The System Modeling and Analysis of Resiliency in STEReO (SMARt-STEReO)

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AIAA Aviation, August 2nd-6th

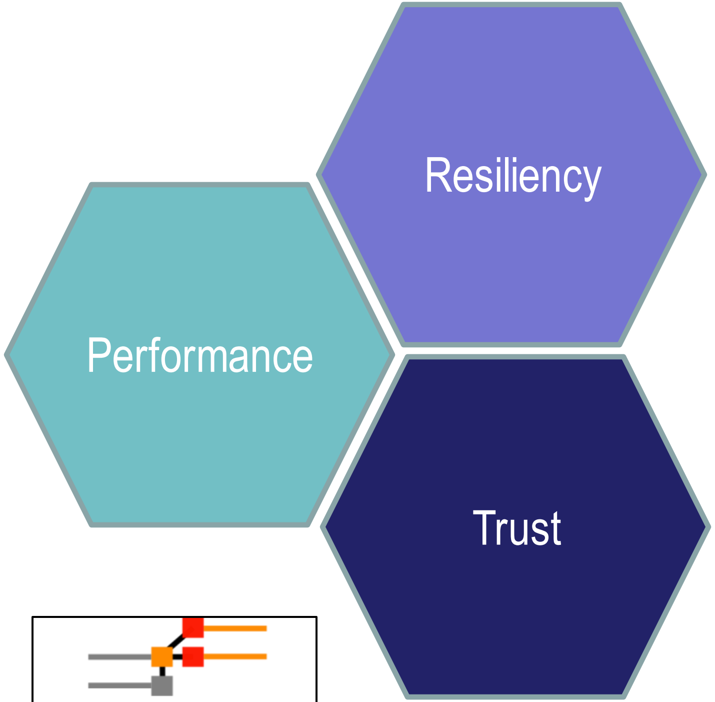
Motivation

[1]

- Wildfires increasing in size and number from 1984-2011 [2]
- Aerial Firefighting and suppression:
  - Account for **26%** of firefighter **deaths** from 2000-2013 [3]
- **STEReO**: Scalable Traffic for Emergency Response Operations
  - Leverage new technology to improve **safety** and **performance**

Introduction and Background

- Resilience: prevention, adaption, and recovery
- Existing Models: BehavePlus, FARSITE, DEVS-FIRE, etc.
- SMARt-STEReO Model: integrated fire **propagation** and **suppression** model, allows for **resilience analysis** and inclusion of **emerging operations**, such as UAS

