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Model Validation of a Structure Subjected to Internal Blast Loading

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V&V/UQ: Ideal versus Reality

Ideal:

- Customer critically concerned about V&V/UQ.
- Unlimited time.
- Unlimited computational and experimental budget.
- In-depth access to and knowledge of simulation codes.
- In-depth knowledge of all uncertain parameters.

Product:

- V&V/UQ studies provide broad and deep understanding of simulation credibility.
- Quantified uncertainty on all code predictions.

SNL V&V/UQ Efforts

Research:

- Create mathematically and statistically rigorous V&V/UQ methods.

Applications:

- Find the right balance of V&V/UQ “ideal” and “reality” that meets the needs of the customer.

Reality:

- Customer (sometimes) indifferent to V&V/UQ.
- Short/limited time schedule.
- Finite budget for simulations and experiments.
- Code access and knowledge varies greatly (especially for commercial codes).
- Vague knowledge of some/all uncertain parameters.

Product:

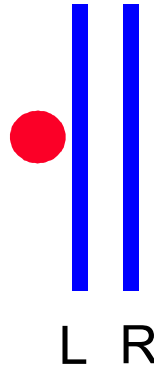
- V&V/UQ-informed assessment of simulation credibility (might be only partially complete).
- “Best estimate + uncertainty” on all code predictions
 - on-time and on-budget for customer

Outline

- **Ideal vs. realistic V&V/UQ approach**
- **Physics of blast-structure interaction problems**
- **High performance computing challenges and scaling**
- **One-way coupling procedure for blast-structure interaction problem and test data**

Capability Challenge—Blast/Structure Interactions

- The computational demands of predicting damage to **thin, shell-like** targets often **exceeds available resources**
- *No one numerical method can economically model the wide range of length scales typical of a blast against a large thin-walled structure.*



Left



Right

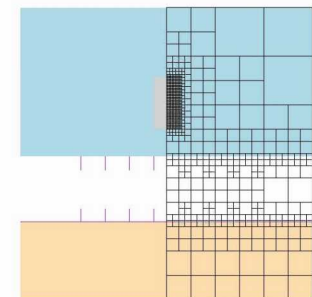


Fragments & Tearing

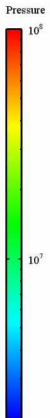


Weld Failure

SNL Standoff Study



Time = 0.00 ms



Analysis Code Descriptions

CTH

- Time step controlled by thickness
- Billions of cells are required
- Failure models are limited
- Air and explosive shocks captured
- Air blast inside structure captured
- Spall can be captured
- Fragments tracked

Too Costly

PRONTO3D

Shell elements

- Through thickness time step requirement eliminated (larger time step)
- Limited tearing and/or failure model
- Blast not modeled directly
- Pressures inside structure not captured
- Shock not captured
- Spall not captured
- Fragments deleted
- Very fast to run

