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AEROSPACE PLASMA GROUP

Understanding and Controlling the Interactions of Plasmas with Flames and Flowing Gases

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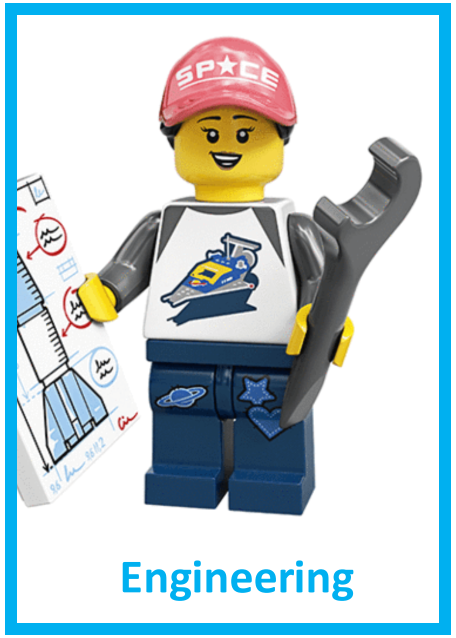
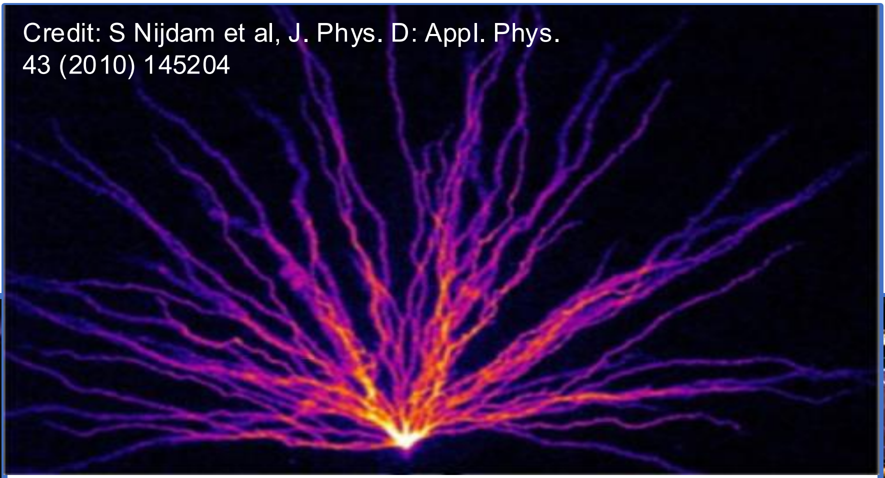


Mission of the Aerospace Plasma Group

AEROSPACE PLASMA GROUP

Unveil the physics of transient electrical discharges to understand our natural environment and *enable their control for the benefit of our planet and beyond*



Fundamentals of electrical breakdown

Plasma-assisted aerospace technologies

Lightning safety

Mission of the Aerospace Plasma Group

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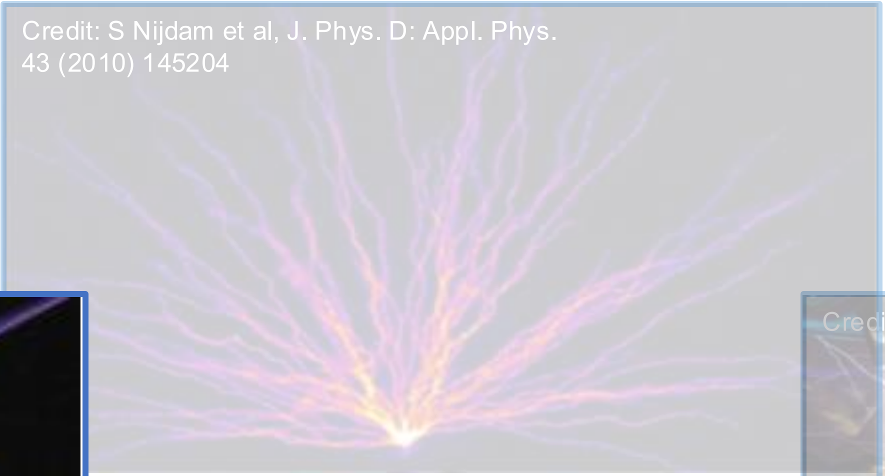
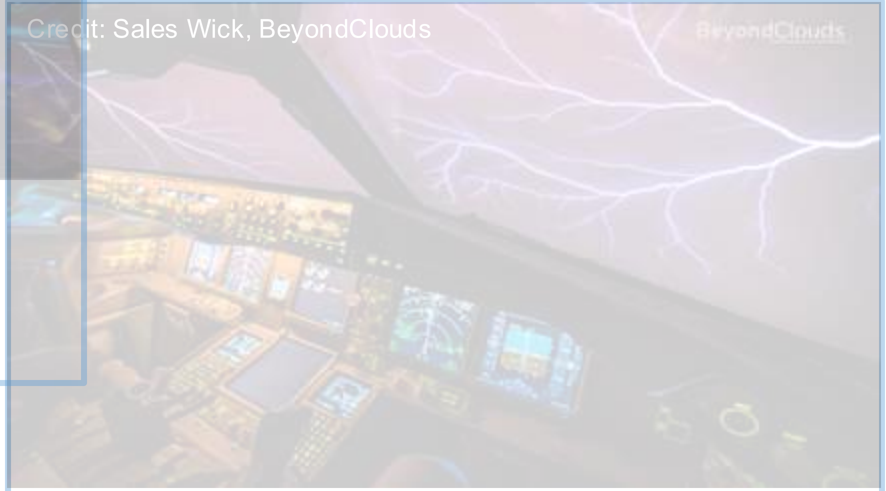
Plasma-assisted aerospace technologies

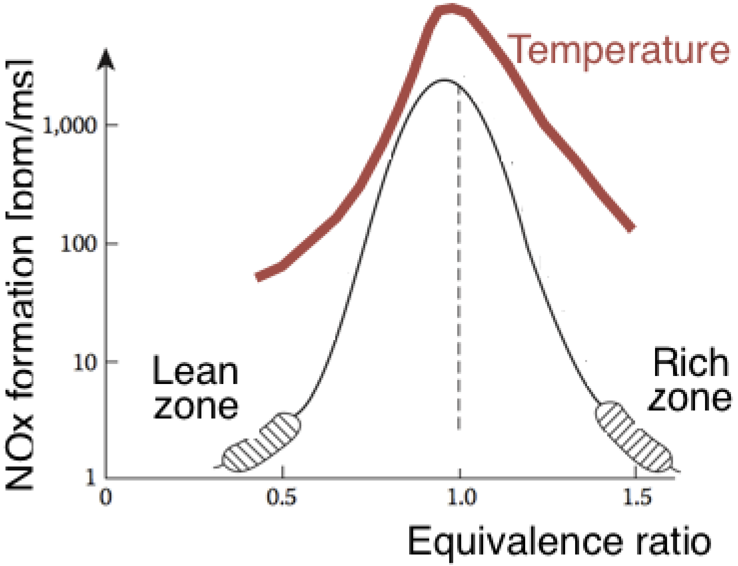


Fundamentals of electrical breakdown



Lightning safety

Plasma-assisted combustion for zero-carbon and net-zero aviation



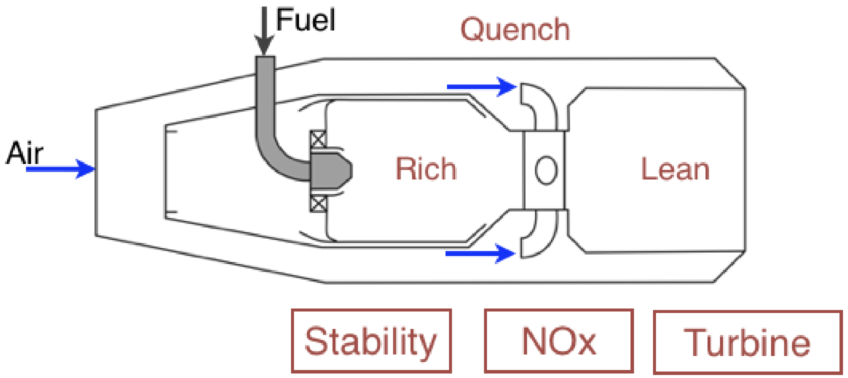


Figure adapted from: Gas Turbine Combustion, Lefebvre and Ballal, 2010

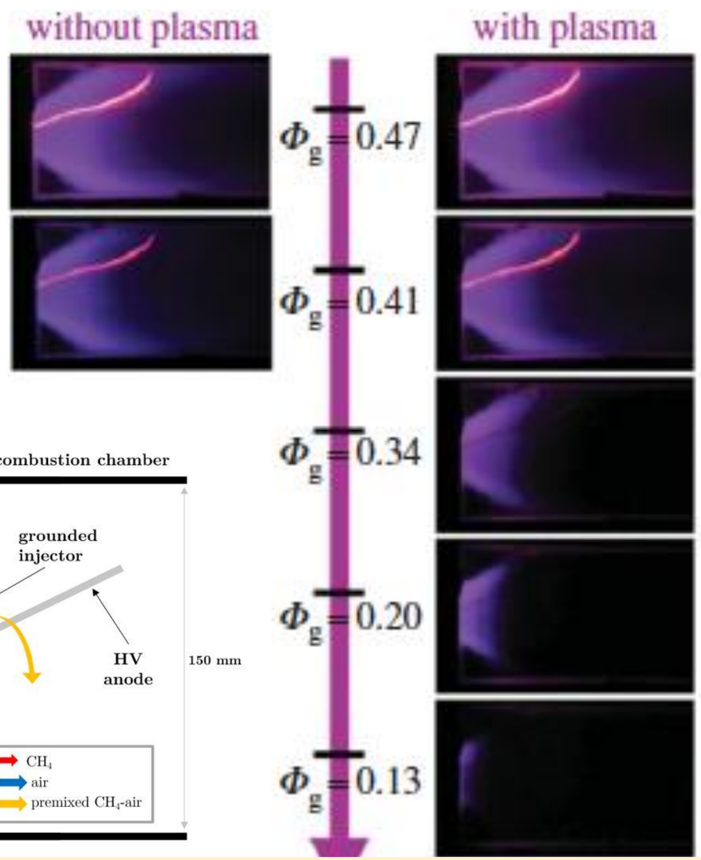
Requirement: Eliminate CO_2 emissions but not offset other emissions!

Approach: Short residence time at high temperature, low temperature preferred

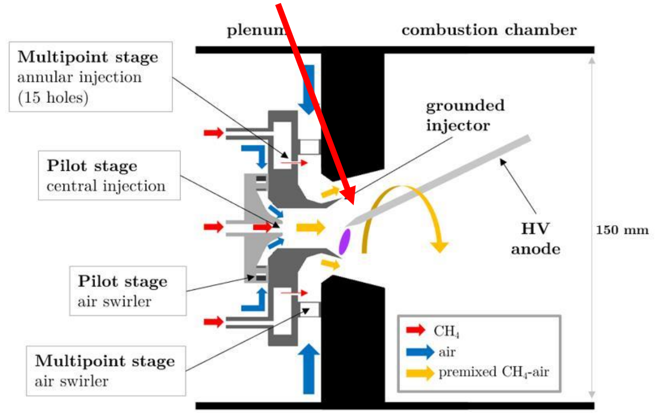
Challenges: Operate fuel lean, unstable, extinction, high altitude relight, thermo-acoustic instabilities

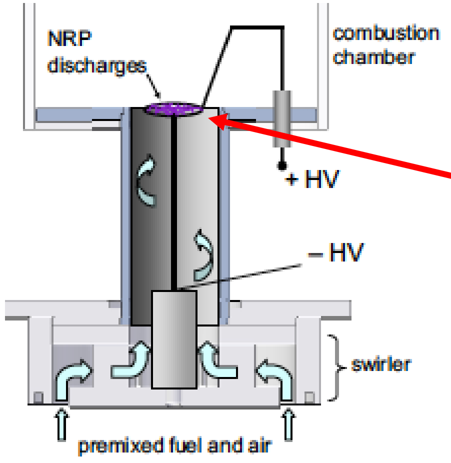
Demonstration: Plasma on (industry-relevant) flames

Nanosecond pulsed plasmas extend **static and dynamic stability limits of lean** flames, albeit variable response

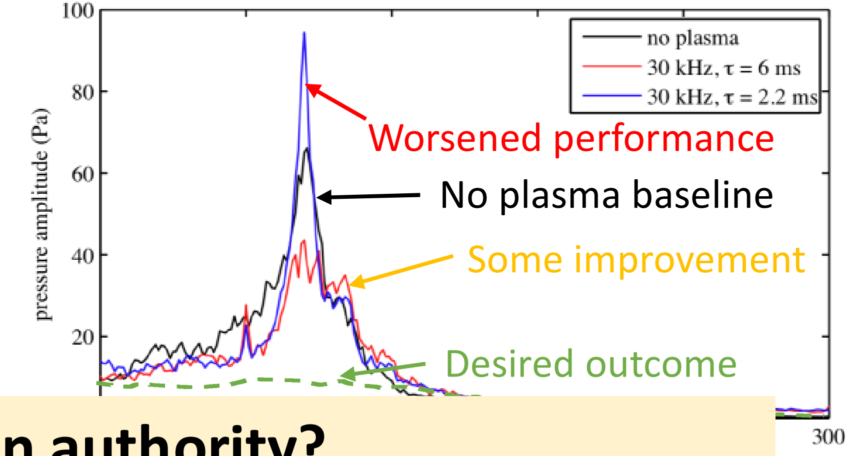


Swirl-stabilized burner
Pin-**ring** electrodes





Swirl-stabilized burner
Pin-**ring** electrodes



How can we maximize actuation authority?

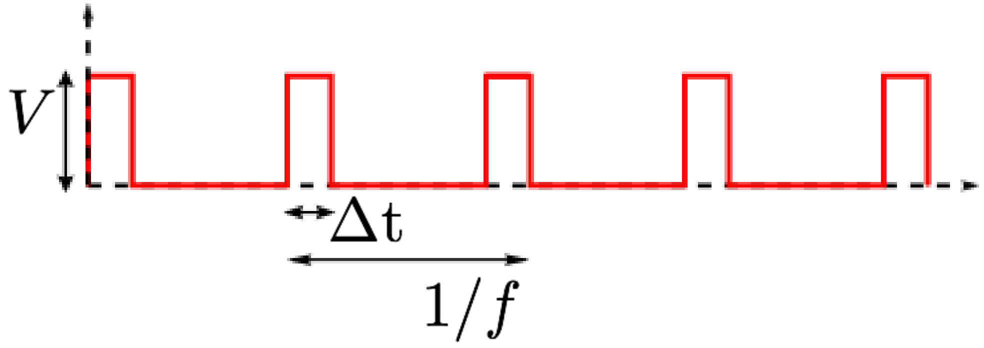
What controls the plasma-energy deposition and energy pathways?

S. ... A
Veynante. *Phil. Trans. R. Soc. A* 373, 2015.   V Blanchard's PhD Thesis 2023   *Aerospace Sciences Meeting*, 2013

WHY Nanosecond Repetitively Pulsed Discharges (NRPD)

Nonthermal

- Electrons have much higher energy than heavy species ($T_e \sim eV$, $T_i \sim T_{gas}$, $T_e \gg T_i$)
- Low ionization fraction
    - Most collisions are electron – neutral



Access high E/N

Local Field Approximation (simplified)

- Electrons gain energy from the field

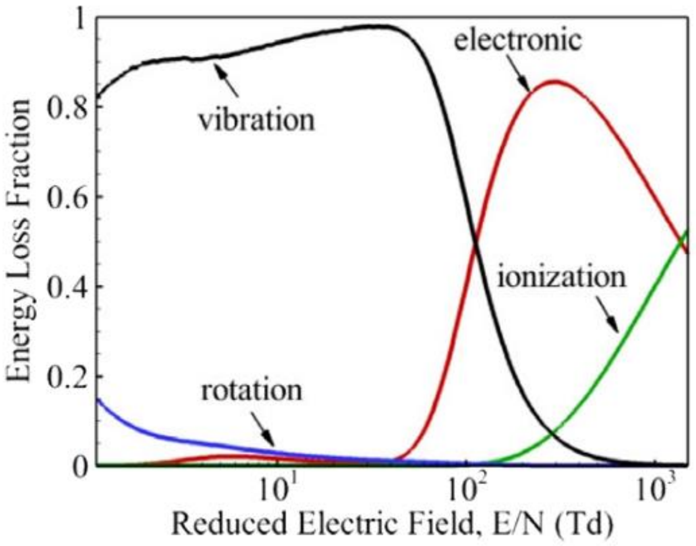
$$\epsilon_{gain} = \overrightarrow{-j_e} \cdot \vec{E}, \vec{j_e} = -en_e\mu_e \vec{E}$$

- And spend it in collisions (locally). For low energy electrons ~1-2 eV:

$$\epsilon_{lost} = n_e \nu_{eh} \frac{2m_e}{m_h} \delta \frac{3}{2} k (T_e - T_h)$$

- Electron temperature/ energy is defined by the reduced electric field

$$\epsilon_{gain} = \epsilon_{lost} \rightarrow T_e = f(E/N)$$



S Nagaraja et al. J. Phys. D: Appl. Phys. 46 (2013) 155205

Electrical parameters

- Gas gap: 1-10mm
- Electrical: 10kV, 20ns, 1-100kHz
- Energy per pulse: 100μJ-10mJ
- Power: 0.1-1000W
- **P_{plasma}/P_{flame} < 1%**
- **E/N ~ 180-500 Td**

What impacts combustion

Combustion chemistry involves a reactions of the form:

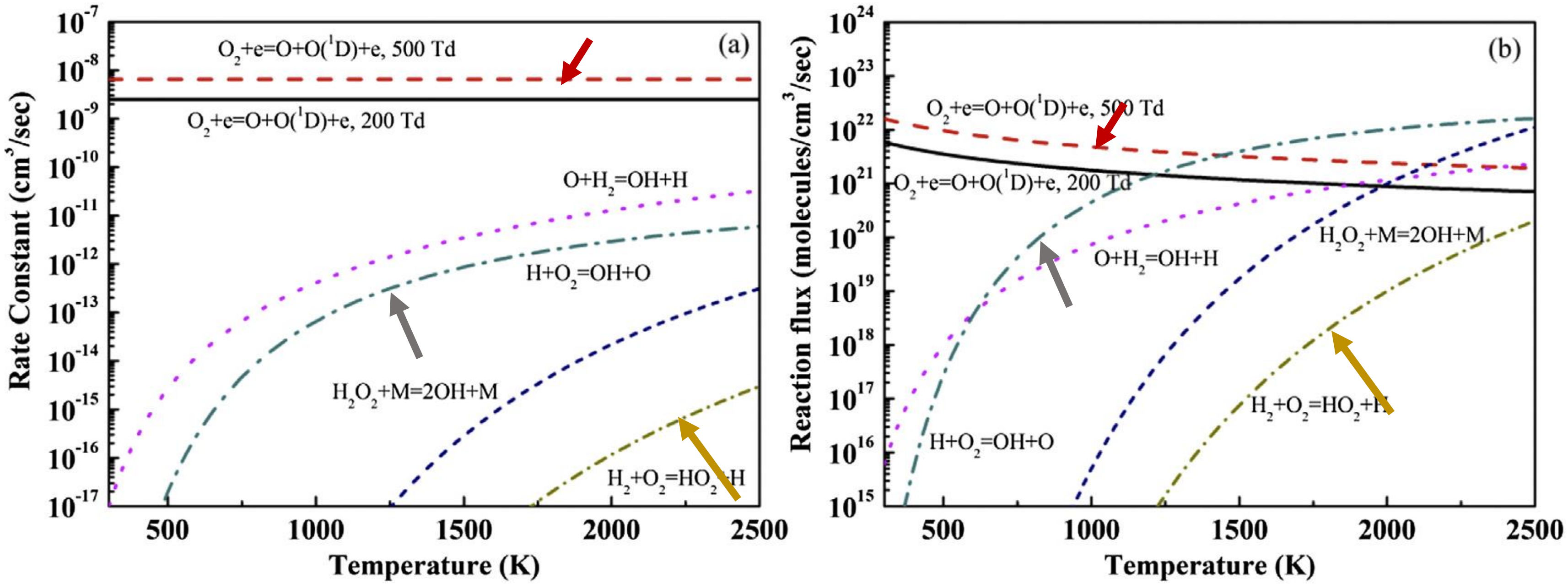
$$A + B \underset{k_b}{\overset{k_f}{\rightleftharpoons}} C$$

$$\frac{\mathrm{d}[C]}{\mathrm{dt}} = k_f(T)[A][B] - k_b(T)[C]$$

$$k_f(T) = A_f T^n \exp\left(-T_a/T\right)$$

- Thermal effects: accelerate Arrhenius rates
- Kinetic effects: bypass slow reactions

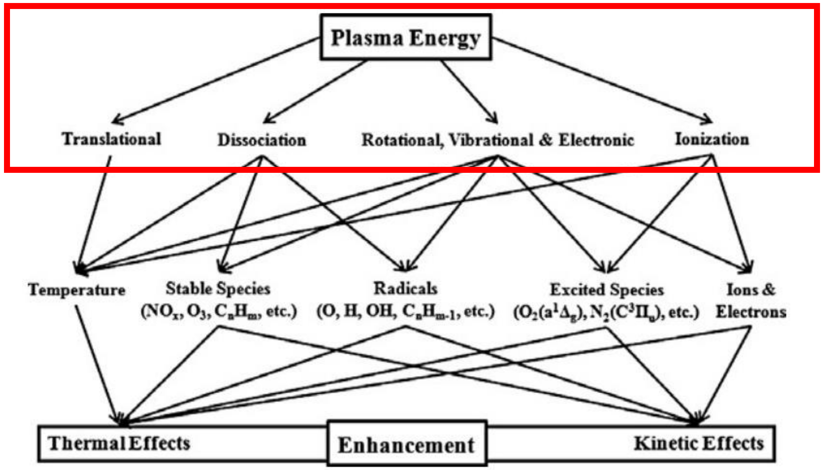
Chain-initiation	
$H_2 + O_2 = HO_2 + H$	(R1)
Chain-branching/propagation	
$H + O_2 = OH + O$	(R2)
$O + H_2 = OH + H$	(R3)
$OH + H_2 = H_2O + H$	(R4)
$HO_2 + H = OH + OH$	(R5)
$H_2O_2 = OH + OH$	(R6)
Chain-termination	
$H + O_2(+M) = HO_2(+M)$	(R7)
$HO_2 + H = H_2 + O_2$	(R1)
Electron and $N_2(^*)$ impact dissociation	
$e + O_2 = O + O(^1D)$	(R8a)
$e + O_2^+ = O + O$	(R8b)



