
NASA Langley	Aero & Defense	CAD/Structural/ Thermal/Optical	CLARREO commercial satellite program
NASA Kennedy	Aero & Defense	CAD/Thermal	Next generation space shuttle
Air Force Research Lab	Aero & Defense	CAD/Structural/ Thermal/Optical	Directed Energy program/High Energy Laser (HEL)
JOHN DEERE	Off-Highway	CAD/MBD Structural	Agriculture and forestry equipment and harvesters
GENERAL DYNAMICS Strength On Your Side	Military Vehicles	Concept Eng/ In-House/MBD	Mobility performance of military tracked vehicles
YTO	Off-Highway	CAD/Structural	Agricultural equipment in China
CNR	Off-Highway	CAD/Structural	High-speed rail locomotive in China
Whirlpool	Consumer	Excel-based Concept Design	Refrigerator cooling systems

Comet Statistics For This Project

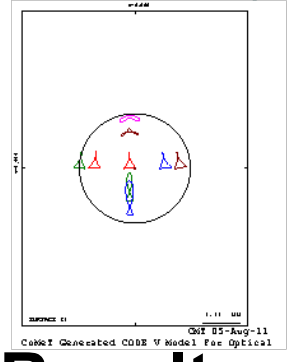
- Analysis process set up by one engineer; run on one computer
  - Still requires input/review from discipline experts, doesn't eliminate this need
- Process and tagging take the most time to set up
  - < 1 week assuming dedicated team
  - Start out with simplified analysis assumptions to verify process
  - Iterate between CAD tagging and process until desired results obtained
- Full STOP analysis runs in ≈ 30 minutes
- Re-running analysis with new geometry dependent on how fast CAD and tagging can be completed
  - Example: Adding tie rods, adding CPC entrance geometry, updating sequence file and rerunning completed in ≈ 8 hours

≈ 8 hours

Original System



Detailed System



Results

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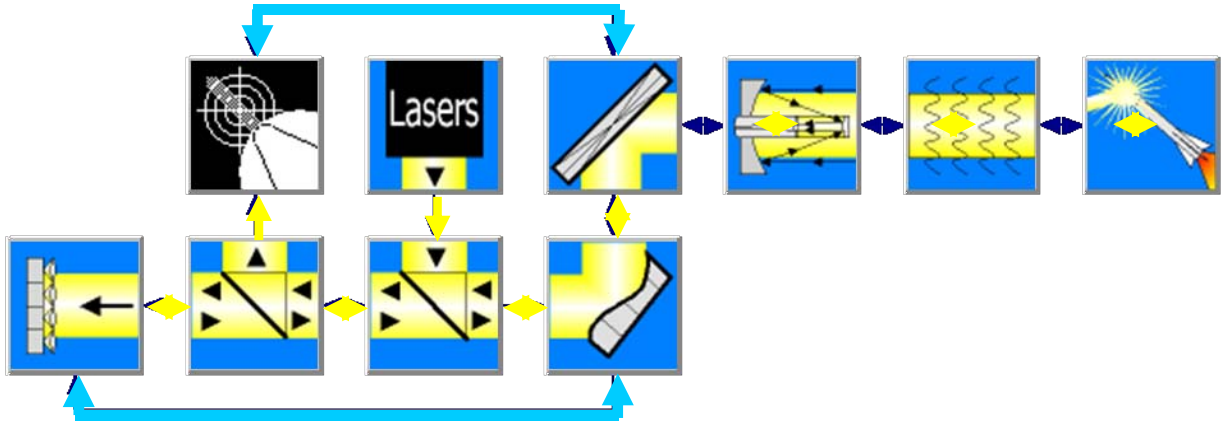
WaveTrain & Tempus

- **Tempus: General-purpose systems engineering simulation within a user-friendly connect-the-blocks visual framework**
  - Multidisciplinary, multi-fidelity modeling and simulation
  - Ability to create/use any arbitrary types of system components
  - Customize the behavior and interactions of each type of system component
  - Connect smaller systems to create larger systems; break larger systems into smaller systems. Cut and paste components and assemblies from one model to another.
  - Works the way engineers naturally think about systems

- **WaveTrain: Wave Optics simulation toolkit within Tempus**
  - Toolbox of reusable components providing high fidelity modeling of optical systems and effects
  - Used for modeling laser resonators, beam control systems, propagation through turbulent media, novel sensors and algorithms, and effects
  - Used in combination with other tools (structures, thermal, CFD, etc.) to capture all the physical effects impacting optical system performance.