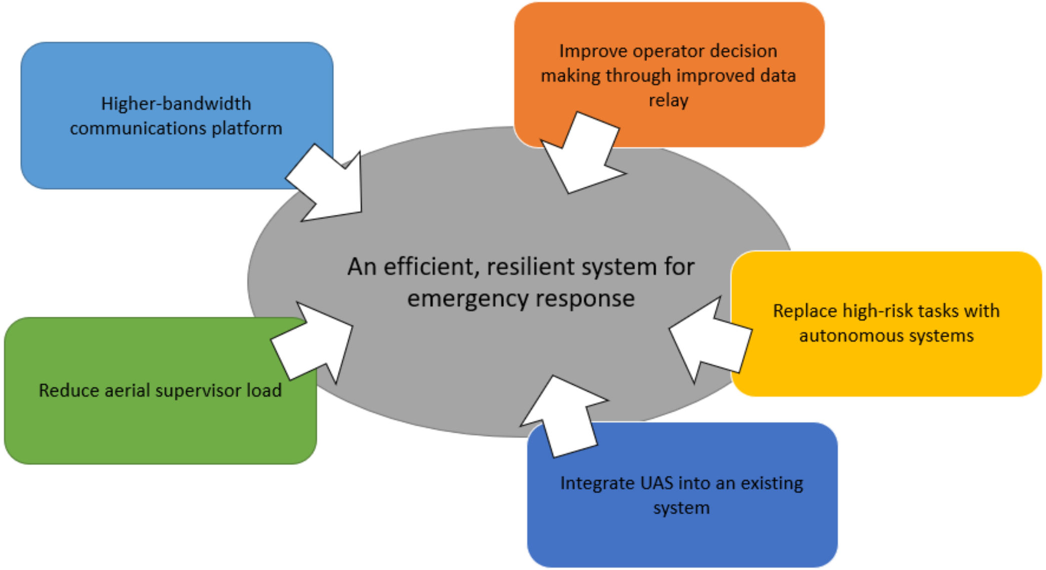


fmdtools

Model Development: Wildfire Operations

- Present Day Wildfire Response:
  - **Airplanes** – airtankers, aerial supervisor, surveillance
  - **Helicopters** – surveillance, drops delivery
  - **Engines** – direct attack, dust abatement, refills
  - **Dozers –** fire line construction
  - **Ground Crews** – fire line construction
  - **Comms –** radio, line-of-sight