Example from Ju & Sun, *Progress in Energy and Combustion Science* 48 (2015)

Mechanisms of plasma-flame interaction (0D)

Fundamental mechanisms: E/N and energy deposition (electron temperature and electron density) determine the plasma-activated chemistry – 0D problem

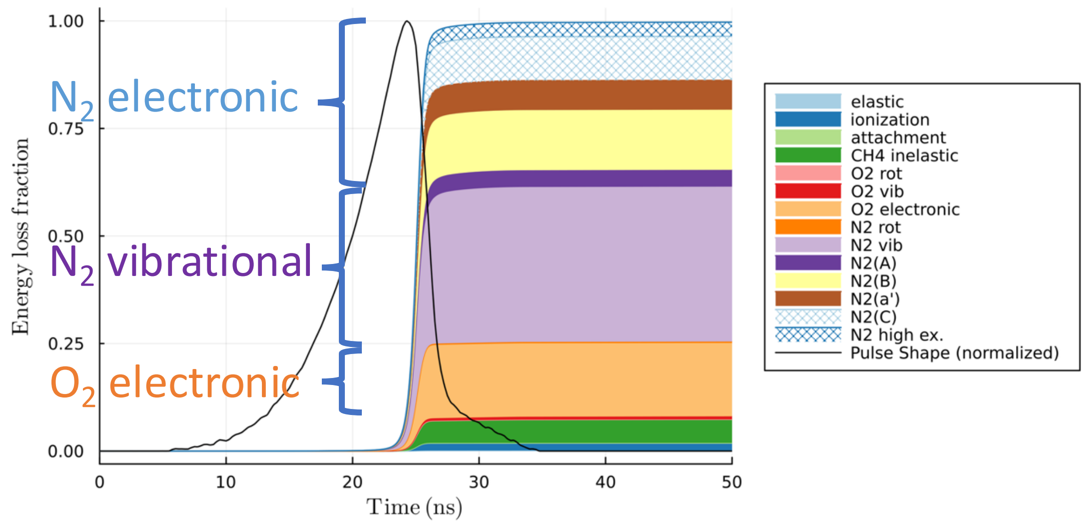


T. Ombrello et al. Comb and Flame 157 (2010)

First level of energy transfer: Electron-impact excitation (Popov, Plasma Phys. Rep. 2001)

$$N_2 + e \rightarrow N_2(v) + e$$
$$N_2 + e \rightarrow N_2(A, B, C, a' \ldots) + e$$
$$O_2 + e \rightarrow \boxed{O + O} + e$$

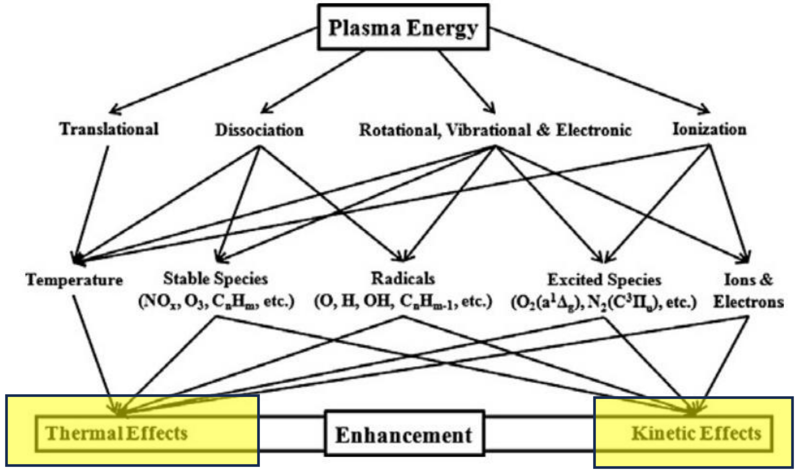
Radicals



Case: stoichiometric methane/air mixture

Mechanisms of plasma-flame interaction (0D)

Fundamental mechanisms: E/N and energy (electron temperature and electron density) determine the plasma-activated chemistry – 0D problem



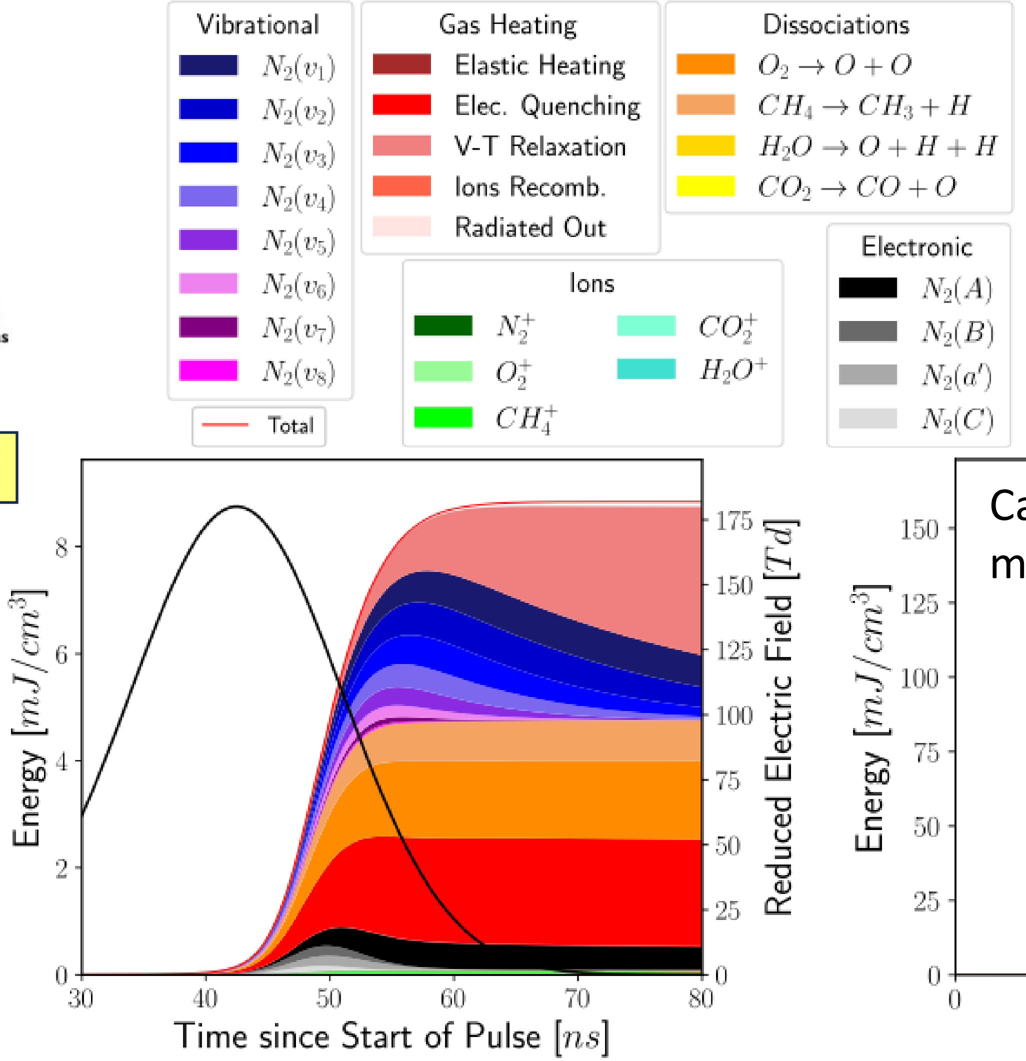
T. Ombrello et al. Comb and Flame 157 (2010)

Second level of energy transfer:

- Quenching of elec. states: Kinetic effects and thermal energy in **ns**
- Quenching of vib. states:

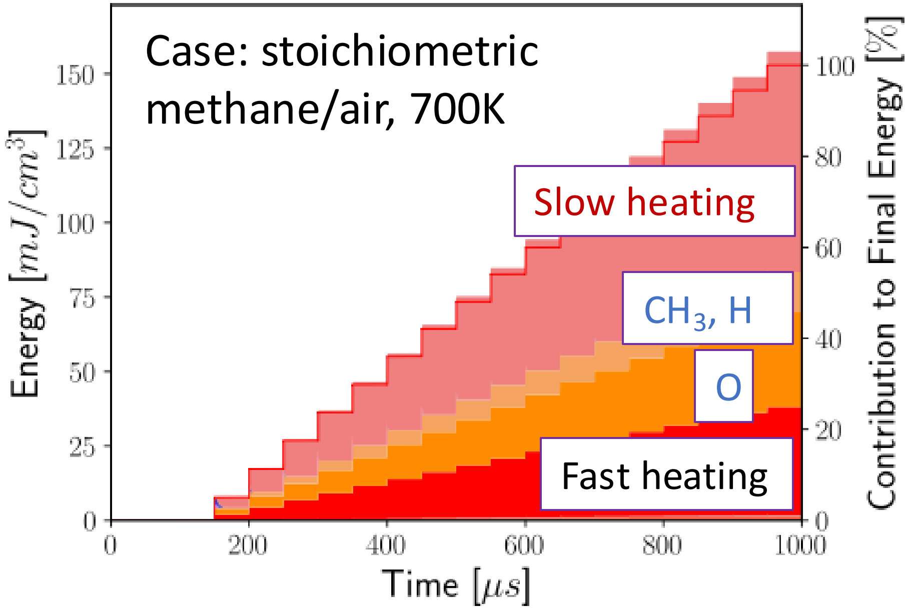
Thermal energy in **µs**

R. Dijoud, N. Laws, and C. Guerra-Garcia. *Combustion and Flame*, 271, 113793, **2025**



What impacts combustion:

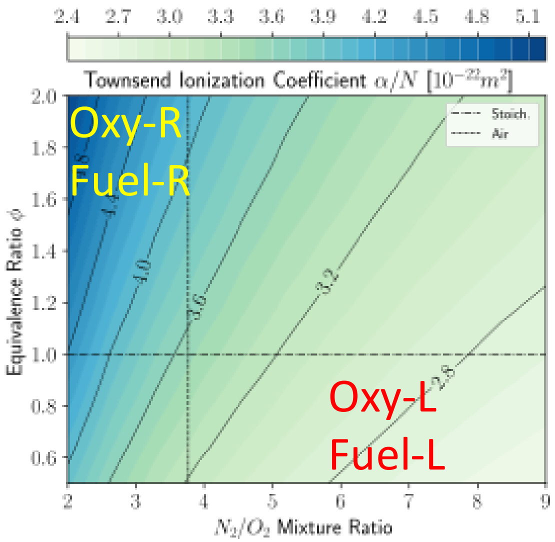
- Accelerated Arrhenius rates
- Bypassing of slower chain initiation and branching steps

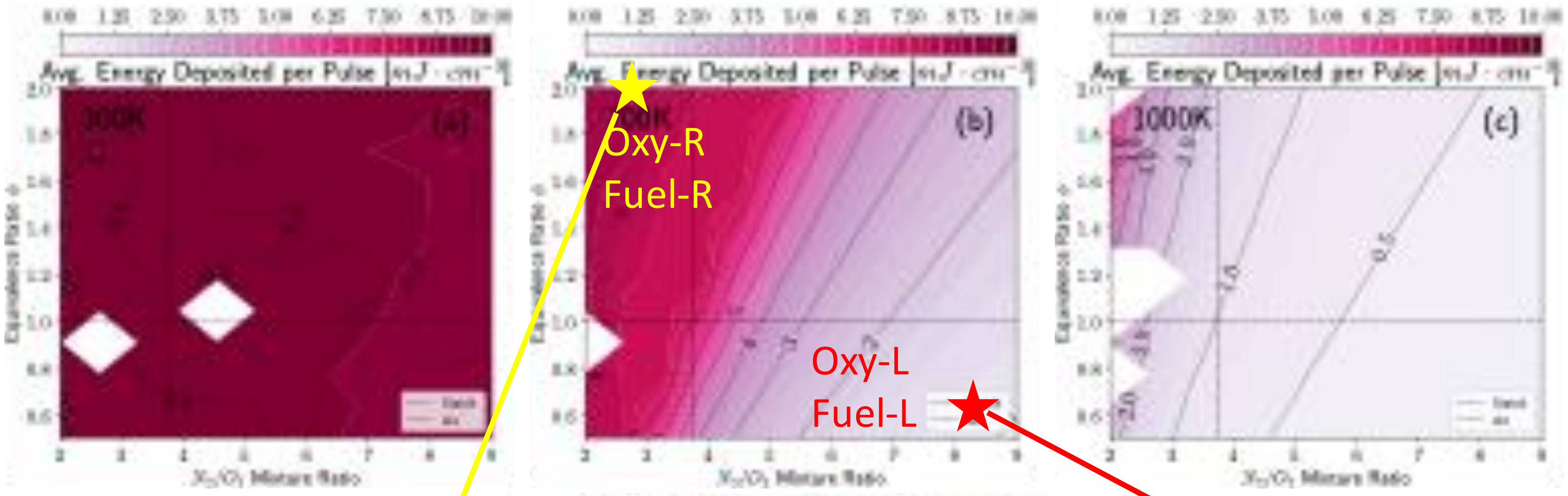


Influence of mixture composition on mechanisms of interaction

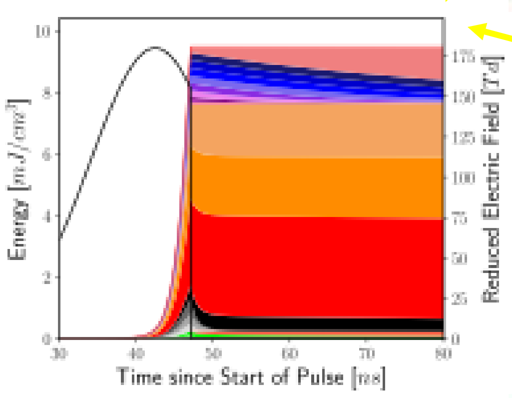
Challenge: E/N and energy deposition are coupled to the mixture composition and state

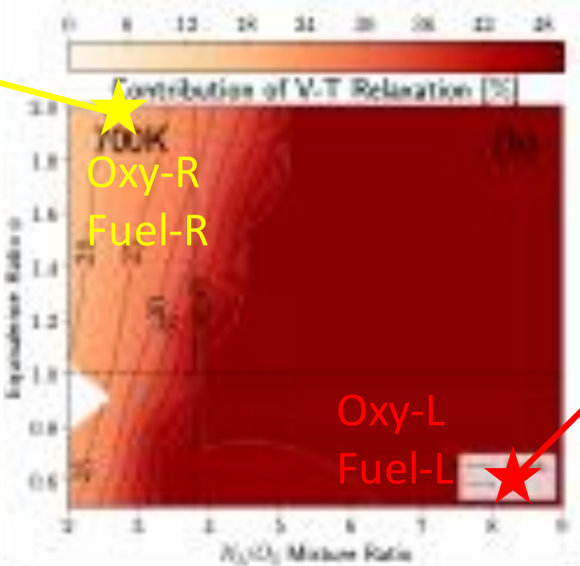
Systematic evaluation of the impact of NRP plasmas on **energy deposition and energy pathways**

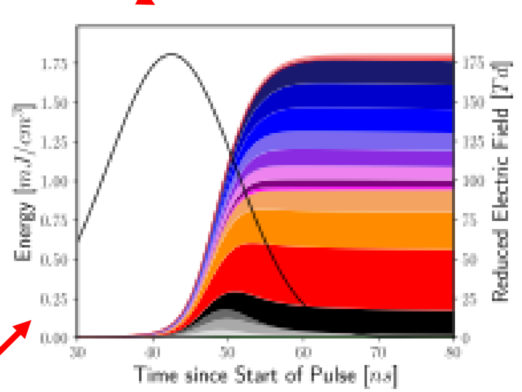




$$energy \propto N \cdot n_e \propto \frac{1}{T} \cdot n_e$$





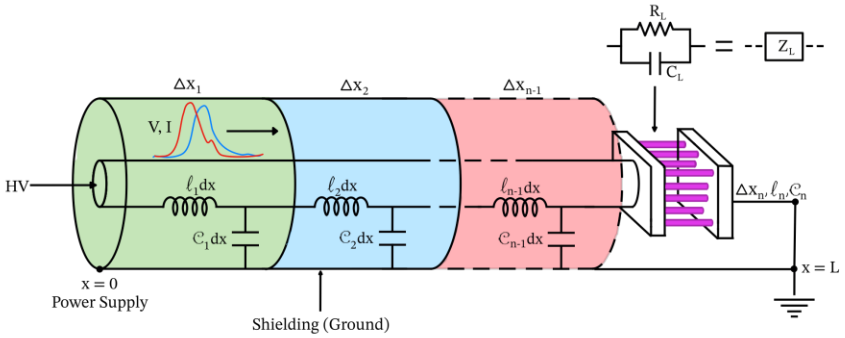


R. Dijoud, N. Laws, and C. Guerra-Garcia. *Combustion and Flame*, 271, 113793, **2025**

$CH_4/O_2/N_2$ mixtures, 1atm

Voltage and energy depend on electrical circuit and load

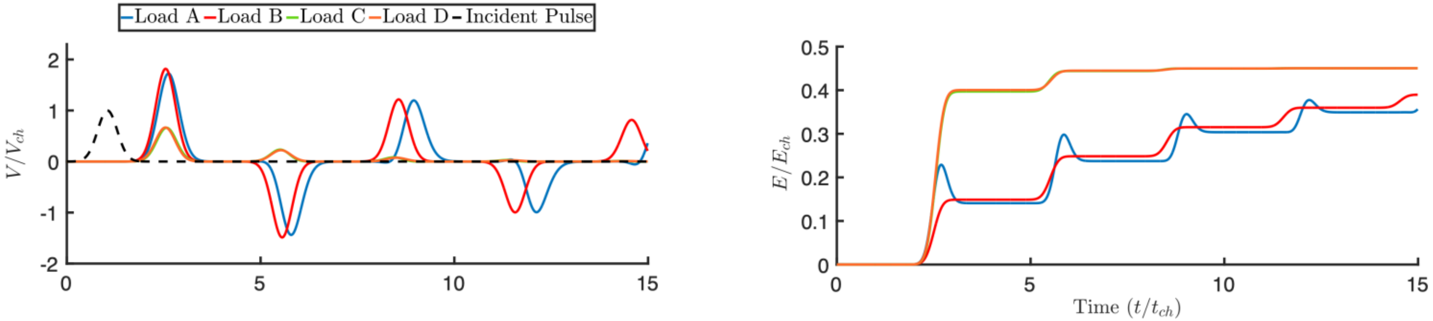
Challenge: voltage and energy deposition are dependent on load properties and circuit. **Telegrapher's equations** need to be used to interpret electrical measurements and translate power source information into values on load



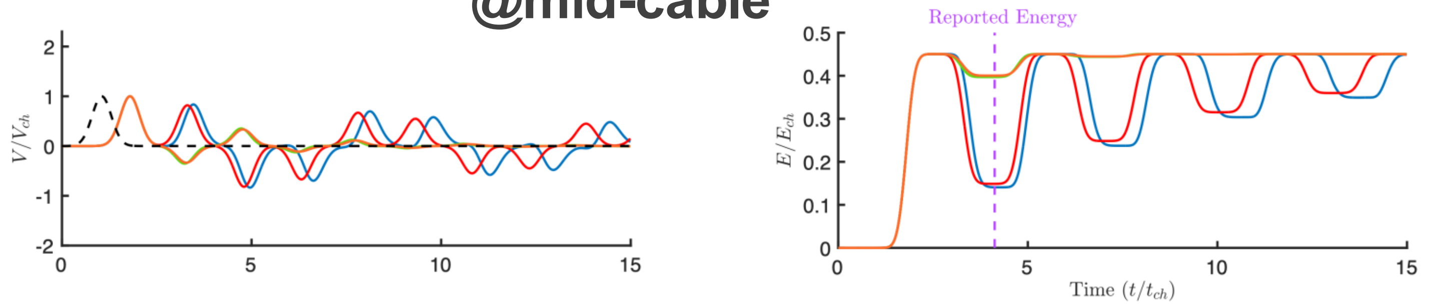
$$\frac{\partial}{\partial t}\begin{bmatrix} V \\ I \end{bmatrix} = -u \begin{bmatrix} 0 & Z_c \\ Z_c^{-1} & 0 \end{bmatrix} \frac{\partial}{\partial x}\begin{bmatrix} V \\ I \end{bmatrix}$$

Load	Description	R_L/Z_{ch}	C_L/C_{ch}
A	High R_L/high C_L	10	0.1
B	High R_L/low C_L	10	0.01
C	Low R_L/high C_L	0.5	0.1
D	Low R_L/low C_L	0.5	0.01