Why WaveTrain?



- First integration of a wave optics code into Comet.
- Especially stressing test case for Comet.
  - WaveTrain is highly flexible and extensible.
- Identify “showstoppers”.

WaveTrain: Physics
Comet: Process + Data

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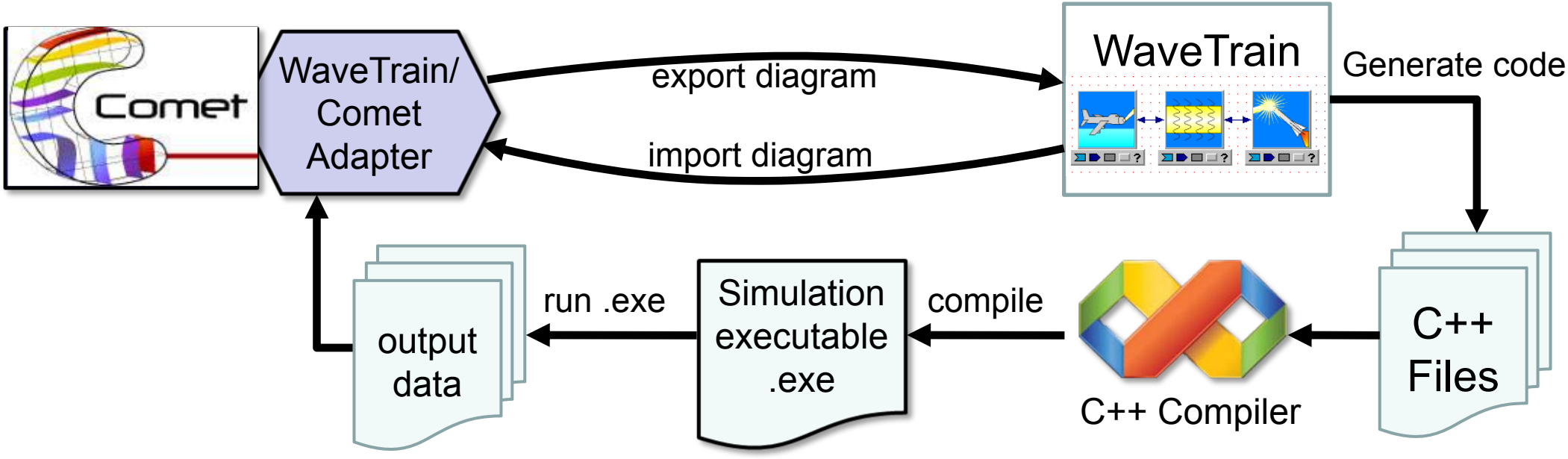
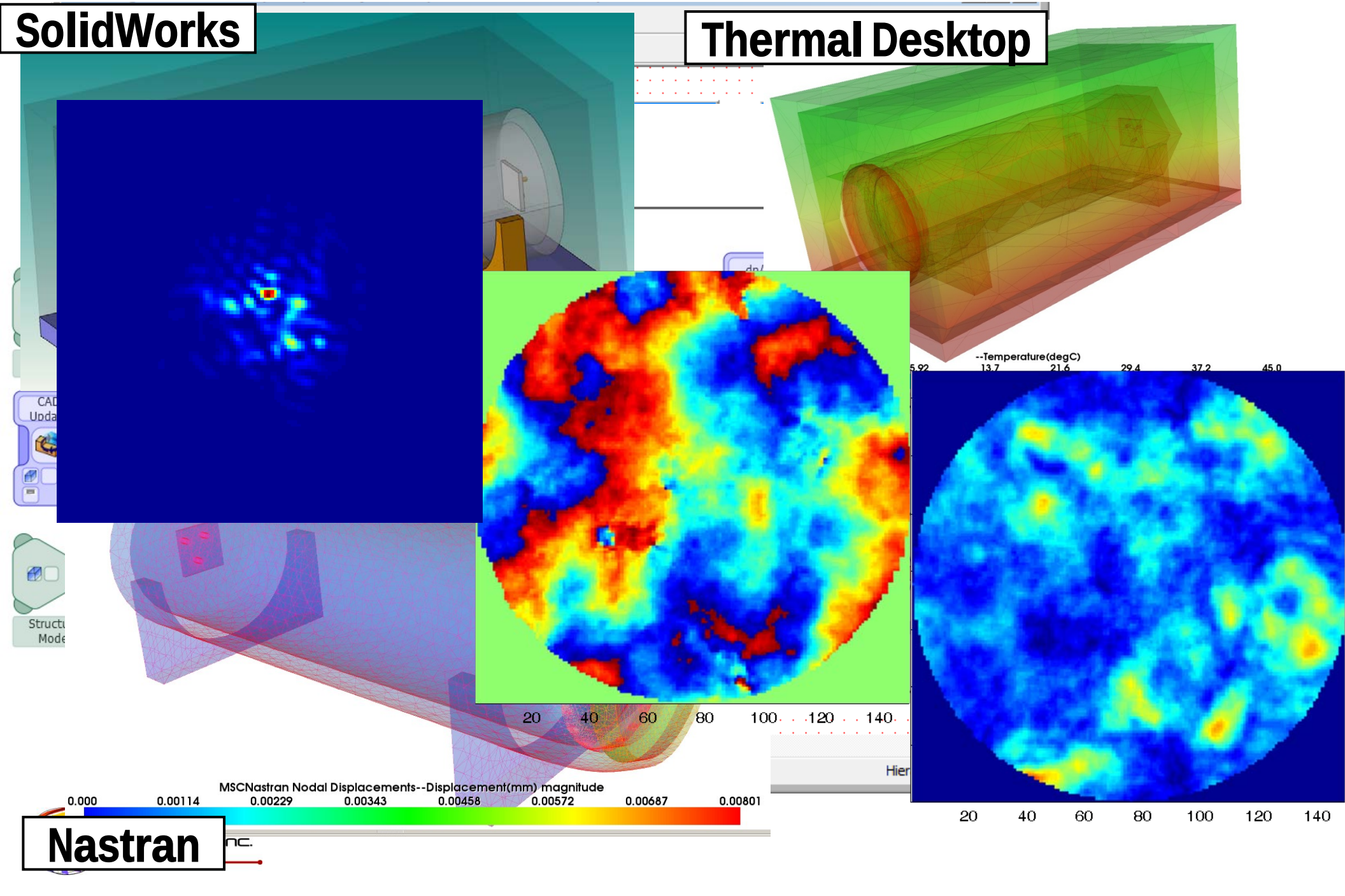
Integrating WaveTrain into Comet



Major Tasks:

- Import WaveTrain block diagrams into Comet data model.
- Export block diagrams from Comet to WaveTrain
- Invoke tool chain: (generate C++, compile C++, run executable)
- Import result data into Comet

Test Case: Comet + WaveTrain



Conclusions

- WaveTrain can be integrated into Comet.
- No “showstopper” problems encountered.
- Some challenges encountered and overcome.
  - Some API issues: first adaptor developed outside Comet Solutions.
  - Adaptors can take ~1-6 man-months depending on the complexity of the data.
- Next Steps:
  - Enhance WaveTrain adaptor for production use.
  - Implement adaptors for other DE modeling tools.

Comet and WaveTrain/Tempus have the potential to be an effective MBE tool for the rapid design and validation of complex optical systems such as directed energy laser weapons.

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Comet+WaveTrain Software Demonstration