Large Scale Cluster Computing for Comprehensive Risk Assessment

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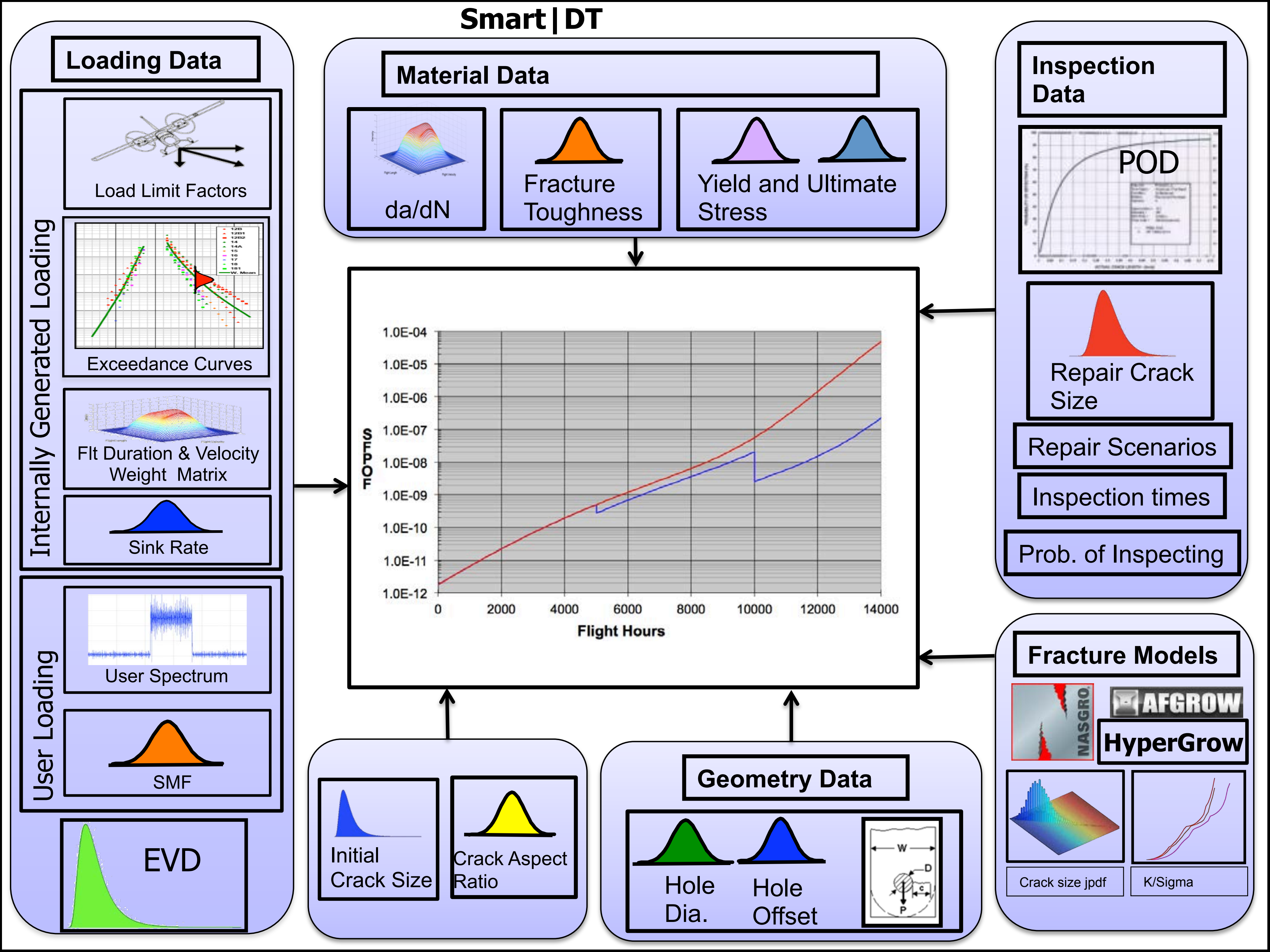
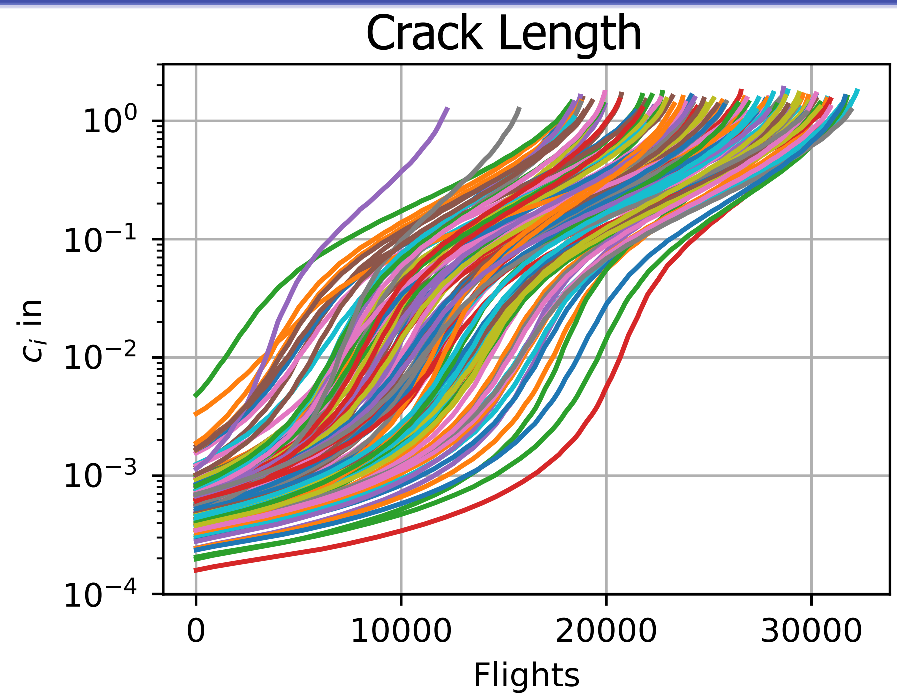
Overview