Measurement @load



@mid-cable



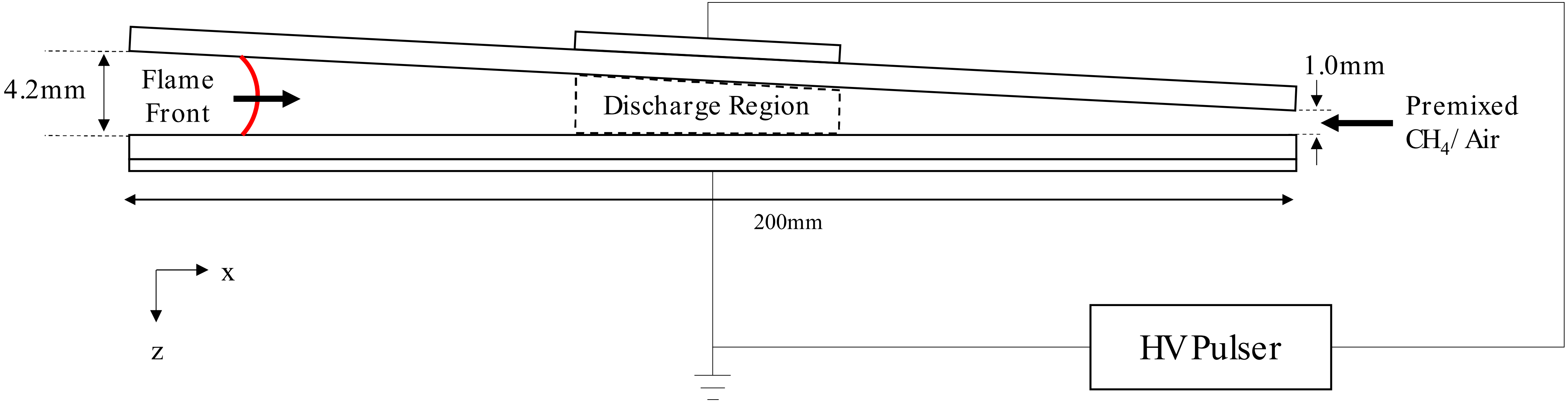
- High R_L (A&B): voltage ~doubled, lower energy, higher distortion by C
- Low R_L (C&D): voltage reduced, higher energy, small distortion by C
- Plasma is more complex: starts from high R_L and ends in low R_L
- Careful how you interpret measurements depending on probe location, probe selection, etc

C. A. Pavan*, S. Rao*, and C. Guerra-Garcia (*1st). TUTORIAL: Electrical Measurements in Nanosecond Pulsed Plasma Reactors, *J. Phys. D: Appl. Phys.* 58 032502, **2025**

Plasma on fundamental flames

Systematic evaluation of the impact of NRP plasmas on **laminar flame speed**

- Laminar flames present a 1D platform to systematically explore the influence of:
  - Fuel, composition, pressure, temperature, kinetics → can be accessed in 0D
  - Electrical parameters (e.g., **pulse repetition frequency**) → can be accessed in 0D
  - Actuation strategy (e.g., **positioning** of plasma with respect to flame front) → Need 1D



C. A. Pavan, C. Guerra-Garcia (**2025**) Laminar Flame Speed Modification by Nanosecond Repetitively Pulsed Discharges. Part II: Experiments. Combustion & Flame. https://doi.org/10.1016/j.combustflame.2025.114475

$\phi = 1.06$, 1atm, 300K, $u_i = 6.5 cm/s$
Electrode gap 3.1-3.7mm, length 30mmx36mm
NRPD @ 2-8kHz, V_{pk} 22.5kV

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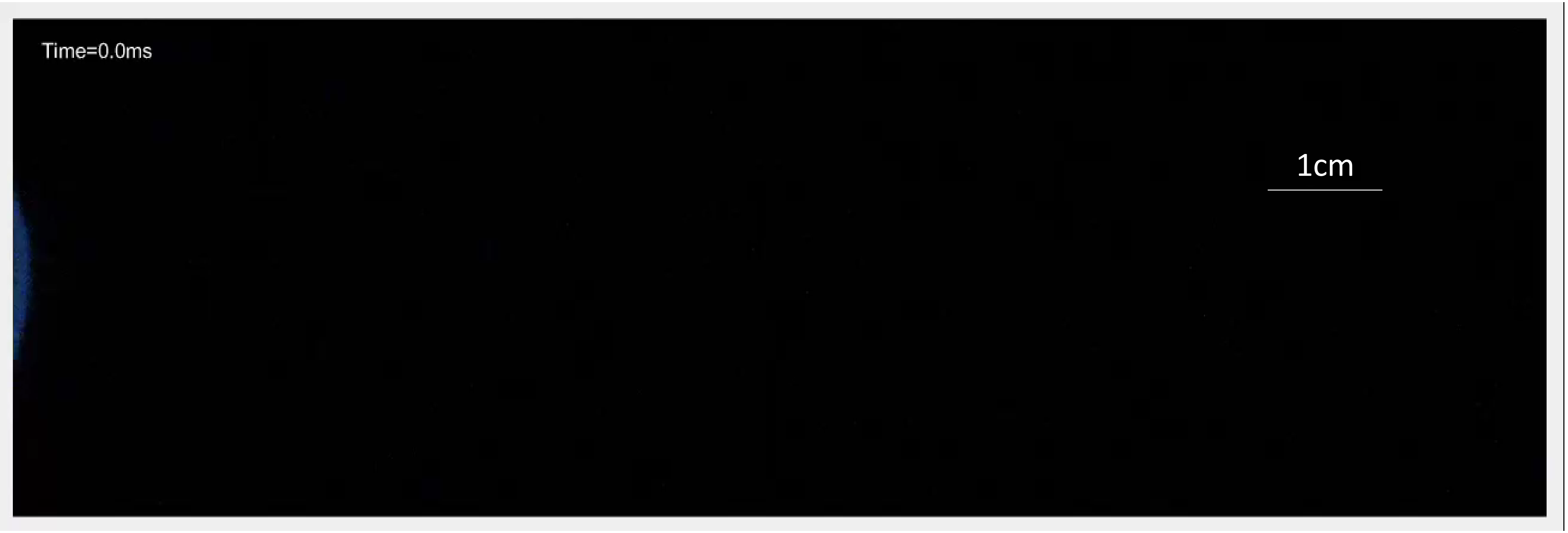
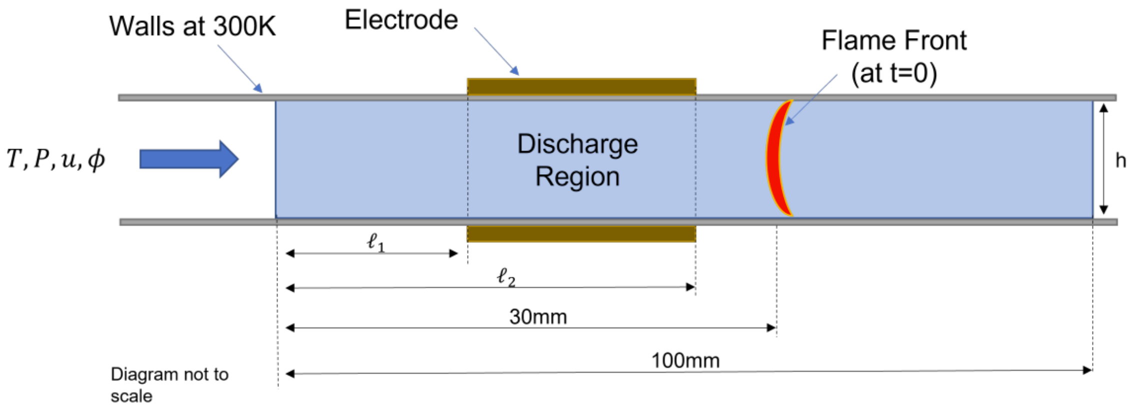


C. Pavan, C. Guerra-Garcia. Imaging of Dynamic Plasma-Combustion Interactions Through a Transparent Electrode. Frontiers in Physics 13 1654714 **(2025)**

Experimental & numerical calculation of laminar flame speed



- Convection-diffusion equations for mass, momentum, energy, species

$$\frac{\partial \boldsymbol{\phi}}{\partial t} + \frac{\partial}{\partial x}(u\boldsymbol{\phi} + \boldsymbol{D}) = \boldsymbol{S_f} + \boldsymbol{S_r}$$

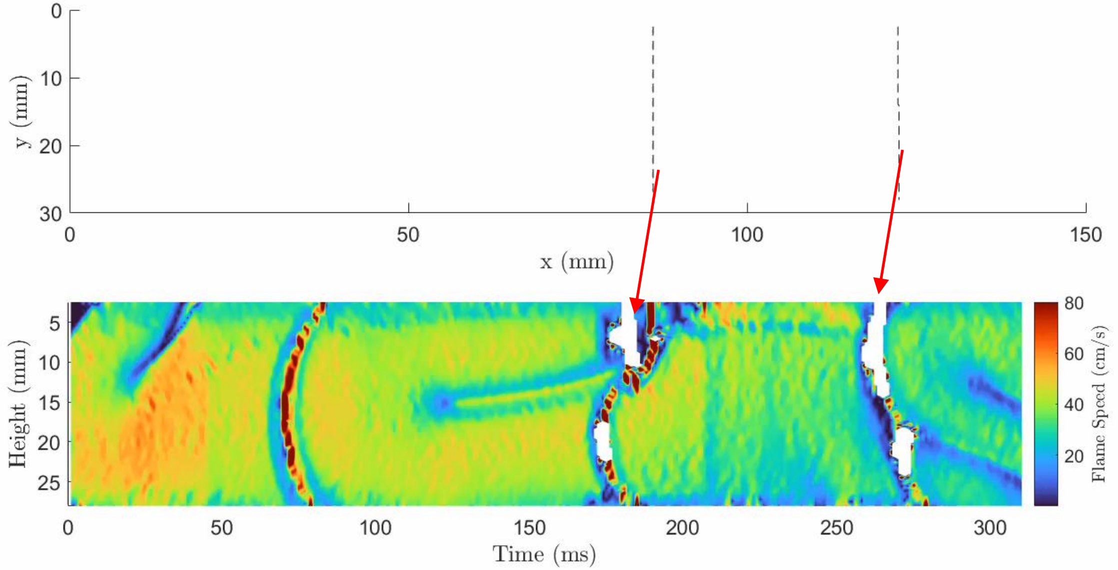
$$\boldsymbol{\phi} = \begin{bmatrix} \rho \\ \rho u \\ \rho e \\ \rho \boldsymbol{Y} \end{bmatrix}, \quad \boldsymbol{D} = \begin{bmatrix} 0 \\ 0 \\ -\lambda \frac{\partial T}{\partial x} + \sum j_k h_k \\ \boldsymbol{j} \end{bmatrix}, \quad \boldsymbol{S_f} = \begin{bmatrix} 0 \\ -\frac{\partial P}{\partial x} \\ -P\frac{\partial u}{\partial x} - \dot{L} \\ 0 \end{bmatrix}, \quad \boldsymbol{S_r} = \begin{bmatrix} 0 \\ 0 \\ \dot{q}_{plas} \\ \dot{\boldsymbol{w}} \end{bmatrix}$$

- Solution by operator splitting scheme

C. A. Pavan, C. Guerra-Garcia (**2025**) Combustion & Flame.
https://doi.org/10.1016/j.combustflame.2025.114475
https://doi.org/10.1016/j.combustflame.2025.114484

- Flame tracking gives $x(t, y)$
- Velocity calculated by:

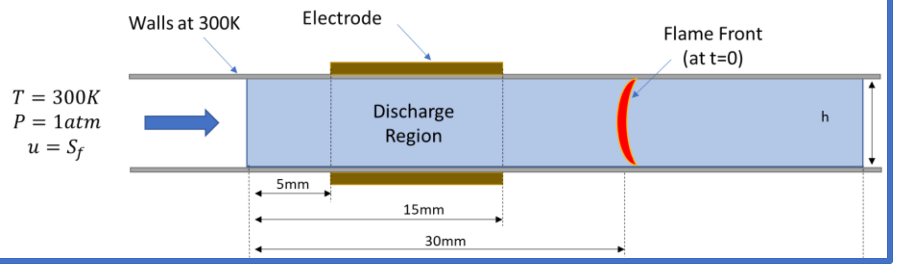
$$v = \frac{d}{dt}\begin{bmatrix} x(t,y) \\ y \end{bmatrix}$$



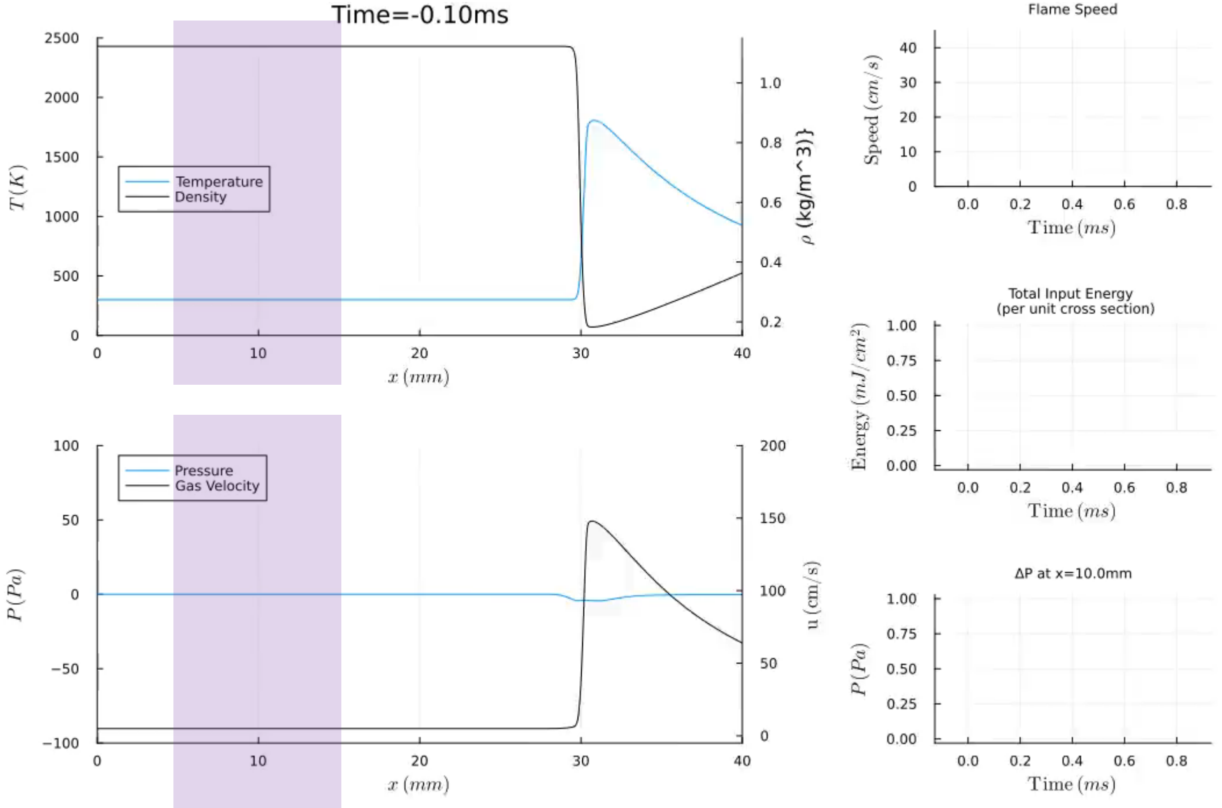
Influence of positioning on mechanisms of interaction and impact on flame speed

Strategy 1: Plasma far ahead of flame

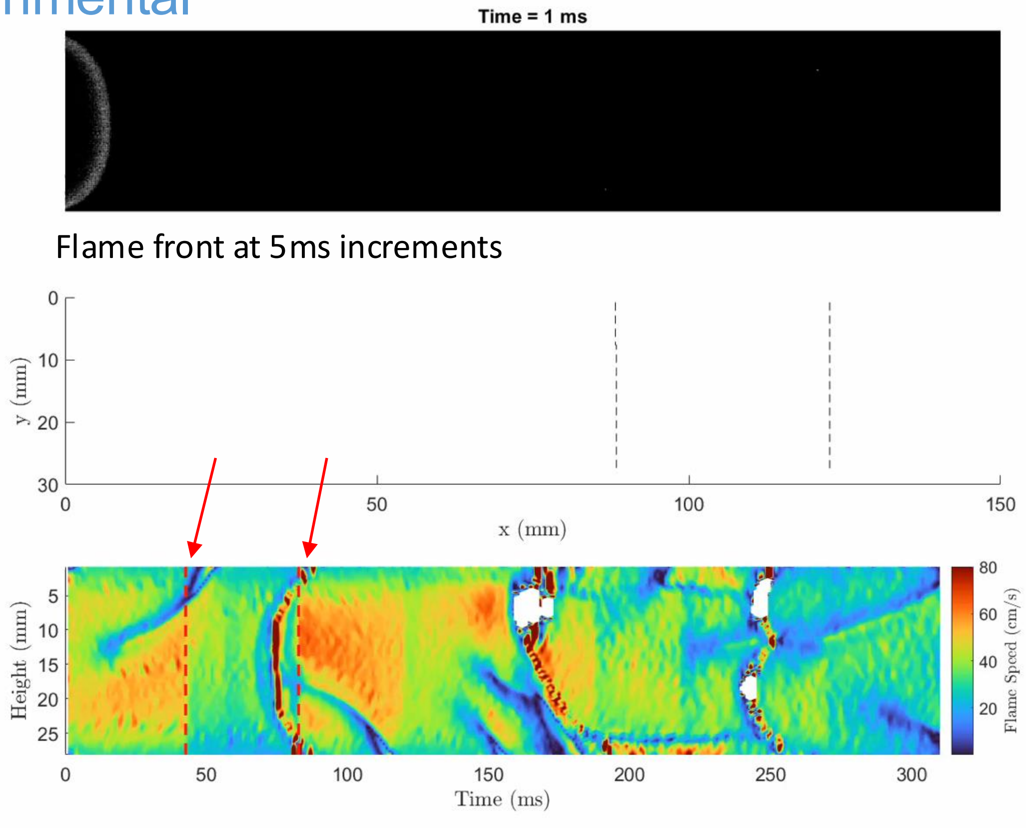
- Interaction via acoustic waves
- Flame speed decrease of up to 30%



Numerical



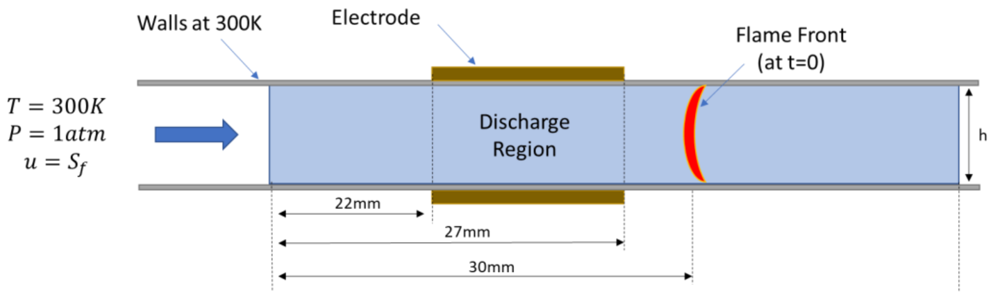
Experimental

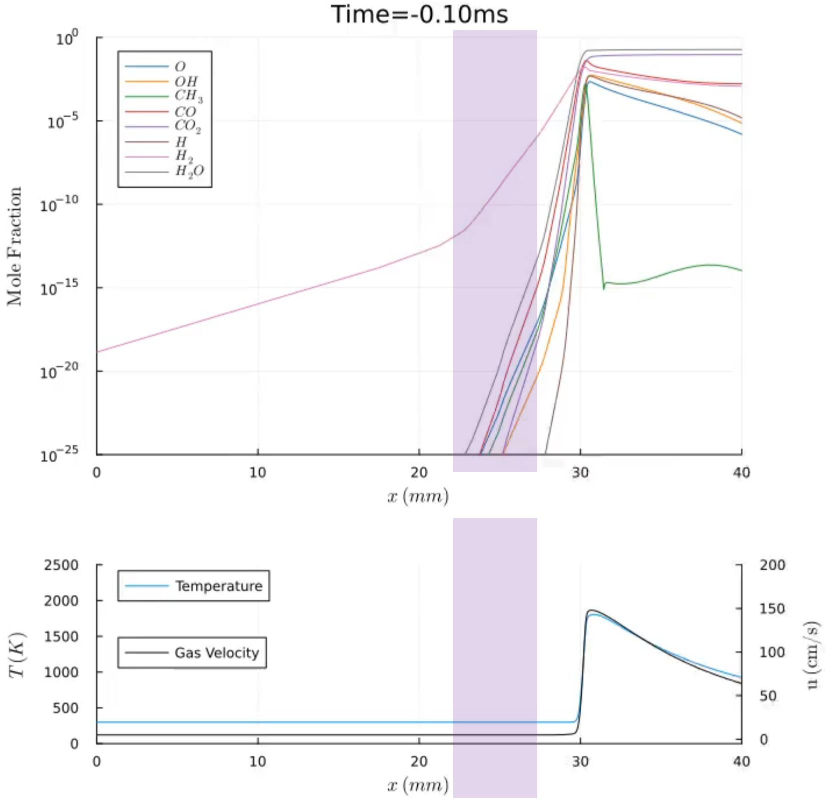


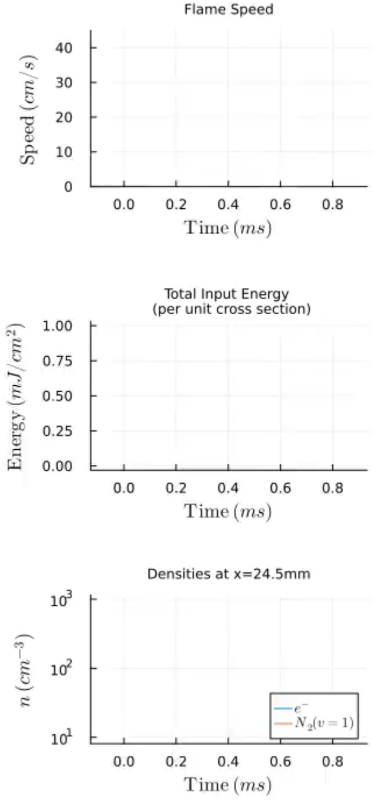
Influence of positioning on mechanisms of interaction and impact on flame speed

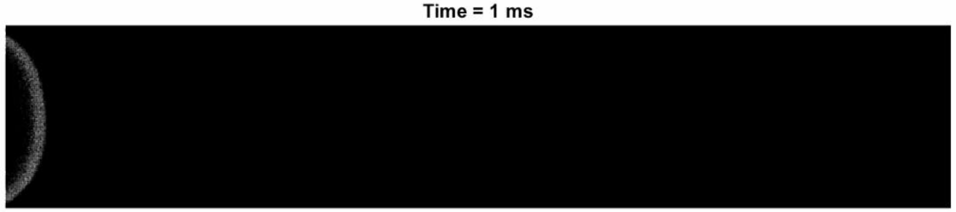
Strategy 2: Pre-conditioning of reactants

