INL/CON-24-79673-Revision-0

Intern Poster - Characterizing Wildland Fire Conditions for Lab-Scale Testing of Advanced Conductors

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Characterizing Wildland Fire Conditions for Lab-Scale Testing of Advanced Conductors

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U.S. DEPARTMENT OF ENERGY

INTRODUCTION

Rising energy demands challenge utilities to deliver more power. Traditional overhead cables are unable to physically meet such demands, Advanced conductors, with their fiber composite cores, promise higher capacity. Yet, adoption lags due to the scarcity of usage data around wildland fires' impact on this new tech – a significant barrier to grid modernization.

***Figure 1**: Wildland fire approaches operational transmission tower[1]*

OBJECTIVE

To address utilities' concerns, this project aims to test and analyze the mechanical performance of advanced conductors subject to wildland fire events. These initial steps (the focus of this poster) will be:

- Designing and constructing a fire table apparatus to imitate wildland fire conditions
- Establishing wildland fire behavior parameters for testing
- Estimating theoretical heat transfer impact for comparison

FIRE TABLE DESIGN

Our team visited the USDA Forest Service's Fire Science Laboratory[2] in Missoula, MT, to seek professional expertise in the design of a fire table suitable for our project's needs.

The Fire Science Lab's fire protection engineers developed a sand-diffused propane fire table for controllable, even, and on-demand flames.

Our design incorporates these aspects, along with thermocouple temperature sensors to measure heat fluctuation underneath a 6-foot suspended section of advanced conductor in real time.