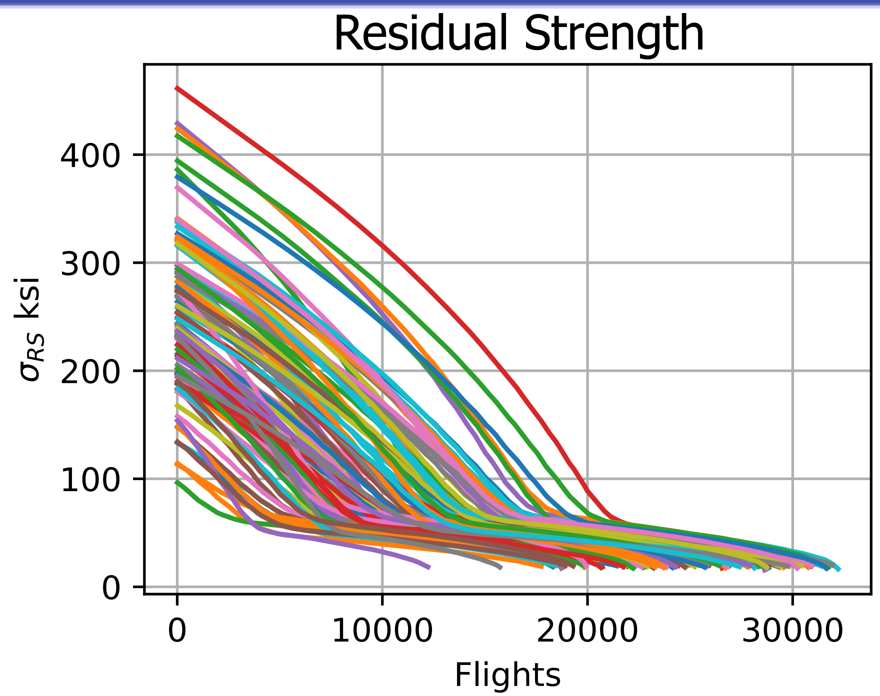
- SMART|DT and Comprehensive Probabilistic Damage Tolerance Analysis (PDTA)
- Large Scale Computing
- Example: Through Crack in Fastener Hole
- Conclusions and Future Work



Smart | DT
Loading Data
Internally Generated Loading
Load Limit Factors
Exceedance Curves
Flt Duration & Velocity
Weight Matrix
Sink Rate
User Loading
User Spectrum
SMF
EVD
Material Data
da/dN
Fracture Toughness
Yield and Ultimate Stress
Inspection Data
POD
Repair Crack Size
Repair Scenarios
Inspection times
Prob. of Inspecting
SFPOF
1.0E-04
1.0E-05
1.0E-06
1.0E-07
1.0E-08
1.0E-09
1.0E-10
1.0E-11
1.0E-12
0
2000
4000
6000
8000
10000
12000
14000
Flight Hours
Fracture Models
NASGRO
AFGROW
HyperGrow
Crack size jpdf
K/Sigma
Initial Crack Size
Crack Aspect Ratio
Geometry Data
Hole Dia.
Hole Offset
W
D
c
P

Challenge of Comprehensive PDTA

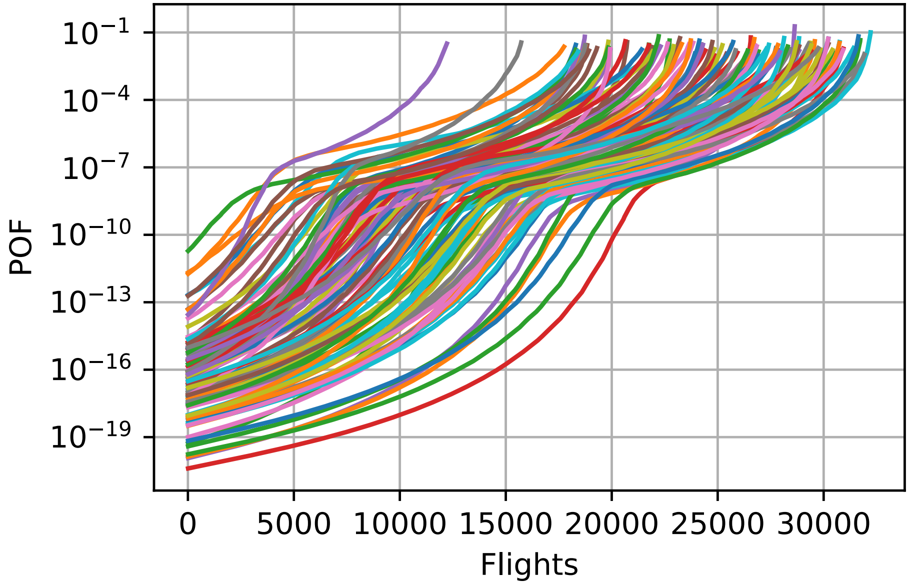


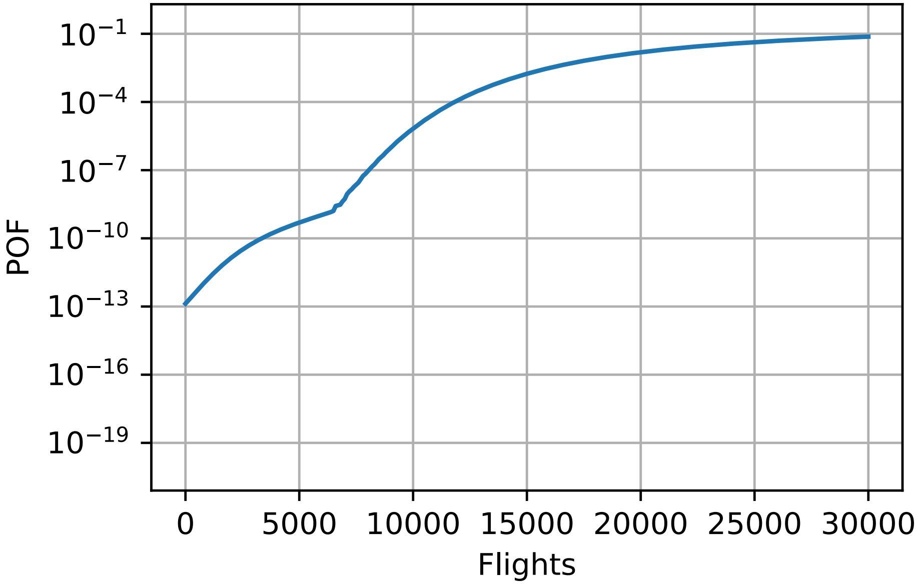


- Comprehensive PDTA requires evaluating the crack growth curve for every realization
- To estimate POF < 10^{-7}, Monte Carlo integration requires minimally 10^8 realizations
- O(10) seconds per realization for 10^8 realizations
  - at least 30 years on a 10 core computer
  - at least 3 year on a 100 core cluster
  - at least 3 months on a 1000 core supercomputer

