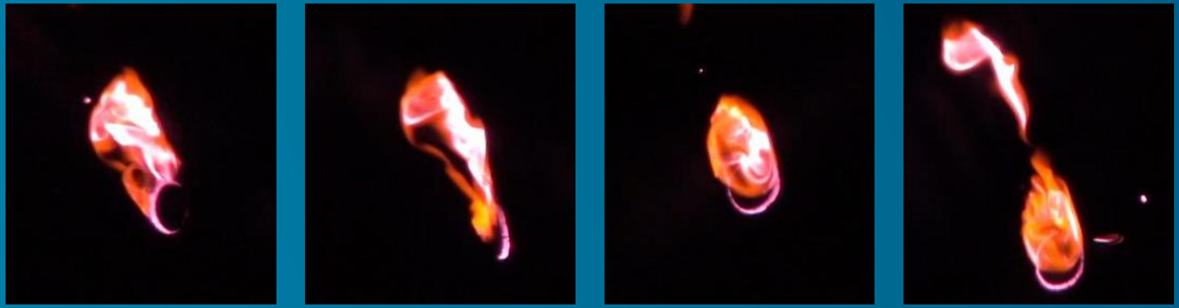
NIST WUI Fire Days 2022



NIST Emberometer Research

N. Bouvet, E. Link, M.H. Kim , S. Fink & K. Prasad*

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National Institute of Standards and Technology
U.S. Department of Commerce

07/20/2022

WUI & the Firebrand Problem

Post-fire investigations

"*In 50% of cases, the bushfire attack mechanisms were via embers only, and 35% were via ember and some radiant heat from surrounding isolated vegetation or other structures*"
(Canberra Bushfire 2003 / Blanchi & Leonard, Bushfire CRC Report, 2005)

"*Direct ember ignitions accounted for one out of every three destroyed homes*"
(Witch and Guejito fires 2007 / Maranghides & Mell, NIST TN 1635, 2009)

"*Embers cause up to 90% of home and business ignitions during wildfire events*"
(Institute for Business and Home Safety, 2019)

Engineering literature

- Firebrand is an old research topic… →
- Low stream of scientific papers until the early 2000s
- Ramp-up of scientific studies in the past 15 years including a broad range of topics:

Ignition by firebrands

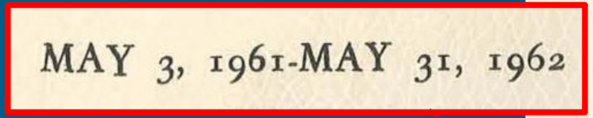
Firebrand surface temperature

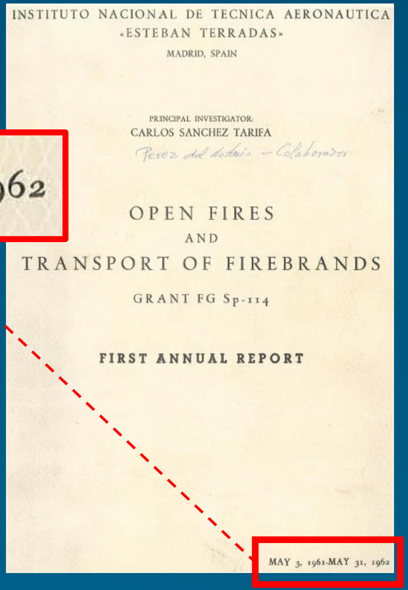
Firebrand combustion characteristics

Firebrand & firebrand piles thermal characteristics

Firebrand generation (structures/vegetation)

Firebrand transport




INSTITUTO NACIONAL DE TECNICA AERONAUTICA
«ESTEBAN TERRADAS»
MADRID, SPAIN

PRINCIPAL INVESTIGATOR:
CARLOS SANCHEZ TARIFA

OPEN FIRES
AND
TRANSPORT OF FIREBRANDS

GRANT FG Sp-114

FIRST ANNUAL REPORT

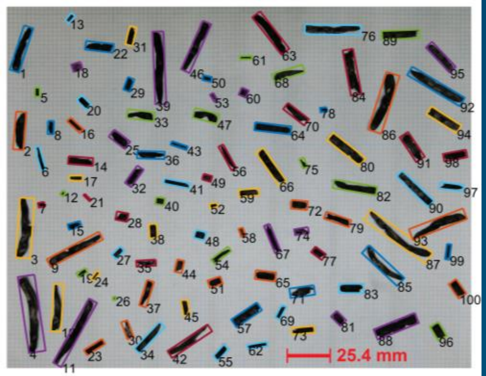
MAY 3, 1961-MAY 31, 1962

The Firebrand Problem

- Despite recent progress, still significant hurdles to characterize firebrand shower phenomena in wildland and WUI fires:

→ Very scarce number of studies in situ (prescribed/real fire event)

→ When available, measurement describing firebrand exposures focus on time- and space averaged post-fire data (very little is known during actual firebrand assault!)



Develop the measurement science to quantify the threat of firebrand exposure from WUI fires on structures and structural materials = **Design and fabricate a device to measure firebrand exposure, aka "Emberometer".**

Measuring realistic firebrand exposures… impacts:

→ Enable the developments of metrics that facilitate firebrand shower exposure comparisons

→ Build a firebrand exposure scale (Maranghides & Mell, NIST TN 1748, 2013)

→ Inform test methods about experimental conditions to be replicated

→ Provide anchoring points to the modeling community in term of firebrand generation

…

⇒ Form the technical/scientific basis for further improvements to WUI codes and standards

Firebrand Shower Characteristics… Challenges !


Camp Fire / Credit: CAL FIRE

Exposure = set of characteristics that defines a firebrand shower

A very complex set of variables:

- Particles with various sizes, shapes, masses, nature (WUI → vegetative/structural fuels)
- Particles with complex transport: wide range of velocities, convoluted trajectories (strong 3D motion)
- Particles with various thermal states (smoldering, flaming, ≠ energy contents)

AIRBORNE FIREBRANDS

How "intense" the exposure is (numbers) ⟵ ✓ Flux (Speed / Trajectory)

What do the particles look like (aggregation, trapping) ⟵ ✓ Shape/Size

✓ Surface temperature

"LANDED" FIREBRANDS

✓ Shape/Size, Mass
✓ Surface temperature /Thermal footprint

Emberometer Snapshot

Deployability

3D Firebrand Tracking

Time-resolved firebrand trajectories in 3D

Firebrand Morphology

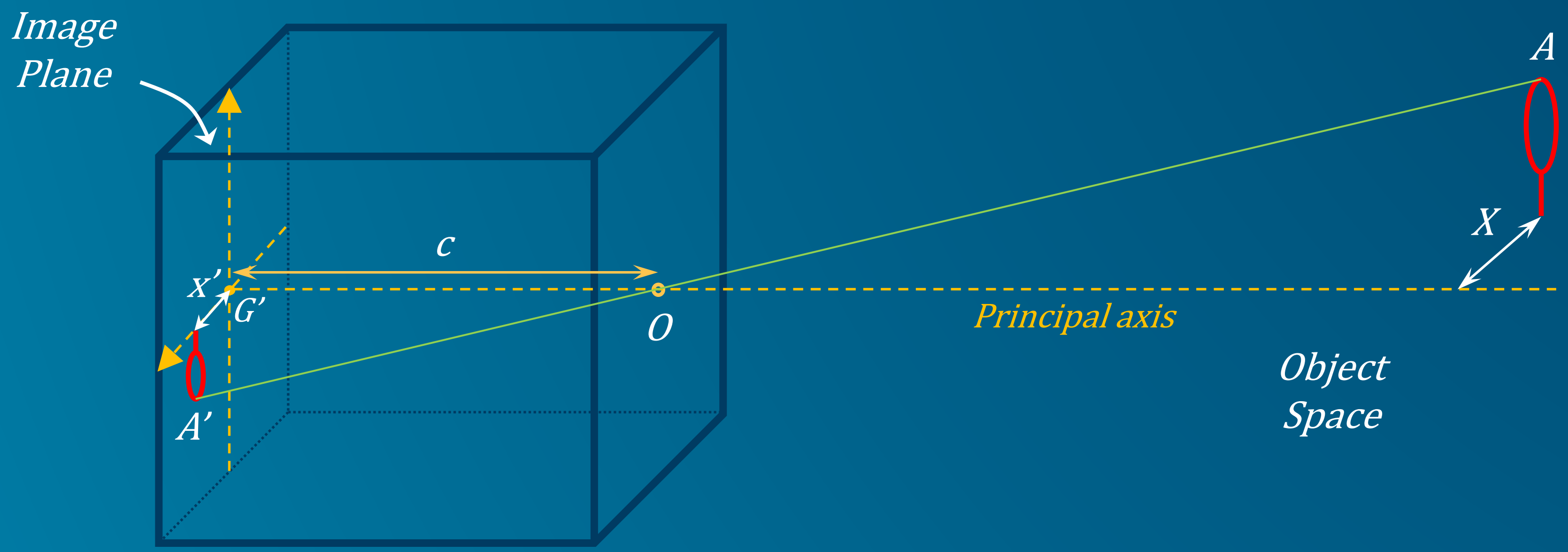
Size/shape characterization

Data 3D Visualization & Analysis Tools/ Metrics Development

3D Particle Tracking Velocimetry (3D-PTV)