Blast not modeled

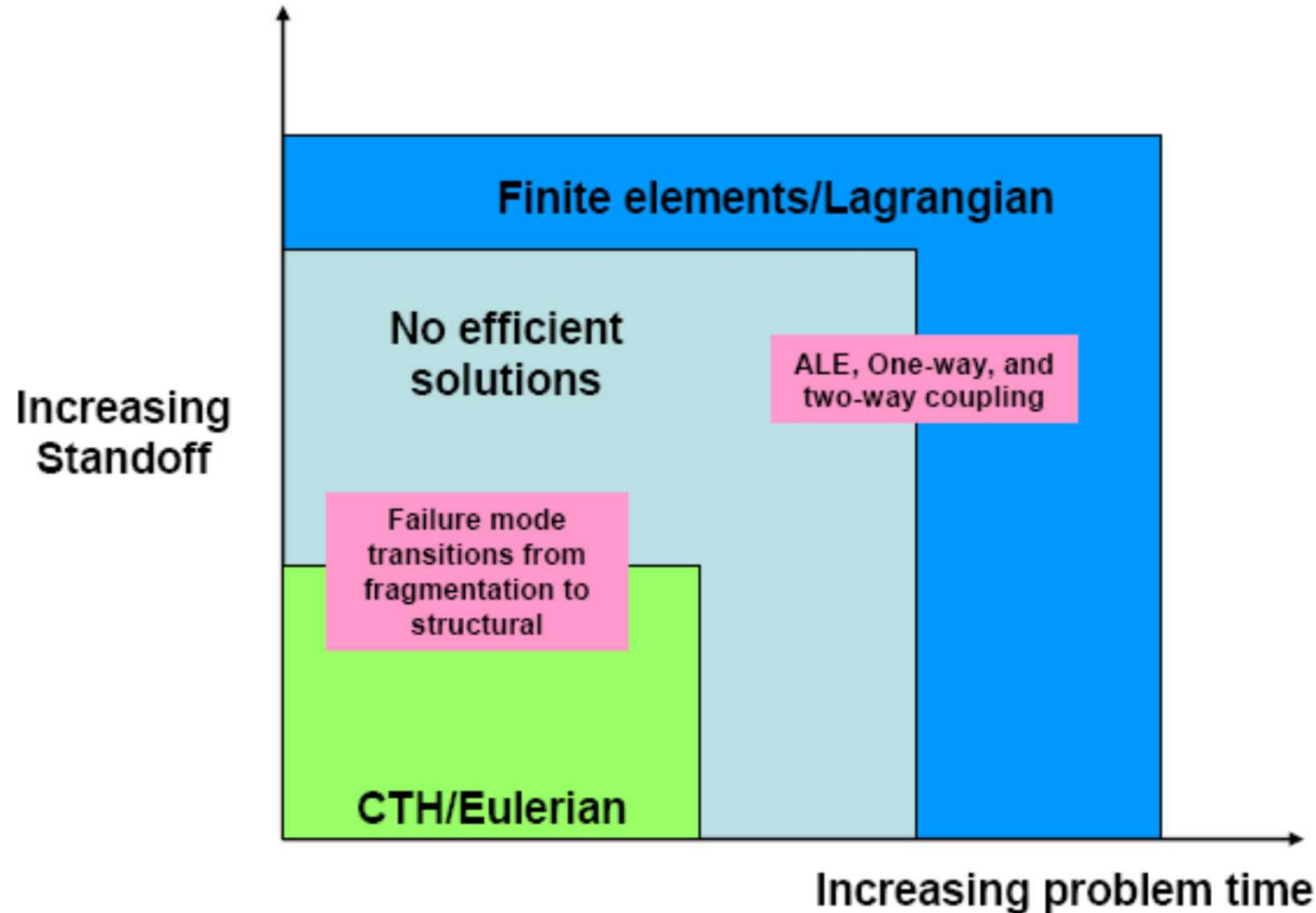
One-way coupling:
Works well, provided
blast wave does not get
inside structure

Pressures

Two-way coupling:
Does not work with
shells

No shells

Computational Regimes



Computational Regimes

- **Regime 1: small standoff – early time (fragmentation).** CTH is largely accepted as the model of choice provided region of interest is small.
- **Regime 2: small standoff – late time structural failure:** CTH can possibly handle this but computationally become very intense. A CTH handoff to PRONTO3D is likely a workable method
- **Regime 3: Intermediate standoff (Combination of fragmentation and structural failure with internal blast pressures)**
- **Regime 4: Large standoff – early structural failure before blast wave has passed.** One-way coupling may work here provided that pressures are collected on the front and back of the surface.
- **Regime 5: Large standoff – late structural failure.** FEM is likely model of choice but the gray area is the definition of “large standoff”. Blast pressures will need to be supplied.

Doable
3

Hard
4

Impossible?
5

Hard
4

Doable
3

Necessary Resolution for Representing Phenomena in Eulerian Shock Physics Codes



Physics Feature	Resolution			
	Minimum	Low	Medium	High
	1 to 2 cells	3 to 5 cells	5 to 7 cells	7 to 15 cells
Air shock	yes	yes	yes	yes
Blast impulse	some	yes	yes	yes
Through thickness shock	no	some	yes	yes
Fragmentation	no	no	some	yes
Debris tracking	no	no	some	yes
Spall	no	no	some	some
Ductile tearing	no	no	no	some
Bending strength	no	no	some	yes
Welds	no	some	some	yes
Blast pressures inside structure	some	some	yes	yes