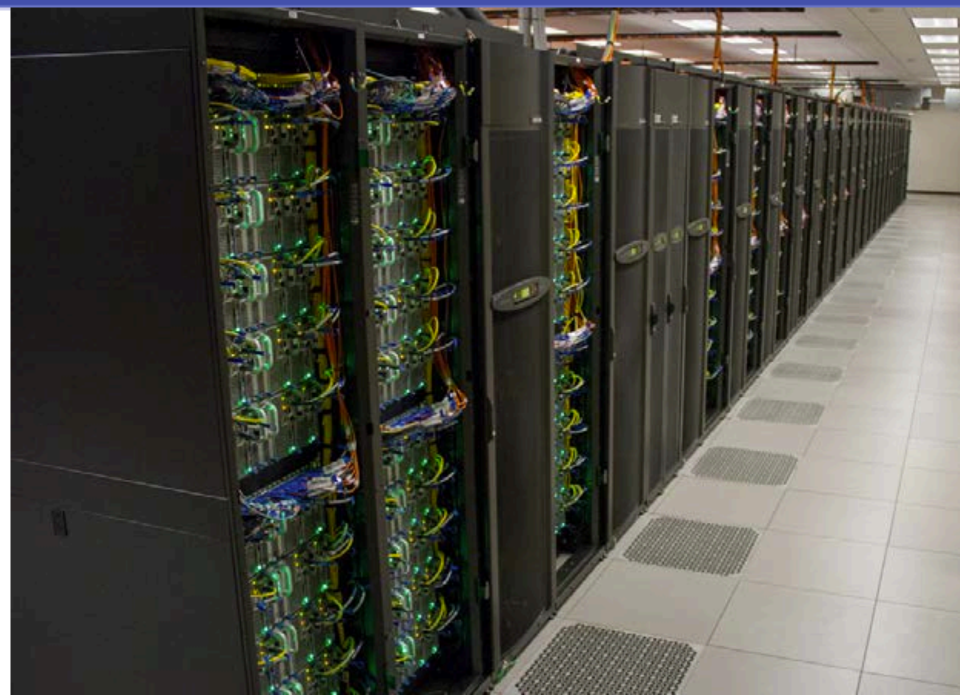
Motivation

- Verification – check results of fast methods against 10^8+ runs of conventional crack growth codes
- Capability – increase the speed of fast methods by 100x or more
- Access – give SMART|DT users the option to leverage large cluster / cloud systems





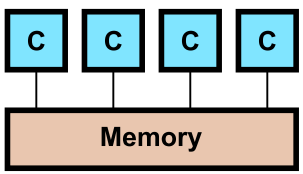
Large Scale Computing



- Large scale computing systems are becoming more available
- High Performance Computing cluster configurations can be configured and used on a pay as you go basis at the 3 major cloud computing providers
- Coding for distributed memory parallelization is required to take advantage of these systems
  - More details in the next slides

Large Scale Computing

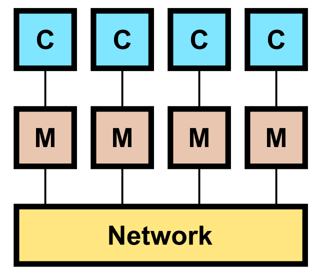
- Shared Memory (OpenMP)
  - communication via shared variables