- Emerging Fire Fighting: STEReO



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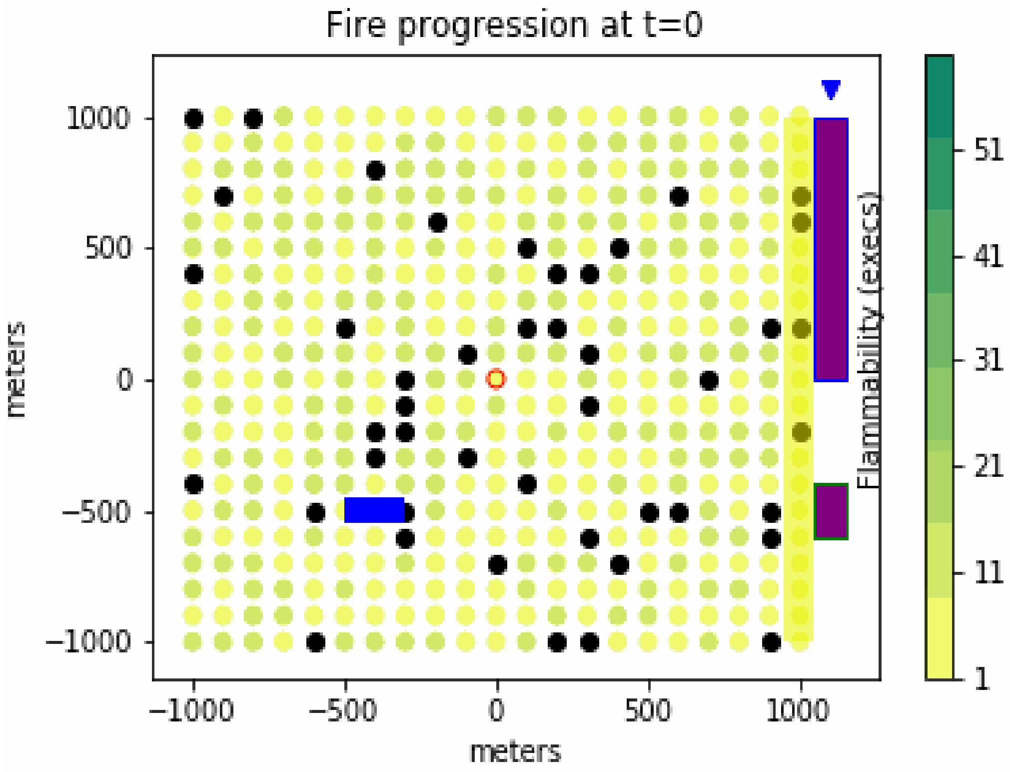
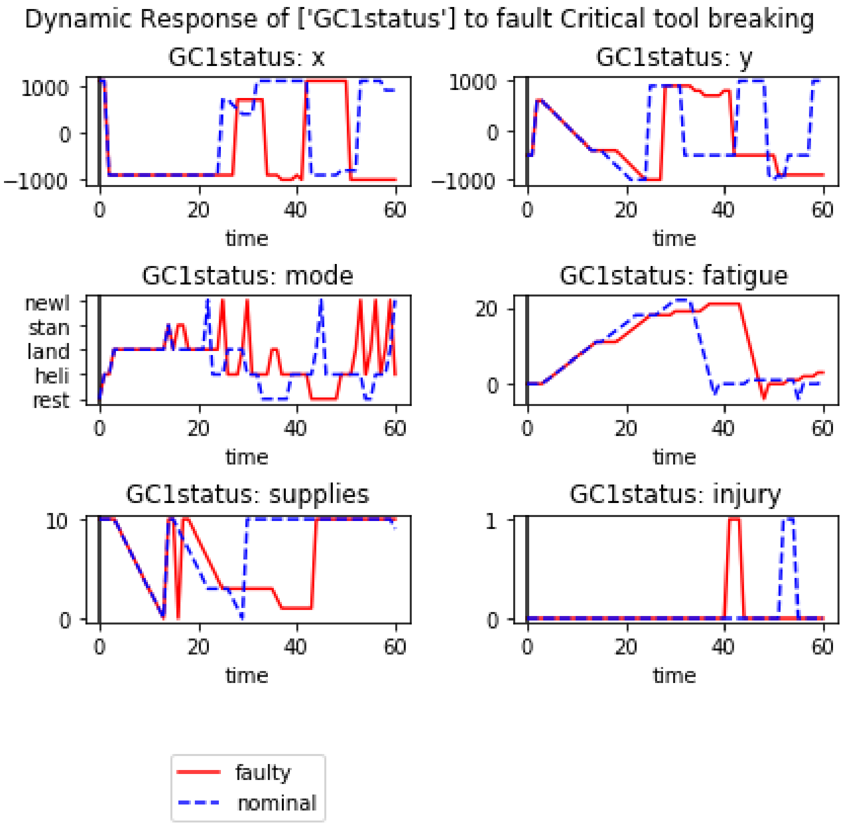
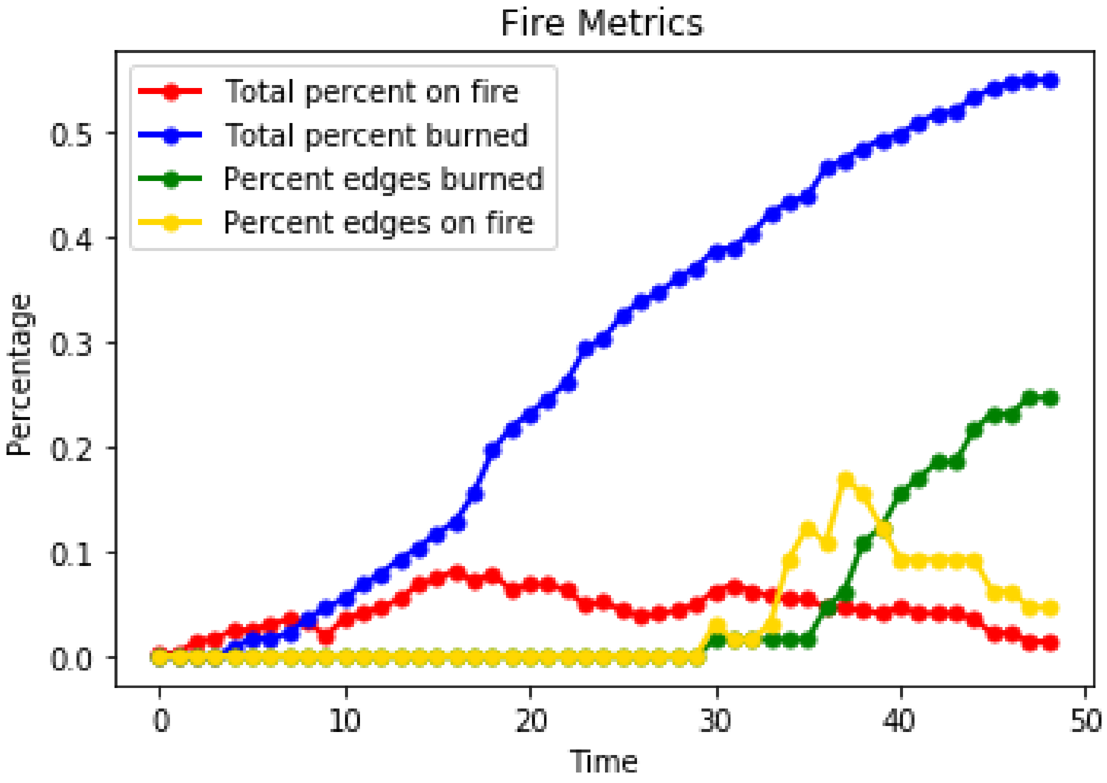
Model Development: Outputs