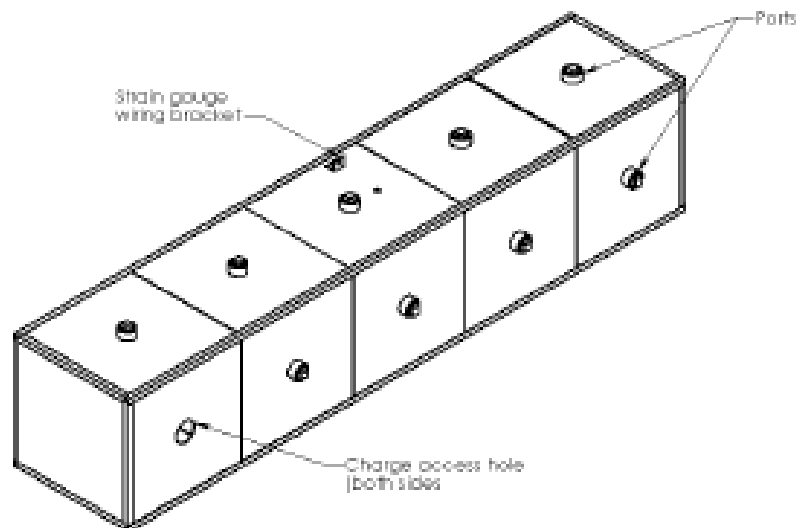
- Isotropic material response and representative physics resolution
- Necessary resolution conditions, but not sufficient conditions
- Accurate models for each feature are required to capture necessary physics
- Assumptions should be validated and are problem dependent

Run Time Estimates for Eulerian Shock Physics Example Problem



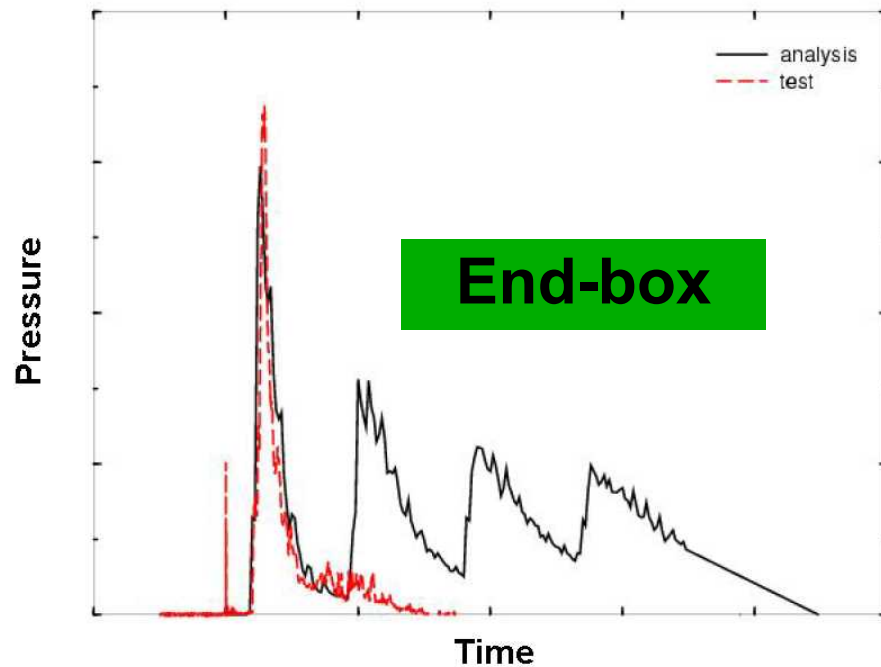
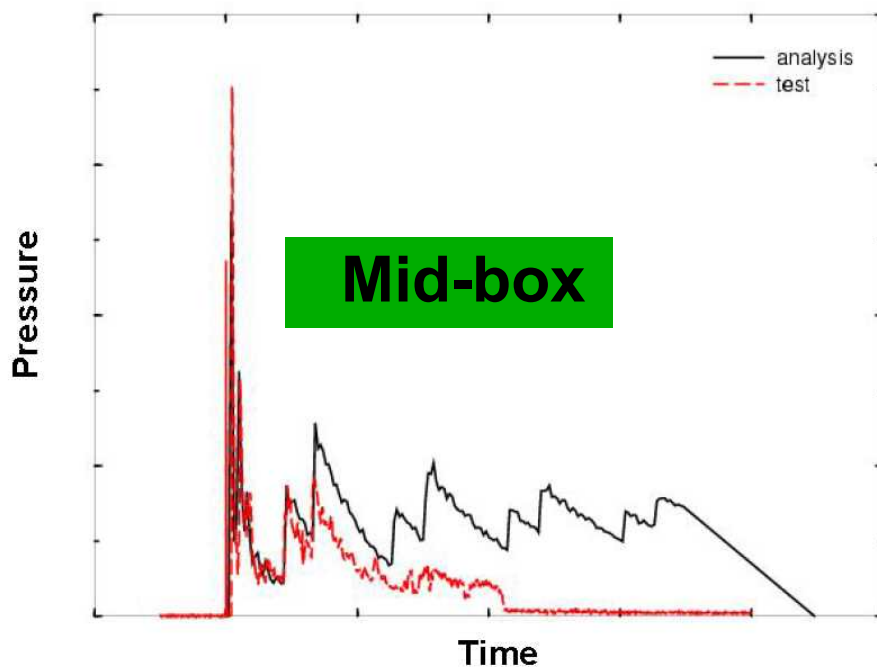
Wall-to-cell thickness ratio	7.0	3.5	1.7	0.9
Cell thickness (cm)	0.027	0.054	0.11	0.22
Blocks	11000000	2750000	500000	64000
Steps	80000	40000	20000	10000
Processors	10000	10000	5000	1000
Blocks/processor	1100	275	100	64
CPU time (days)	257	32	6	2
Physics resolution	Air shock, Fracture, through thickness shock, spall, ductile tearing, bending strength	Air shock, Fracture, some bending strength features, some tearing	Air shock, blast impulse	Air shock and impulse dependent on mixed cell numerics, numerical fragmentation by interface tracker