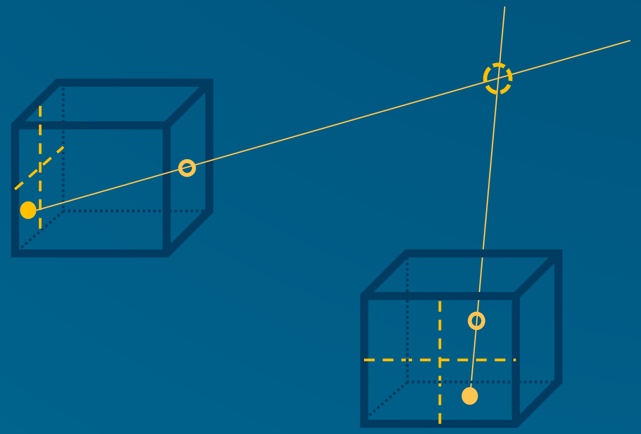
3D Particle Shape Reconstruction (3D-PSR)

3D-PTV & Object Positioning in 3D: Close-range Photogrammetry Principle



Pinhole Camera Model

Point location in 3D given 2 images



More… Bouvet, Link, Fink, NIST TN 2093, 2020.

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3D-PSR & firebrand sizing: the Visual Hull method

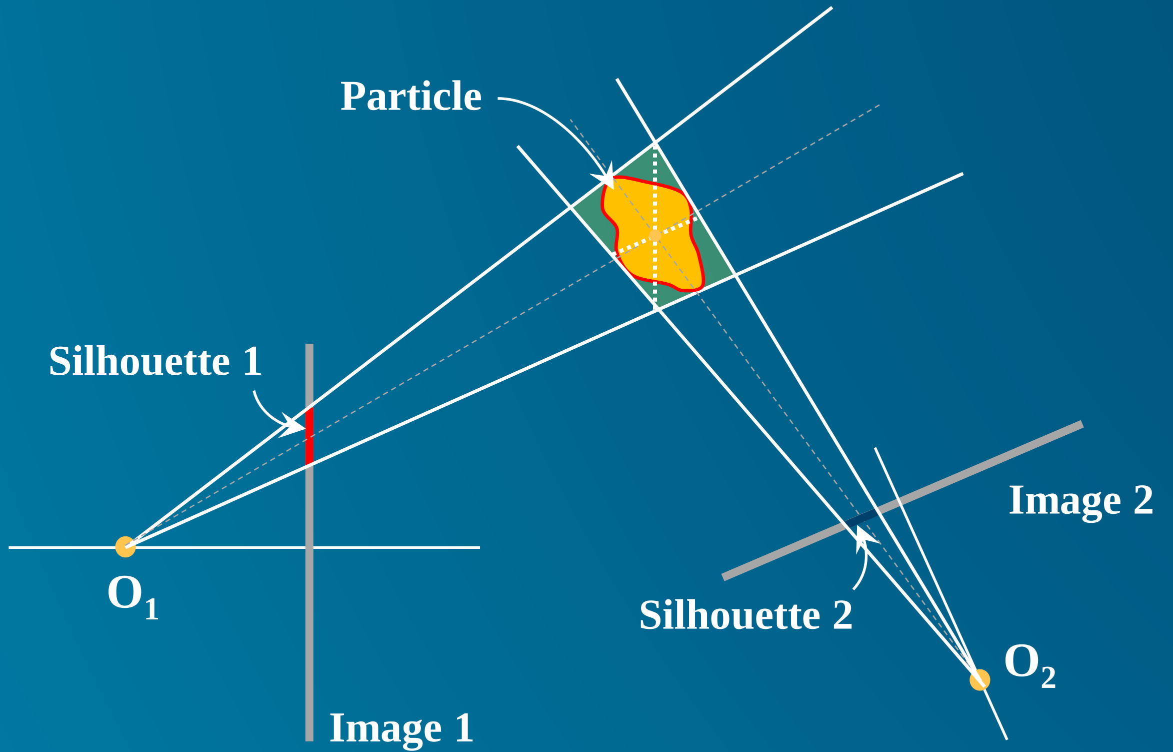


Illustration of the Visual Hull method

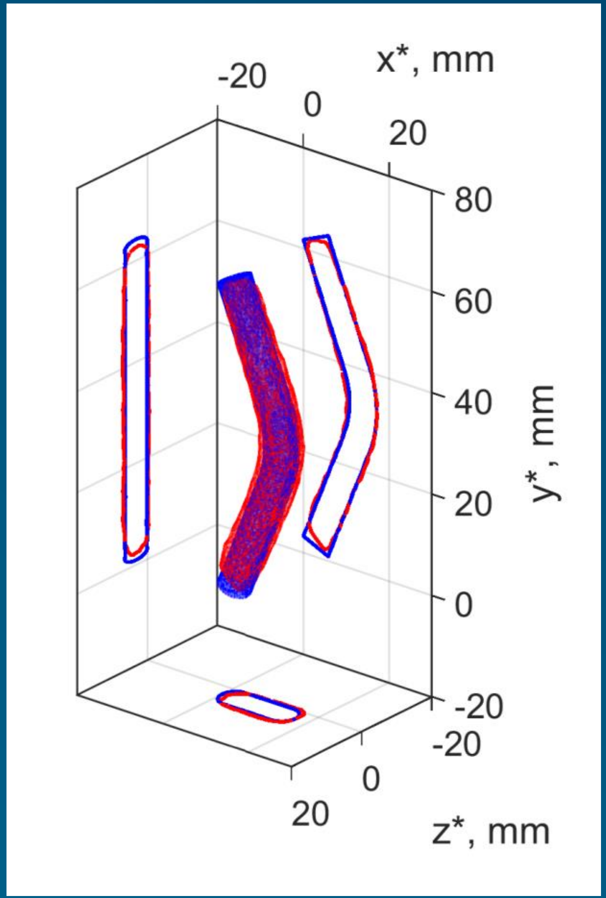
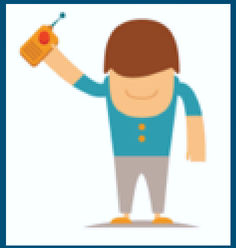
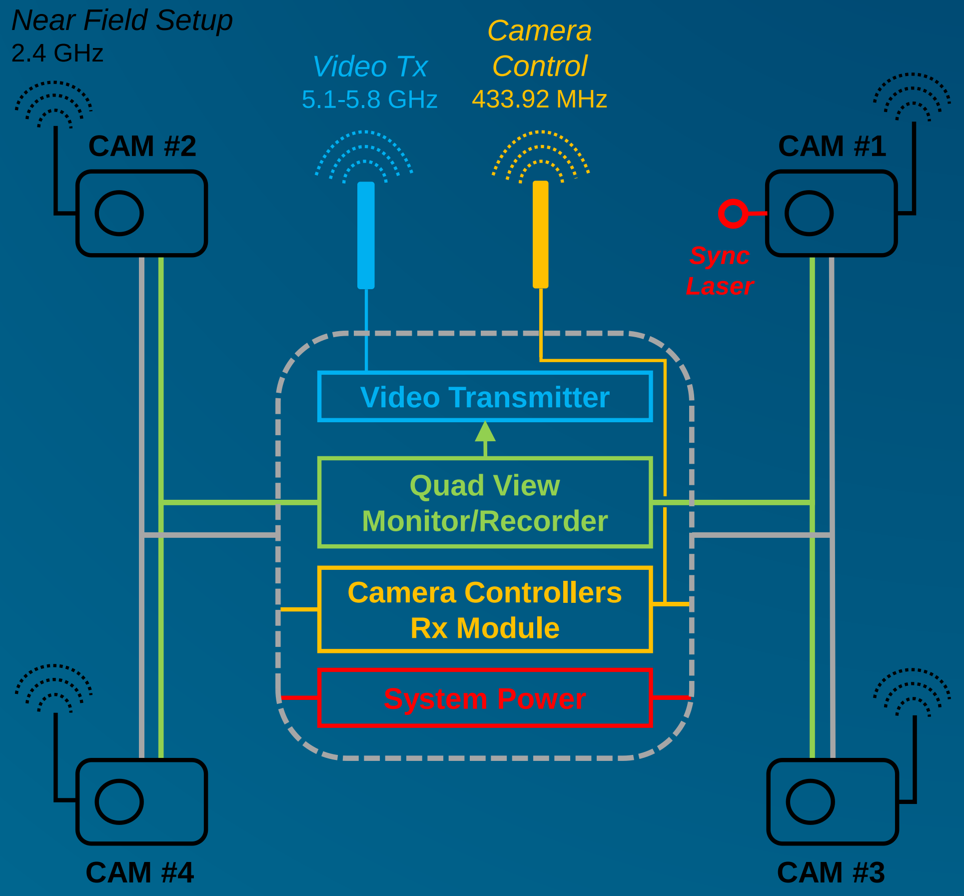


Illustration of the Visual Hull method

More… Bouvet, Link, Fink, NIST TN 2093, 2020.