- Interaction via acoustic waves + long lived plasma-species
- Initial disruption due to pressure waves
- Flame speed increase of up to 30%

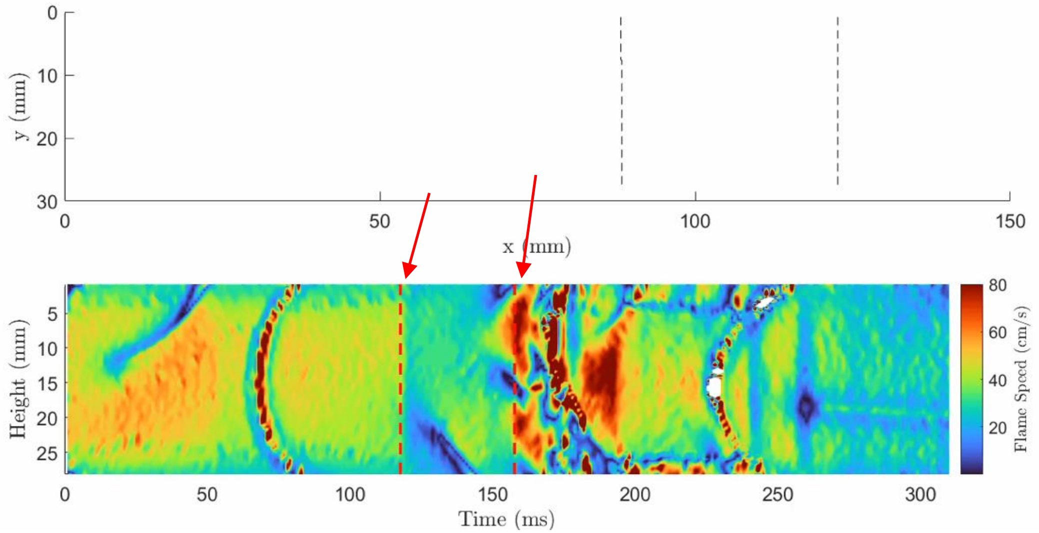








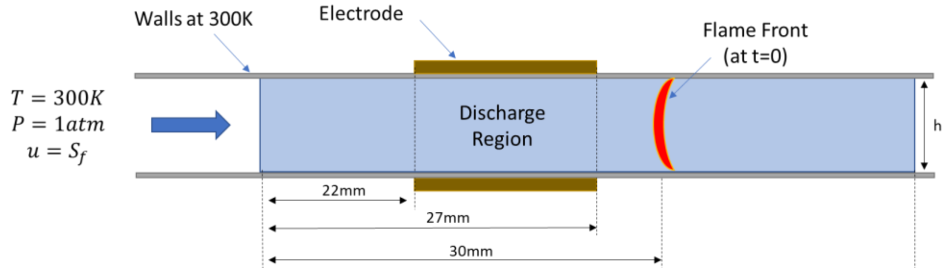
Flame front at 5ms increments



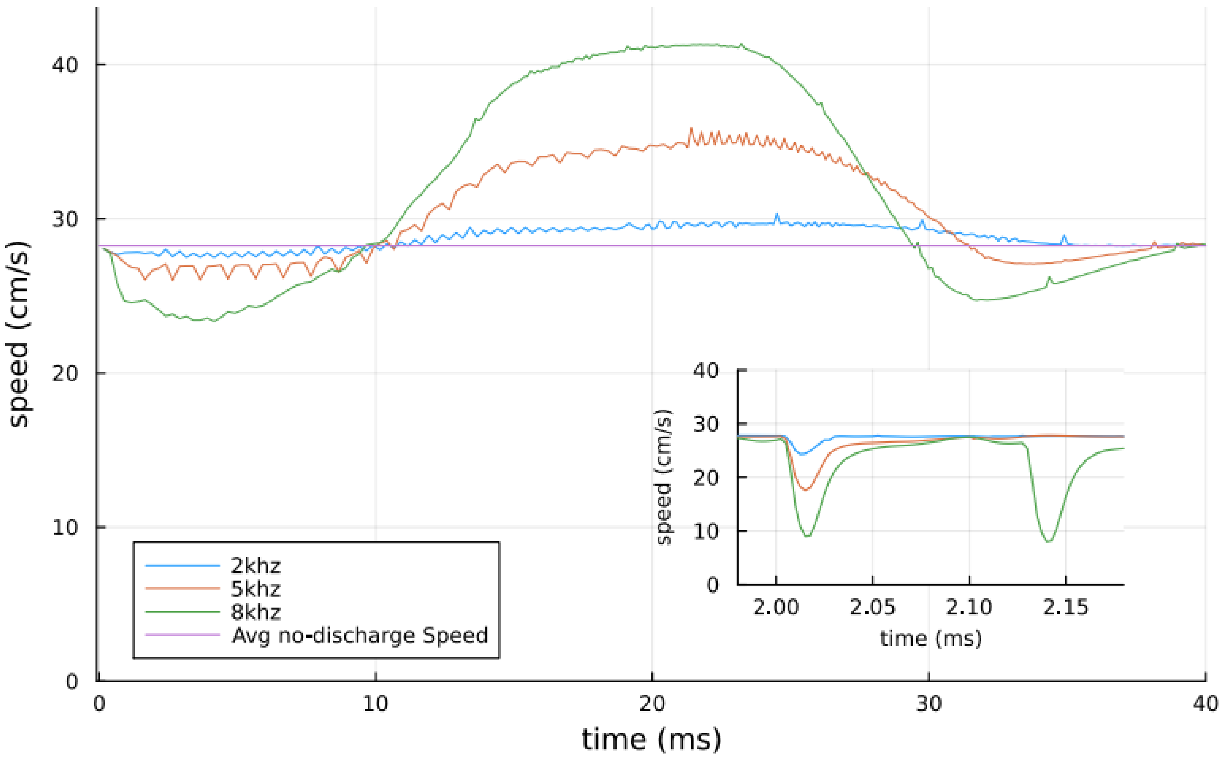
Influence of positioning on mechanisms of interaction and impact on flame speed

Strategy 3: *In-situ* plasma (plasma overlapping flame)

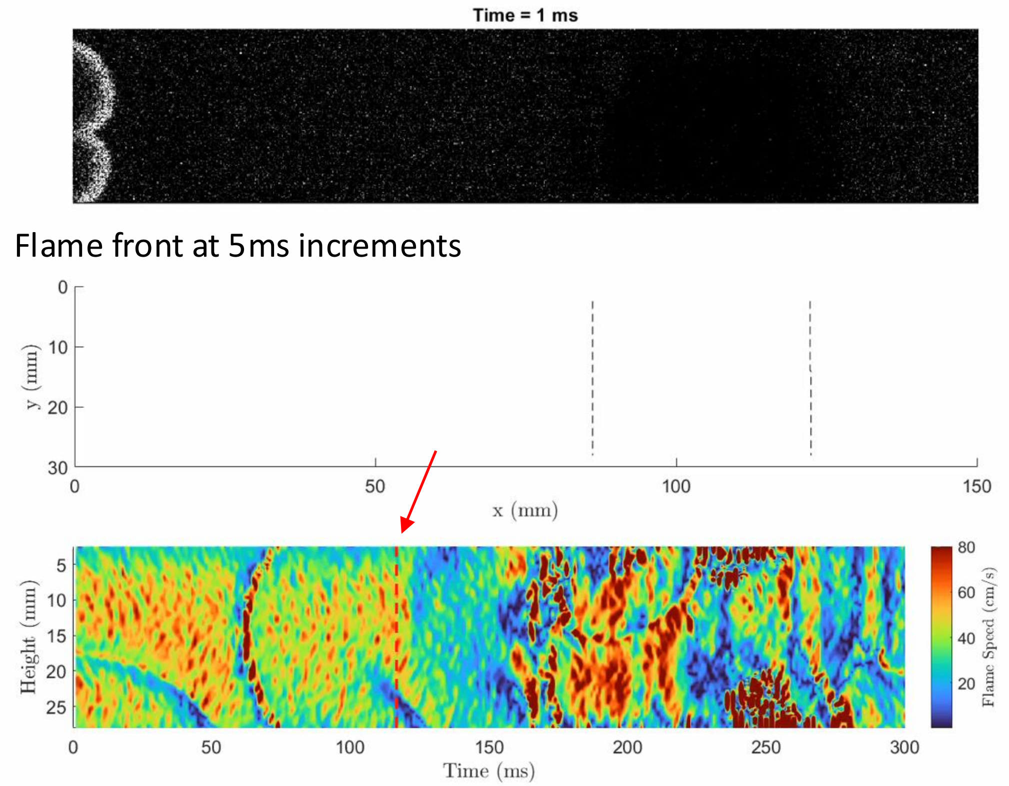
- Interaction via acoustic waves + long lived plasma-species
- Initial disruption due to pressure waves
- Flame speed increase of up to 50%



Numerical



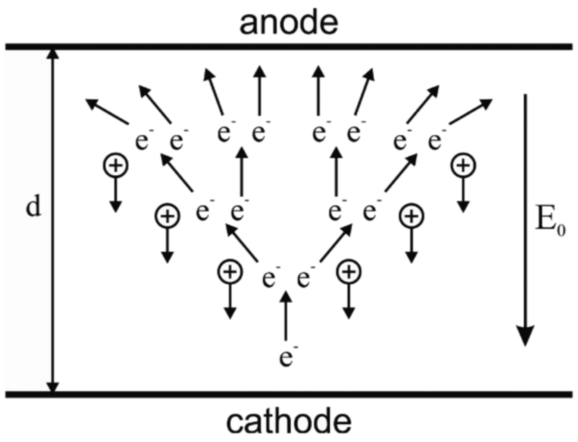
Experimental



A uniform prescribed E/N profile is a blind guess: Need to account for the *backward problem*

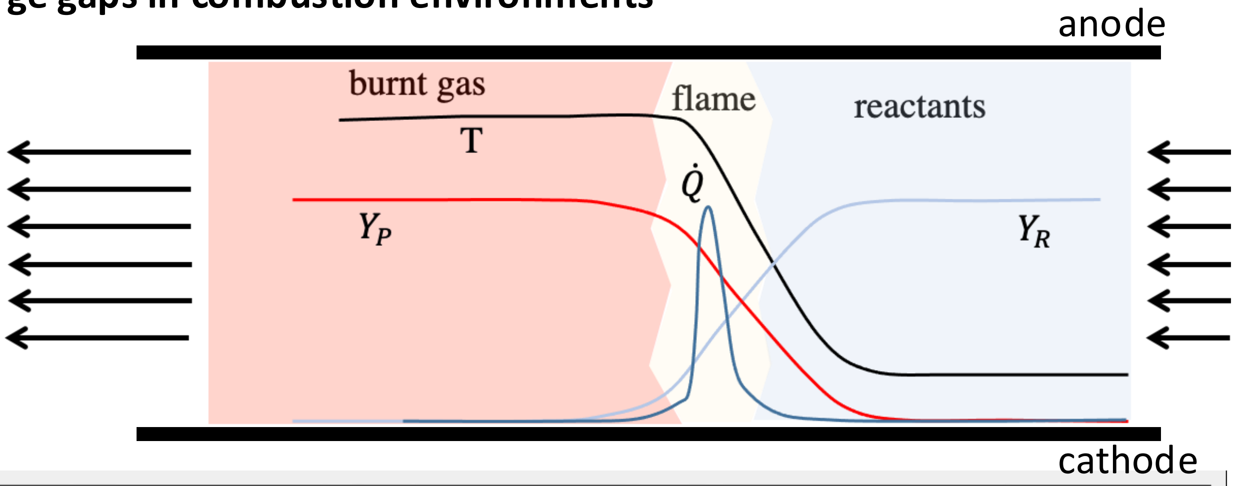
Electrical breakdown happens in a nonuniform and inhomogeneous multi-phase flow environment, in contrast to idealized conditions in classical gas discharge physics (constant pressure, temperature, composition)

Textbook conditions (1D uniform)



A. A. Fridman, Plasma Chemistry, Cambridge University Press, Cambridge 2012

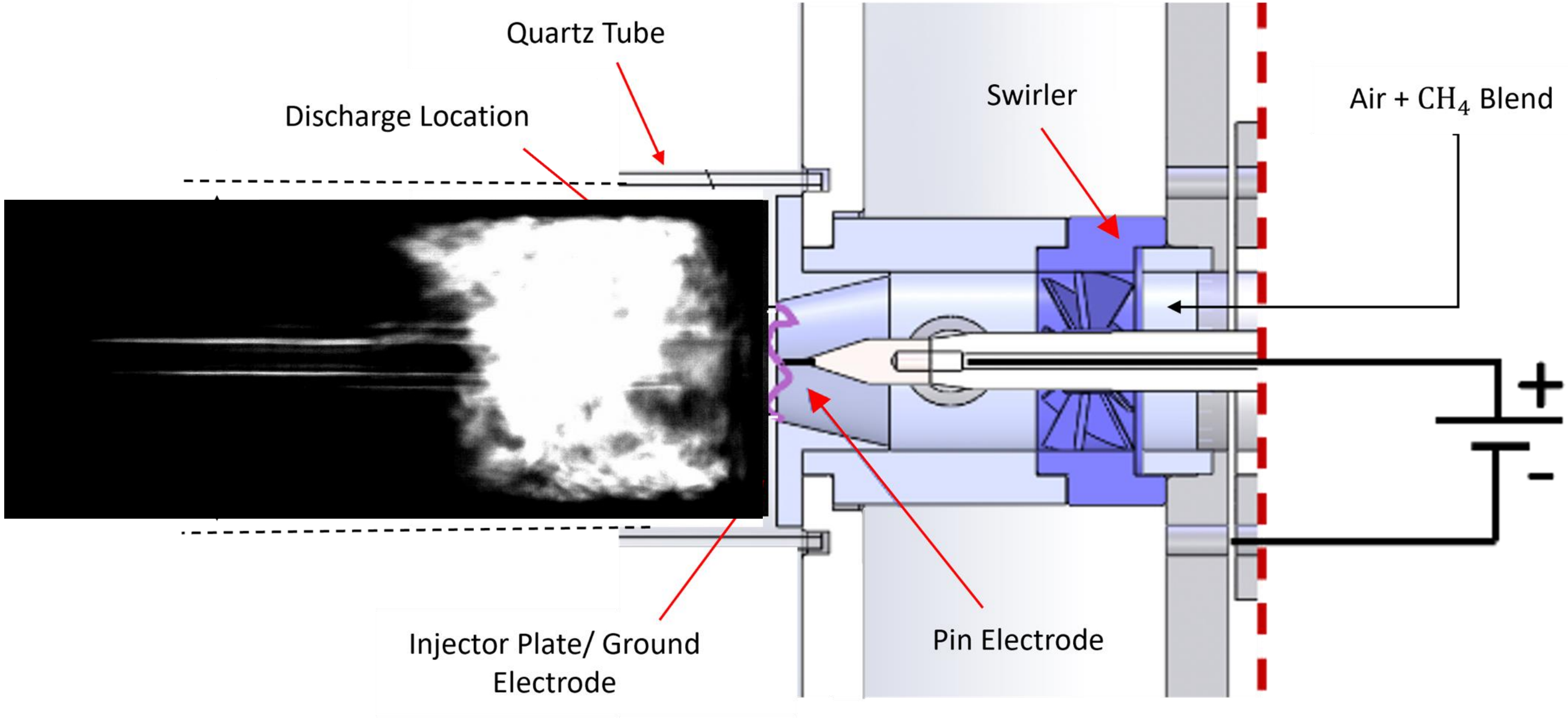
Discharge gaps in combustion environments



- Discharge regimes & energy delivery driven by flame passage
  - Microdischarges in cold reactants
  - Uniform discharge in hot products

C. Guerra-Garcia and C. A. Pavan. The backward problem in plasma-assisted combustion: Experiments of nanosecond pulsed discharges driven by flames. *Applications in Energy and Combustion Science 15*, **2023**, 100155

Control of combustion dynamics @MIT

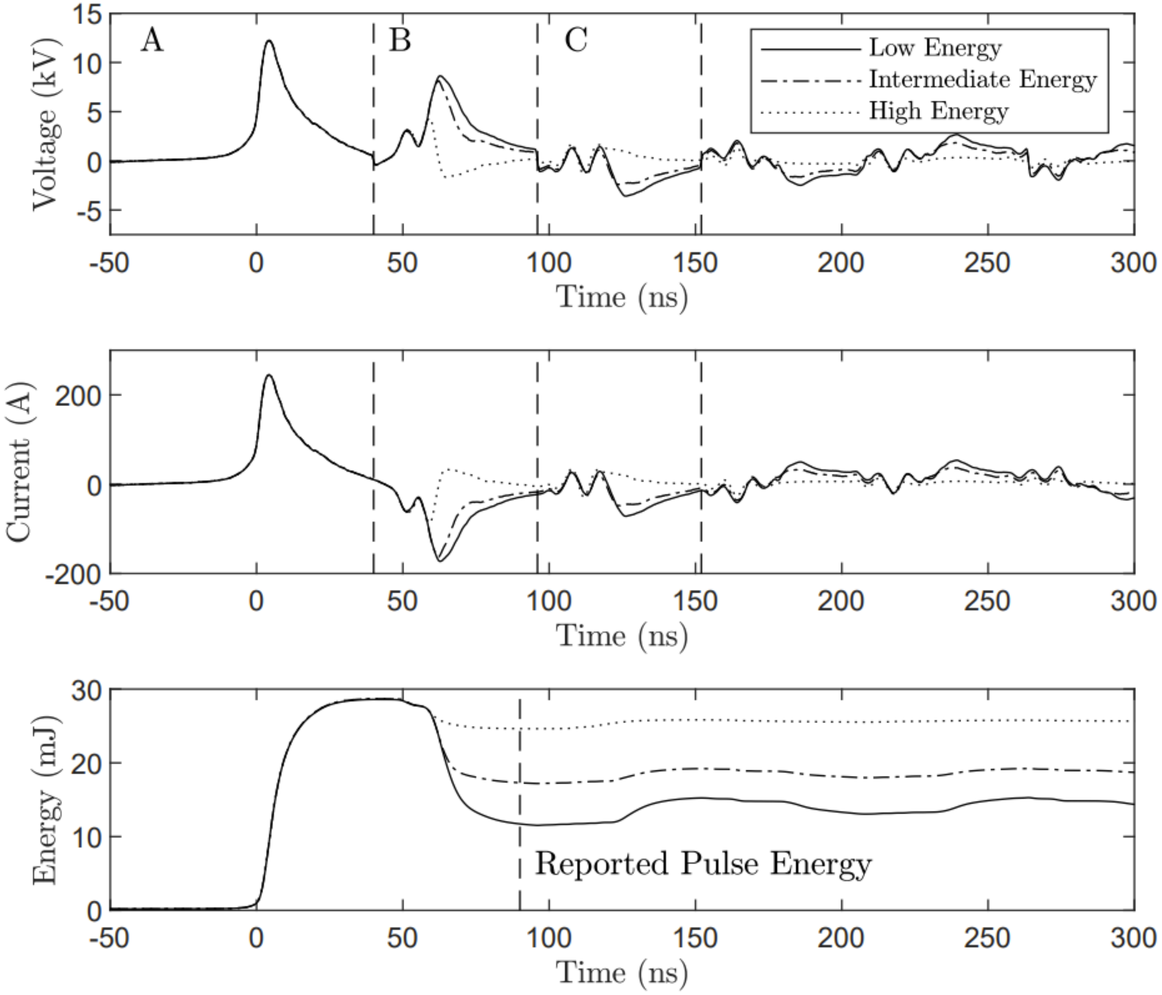


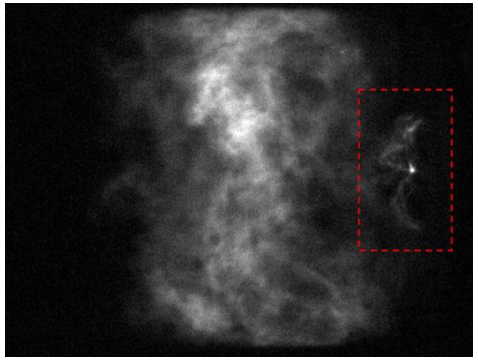
Video of flame (1/67 playback speed)

- 50kW-rated swirl-stabilized combustor with methane/air blends
- Operation point: 14kW power, ϕ= 0.78
- Experiences 120Hz acoustic instability
- Pin-to-cylinder electrodes; V $\leq 20kV$, PRF$\leq 10kHz$

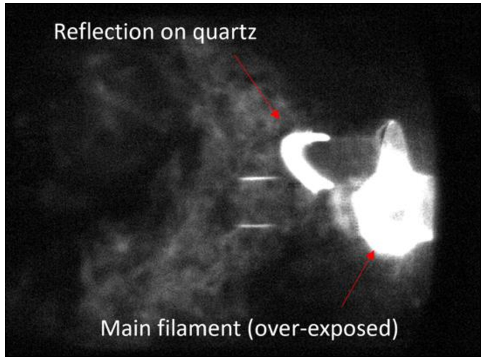
S. J. Shanbhogue, C. A. Pavan, D. E. Weibel, F. Gomez del Campo, C. Guerra-Garcia, and A. F. Ghoniem. *Journal of Propulsion and Power*, **2023**

Discharge regimes – imaging and electrical measurements

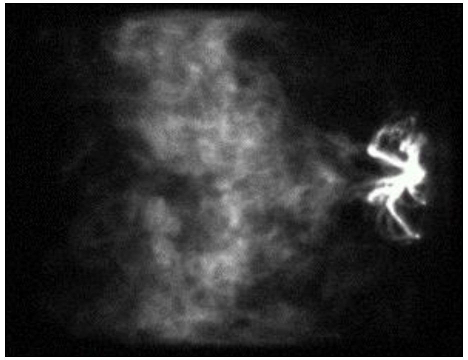




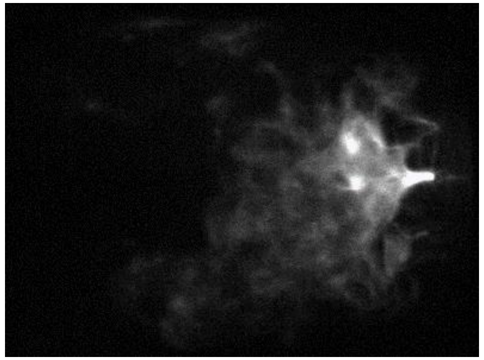
Streamer corona (low energy)