Blast Experiments at SNL



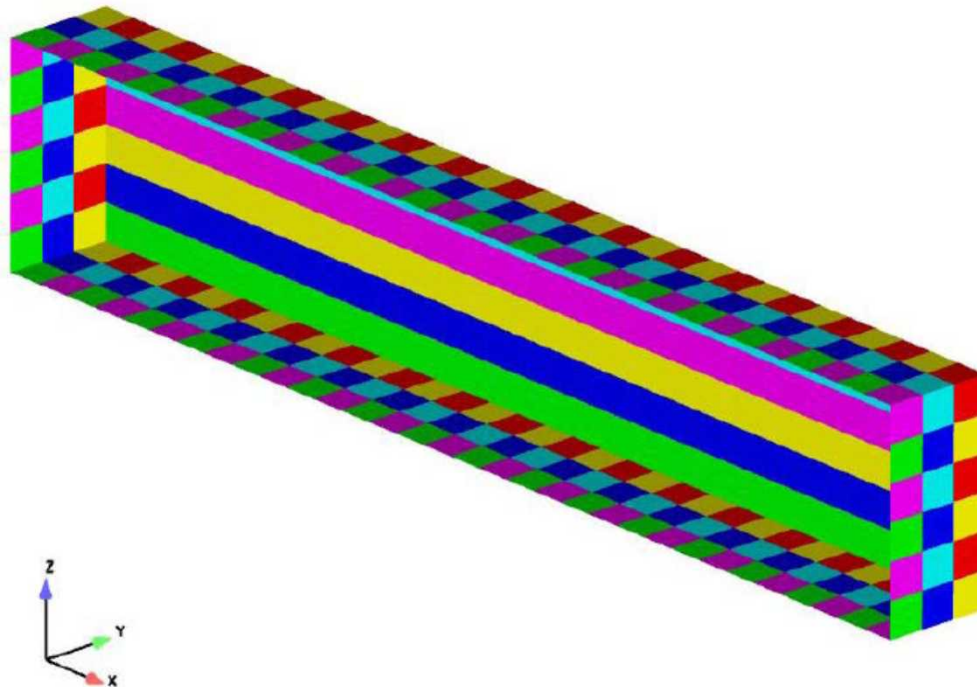
- Economically assess structural response and provide data for engineering model assessment
- Use simplified welded steel box structure
- State-of-the-art data collection and photometric coverage
- Modeled with one-way coupling scheme

Measured and Predicted Pressures



- One-of-a-kind, costly experimental test compared to more cost-effective simulations
- “Good” comparison between model and test in primary wave characteristics
- Engineering judgment used to approximate experimental and model uncertainty
- Computational results provided pre-test; insufficient budget for rigorous V&V/UQ