Emberometer System





Firebrand showers and 3D diagnostic development… An engineering challenge!

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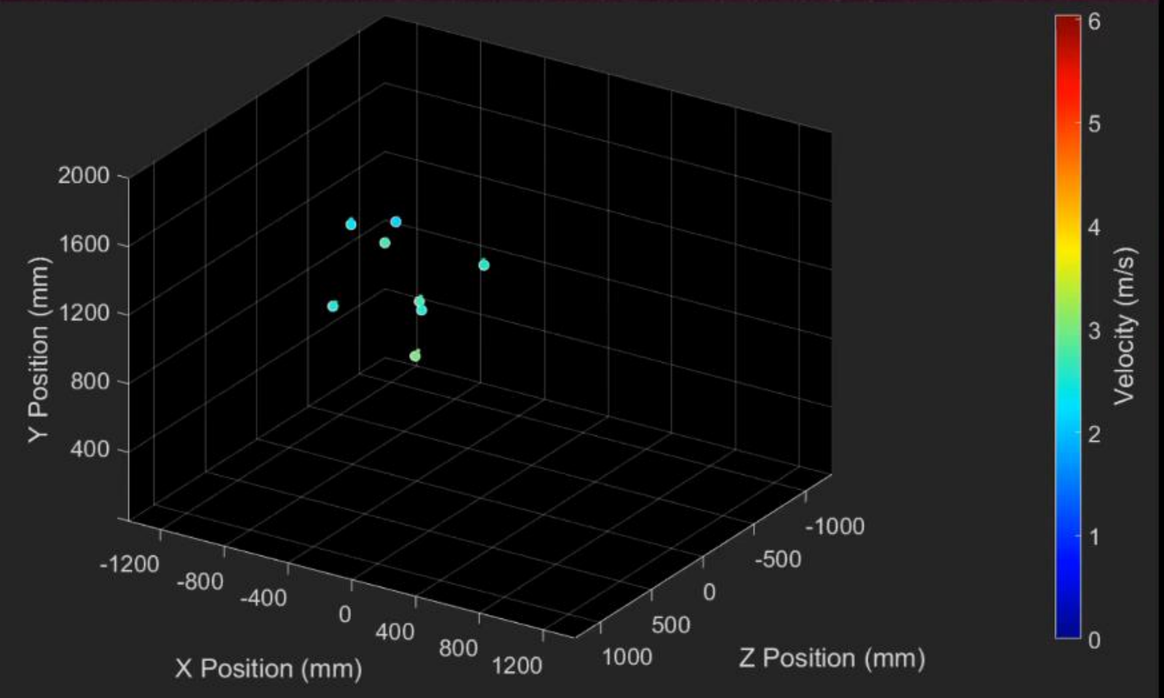
- **Affordability** – based on consumer-grade electronics (camera, micro-controllers, video handling devices, etc.): "*we burn it, so be it…*" $\rightarrow$ low-cost replacement *[Camera module $\approx$ \$2.6K, all components w/o stand $\approx$ \$13K]*
- **Accuracy** – need to achieve reasonable accuracy given chosen techniques (constrains regarding spatial resolution, high rep. rate capabilities, camera synchronization, calibration integrity preservation)
- **Deployability** – compact form factor, hardening, autonomy (power, memory) *[Autonomy power on $\sim$ full day / rule of thumb 20 GB $\sim$ 30 min rec. @ 120 fps/110 M]*
- **Controllability** – remote triggering & monitoring
- Adapted to **large scale settings** – large control volumes, manage non-controlled backgrounds *[Control volume $\approx$ 3.2 m^3]*

Set-up view

VIDEO CONTENT

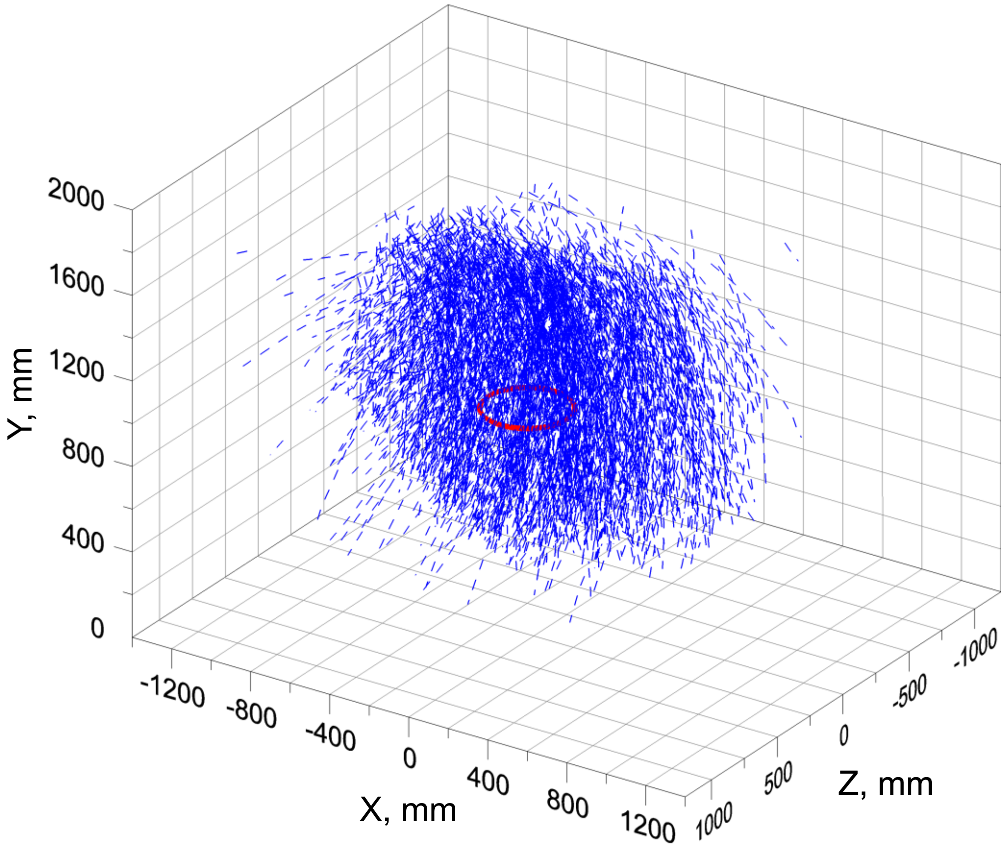
Quad view

(Raw → Conditioned → Superimposed tracks & identifiers)