Ns-spark (high energy)



Streamers-to-spark (intermediate energy)



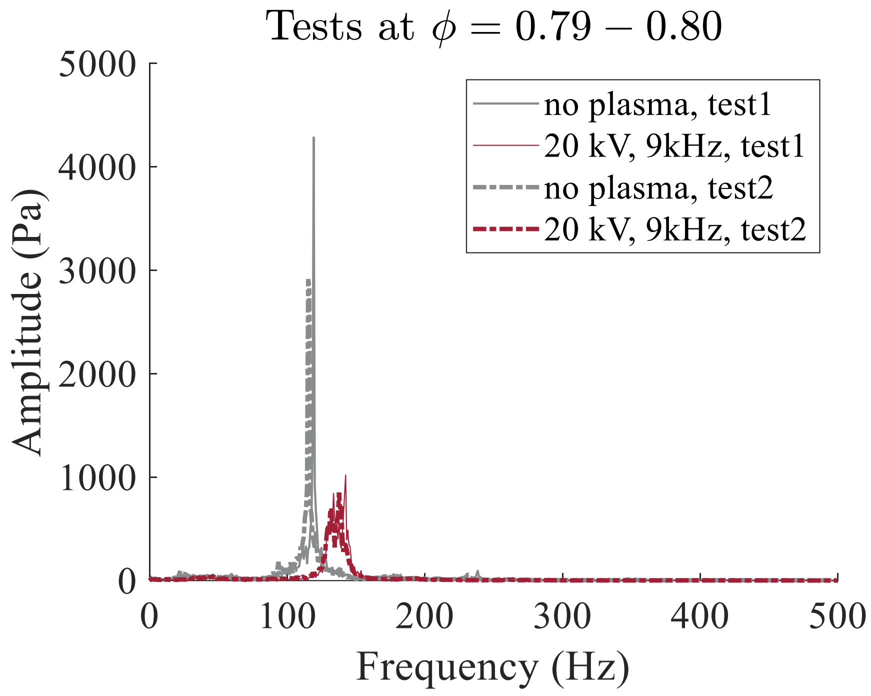
Spark-to-streamers (intermediate energy)

Burner with inaccessible geometry – diagnose discharge with energy measurements

C. A. Pavan, S. J. Shanbhogue, D. E. Weibel, F. Gomez del Campo, A. F. Ghoniem, and C. Guerra-Garcia. Dynamic response of nanosecond repetitively pulsed discharges to combustion dynamics: regime transitions driven by flame oscillations, Plasma Sources Science and Technology 33, 025016 (15pp) **2024**

NRPD to suppress instabilities: a 2-way coupled problem

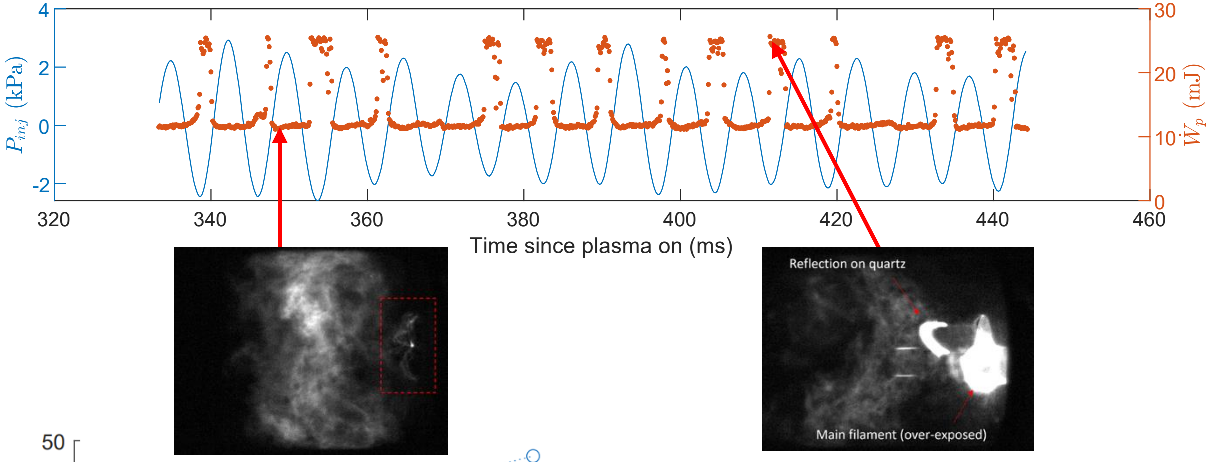
Forward problem

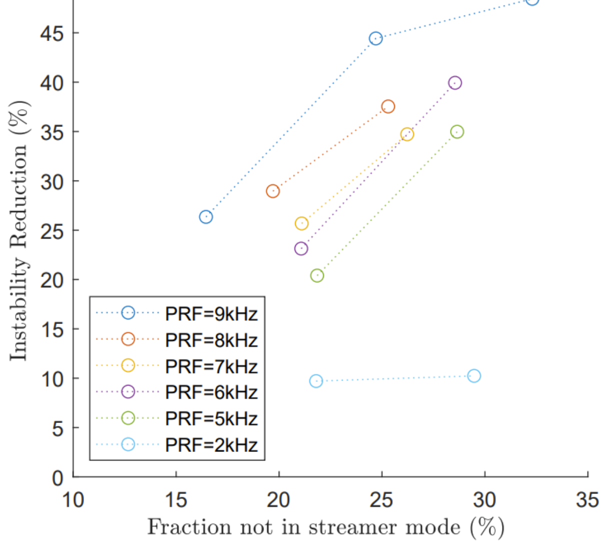


- Oscillations are 1-4% of mean pressure, compared to ~0.1% in prior works
- NRPD applied close to flame anchoring point, premixed stream
- Significant reduction of strong limit-cycle combustion but instability not fully suppressed

S. J. Shanbhogue, C. A. Pavan, D. E. Weibel, F. Gomez del Campo, C. Guerra-Garcia, and A. F. Ghoniem. Control of Large-Amplitude Combustion Oscillations Using Nanosecond Repetitively Pulsed Plasmas. *Journal of Propulsion and Power*, **2023**. https://doi.org/10.2514/1.B38883

Backward problem





- Energy deposition is controlled by electrical parameters and gas dynamics
- High energy mode has greater actuation authority

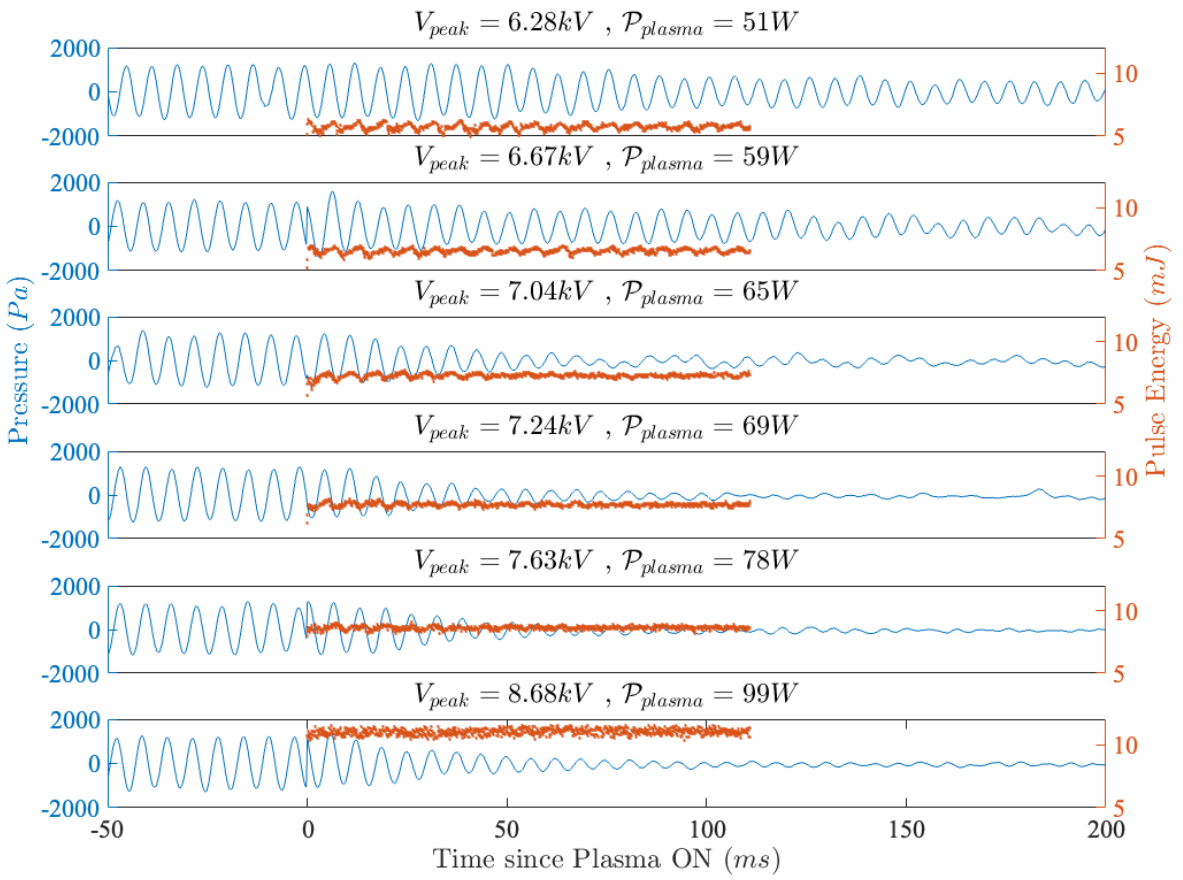
➢ **Re-design system to access high energy mode regardless of flame location**

C. A. Pavan, S. J. Shanbhogue, D. E. Weibel, F. Gomez del Campo, A. F. Ghoniem, and C. Guerra-Garcia. Dynamic response of nanosecond repetitively pulsed discharges to combustion dynamics: regime transitions driven by flame oscillations, Plasma Sources Science and Technology 33, 025016 (15pp) **2024**

NRPD to suppress instabilities: a 2-way coupled problem

Backward problem

- New injector/ electrode-gap (Specter Aerospace): gap is 4.55 mm vs. original 12.7 mm
- Discharge affected by electrode-gap geometry
  - Discharge regime
  - Discharge energy



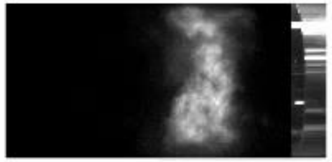
- For power > 69W instability suppressed for this 6kW flame
- At these voltage levels, the discharge remains consistent across the oscillation and no regime-fluctuations are observed

S. J. Shanbhogue, R. Dijoud, C. A. Pavan, S. Rao, F. Gomez del Campo, C. Guerra-Garcia, and A. F. Ghoniem. Improvements in Premixed CH4/NH3 swirling flames with nanosecond pulsed discharges. AIAA Aviation Forum **2024**, Las Vegas, NV, AIAA-2024-3898

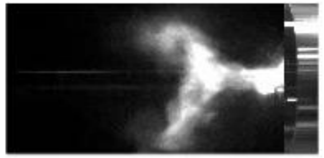
NRPD to suppress instabilities: a 2-way coupled problem

Forward problem

- Combustion affected by new geometry
  - Flame macrostructure
  - Combustion dynamic stability

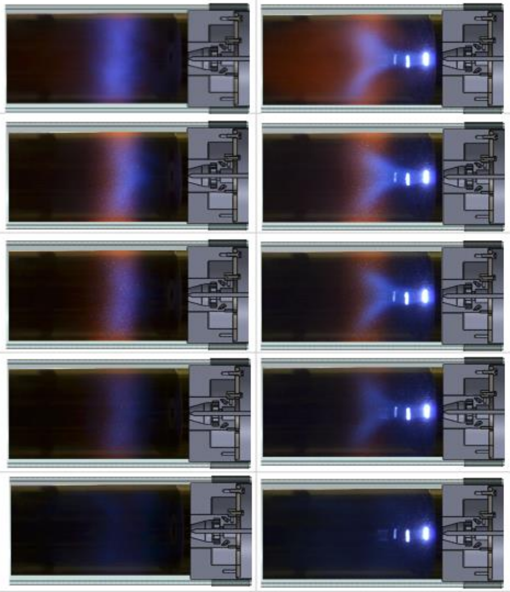


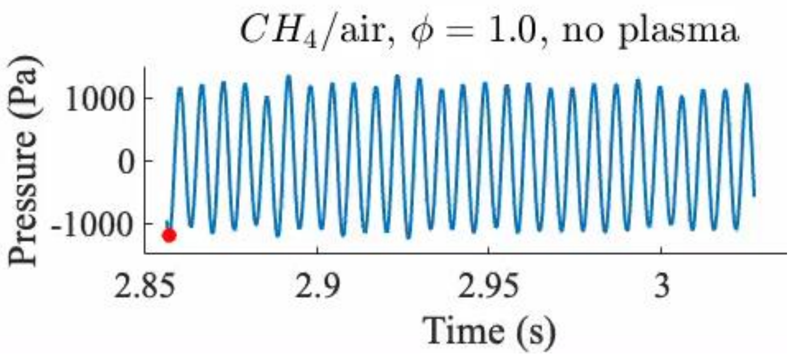
BASELINE

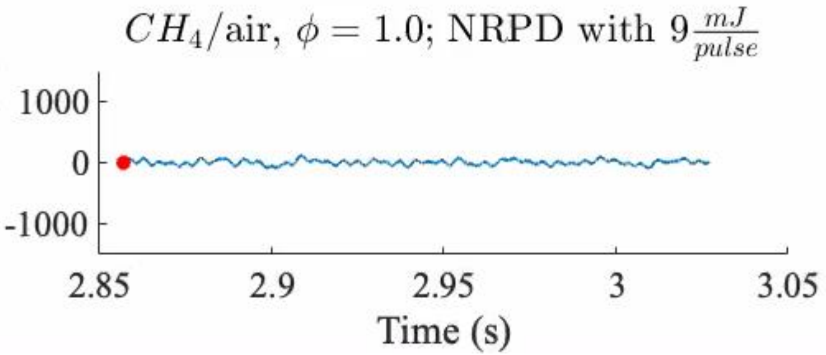


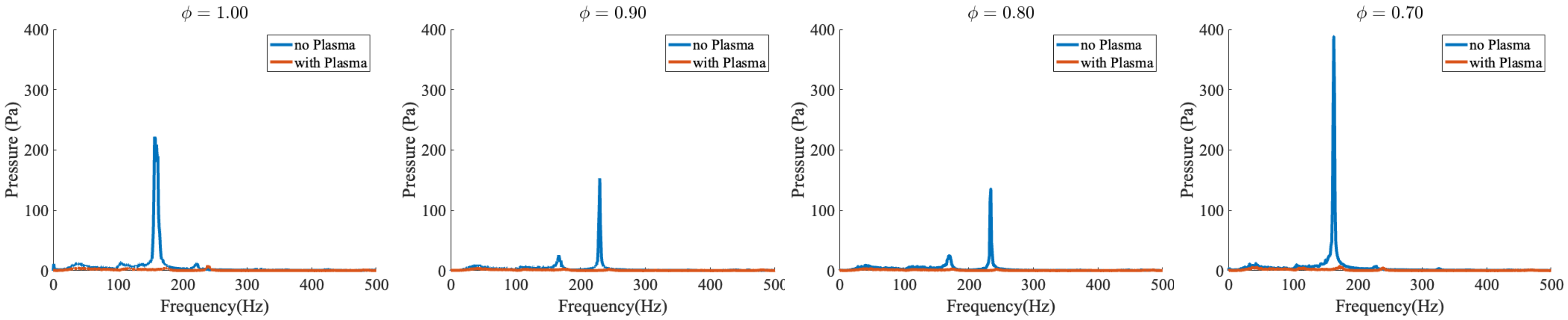
PLASMA

Equivalence Ratio	Flame Without Plasma	Flame With Plasma
1.0		
0.9		
0.8		
0.7		
0.6		





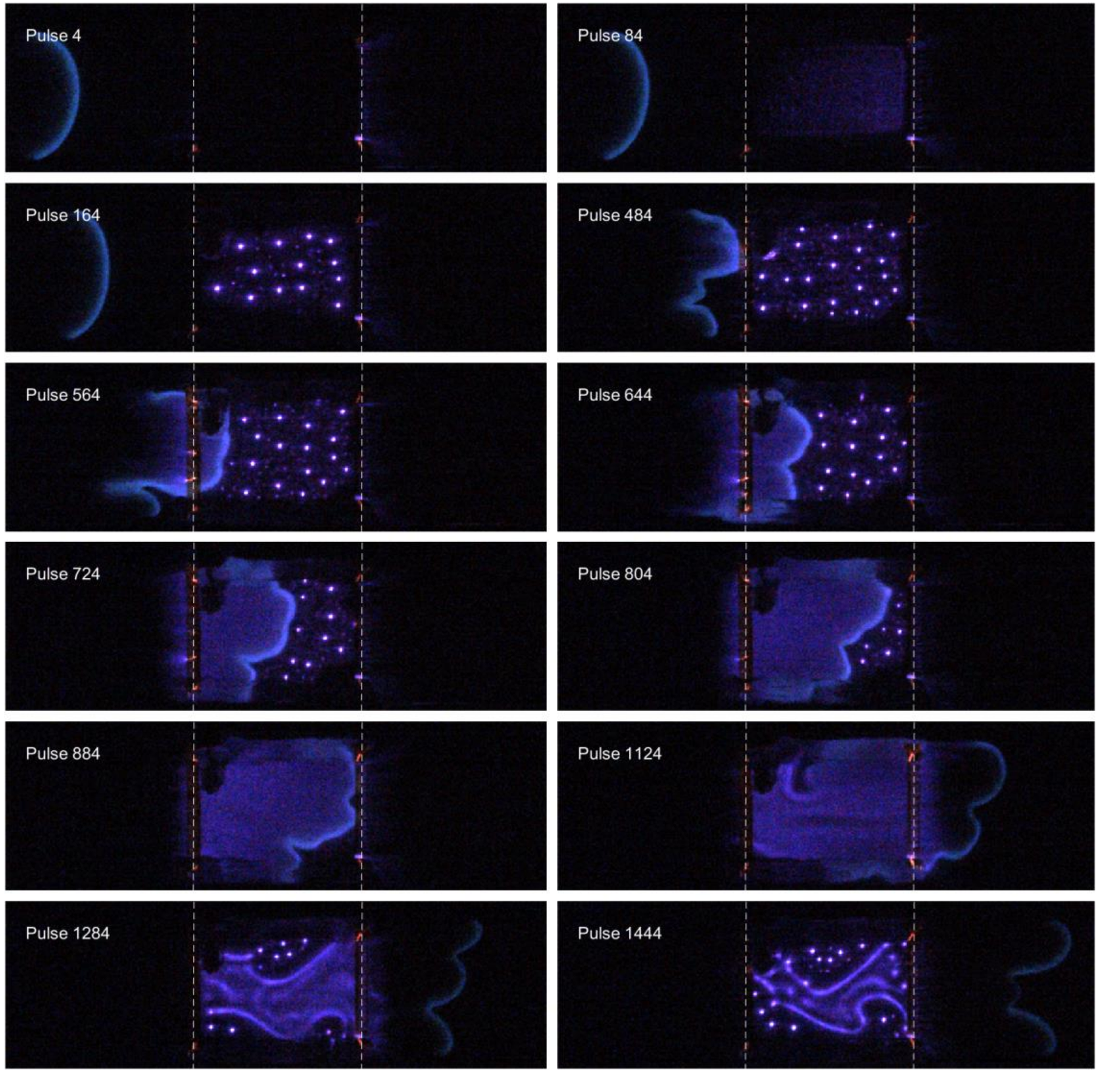




S. J. Shanbhogue, R. Dijoud, C. A. Pavan, S. Rao, F. Gomez del Campo, C. Guerra-Garcia, and A. F. Ghoniem. Improvements in Premixed CH4/NH3 swirling flames with nanosecond pulsed discharges. AIAA Aviation Forum **2024**, Las Vegas, NV, AIAA-2024-3898

Summary

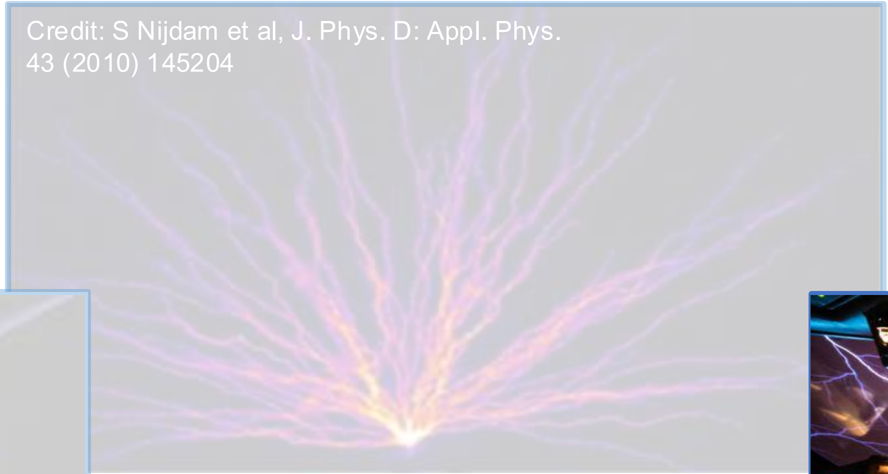
- Plasma-flame interactions need to account for considerations from gas discharge physics, combustion, and pulsed-power engineering
- The two-way coupled problem can rarely be bypassed: plasma influences combustion & combustion influences plasma
- E/N and energy are key to controlling the mechanisms of interaction, but they are affected by gas state, mixture composition, electrical parameters, and circuit elements in complex ways
- Plasmas can have both beneficial and adverse effects on flames, positioning and timing are key in achieving a favorable outcome