Model Development: Outputs



Model Development: Outputs



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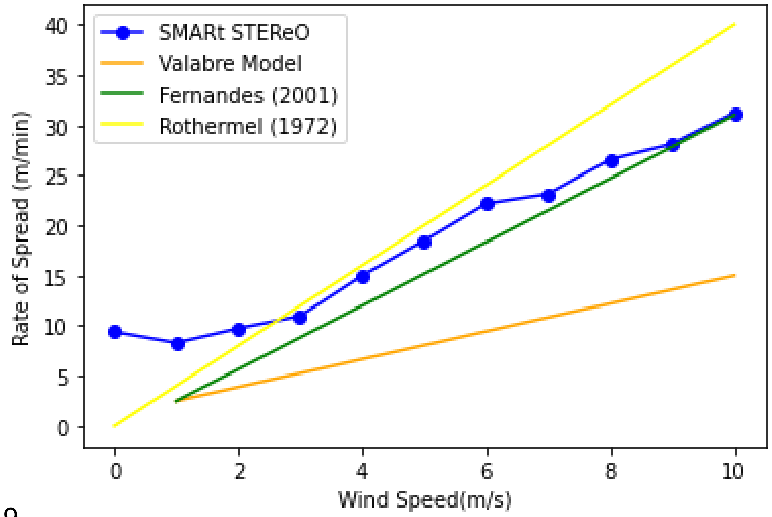
Research Questions: Q1-Q3

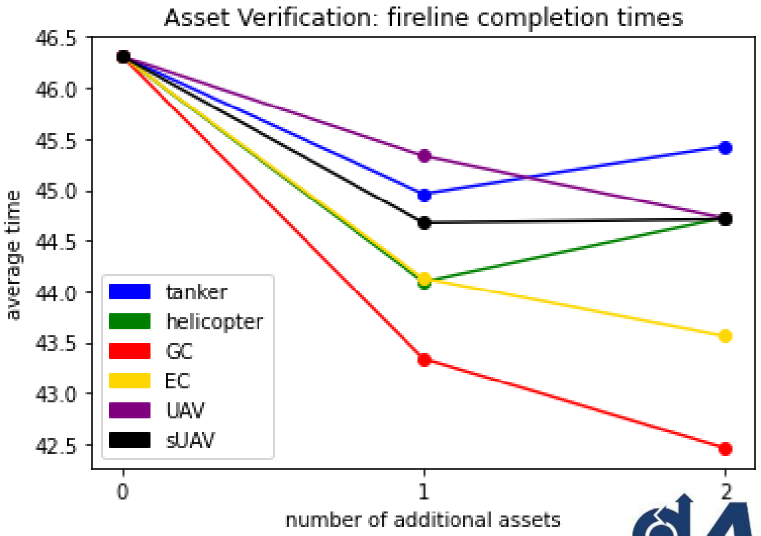
- Q1. What is the appropriate scope of applications that the model is currently verified and valid for?
- Q2.
  - a) Is there a difference in performance, in terms of metrics such as acres burned, when UAS is added into wildfire response?
  - b) If so, is this difference apparent in both nominal and off-nominal conditions?
- Q3.
  - a) Does the addition of UAS in wildfire response increase resilience in the system in response to an individual fault?
  - b) If so, what is the effect size?

Verification and Validation Efforts: Q1

- Fire propagation:
  - Windspeed, slope



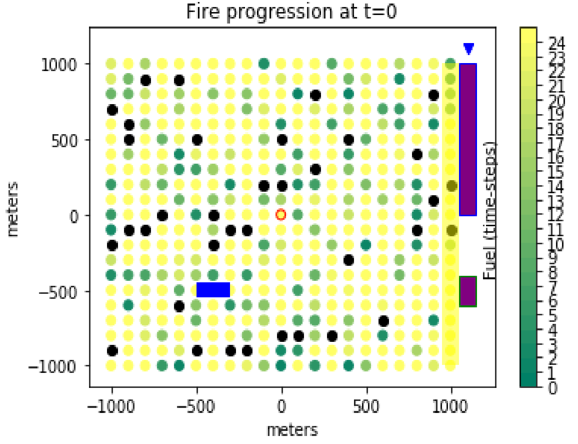
- Suppression Verification
  - State awareness, rate of fire line construction, rate of injury, assets