2 cores

16 cores

- Distributed Memory (MPI)
  - communication via message passing over network

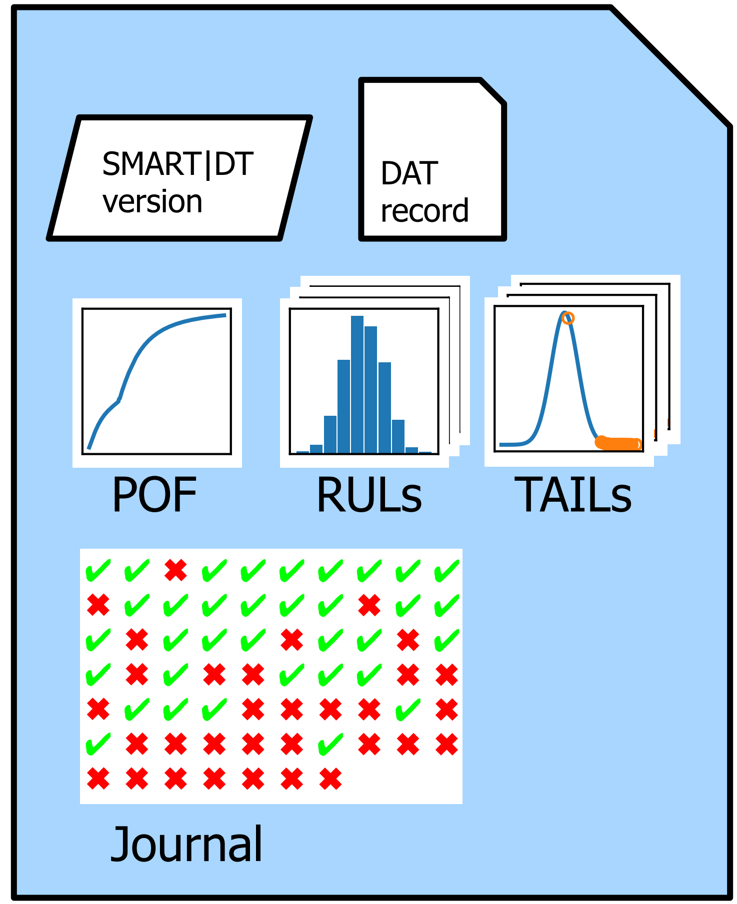


320 cores

102400 cores

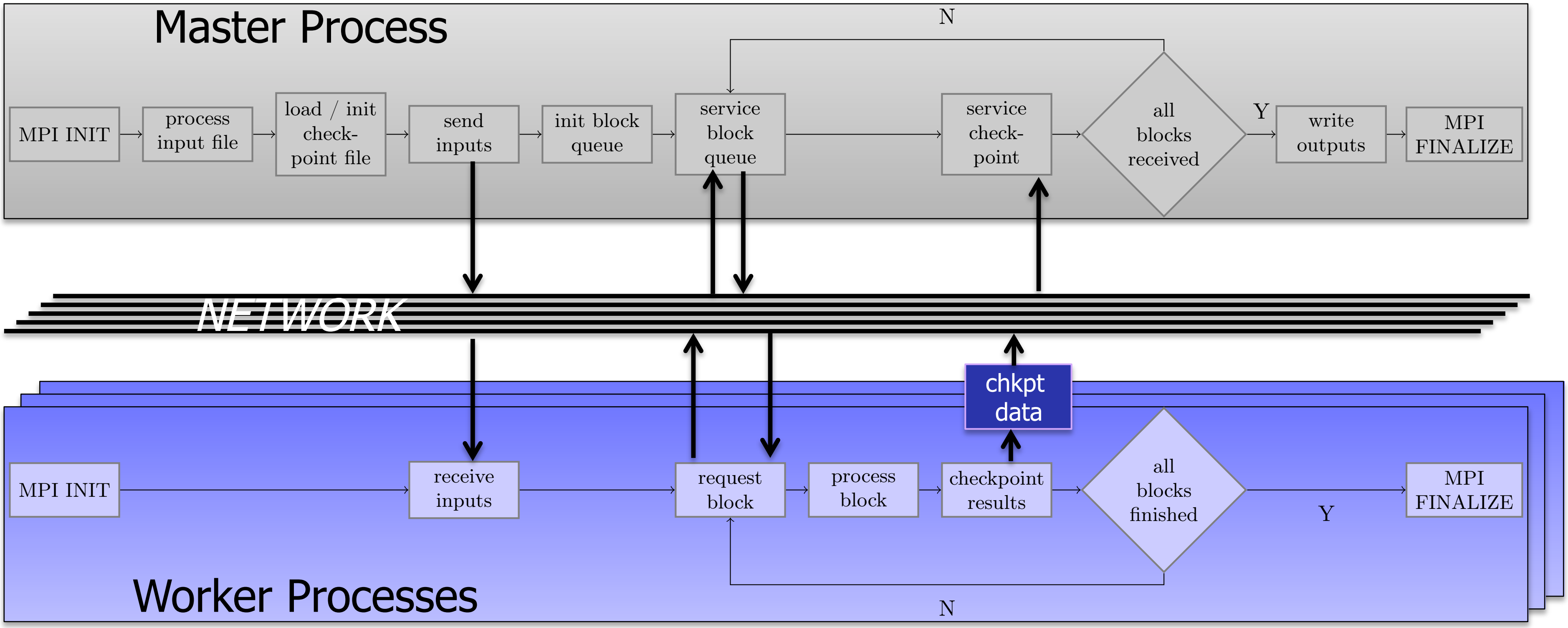
Checkpointing Capability

- Large scale computing incurs an increased risk of system faults
- Checkpoints allow jobs to be restart from somewhere in the middle
- Restarting requires some consistency checks in case files have been modified or the SMART|DT version has changed



jobname.chkpt

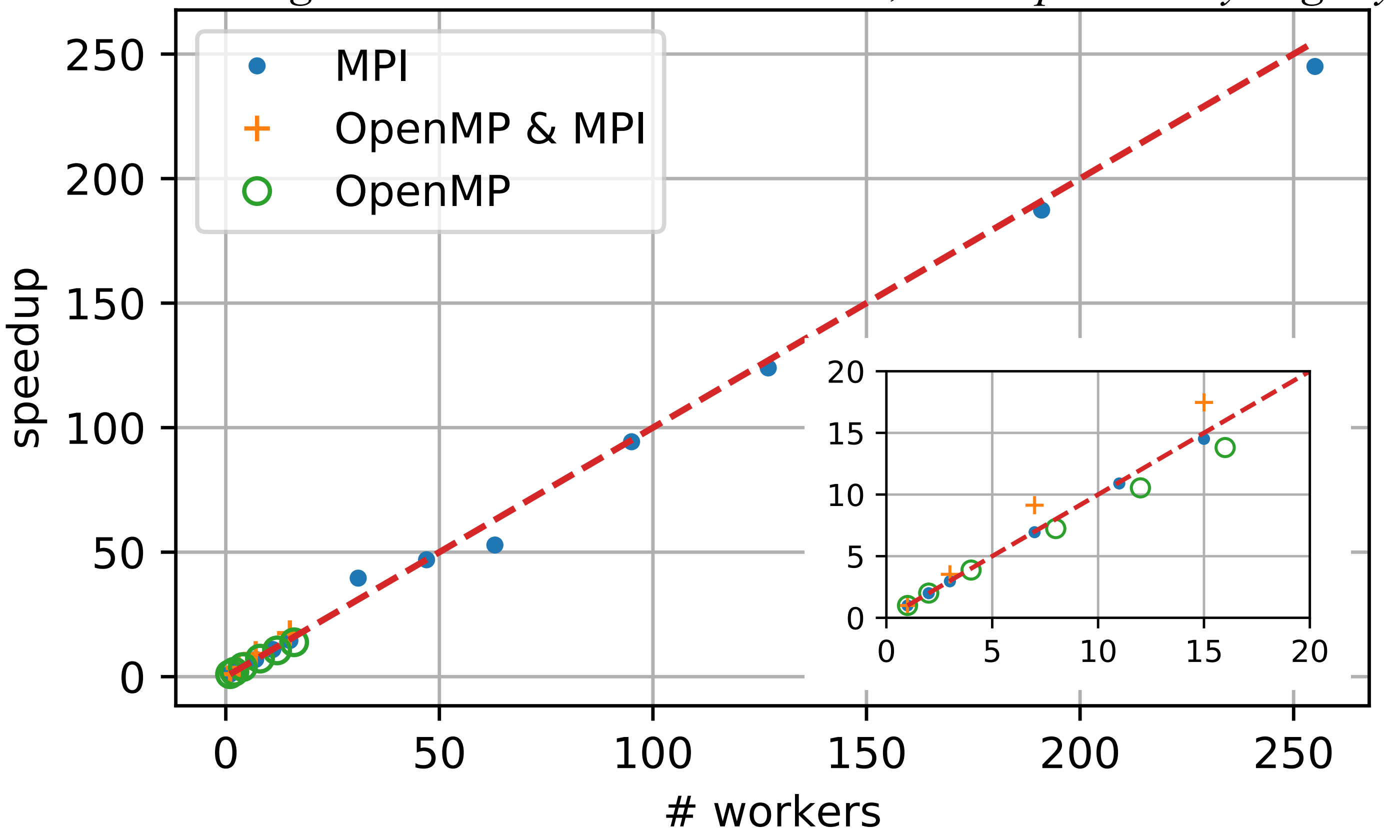
SMART|DT MPI overview



- Master process performs all of the input reading and checking once and sends processed inputs to the workers
- Small data packets exchanged to assign blocks and report block processing complete
- Checkpoint data is buffered so the worker can start processing the next block while the results are transferred

SMART|DT MPI Scaling

Scaling measured on Shamu at UTSA, node speeds vary slightly

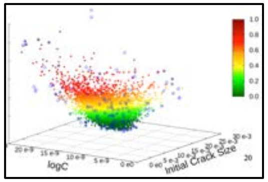


- Near ideal scaling for 250+ processes running HyperGrow realizations

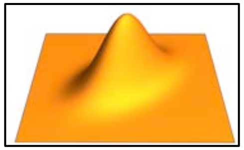
Approaches to Speed Up PDTA

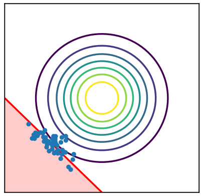
- Run realizations in parallel
  - Large scale computing (uses lots of resources)

- Reduce cost of each realization
  - Master Curve (limited to 3 RVs)
  - HyperGrow (no retardation)
  - Surrogate Model (adds complexity and uncertainty)