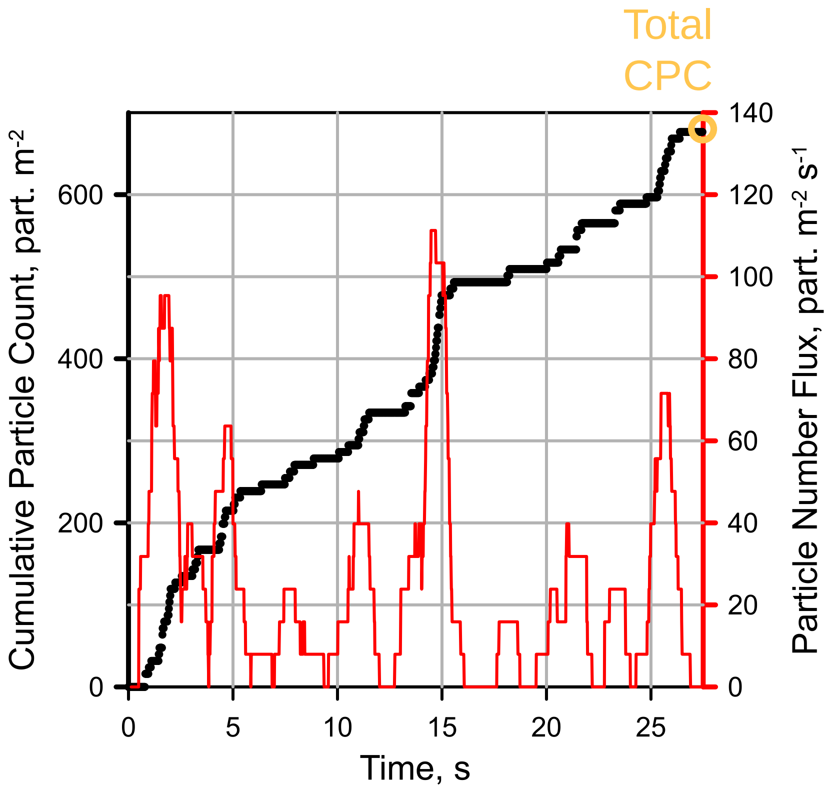


Reconstructed firebrand 3D motions

Cumulative Particle Count (CPC) and Particle Number Flux (PNF)



Firebrand 3D Trajectories

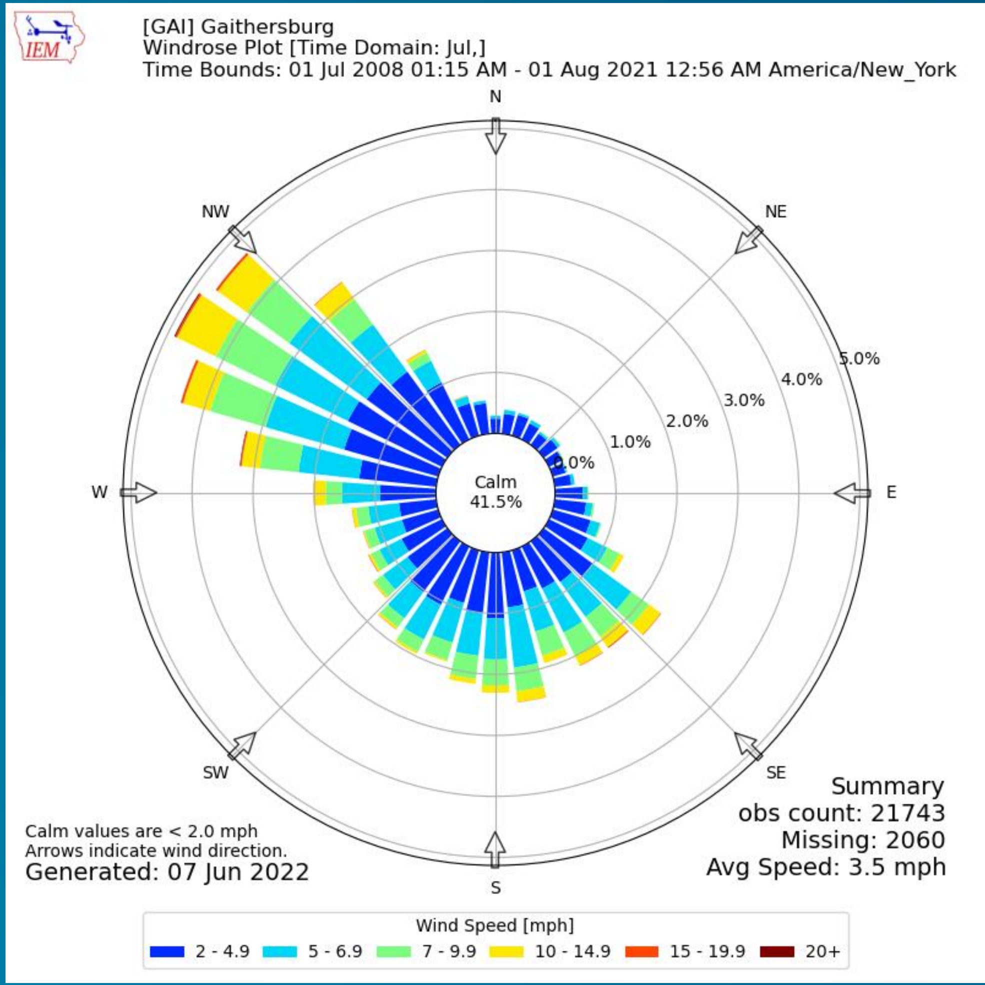


Cumulative Count / Number Flux

Single direction probing good but <u>need</u> a synoptic representation of the firebrand exposure over the entire test duration, for all directions !

The firebrand rose: a wind rose graphic analogy

National Institute of Standards and Technology U.S. Department of Commerce



Credit: Iowa Environmental Mesonet of Iowa State University

	WIND	FIREBRANDS
Graphic Type	**2D**	**3D** (*ember lofting, deposition*)
Spoke Direction	Wind direction	Direction perpendicular to ref. surface
Spoke Length	% time wind blew from specified dir.	Total Cumulative Particle Count (CPC)
Spoke Class	Range of wind speed	Range of Particles Number Fluxes (PNFs)
Class Width	% time wind blew in specified range	% time PNF recorded in specified range (spoke length = 100% time)

More… Bouvet, Link, Fink, Exp Fluids ***62,*** *181 (2021)*

Firebrand Rose Graphic

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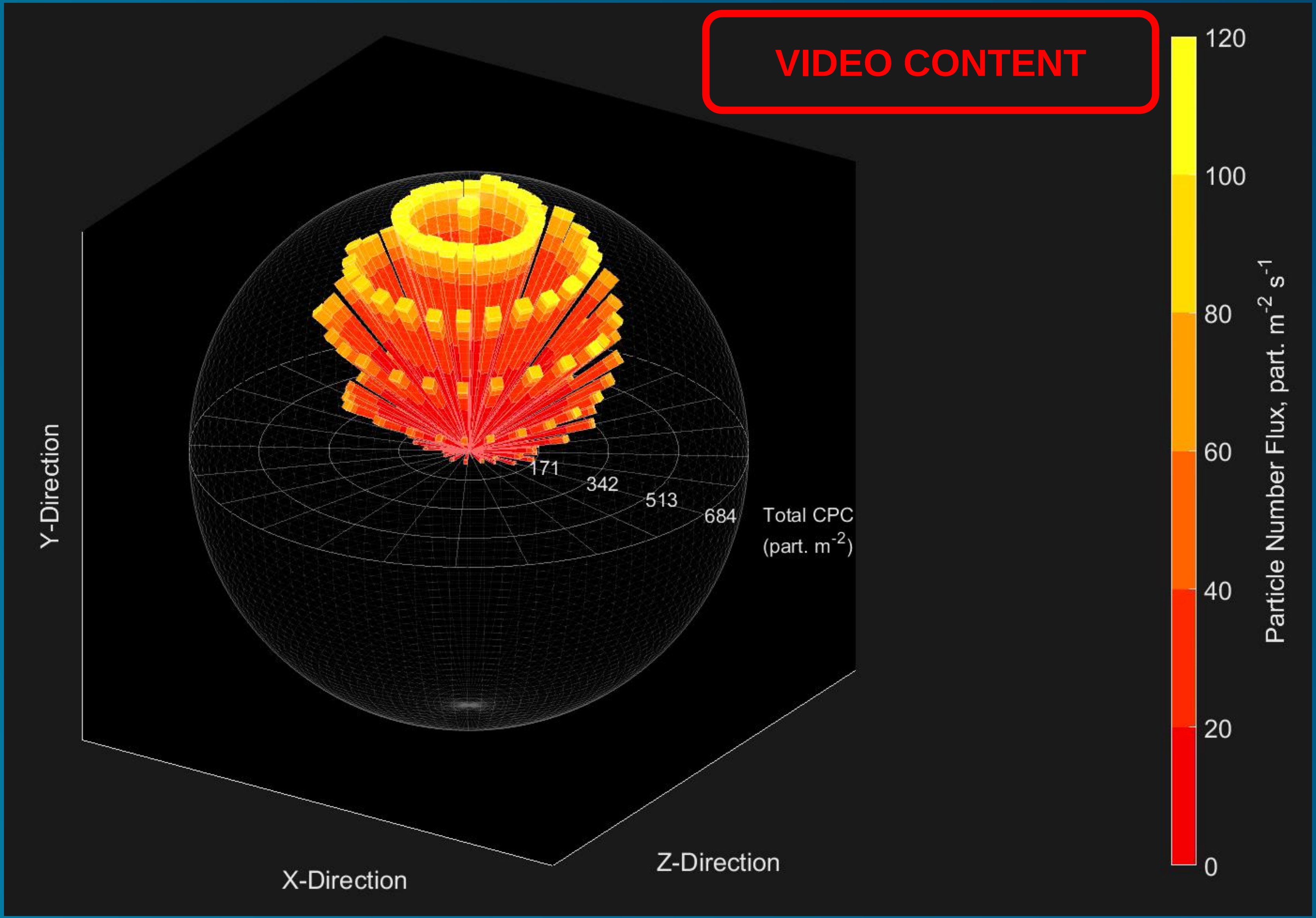