Experimental Analysis: Set-up

- Monte Carlo simulation for 2,000 grids with random fuel distribution
- Injection of 2 separate faults at t=20:
  - Major: major mechanical failure to aerial supervisor
  - Minor: critical tool breaking for ground crew1
- Performance measured in acres burned
- Resilience:

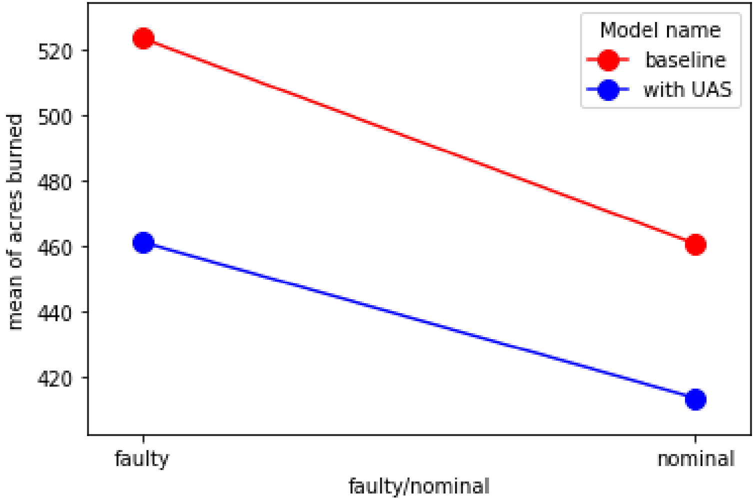
$$Nominal_{acres\ burned} - Faulty_{acres\ burned}$$



Experimental Analysis: Q2

Q2: Is there a difference in performance when UAS is added?

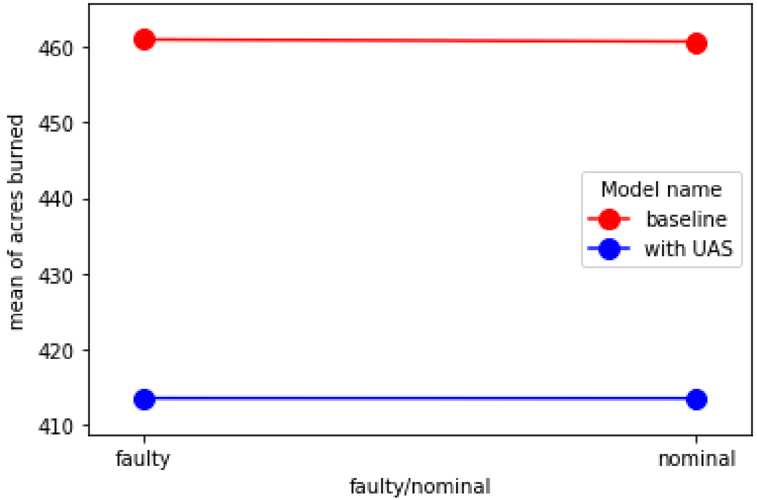
- Major fault:
  - Fault → more acres burned compared to nominal ($F=1538.7; P<0.001^{***}$)
  - UAS → fewer acres burned compared to baseline ($F = 170.8; P < 0.001^{***}$)
  - UAS + faulty or nominal → fewer acres burned ($F = 39.9; P < 0.001^{***}$)



Experimental Analysis: Q2

Q2: Is there a difference in performance when UAS is added?