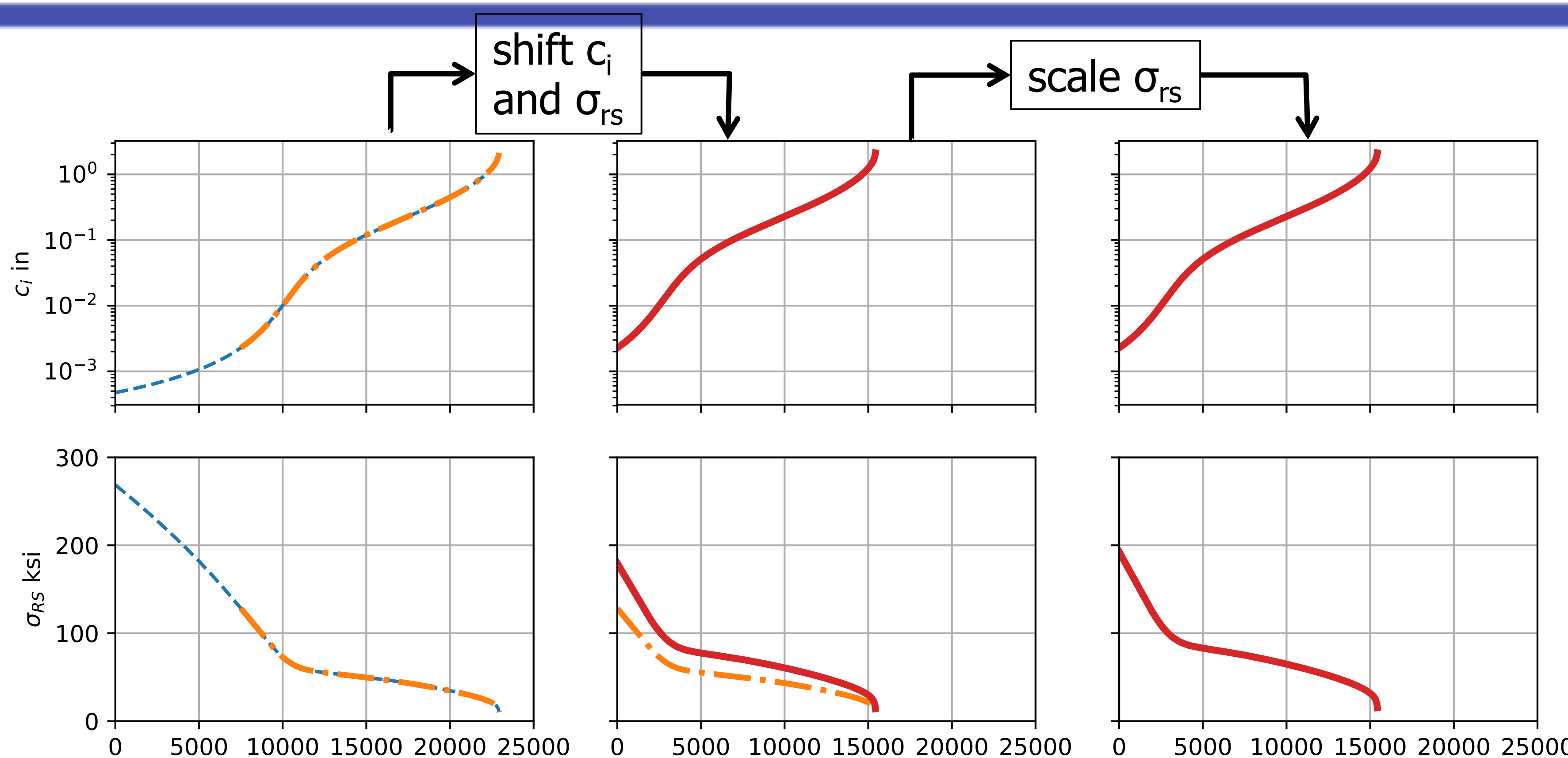


- Reduce total number of realizations
  - Numerical Integration (low dimensions)
  - FORM / SORM (many assumptions)
  - Importance Sampling (requires a priori knowledge)



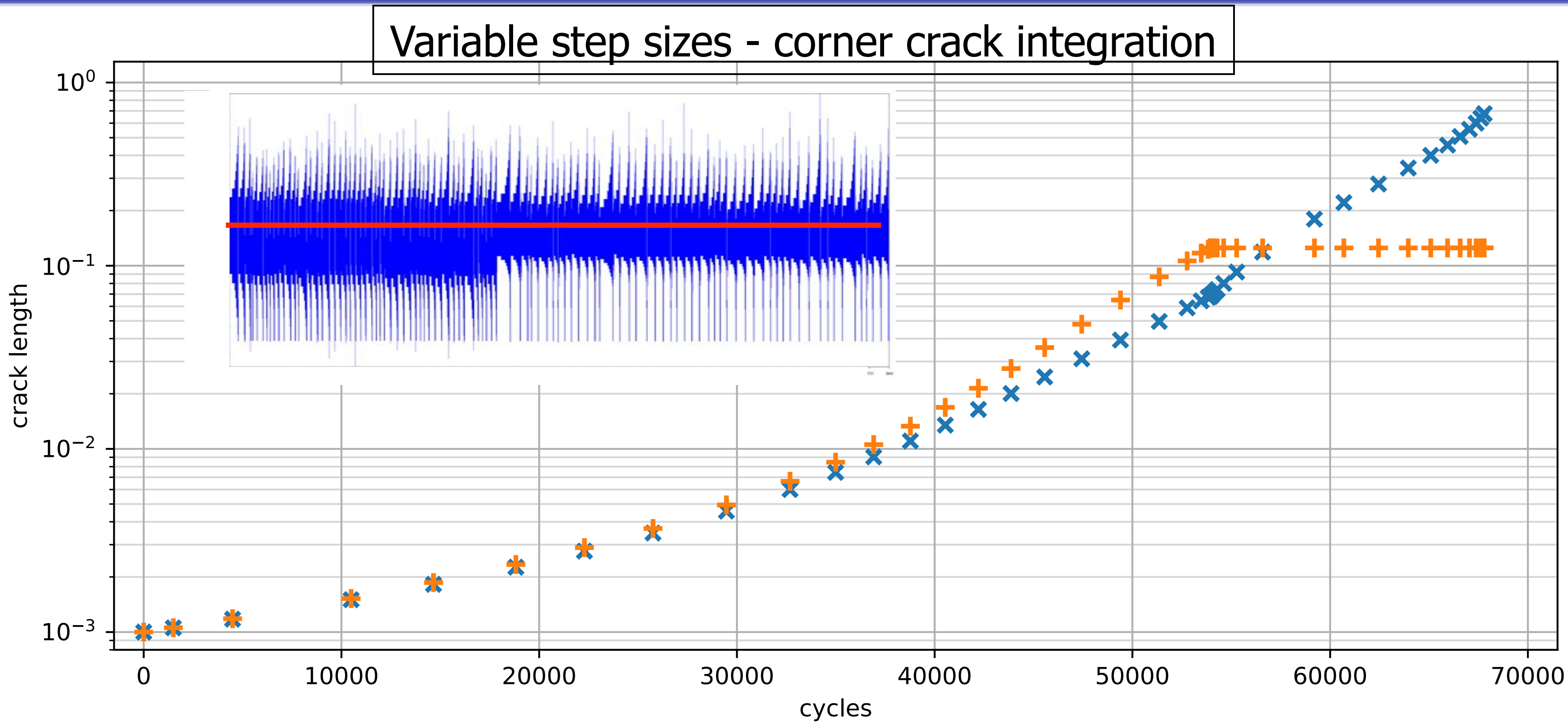


Master Curve



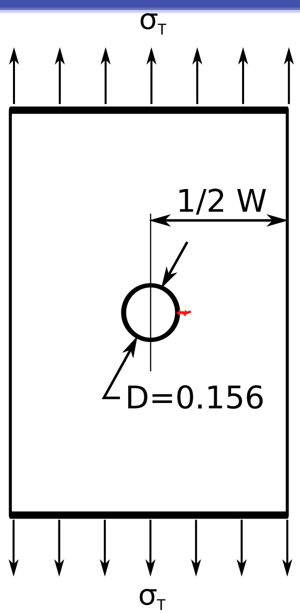
- Ignores variation in crack growth rate, component geometry, etc…