One-way coupling method

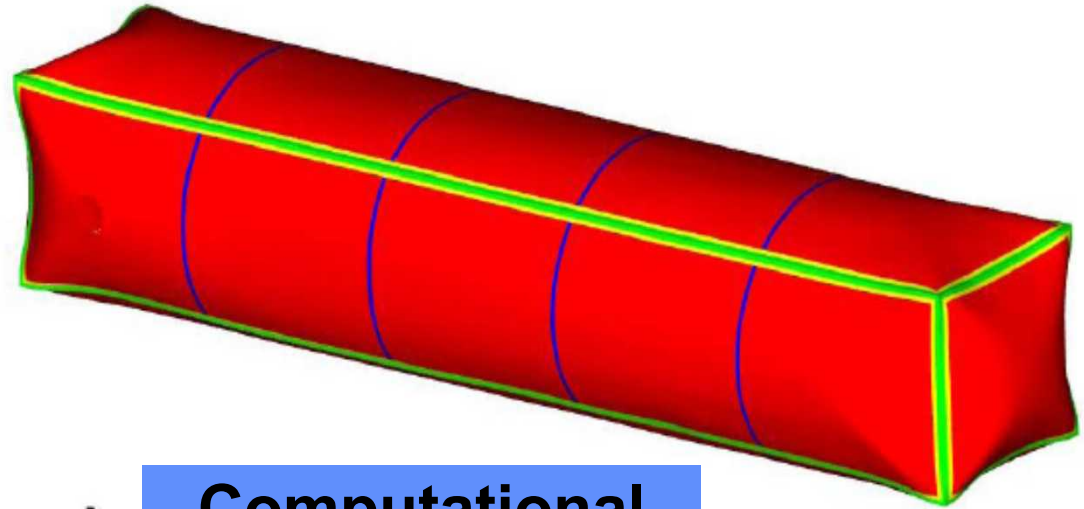


- Local pressures harvested in CTH and spatially averaged
- Pressure-time histories passed to PRONTO3D
- Structural response predicted with PRONTO3D

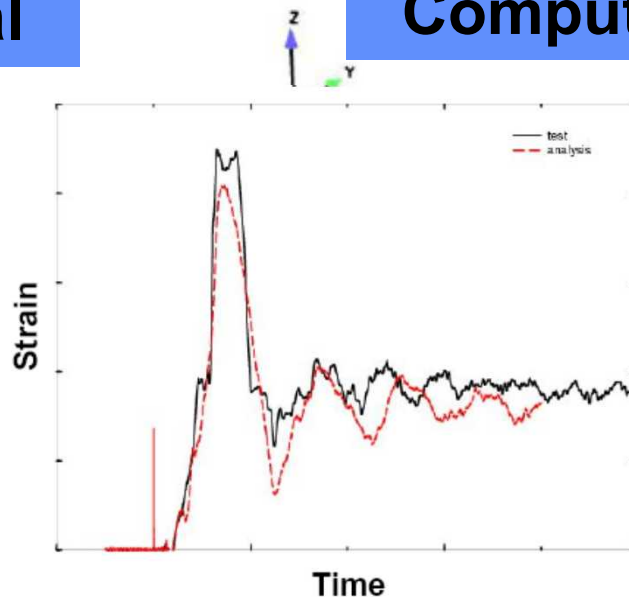
Structural Deformation



Experimental



Computational



Conclusions

- **Test and analysis presented to provide “best estimate+uncertainty” for structural design—pressures and strains well predicted**
- **One-way coupling scheme cost-effective method short standoff, late-time response problems**
- **Expensive explosive testing and high performance parallel computing limited scope of ideal model validation**
- **Ongoing research to balance ideal with real requirements to meet customer needs**

Terminology

-
- **Verification** – “Are we solving the equations correctly?”
 - Includes both code verification and solution verification
 - **Validation** – “Are we solving the right equations?”
 - Sufficiency of physics model, uncertainties in experimental and simulation data, bias between model and experiment
 - **Uncertainty Quantification (UQ)**
 - What are the probability distributions on my code outputs, given the probability distributions on my code inputs?
(aleatoric UQ)
 - What are the possible/plausible code inputs? (epistemic UQ)

High Performance Computing Platform Scaling



Once 30 blocks (30000 cells) per processor are active CTH scales well on computing platform

AMR Benefits

- At least a factor of three improvement in performance and memory utilization is achievable for many large problems.
- Order-of-magnitude performance improvement is possible for some problems.
- Dynamic load balancing using RCB (or similar) is essential for good parallel performance.