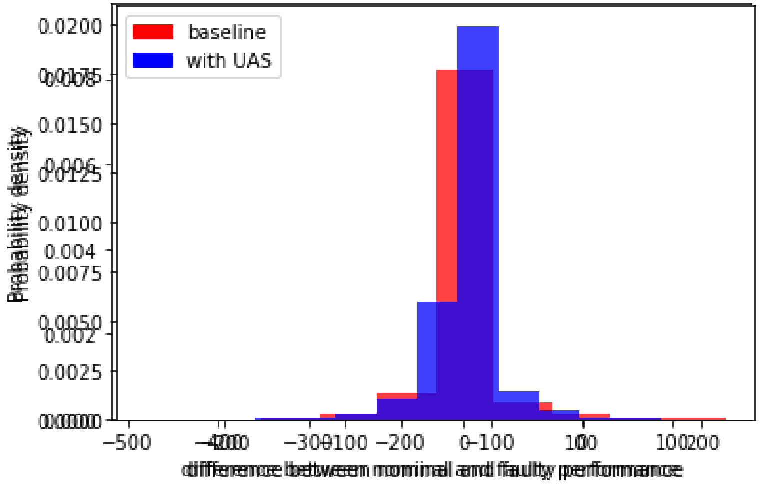
- Minor Fault
  - Fault → no significant difference in acres burned compared to nominal ($F=0.1116$; $P=0.733$)
  - UAS → fewer acres burned compared to baseline ($F = 117.7$; $P < 0.001$***)
  - UAS + faulty or nominal → no significant difference in acres burned ($F = 0.095$; $P=0.758$)



Experimental Analysis: Q3

Q3: Does the addition of UAS increase resilience?

- Major fault:
  - UAS → increased resilience
    - ($T = -6.315$, $p < 0.001^{***}$, $d = 0.183$)
- Minor fault:
  - No significant difference
    - ($T = -0.309$, $p > 0.05$, Cohen's $d = 0.010$)



Discussion

- Q1: model is sufficient for these experiments
- Q2: Performance gains from UAS; etc., generalize over fault scenarios
- Q3: Resilience gains from UAS depend on the severity of the fault injected.

type of fault	model name	total% burned	total% fire	edges % burned	edges % fire	acres burned
major fault	baseline	-6.310 ± 9.110	-0.903 ± 3.241	-5.329 ± 7.833	-1.006 ± 3.294	-62.830 ± 90.801
major fault	with UAS	-4.807 ± 7.450	-0.817 ± 2.973	-2.955 ± 5.946	-0.520 ± 2.406	-47.665 ± 73.864
minor fault	baseline	-0.028 ± 2.743	-0.040 ± 1.393	-0.226 ± 3.093	-0.033 ± 1.309	-0.269 ± 27.327
minor fault	with UAS	-0.004 ± 2.524	0.010 ± 1.459	-0.295 ± 2.939	-0.083 ± 1.204	-0.017 ± 25.063

Conclusions and Future Work

- Developed integrated model of fire propagation and response with ability to simulate:
  - Performance of operational concepts under a wide range of scenarios
  - Performance of operational concepts under faults for **resilience quantification**

- Limitations and Future Work:
  - Ongoing verification and validation efforts
  - Model improvements
  - Different types of resiliency analysis
  - Adaptive stress testing

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- Additional Resources:
  - SMARt-STEReO ConOps: https://ntrs.nasa.gov/citations/20205007665
  - SMARt-STEReO Model Description: https://ntrs.nasa.gov/citations/20205007481
  - Fmdtools: https://github.com/DesignEngrLab/fmdtools
  - Robust Software Engineering: https://ti.arc.nasa.gov/tech/rse/

References

- [1] R. Kahn, K.J. Noyes, NASA Goddard, A. Nastan, JPL Caltech, J. Tackett, J-P Vernier, NASA Langley, "On Aug. 31, MODIS detected several hotspots in the August Complex Fire in California, as well as several other actively burning areas to the north, west, and south.", NASA Observations Aid Efforts to Track California's Wildfire Smoke From Space, https://www.nasa.gov/feature/goddard/2020/nasa-observations-aid-efforts-to-track-california-s-wildfire-smoke-from-space Accessed 06/03/2021
- [2] Dennison, P. E., S. C. Brewer, J. D. Arnold, and M. A. Moritz (2014), Large wildfire trends in the western United States,1984–2011, Geophys. Res. Lett., 41, 2928–2933, doi:10.1002/2014GL059576.
- [3] C. R. Butler, M. B. O'Connor and J. M. Lincoln, "Aviation-Related Wildland Firefighter Fatalities — United States, 2000–2013," Morbidity and Mortality Weekly Report (MMWR), vol. 64, no. 29, pp. 793-796, 2015.

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