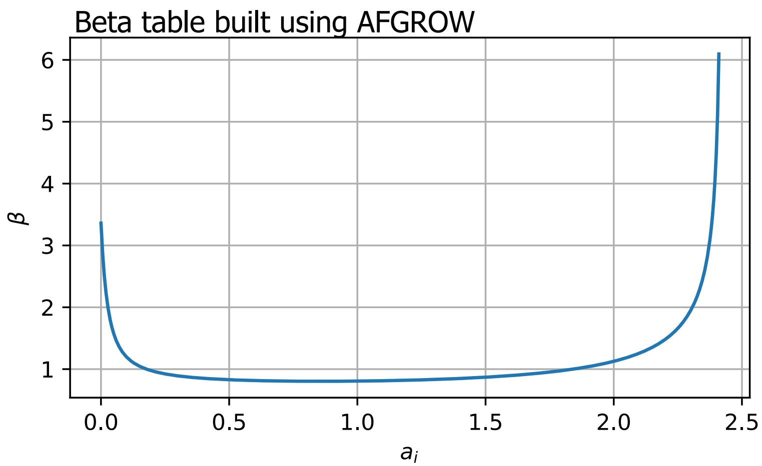
HyperGrow

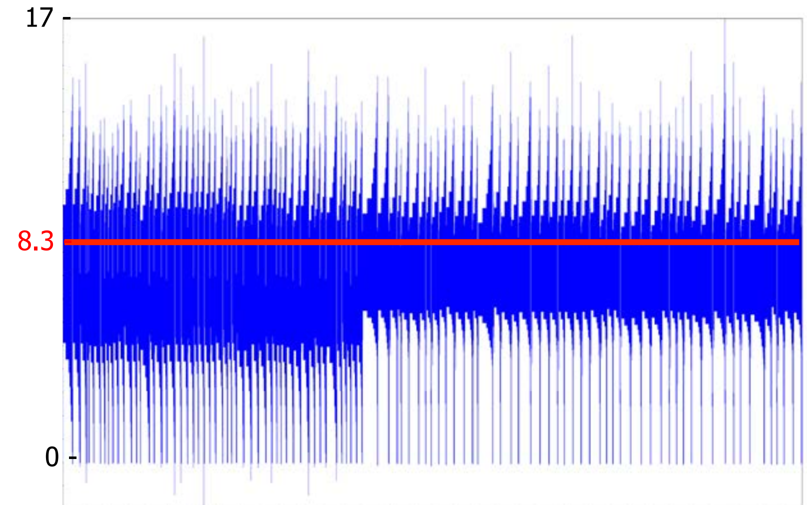


- Calculates Equivalent Constant Amplitude Stress for a given spectrum and uses variable step size integration for significantly faster crack growth evaluation
  - >10000x faster than cycle-by-cycle integration

Example Problem







Geometry	Deterministic(5 wide x 0.125 thick)	in
Initial Crack Size	Weibull(α=0.45, β=4.17e-5)	in
Fracture Toughness	Normal(μ=35.0, σ=3.5)	ksi √in
log(Paris C)	Normal(μ=-9.0, σ=0.08)	
Paris n	3.8	
Maximum Load	Frechet(μ=13.4, σ=1.29, ξ=0.07)	ksi