Firebrand rose and exposure comparison

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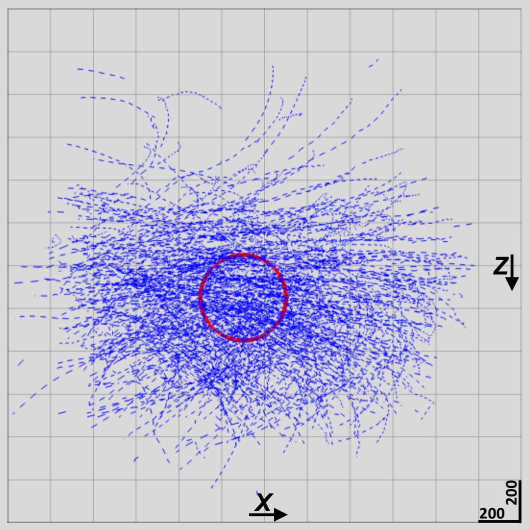
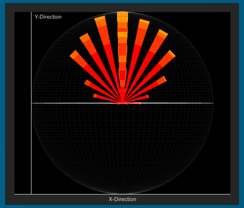
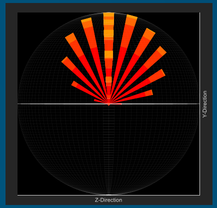
A

968 traj.



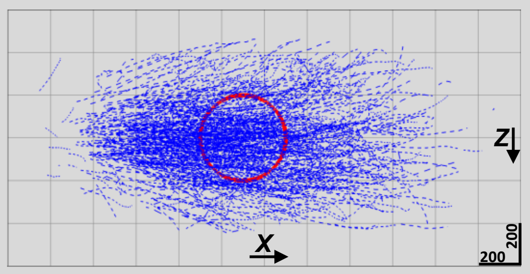
676 part. m^{-2}



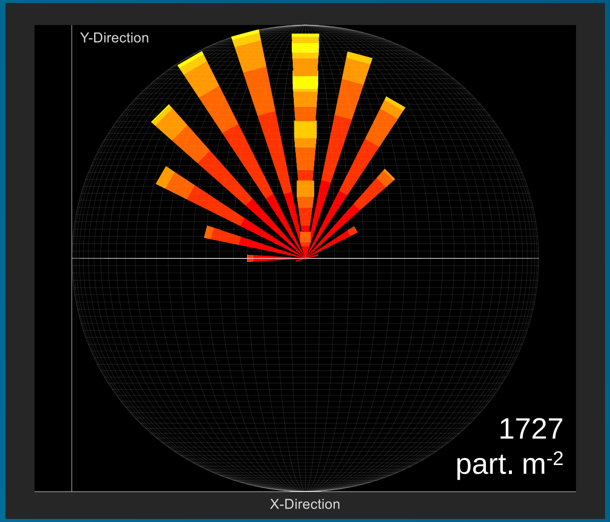


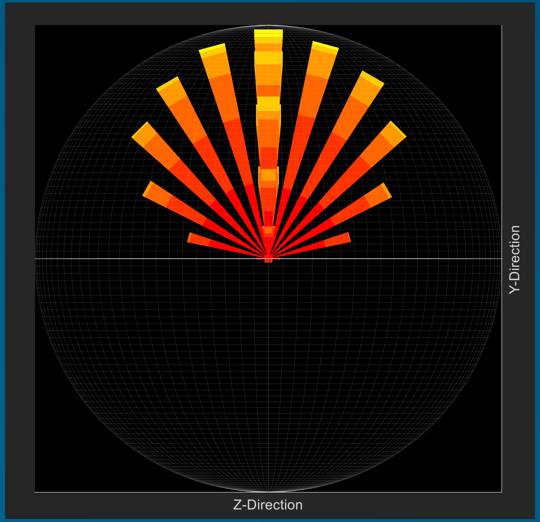
B

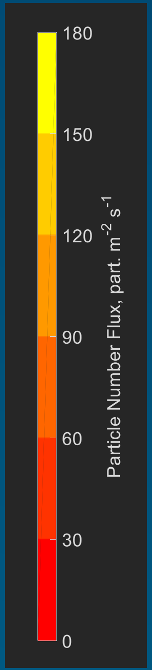
782 traj.



Indoor / no wind*







*Bouvet et al., On the use of time-resolved three-dimensional diagnostics to characterize firebrand showers in the WUI, Advances in Forest Fire Research 2018.

Firebrand rose and exposure comparison

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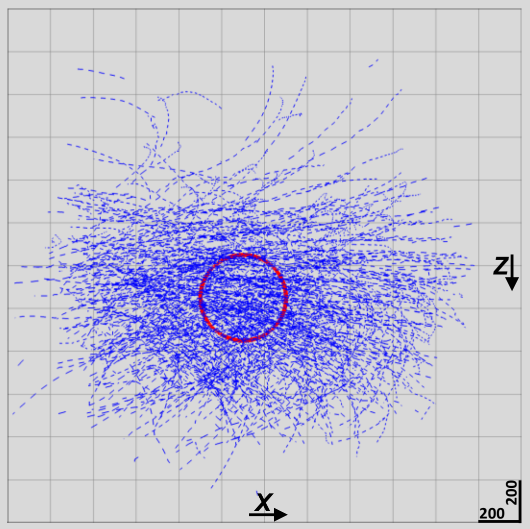
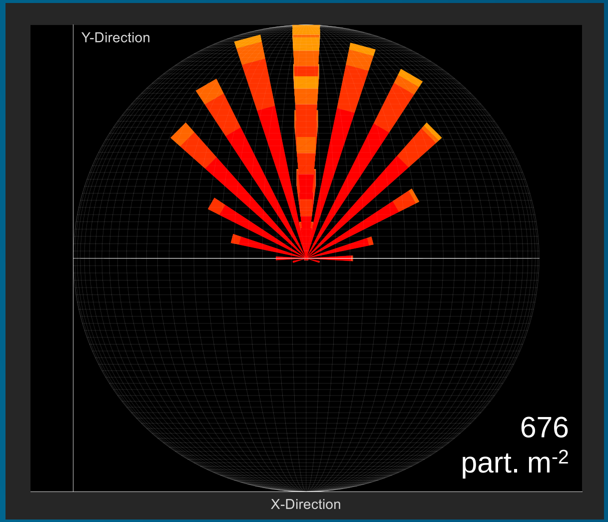
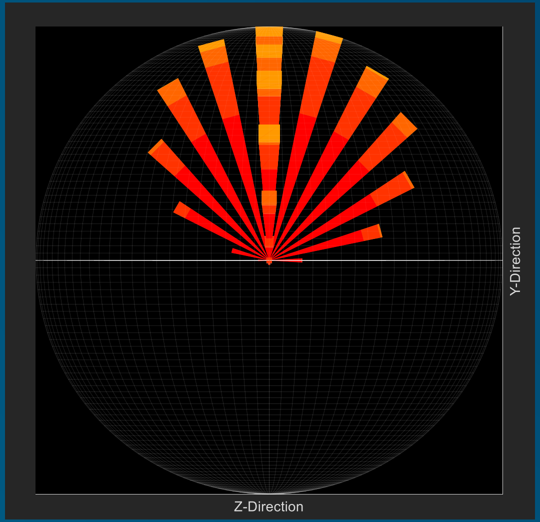
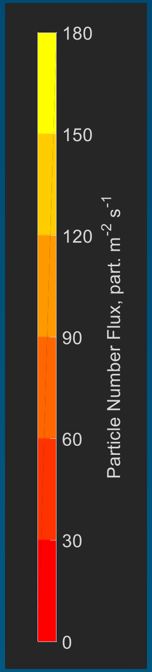
A
968 traj.