C. Pavan, C. Guerra-Garcia. Imaging of Dynamic Plasma-Combustion Interactions Through a Transparent Electrode. Frontiers in Physics 13 1654714 **(2025)**

Mission of the Aerospace Plasma Group

Unveil the physics of transient electrical discharges to understand our natural environment and enable their control for the benefit of our planet and beyond



Fundamentals of electrical breakdown

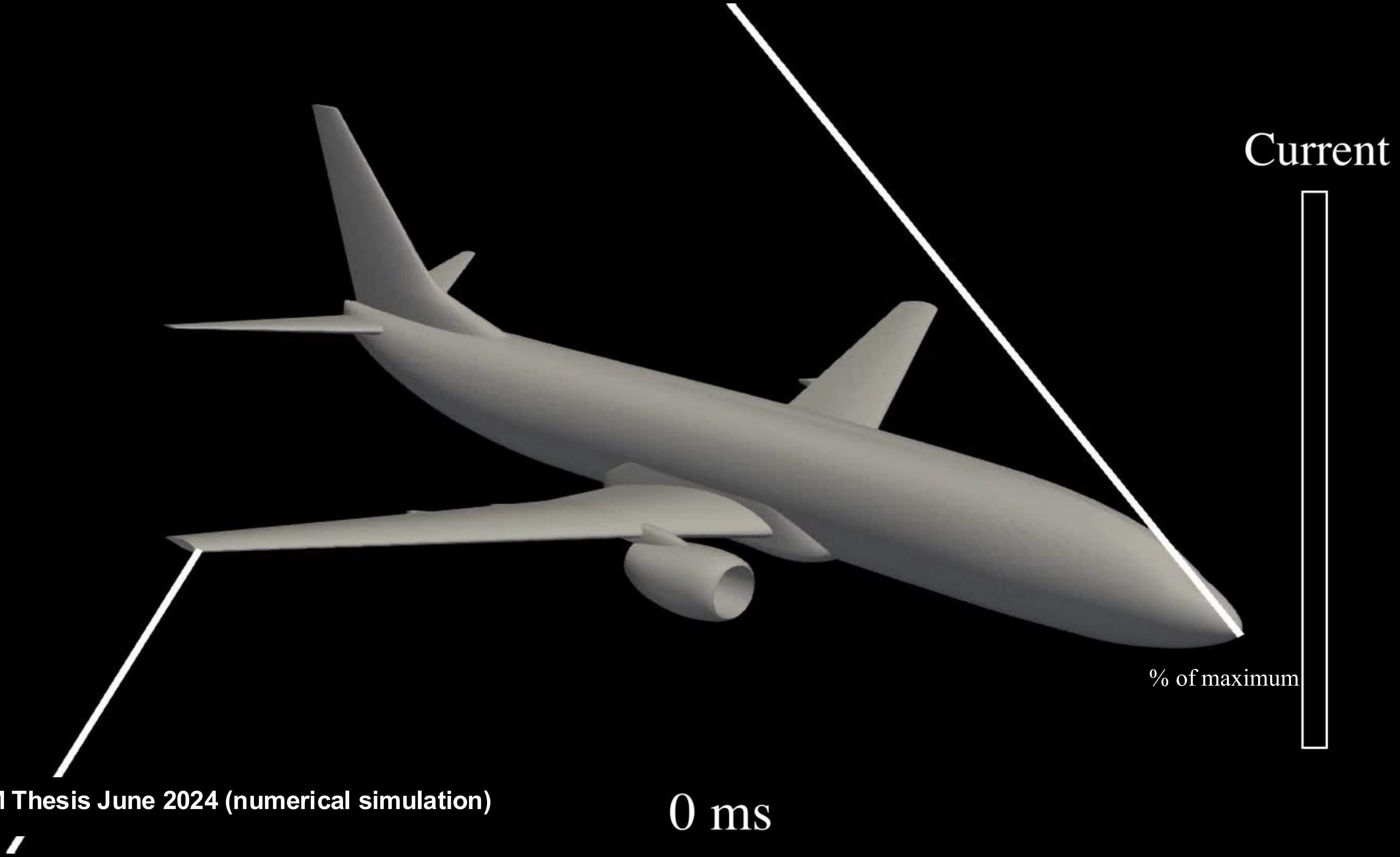
Plasma-assisted aerospace technologies

Lightning safety

Lightning swept stroke – real time

N Jenkins' SM Thesis June 2024 (numerical simulation)

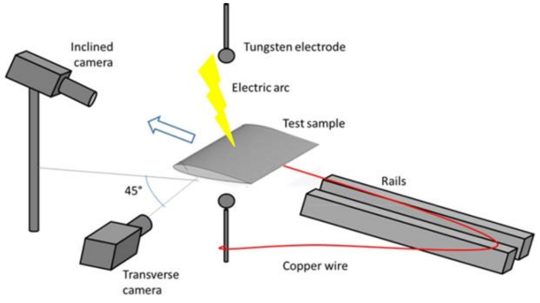
Lightning swept stroke – slow motion



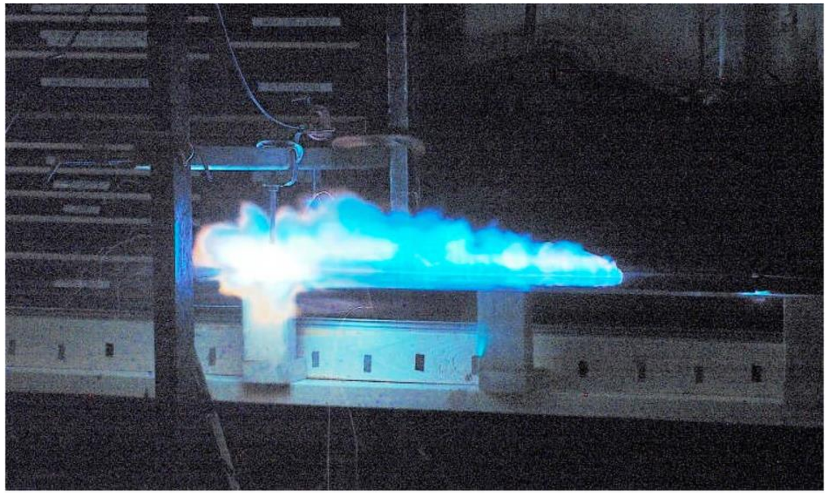
N Jenkins' SM Thesis June 2024 (numerical simulation)

Experimental arrangements for the swept stroke

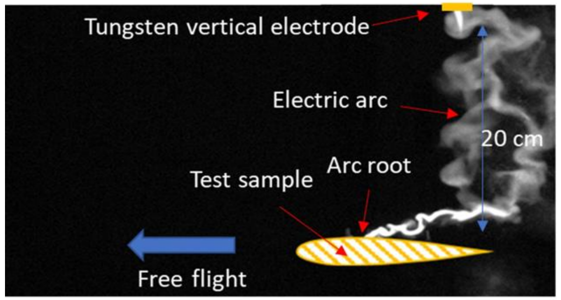
Moving surface experiments



Truck-propelled sample. Plumer, ICLP, 2012

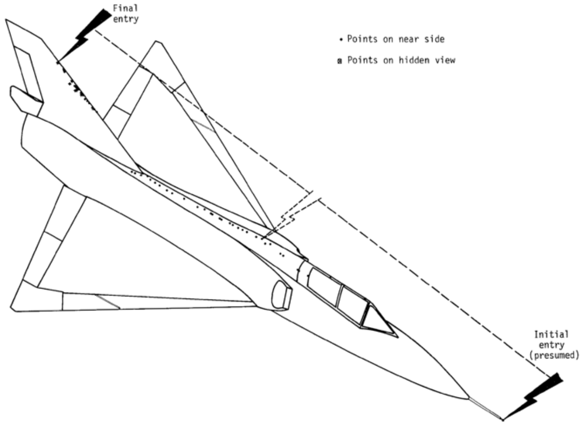


Elastic-propelled sample. Plumer, ICLP, 2012



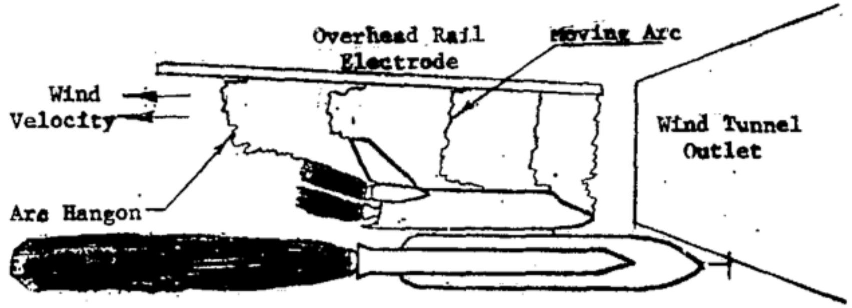
Electromagnetic launcher. Andraud et al., J Phys D: Appl. Phys., 57, 2024

Flight tests: 1980s NASA Storm Hazards Program (SHP)

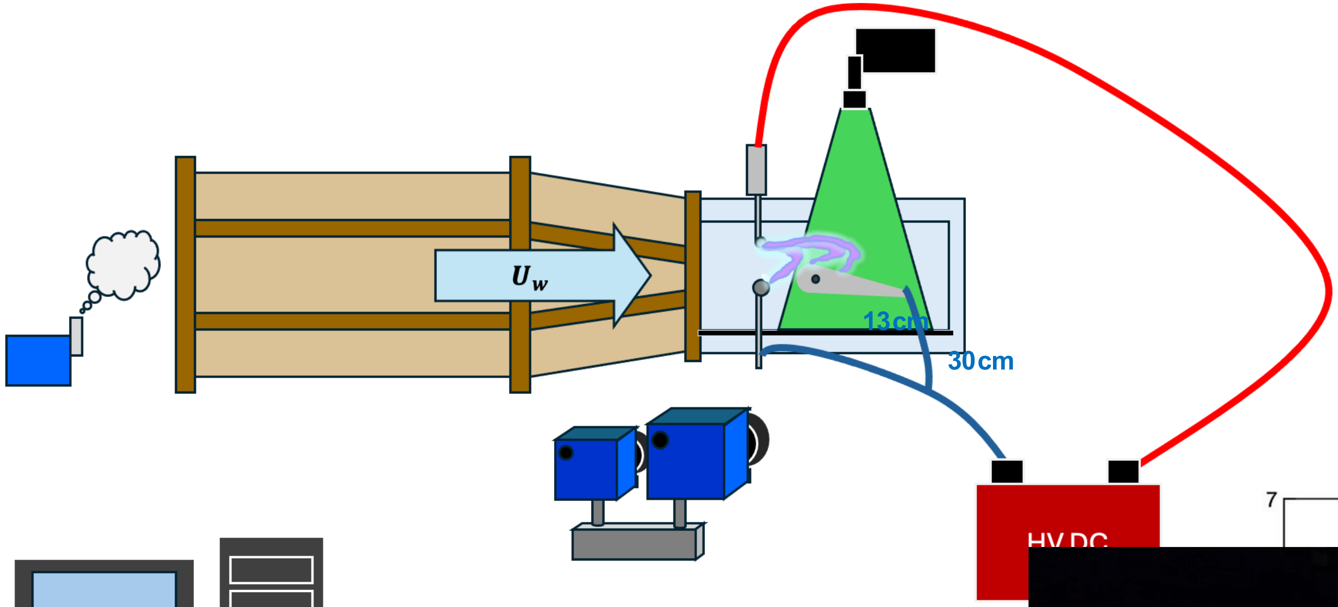


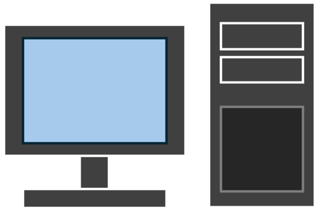
B. D. Fisher, G. L. Keyser, P. L. Deal, NASA TP 2087 1982

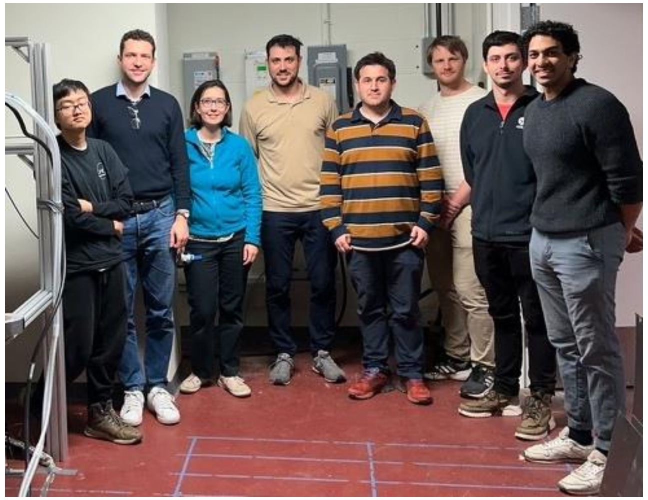
Wind tunnel tests. Clifford et al., NASA Report, 1974



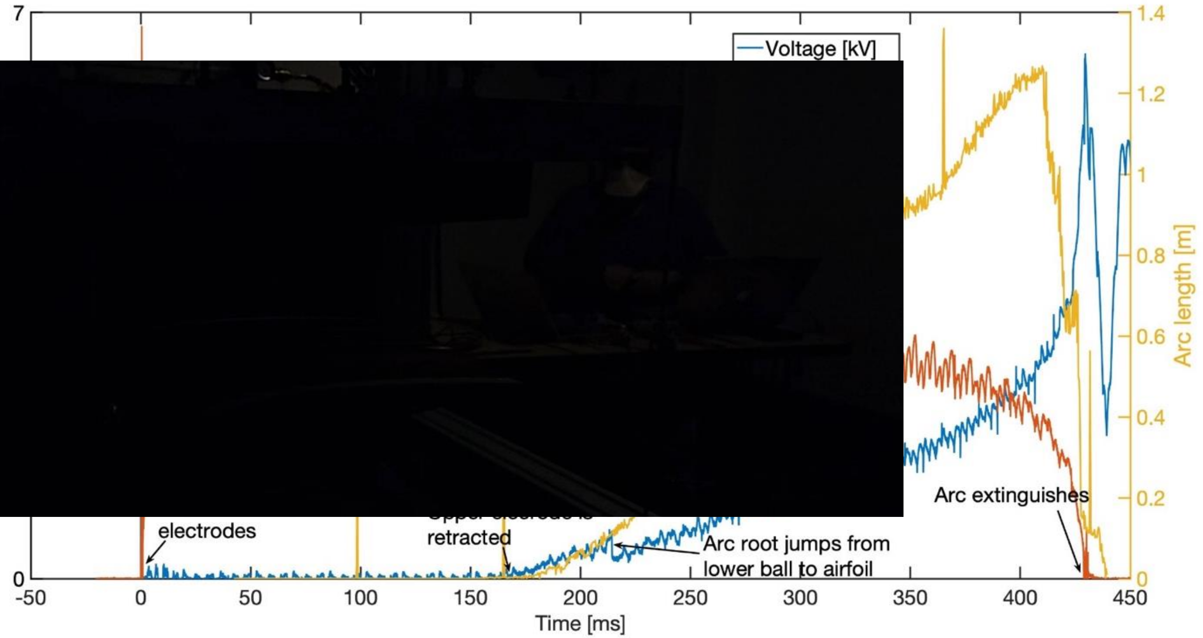
Wind tunnel experiments of long arcs in crossflow







Upper Electrode: Ball or Rail		
Wind Speed [m/s]	Angle of Attack [deg]	Polarity Airfoil
1, 2, 4	0, 10, 20	Positive, Negative

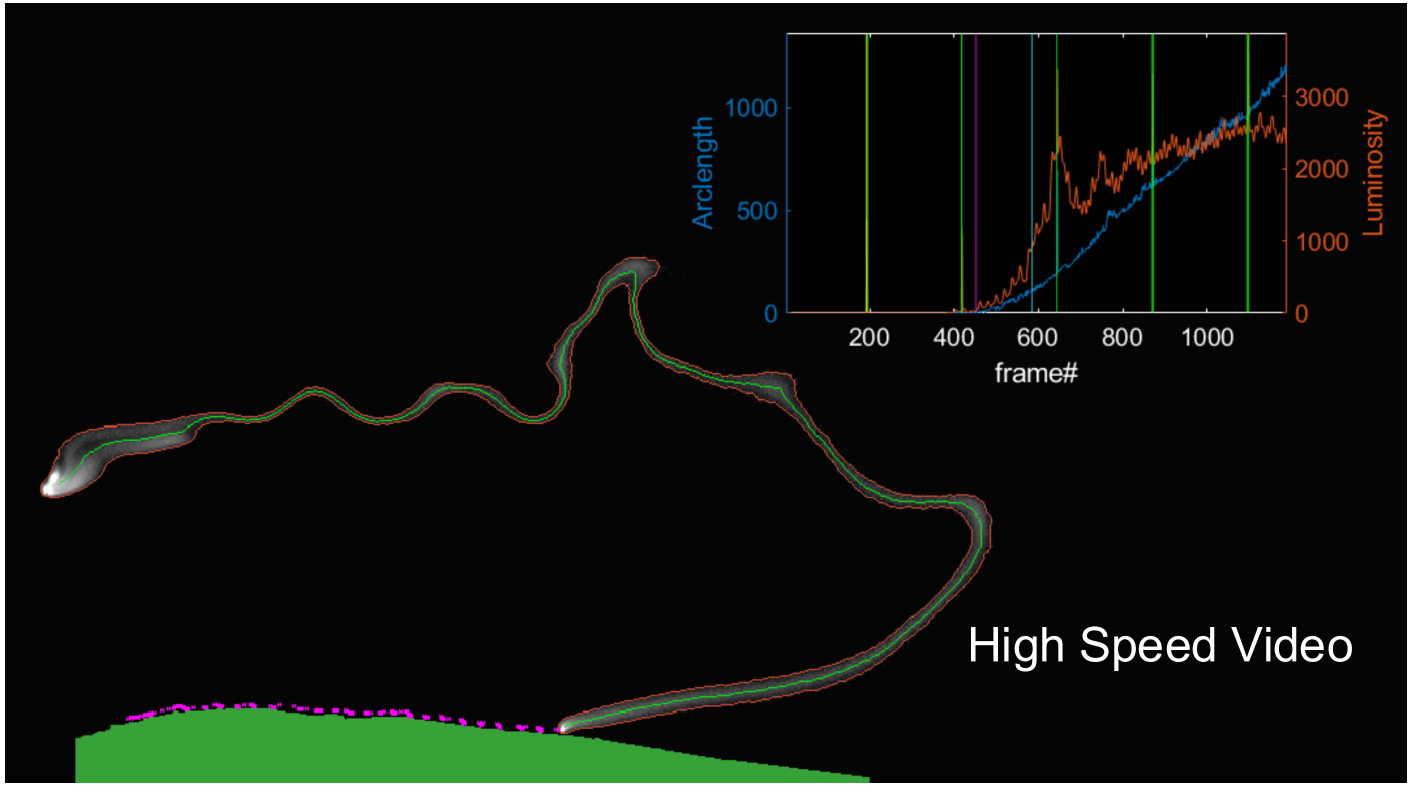


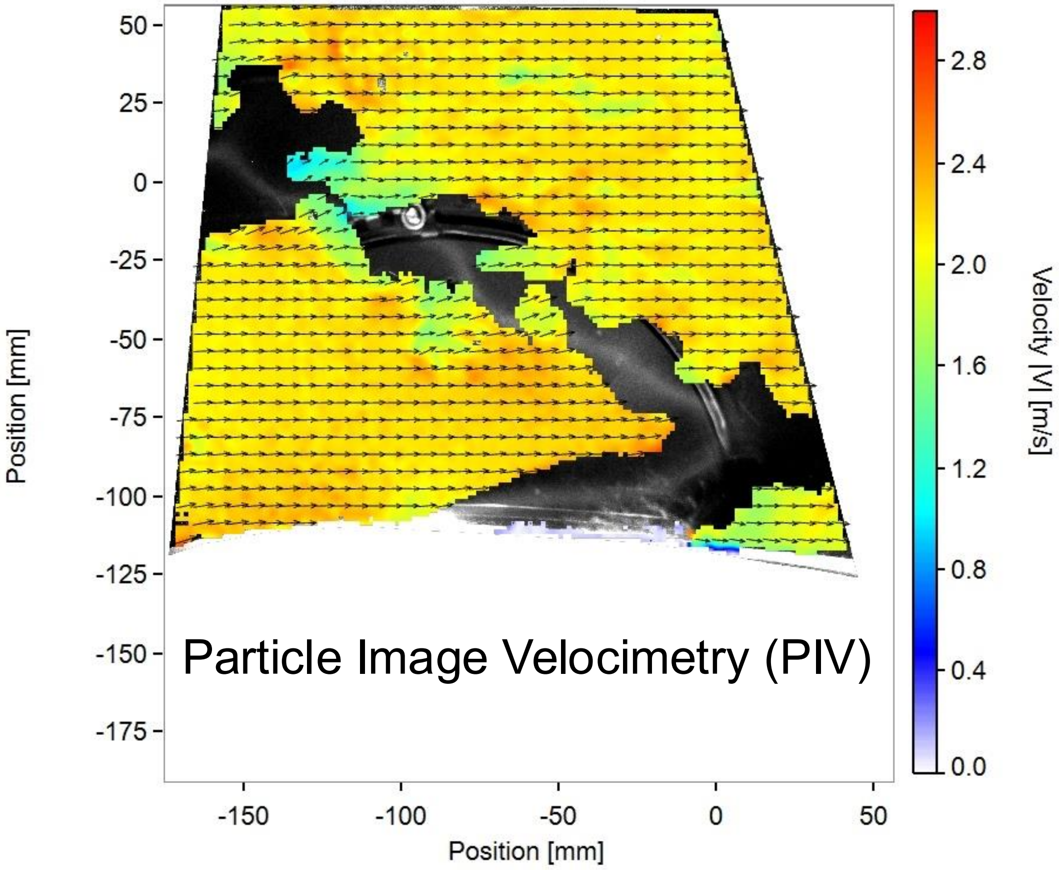
Guerra-Garcia, et al. (September 2024). Wind Tunnel Experiments of Long Arcs in Crossflow. *International Conference on Lightning and Static Electricity*
https://doi.org/10.5281/zenodo.13845312 (2nd Best Paper Award)

Imaging the arc and the flowfield

- What's the influence of the flowfield on the **arc column** dynamics?
- What's the influence of the flow boundary layer on the **arc root** dynamics?