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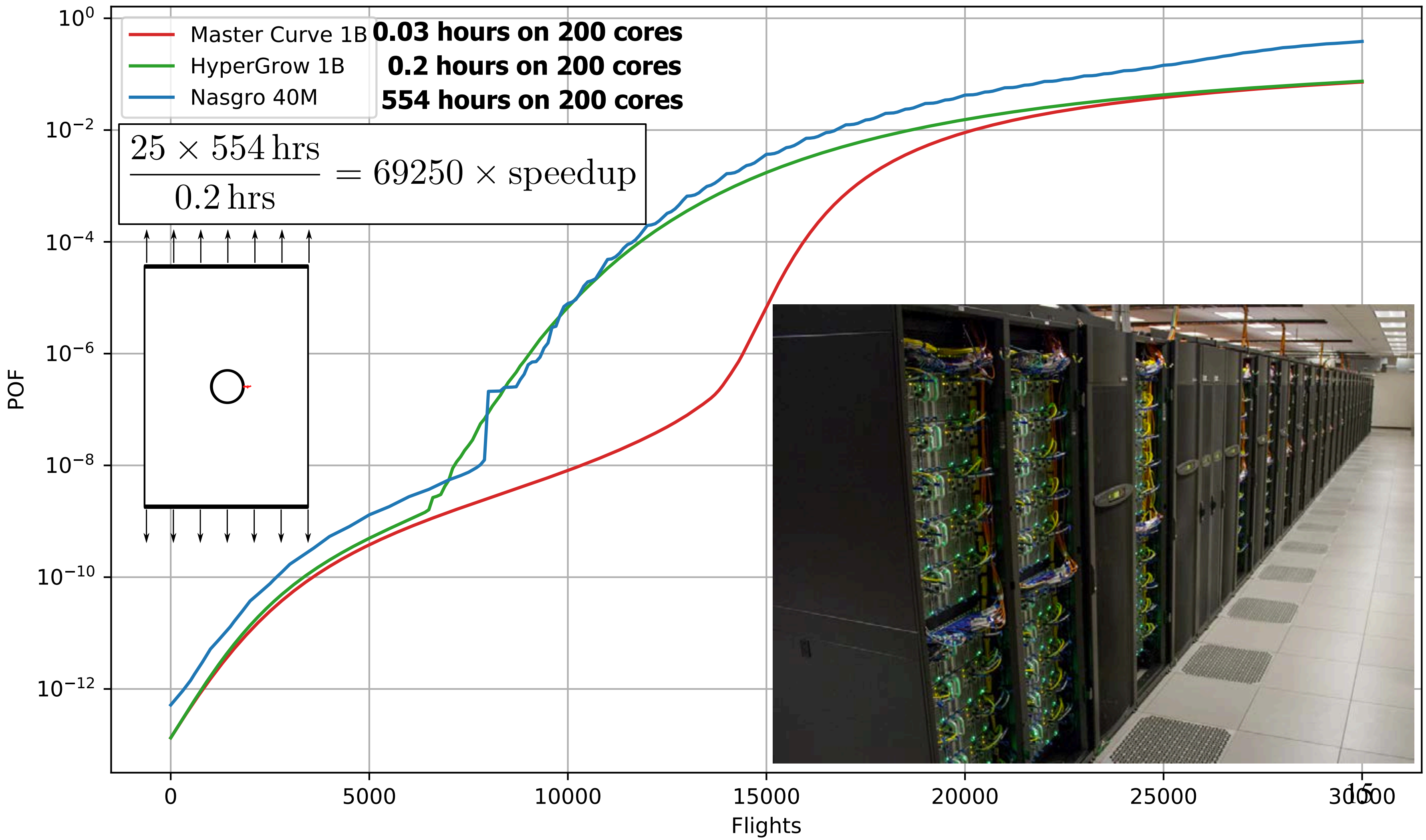
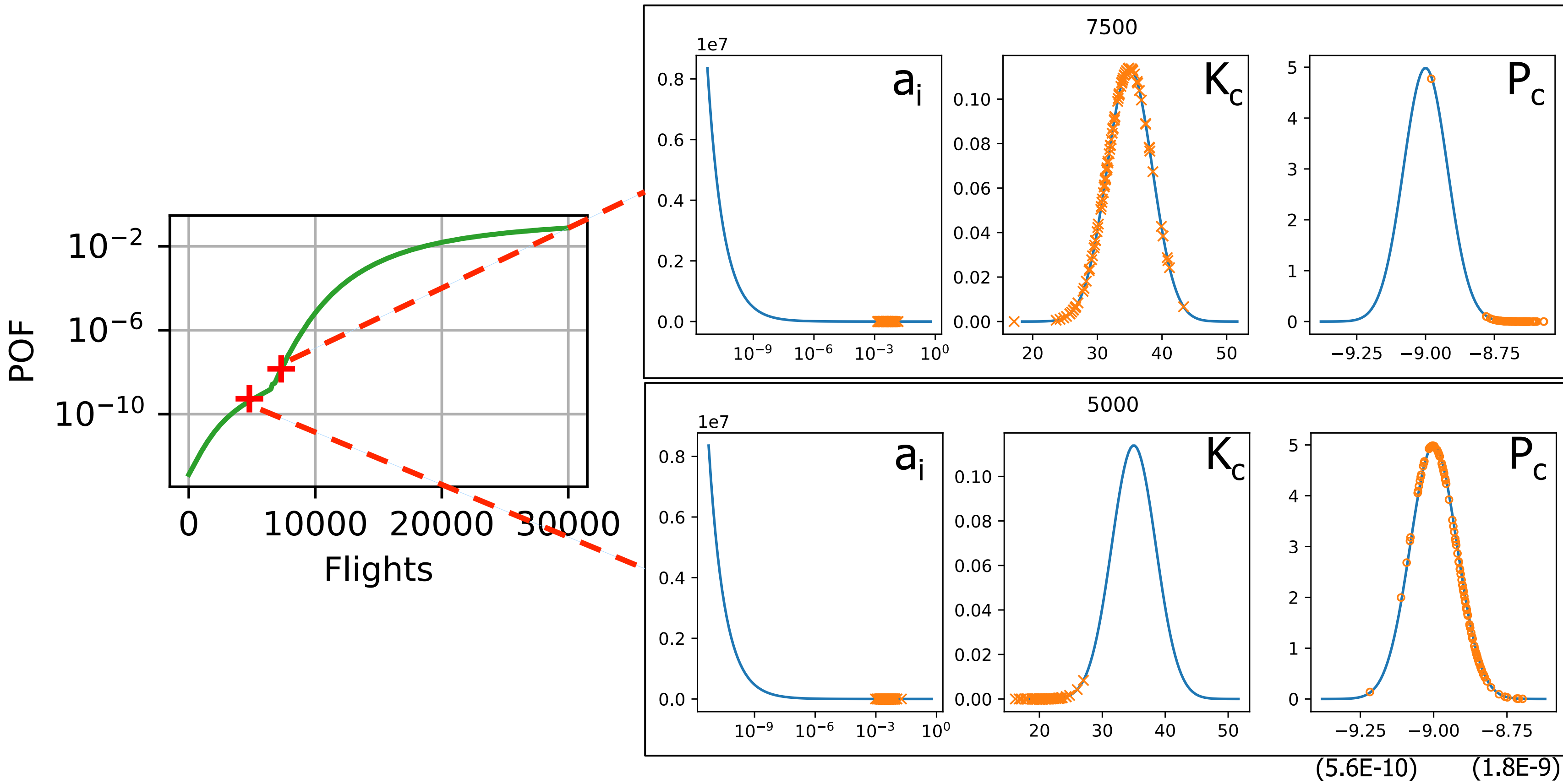
TEXTRON AVIATION