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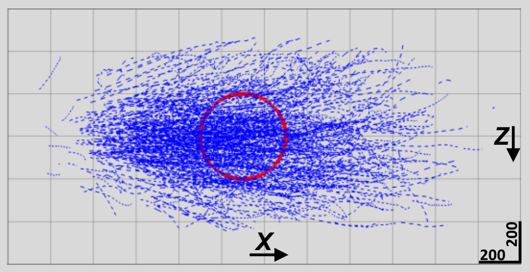
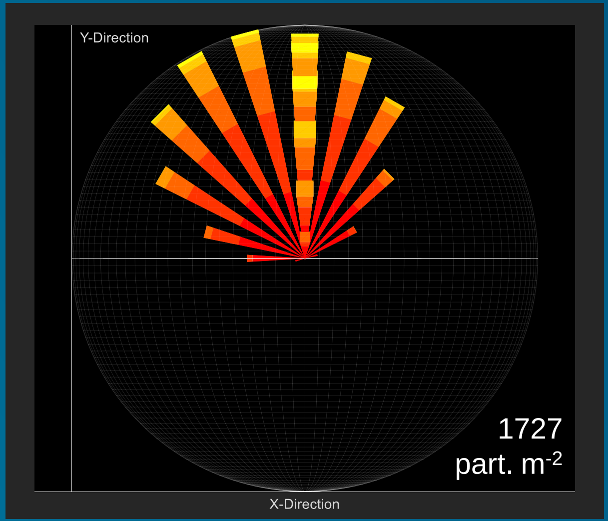
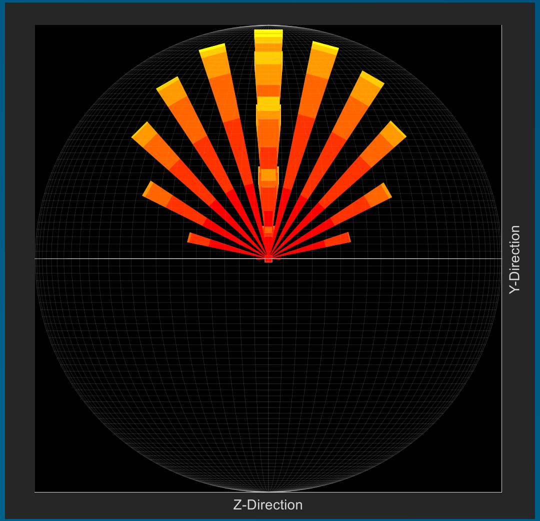


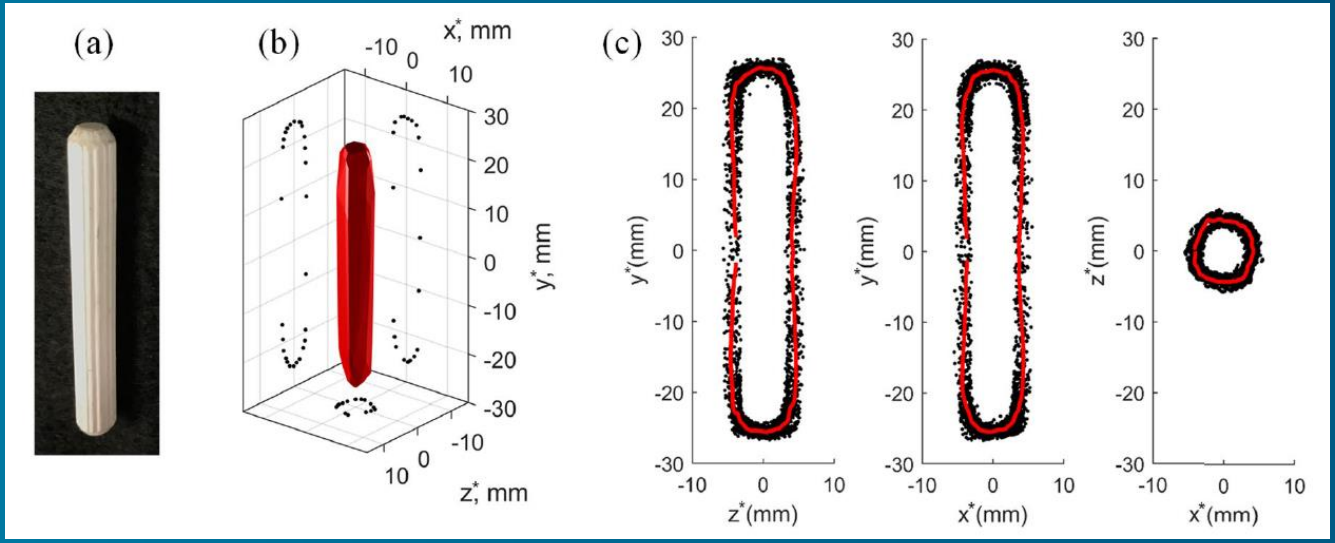
Indoor / no wind*





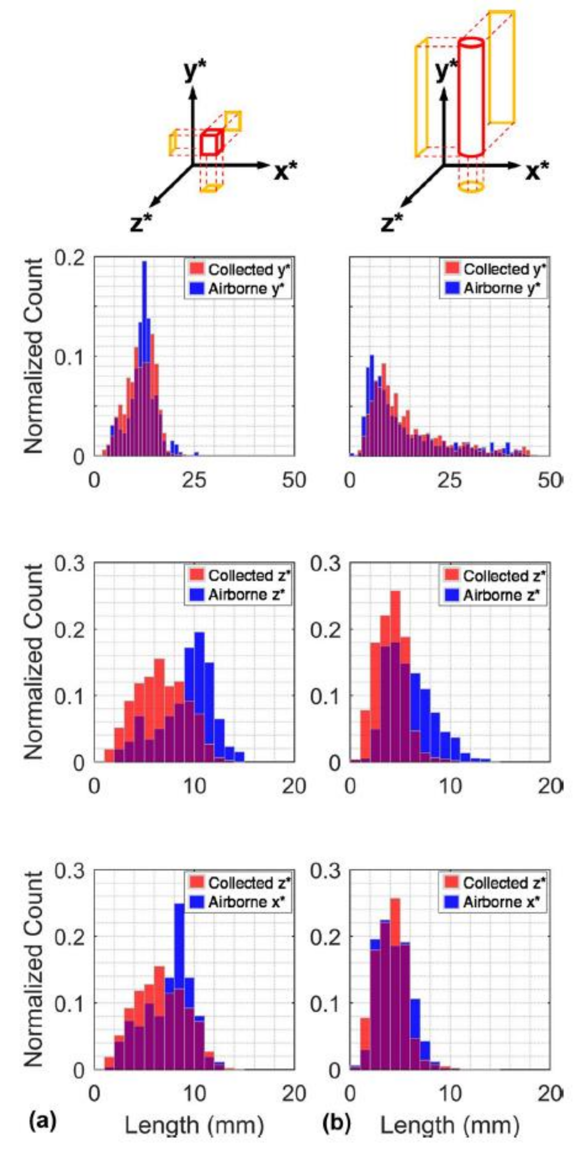
*Bouvet et al., On the use of time-resolved three-dimensional diagnostics to characterize firebrand showers in the WUI, Advances in Forest Fire Research 2018.

Firebrand Sizing



Hull → 1 timestep

Projections → all timesteps



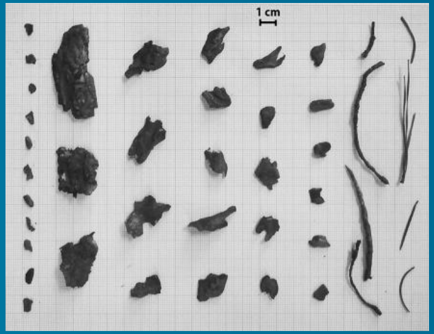
Ember x, y and z dimensions

What about **complex** firebrand shapes…

Is a bounding box approach best suited to report on firebrand size characteristics?

*Bouvet, Link, Fink, Exp Fluids **62,** 181 (2021)*

Towards Firebrand Shape Classification

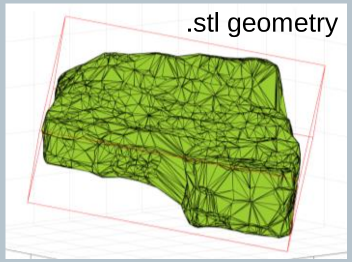


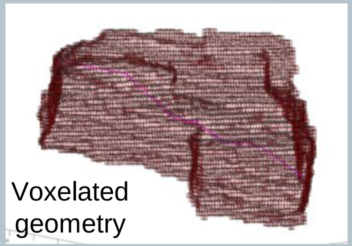
From [1]

3D Firebrand Models

Emberometer data,
3D scan data*

Measurements





Volume,
Surface area,
Thickness,
etc.