Visualize *both* the arc and the flowfield

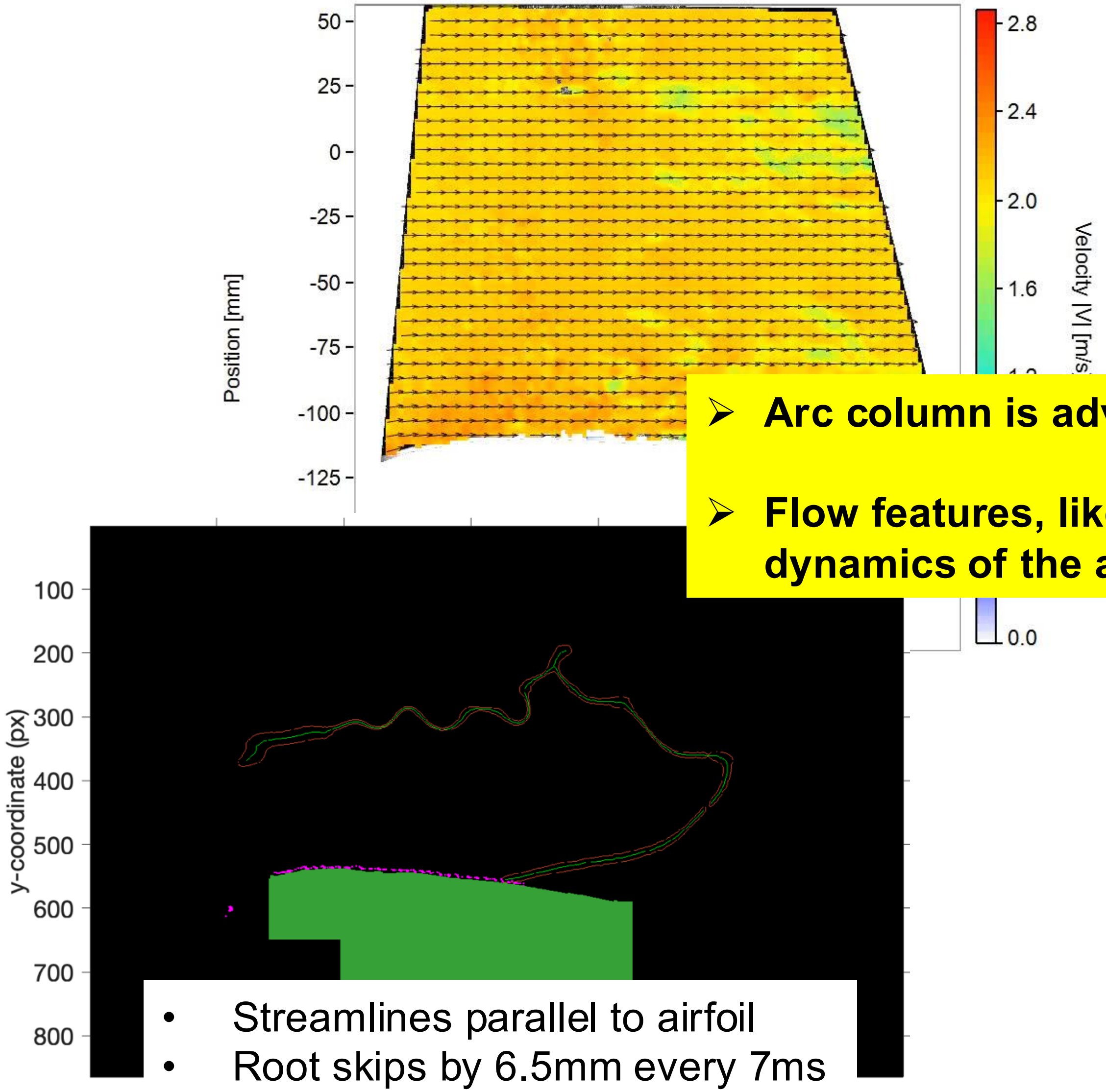




F. Lin, V. Andraud, G. Tobella, J. Montanya, R. Sousa Martins, and C. Guerra-Garcia (2025). Wind tunnel experiments of long arcs in crossflow: anodic roots and influence of flow field, Journal of Physics D: Applied Physics, vol. 58, n. 35, 355205; https://doi.org/10.1088/1361-6463/adfce1

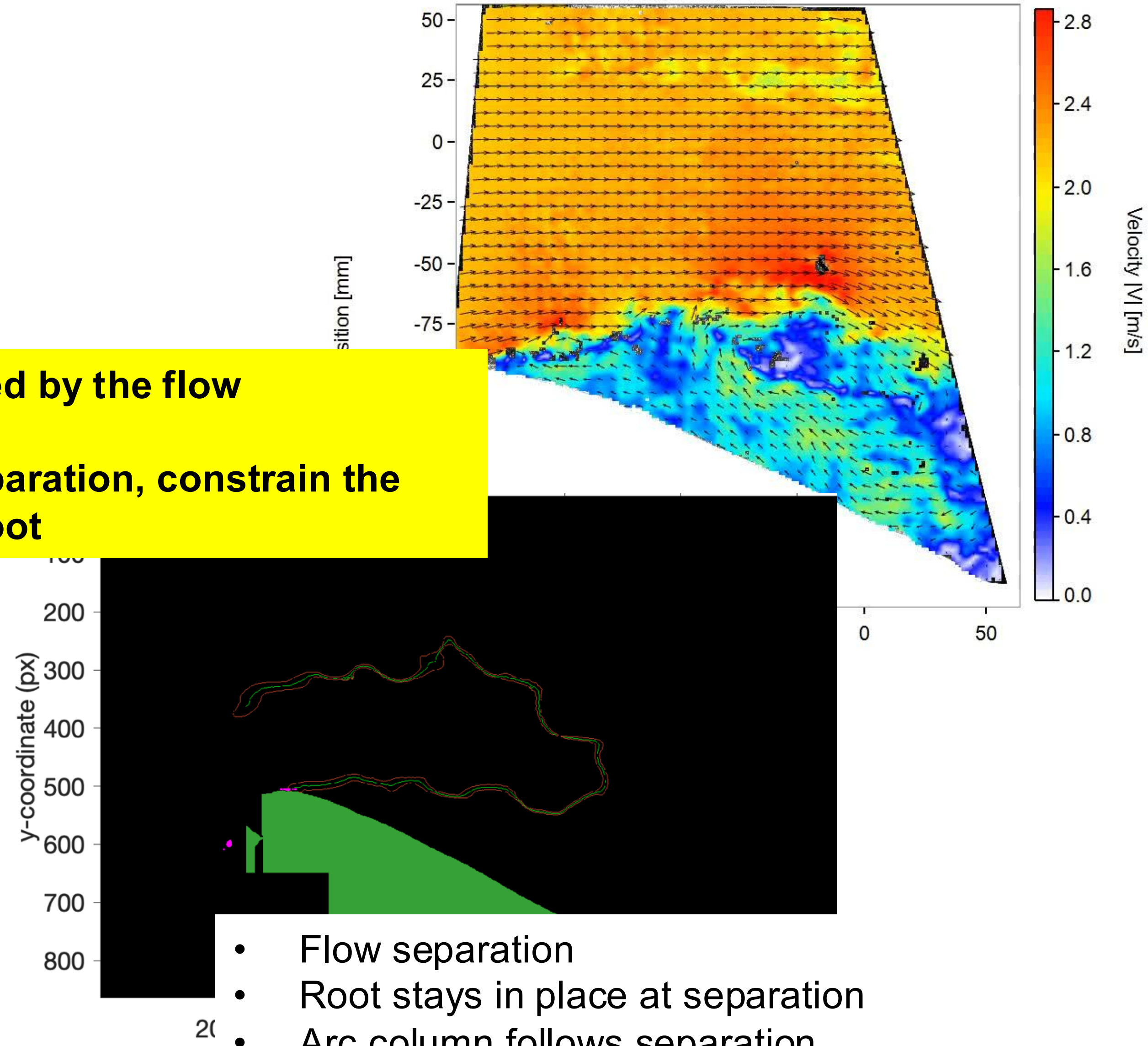
Boundary layer influence on arc root/ column dynamics

Baseline: 0 deg. AoA, Anode



- Streamlines parallel to airfoil
- Root skips by 6.5mm every 7ms
- Arc column advected by flow

Separation: 20 deg. AoA, Anode



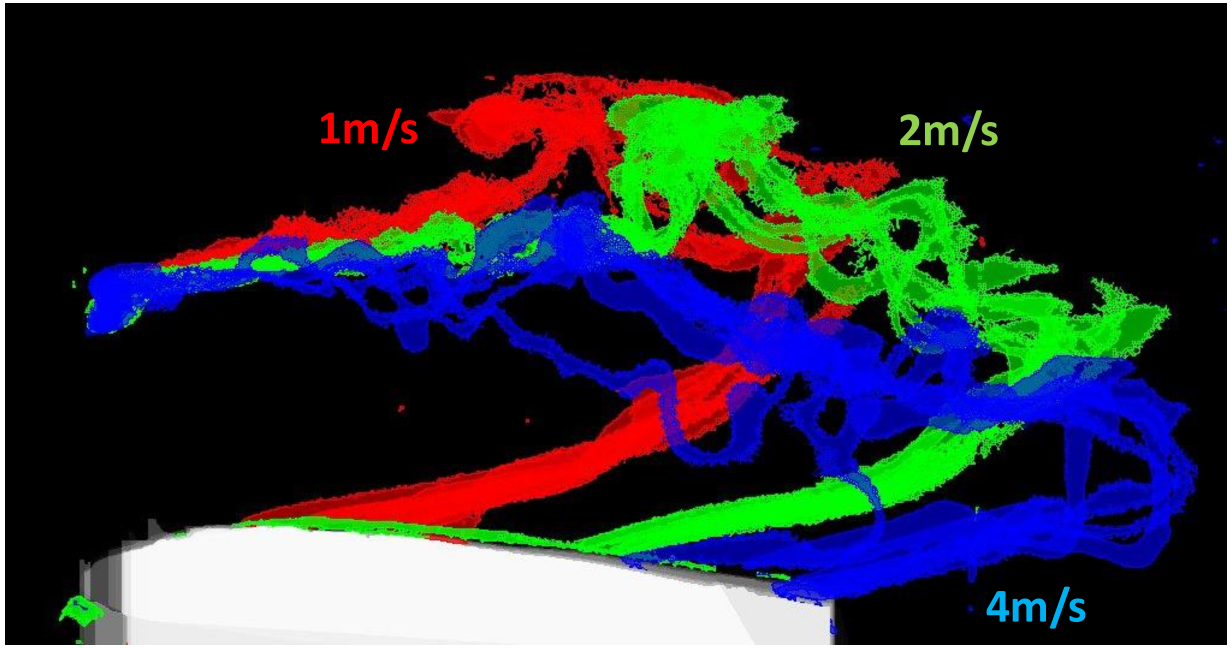
- Flow separation
- Root stays in place at separation
- Arc column follows separation

➢ **Arc column is advected by the flow**

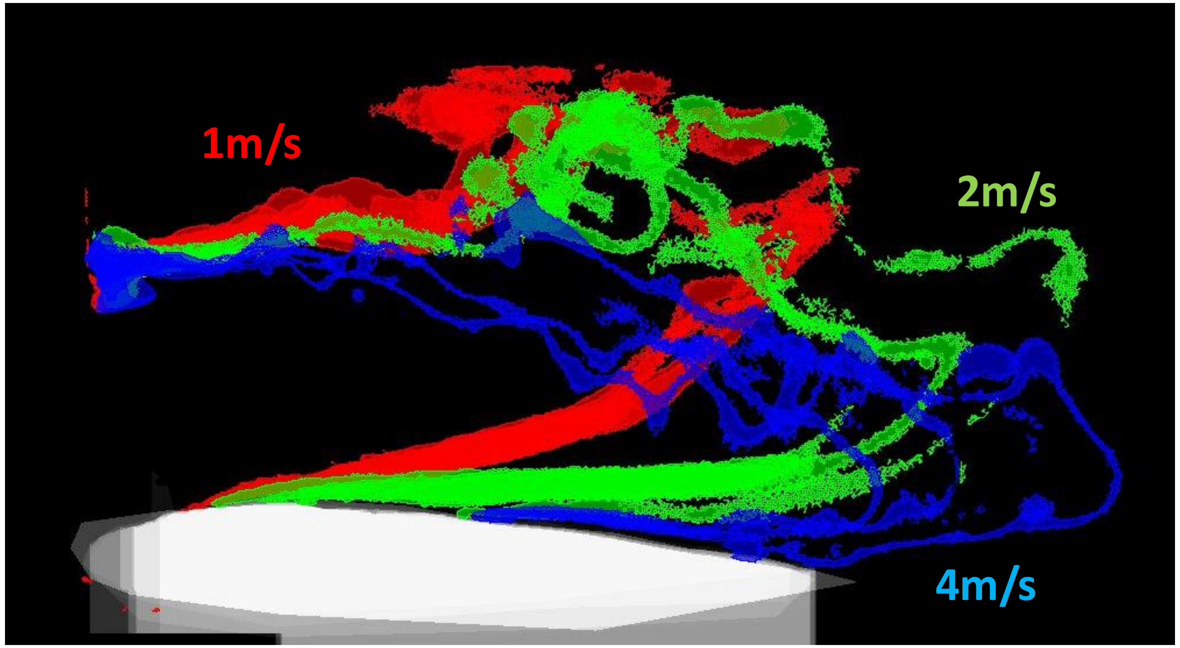
➢ **Flow features, like separation, constrain the dynamics of the arc root**

Influence of polarity on arc root/ column dynamics

Anode: 0 deg. AoA, arc at extinction



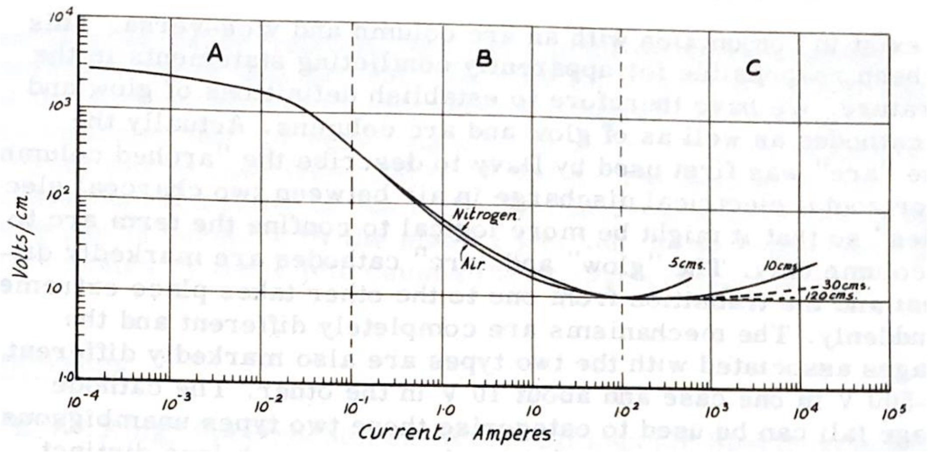
Cathode: 0 deg. AoA, arc at extinction



- Anodic root prone to `skipping’
- Cathodic root stays in place and/or gives long jump
- Different processes for cathode/ anode roots: a cathodic spot has to emit electrons to maintain the arc current
- The ‘low’ current of this arc inhibits thermionic and field emission processes

F. Lin, V. Andraud, G. Tobella, J. Montanya, R. Sousa Martins, and C. Guerra-Garcia (2025). Wind tunnel experiments of long arcs in crossflow: anodic roots and influence of flow field, Journal of Physics D: Applied Physics, vol. 58, n. 35, 355205; https://doi.org/10.1088/1361-6463/adfce1

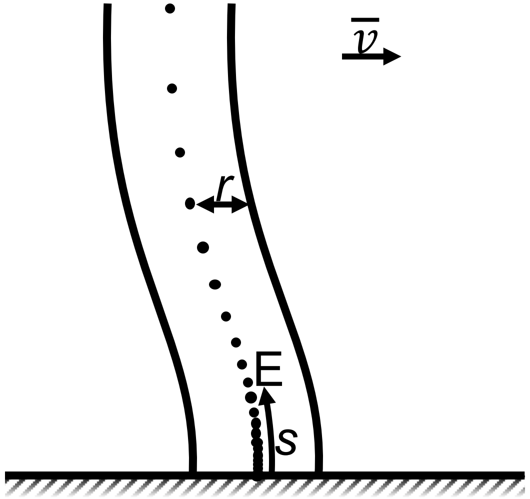
Modeling the swept stroke: Arc approximation



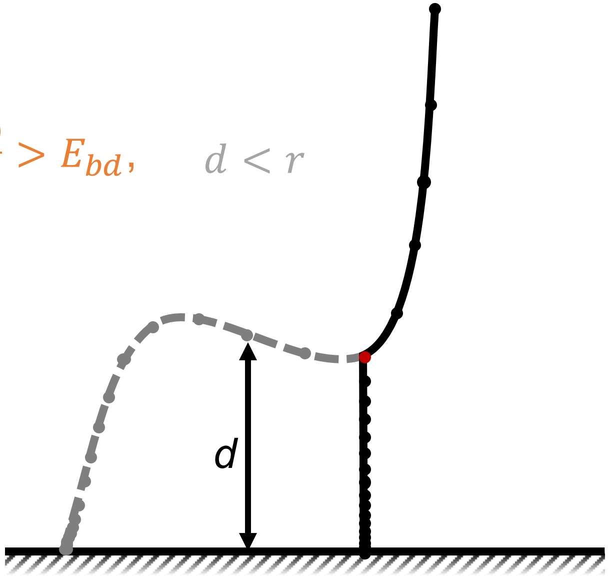
King, L. A. (1961). The voltage gradient of the free burning arc is air or nitrogen. In H. Maecker (Ed.), Ionization phenomena in gases (Vol. 1, p. 871-877)

Internal E-field	$E = \left(\frac{n}{n_0}\right) E_0$
Potential	$U(s) = \int E(s)ds$
Arc radius	$r = \left(\frac{n}{n_0}\right) r_0$
Linear advection	$\overline{x}^{t+1} = \overline{x}^{t} + \overline{v}_{\overline{x}^t} \cdot \Delta t$

Reattachment



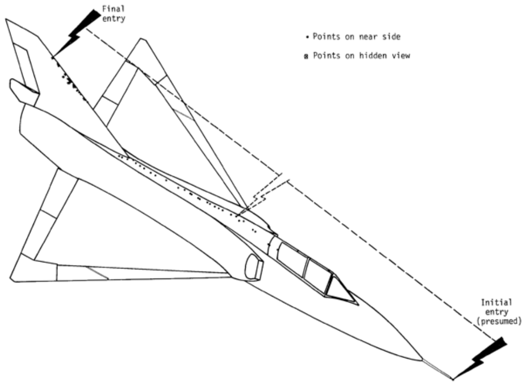
$\frac{U(s)}{d} > E_{bd}, \quad d < r$

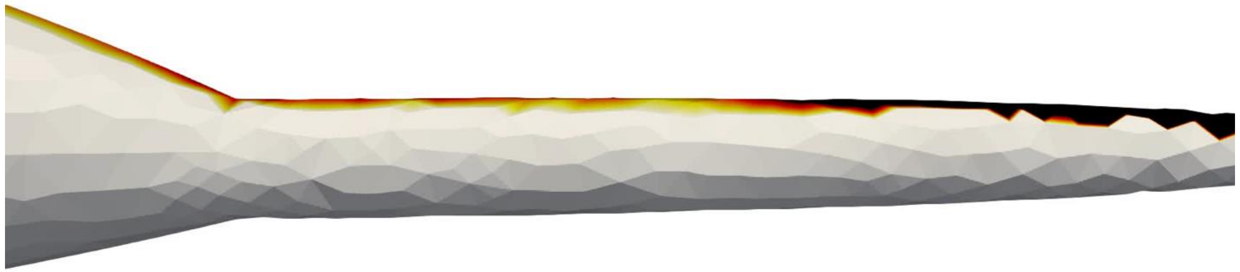


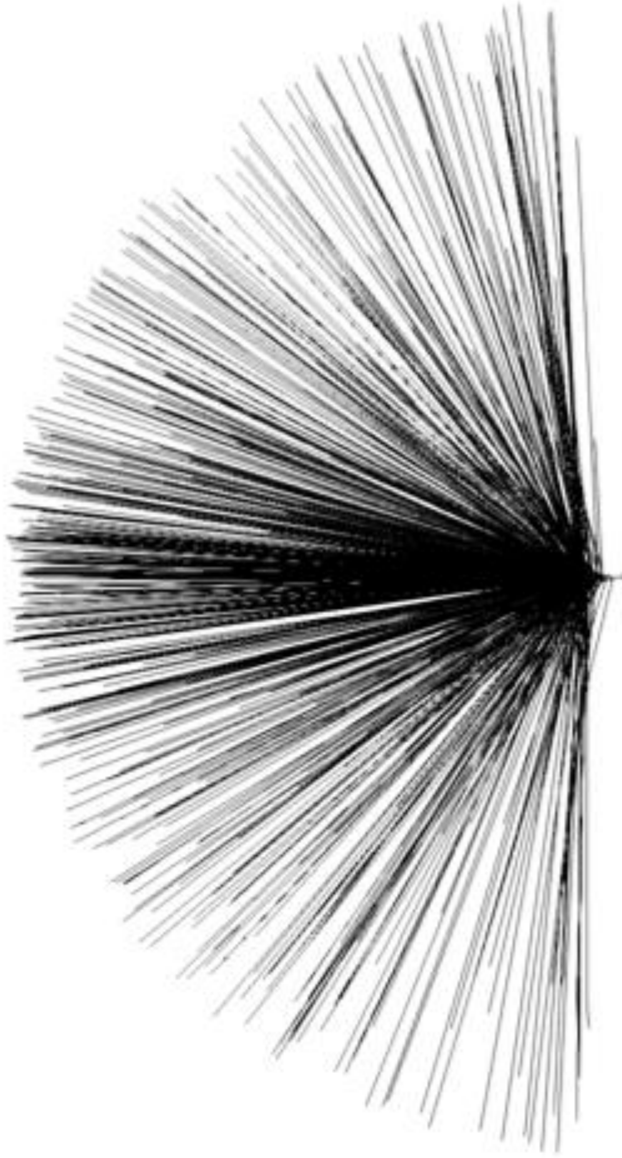
A. Larsson, P. Lalande, A. Bondiou-Clergerie. The Lightning swept stroke along an aircraft in flight. Part II: numerical simulations of the complete process. J Phys D: Applied Phys, 33 (15) 2000