Uninspected POF Output

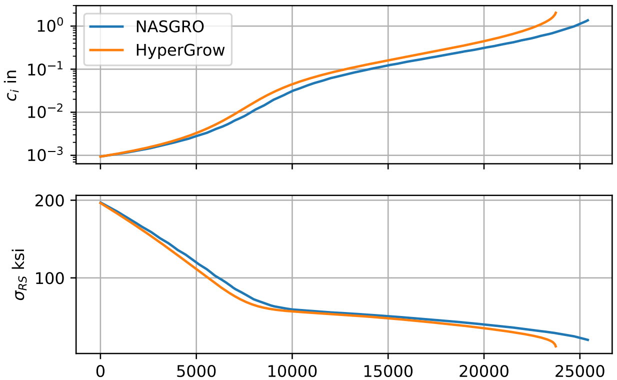


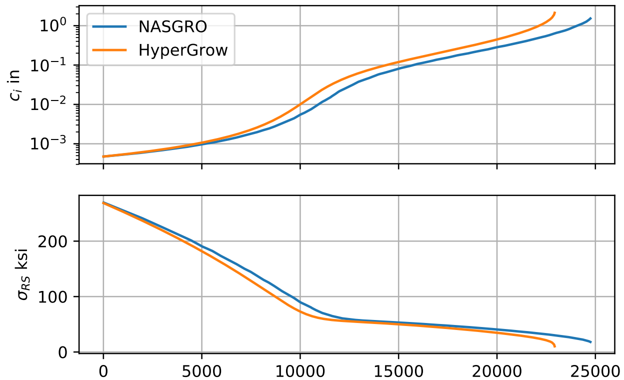
Most Influential Realizations

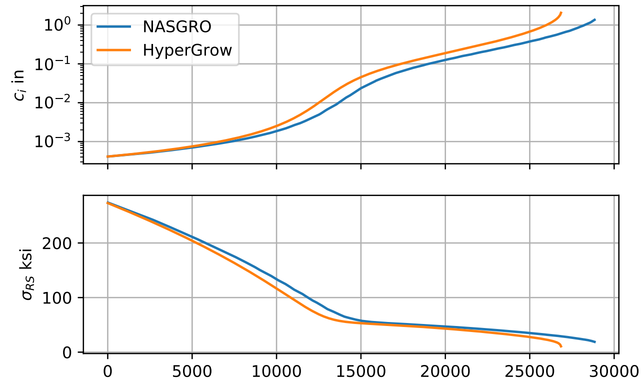


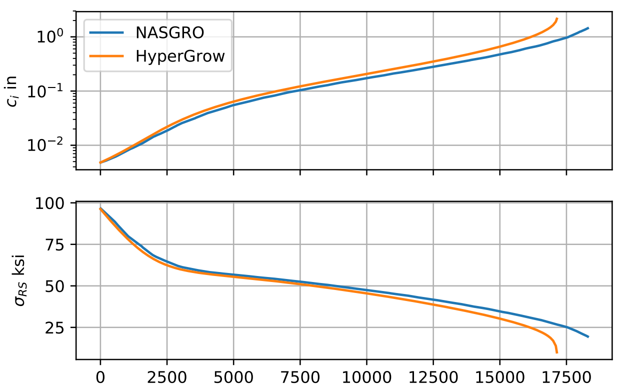
- Visualizes which realizations contribute most to POF

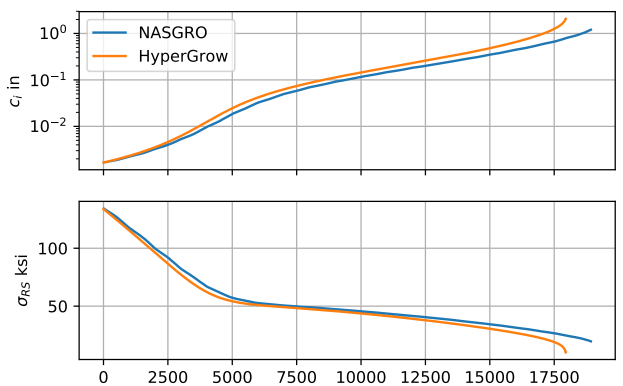
AVSN comparisons - NASGRO and HyperGrow

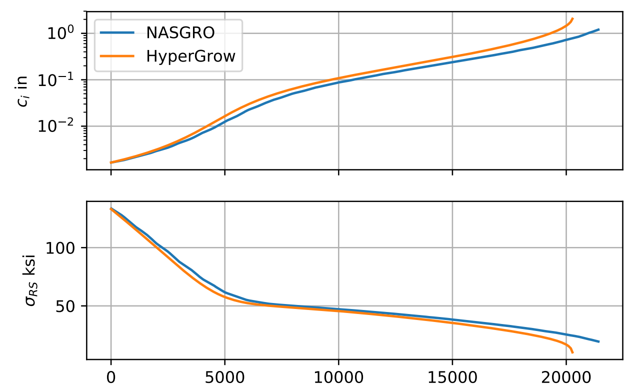




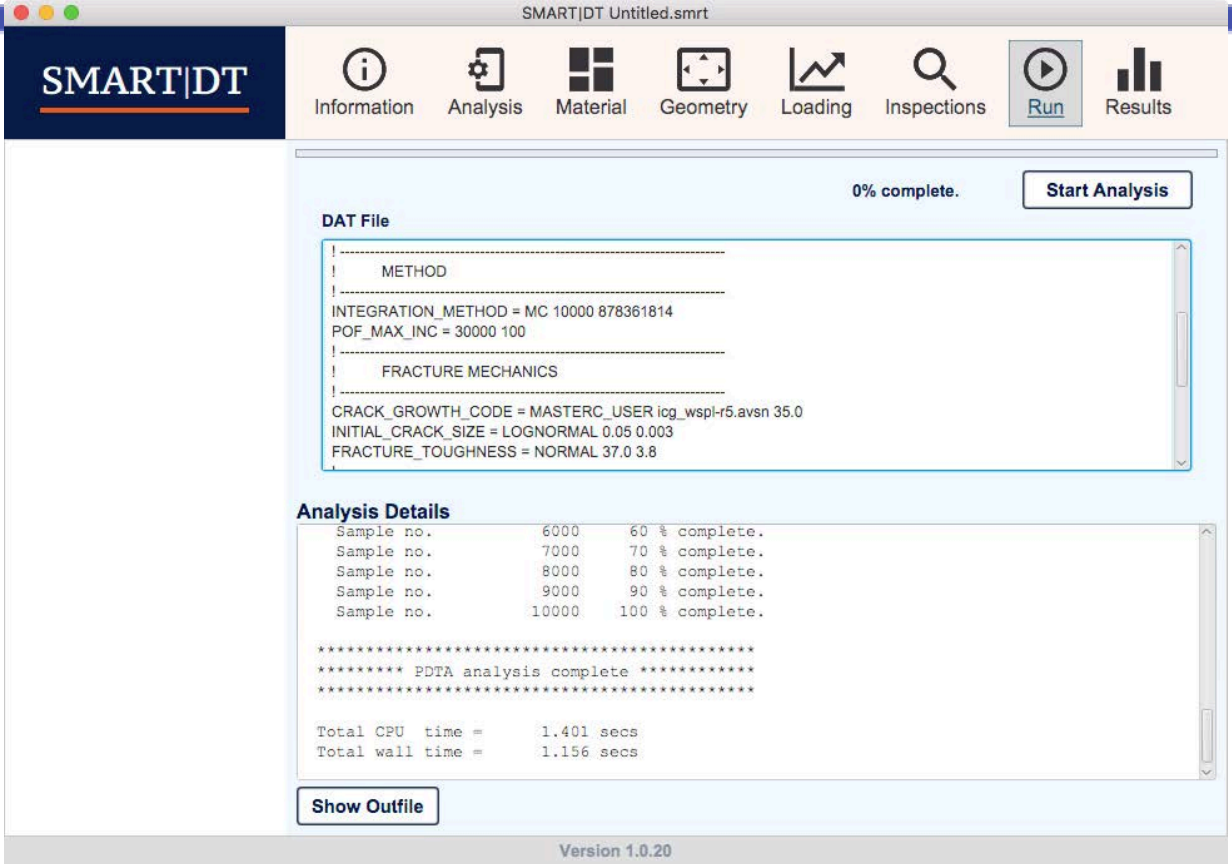








Future Work



- SMART|DT GUI
- Continue HyperGrow Development and Verification
- Add FORM and Importance Sampling Methods

Conclusions

- Large scale computing is necessary to verify methods that speed up the fracture mechanics or probabilistic method

- The combination of HyperGrow and Large Scale Computing makes comprehensive PDTA attainable

Acknowledgments

- Cluster version of SMART|DT funded by UTSA OpenCloud Institute

- This work received computational support from UTSA's HPC cluster Shamu, operated by the Office of Information Technology.

- SMART|DT was developed under FAA grant 16-G-005

Thank you