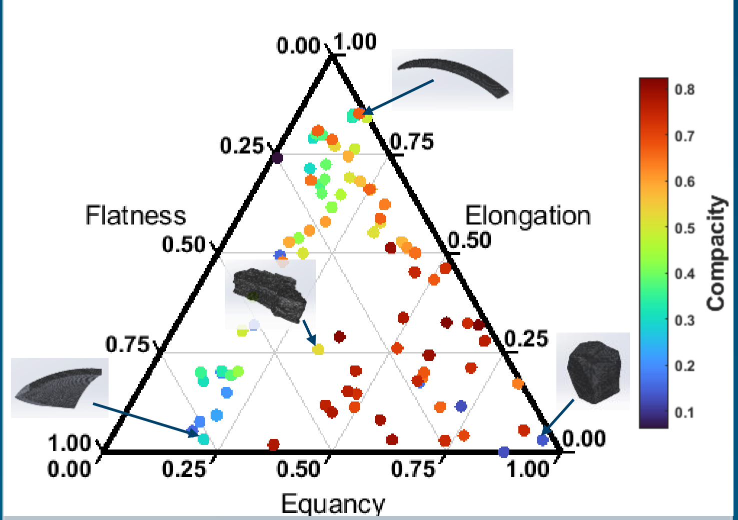
Shape Descriptors

May be 1D, 2D and/or 3D

Examples:

Elongation,
Flatness,
Equancy,
Sphericity,
Convexity,
Compacity,
etc.

Shape Classification

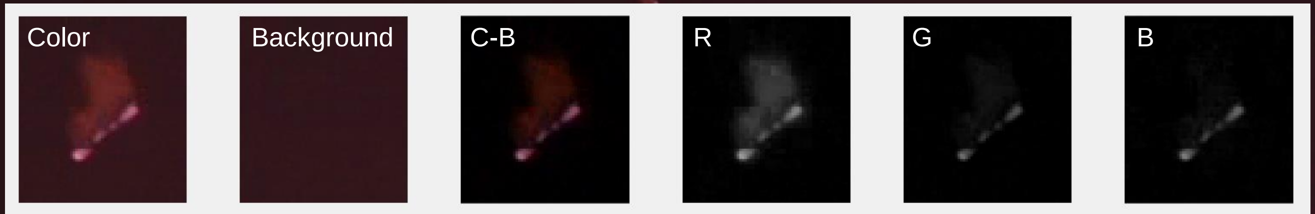


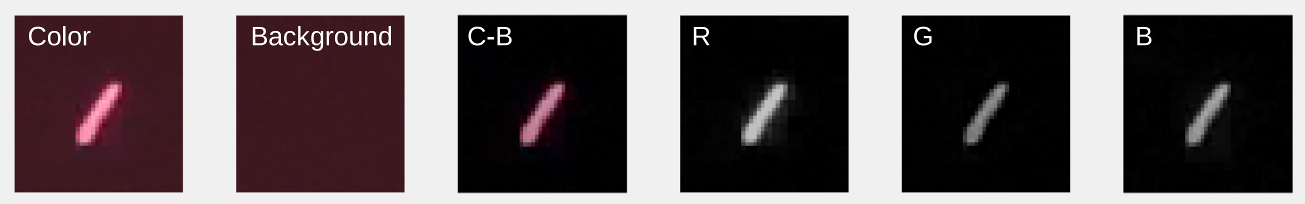
Firebrand Sizing Stat. by Shape Class

[1] El Houssami et al., Experimental procedures characterising firebrand generation in wildland fires, *Fire Technol.* 52 (2016) 731-751.

* 3D scan data example courtesy of Direct Dimensions, Inc.

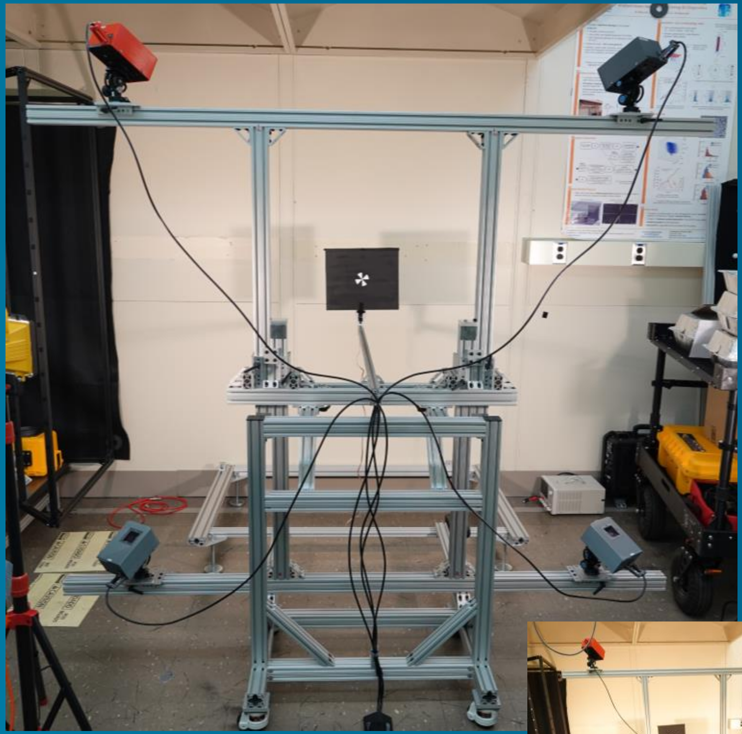
Improving the Emberometer Sizing Methodology: Accounting for Flaming Firebrands

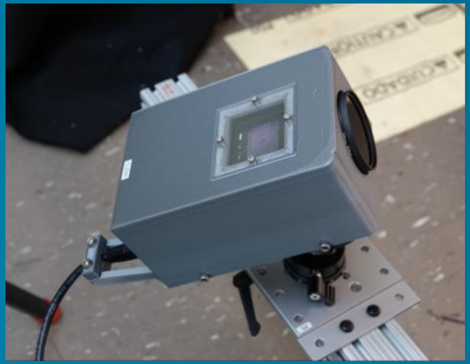




- Segregate **smoldering vs flaming** firebrand to avoid biasing size/shape characterization
- Opportunity to provide a **firebrand smoldering/flaming index** as **new metric** for exposure severity
- An opportunity to assess efficiency of **deep learning tools** at recognizing flaming brands

NIST Emberometer *Light: towards a standard test for firebrand generation*





Emberometer *Light* System

A system ***easy to duplicate****, allowing* ***multiple volumes*** *to be probed* ***simultaneously,*** *using the* ***same analysis tools*** *previously developed.*

- Prototype stage
- Camera boxes with small form factor (6"x4"x 3")
- Tethered emberometer modules, plug & play
- Controlled via dedicated notebook app.
- Up to 200 m span between control volumes
- System currently non-hardened

NIST Emberometer *Light: towards a standard test for firebrand generation*

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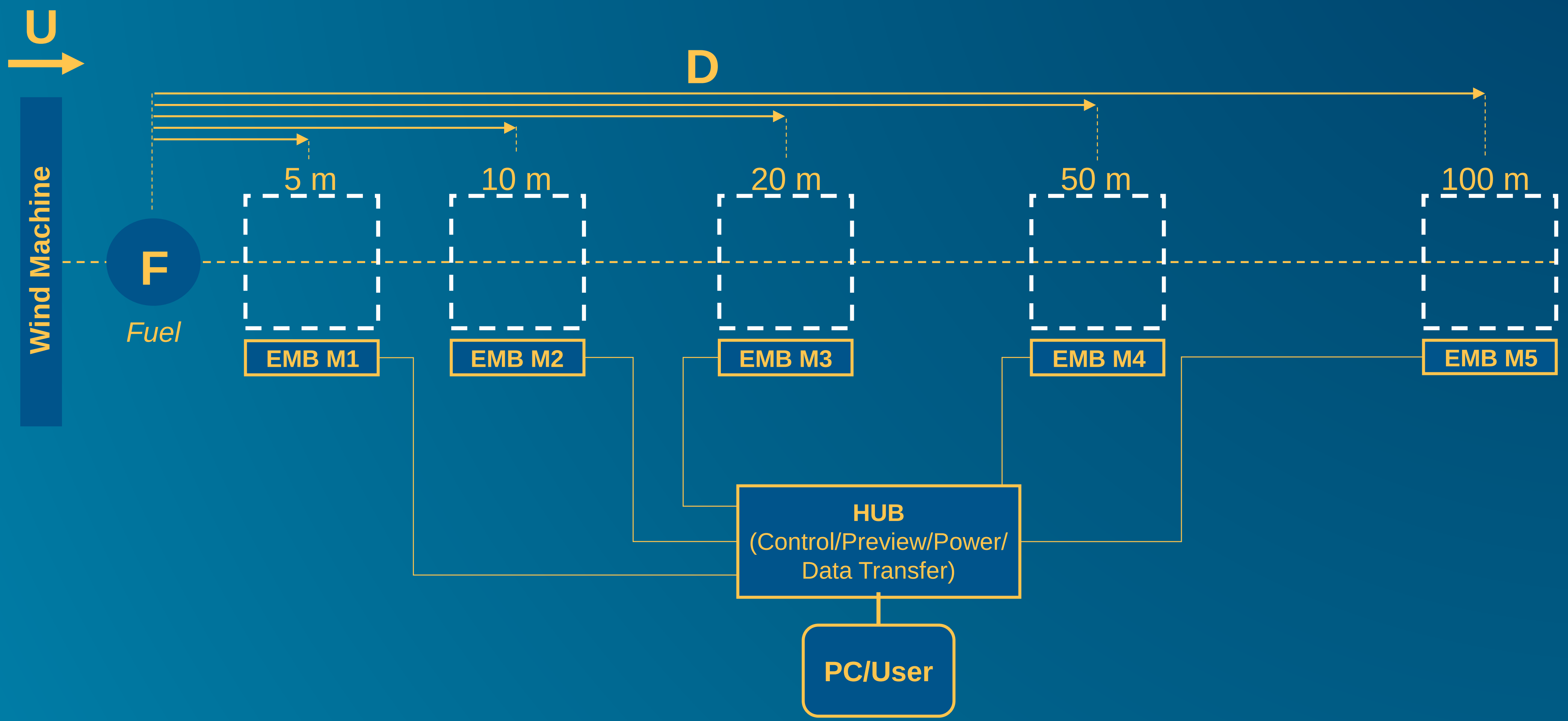