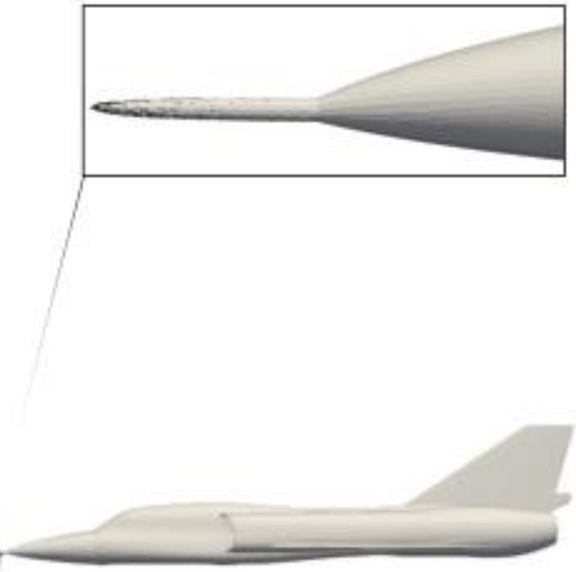
N. Jenkins, C. Guerra-Garcia. Numerical simulation of the lightning swept stroke: application to the results from the NASA Storm Hazards Program. *IEEE Access* vol. 12, pp. 188231-188244, 2024

Modeling the swept stroke: Solving at the aircraft scale





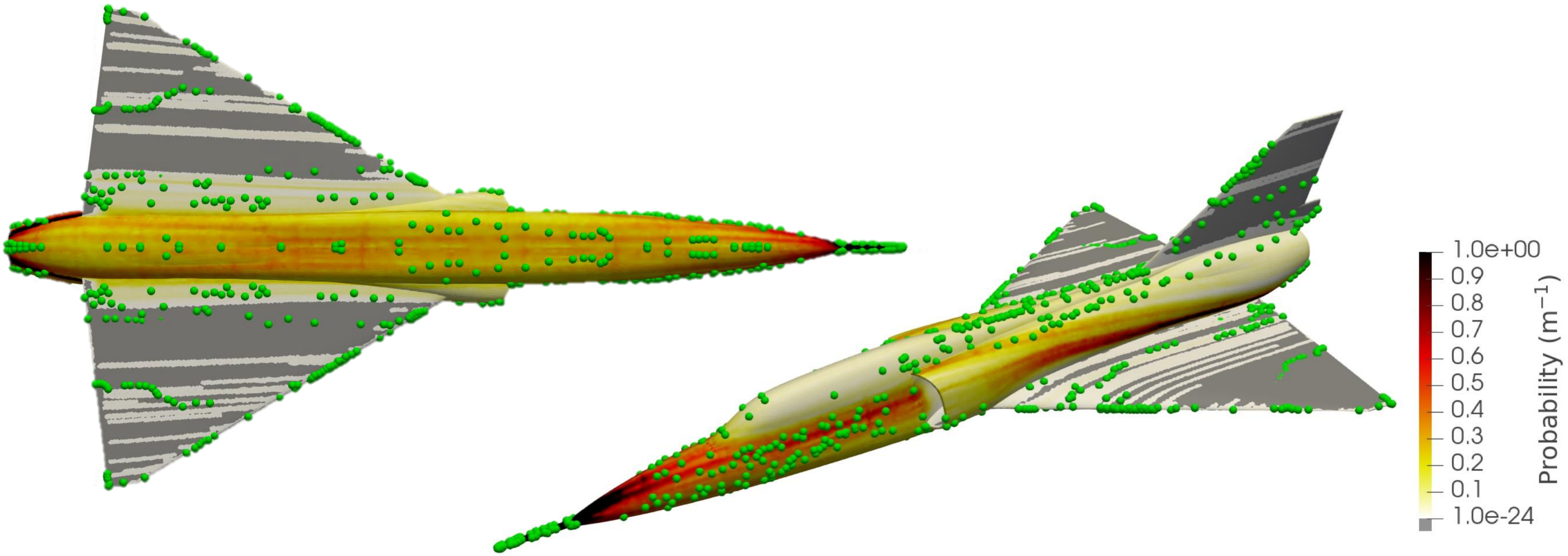




Arc seeding @ initial attachment point, any orientation

N. Jenkins, C. Guerra-Garcia. Numerical simulation of the lightning swept stroke: application to the results from the NASA Storm Hazards Program. *IEEE Access* vol. 12, pp. 188231-188244, 2024

Validity of the physical model: comparison to experimental data from NASA SHP

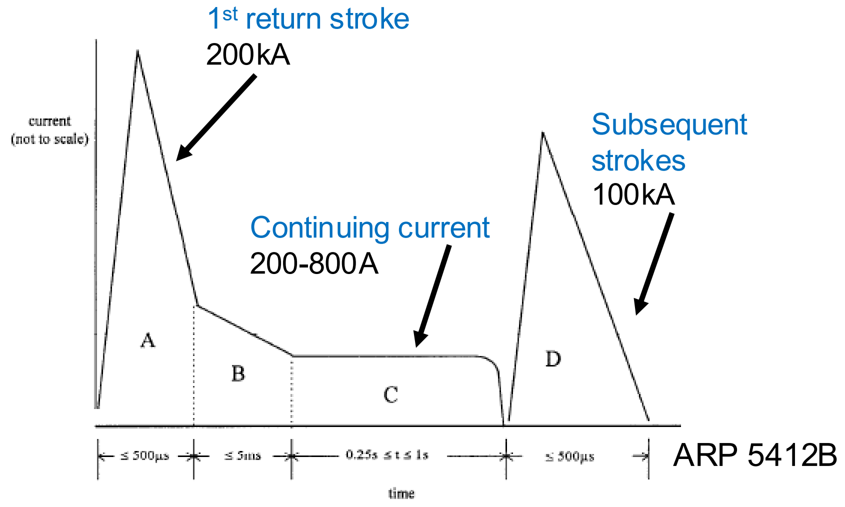


Aggregate strike distribution

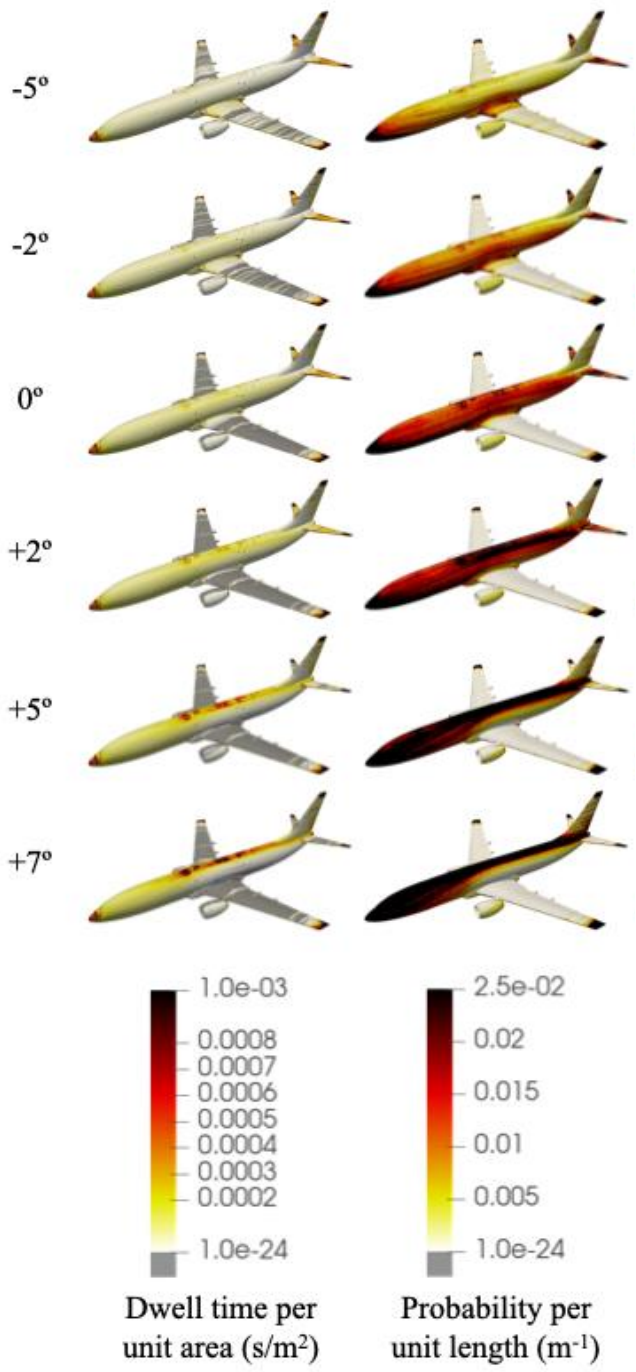
Statistical distribution of lightning attachment patterns

Results of inviscid simulation overlayed with experimental data from the 1980s NASA SHP (green markers)

Mapping to the engineering practice: application to conventional transport

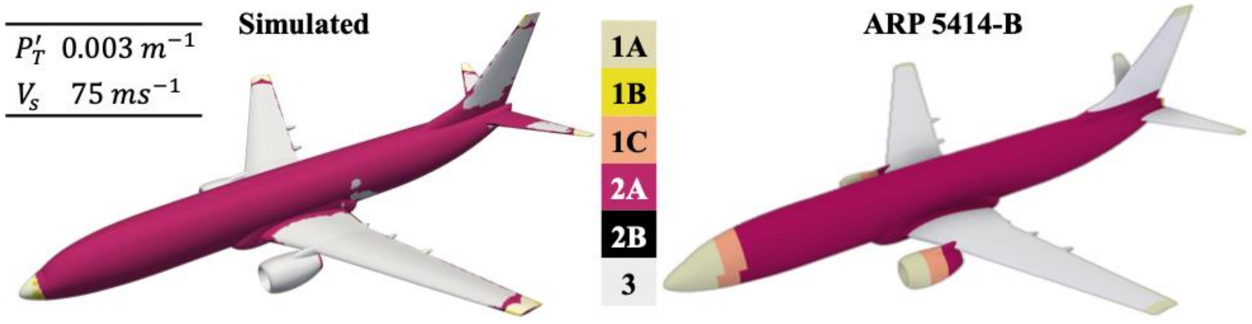


Zone	ARP 5414B *"All the areas of the aircraft surfaces where…"*	Quantifiable interpretation
1A	A **first return stroke** is likely during lightning channel attachment with a low expectation of flash hang-on.	High probability of initial attachment or swept leader
1B	A **first return stroke** is likely during lightning channel attachment with a **high expectation of flash hang-on.**	High probability of initial attachment on a trailing edge.
1C	A **first return stroke** of **reduced amplitude** is likely during lightning channel attachment with a low expectation of flash hang-on.	Extension of Zone 1A to include some swept stroke region.
2A	**Subsequent return stroke** is likely to be swept with a low expectation of flash hang-on.	Swept stroke region outside of Zone 1.
2B	**Subsequent return stroke** is likely to be swept with a **high expectation of flash hang-on.**	Swept stroke region outside of Zone 1 with long hang-on.
3	Those surfaces not in Zones 1A, 1B, 1C, 2A, or 2B.	Everywhere not in Zones 1 or 2.

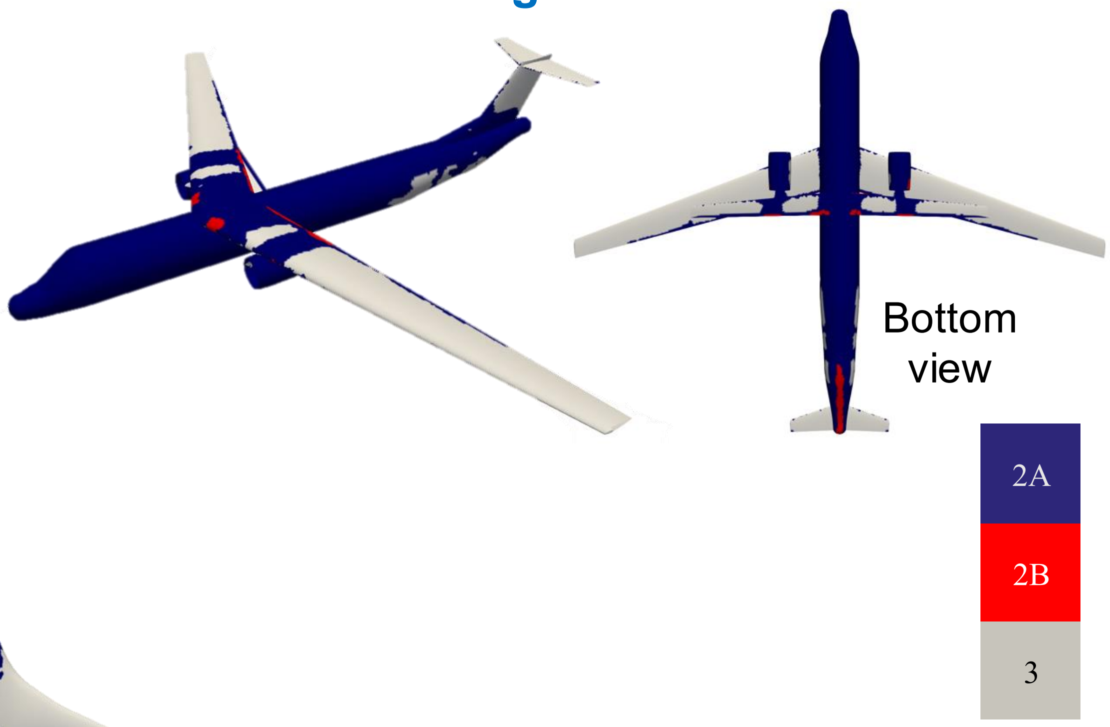


Outlook: Application to novel aircraft

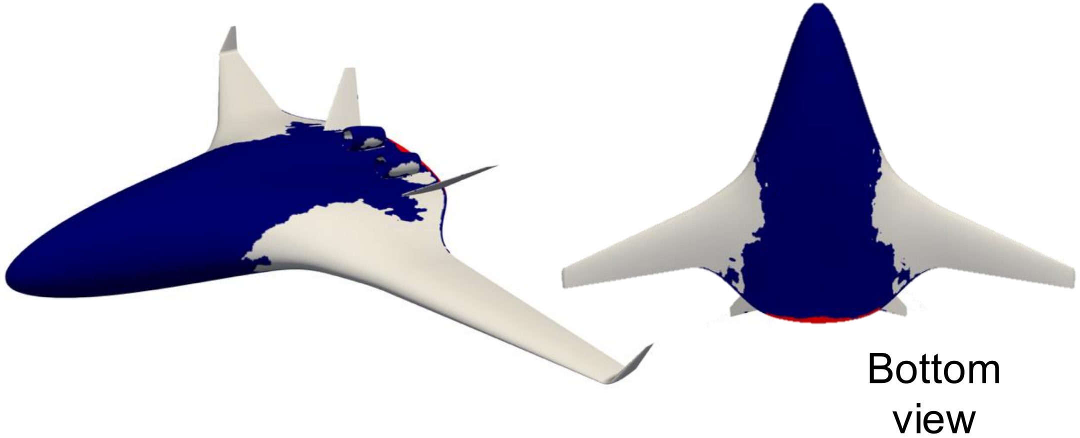
Conventional Transport



Truss-Braced Wing



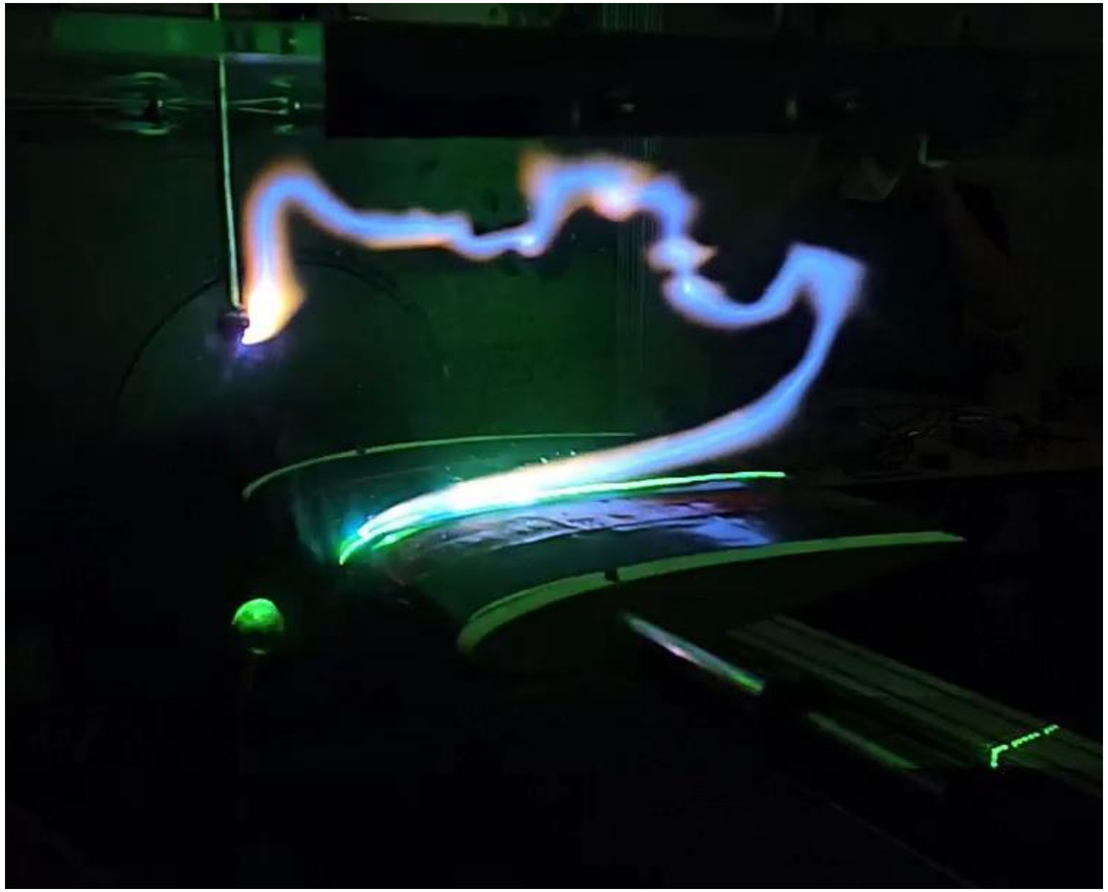
Blended Wing Body (BWB)



Summary

From the Decadal Assessment of Plasma Science*: *'physics of lightning has long been considered as prohibitively difficult to understand from first principles, and so lightning research focused either on observations of the macroscopic phenomena or on lightning protection based on engineering models. Lightning protection remains a topic of growing importance, particularly given the trend toward composites in the aerospace industry. (…)*

Low Temperature Plasma research will play a crucial role in some of the key science challenges in this area including […] lightning attachment […] ***A better understanding of this process could lead to improved lightning protection schemes'***



* National Academies of Sciences, Engineering, and Medicine, 2021. Decadal Assessment of Plasma Science. Washington, DC: National Academies Press.

Final remarks

- Plasma science and engineering go hand in hand
- Engineering and societal challenges give the framework and motivation to pursue fundamental science questions

- To control, first you need to understand, and often you encounter uncharted territories…

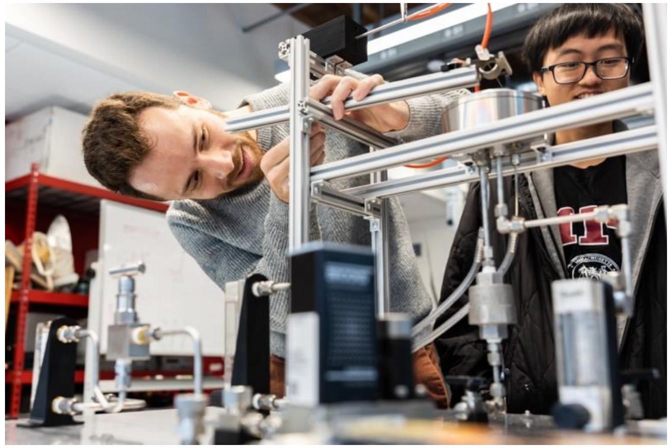
- Aerospace plasmas present unique multiphysics challenges as they often appear in fast-flowing, reactive gas environments

AI generated (DesignerGPT)

ACKNOWLEDGEMENTS

Aerospace Plasma Group students:
C. Pavan (PhD), R. Dijoud, N. Jenkins, S. Rao, F. Lin, L. McKinney, L. Strobel, S. Austin, M. Cherry, N. Hope-Glenn

Collaborators
Plasma-assisted combustion: A. Ghoniem and S. Shanbhogue (MIT), F. Gomez del Campo and D. Weibel (Specter Aerospace)
Lightning safety: J. Montanya (UPC), R. Sousa and V. Andraud (Onera), Louisa Michael and Ben Westin (Boeing), J. Peraire and N. C. Nguyen (MIT)



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QUESTIONS?

Contact: guerrac@mit.edu