Firebrand Flux, Size/Shape Characterization = f (F, D, U)

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Emberometer Snapshot

Deployability

3D Firebrand Tracking

Time-resolved firebrand trajectories in 3D

Firebrand Morphology

Size/shape characterization

Data 3D Visualization & Analysis Tools/ Metrics Development

Field-deployable, hardened system

Cumulative Particle Count

Number Flux

Firebrand shape mapping using particle descriptors

Sizing info by shape class

3D reconstruction/ animation of firebrand shower

Firebrand rose

Flaming/smoldering index

Volumetric flux info (?)

Emberometer(s)… Looking forward

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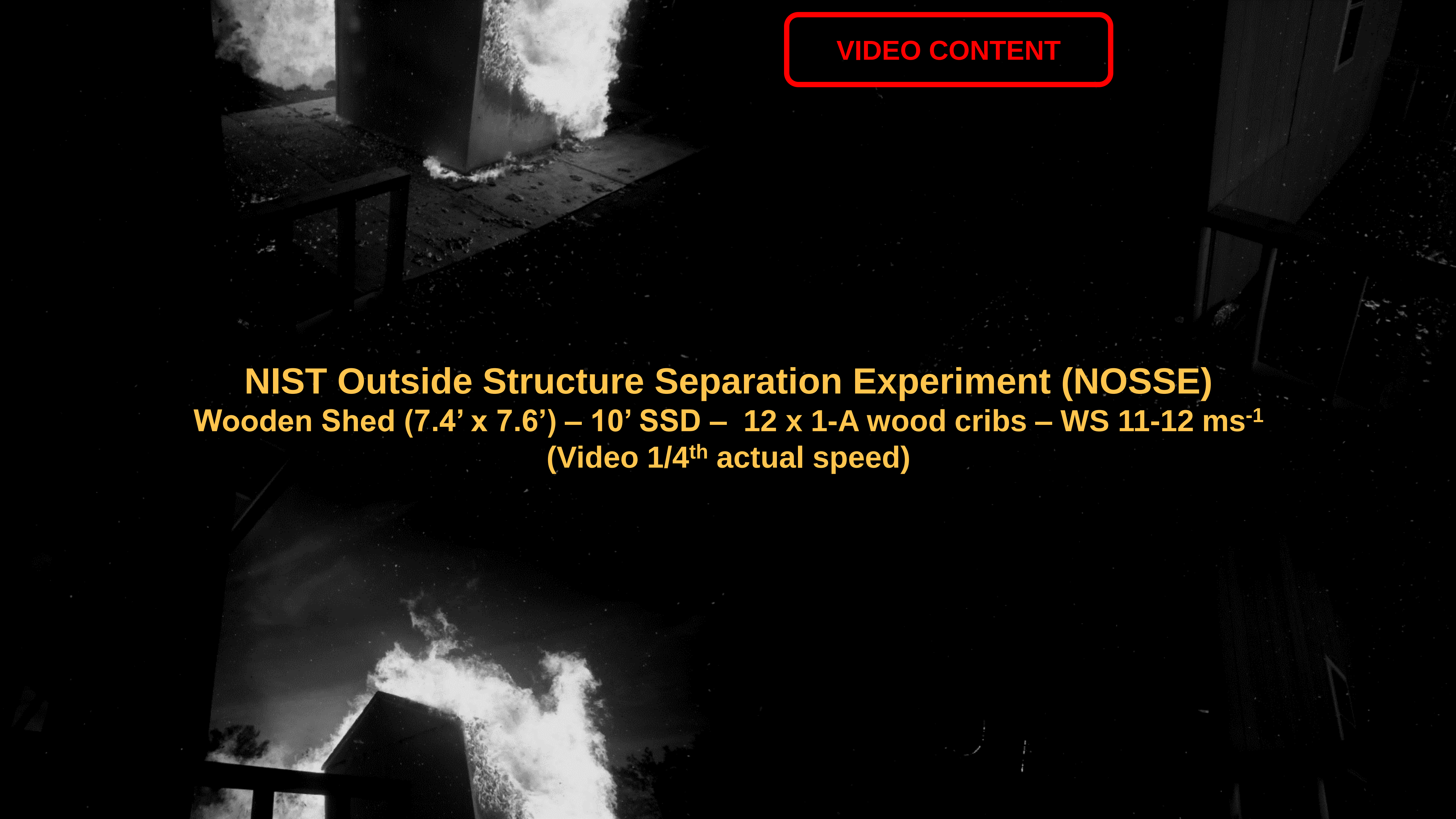
Emberometer (*Large*)

- Streamline operations (deployment → data processing → results)
- Strengthen external collaborations for field measurements to maximize operational experience
- From operational experience (outdoor settings/realistic wildland/WUI fire conditions):
  - better understand system limitations (e.g., particle size threshold, background influence, thermal stressing, etc.),
  - identify deployment best practices (e.g., system positioning/orientation)
- Document firebrand exposure in complex situations for fully characterized experimental conditions
- Use emberometer-derived metrics to guide test methods for ignition studies (vegetation, structures)

Emberometer *Light*

- Outdoor validation of single module
- Fabrication of additional “plug & play” modules
- Outdoor validation of multi-module assembly
- Design/optimize test method for firebrand generation characterization
- Document firebrand exposure from common WUI fuels (vegetative/non-vegetative)
- Extend firebrand characterization studies to simple ignition problems



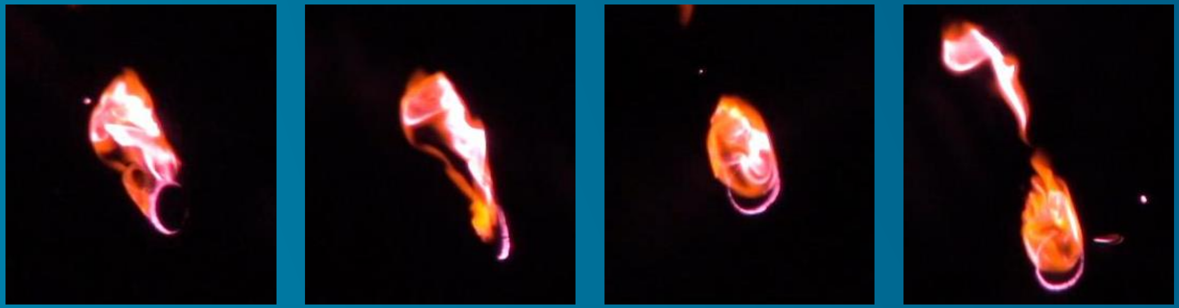
VIDEO CONTENT

NIST Outside Structure Separation Experiment (NOSSE)

Wooden Shed (7.4’ x 7.6’) – 10’ SSD – 12 x 1-A wood cribs – WS 11-12 ms^{-1}

(Video 1/4th actual speed)

NIST WUI Fire Days 2022



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