***Figure 2**: Live demonstration of one of Missoula Fire Lab's test fire tables[2]*

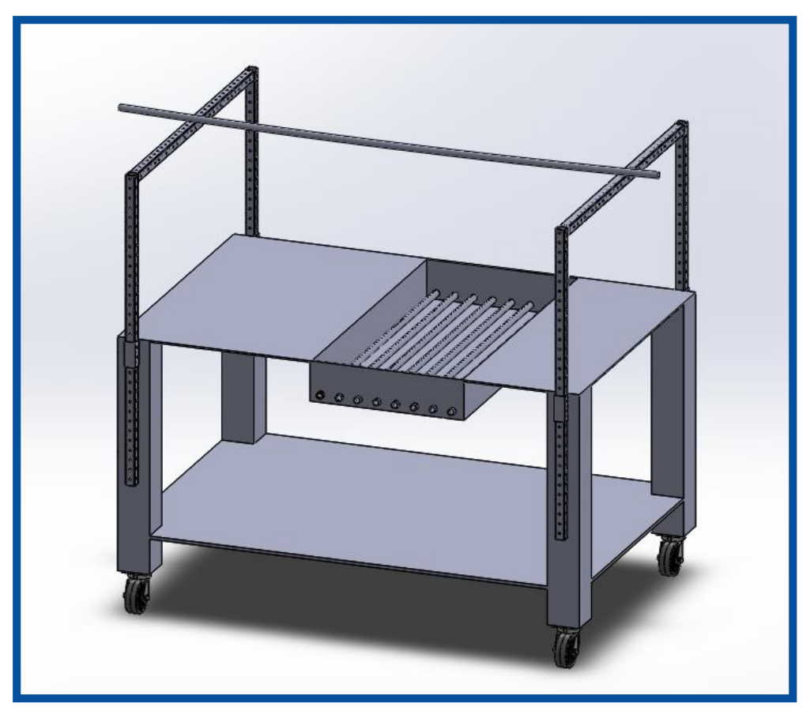


***Figure 3**: Preliminary fire test table design as created in SolidWorks (computer aided design) software[3]*

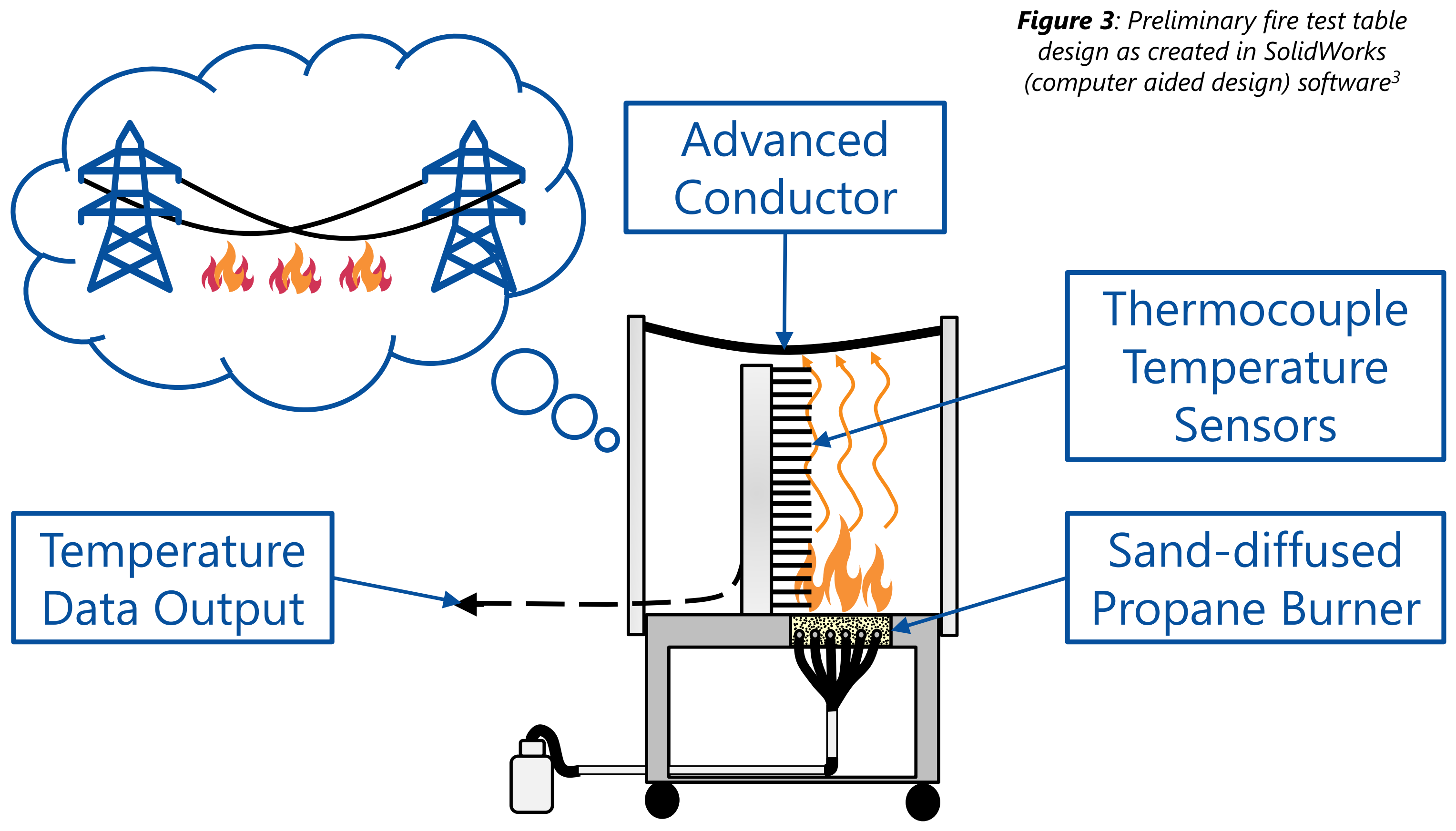


***Figure 4**: Author's diagram of the fire table's proposed design*

PARAMETERIZE FIRE BEHAVIOR

Wildland fires are highly dynamic, but certain behaviors can be modeled and calculated based on the fuel it burns. The U.S. can be summed up into 4 different biome environments: grasslands, forests, deserts, and tundra. Finney[4] provides methods and equations to integrate fuel properties into fire calculations. Each biome has unique characteristics in a fire scenario, but for the most realistic test conditions, only flame residence time and flame height are considered for lab scale experiments. For these calculations, Finney's provided data and averages of properties are implemented.

Flame Residence Time

1. Identify fuel properties of corresponding biome:

- Surface Area-to-Volume Ratio (β)
- Packing Ratio (σ)
- Fuel Load ($m_f^{''}$)

Fuel	Surface Area to Volume Ratio β	Packing Ratio σ	Maximum Fuel Load m''_f (kg/m²)	Avg. Moisture Content	
				Low	High
Grasslands	2494.5	0.05	7.79	10%	30%
Forest	1760.24	0.3	95.89	10%	50%
Desert	3307	0.02	6.95	10%	60%
Tundra	2604.56	0.05	5.77	40%	90%

***Figure 5**: Graphic representation of each considered biome.*
***Table 1**: Summary of fuel loading variables for each biome.[3]*

2. Calculate flame residence time (t_r)

$$t_r = 566\beta + \frac{4894}{\sigma} + 4.6m_f^{''}$$

Flame Height

1. Fire rate-of-spread (r)

- Flame depth (D) (cable span length)
- Flame residence time (t_r)

$$r = \frac{D}{t_r}$$

2. Heat of combustion ($H_{\text{c,eff}}$)

- Consumed fuel mass (M_c)

$$H_{c,eff} = 16.52 - 0.057M_C$$

3. Fire line intensity (I_B)

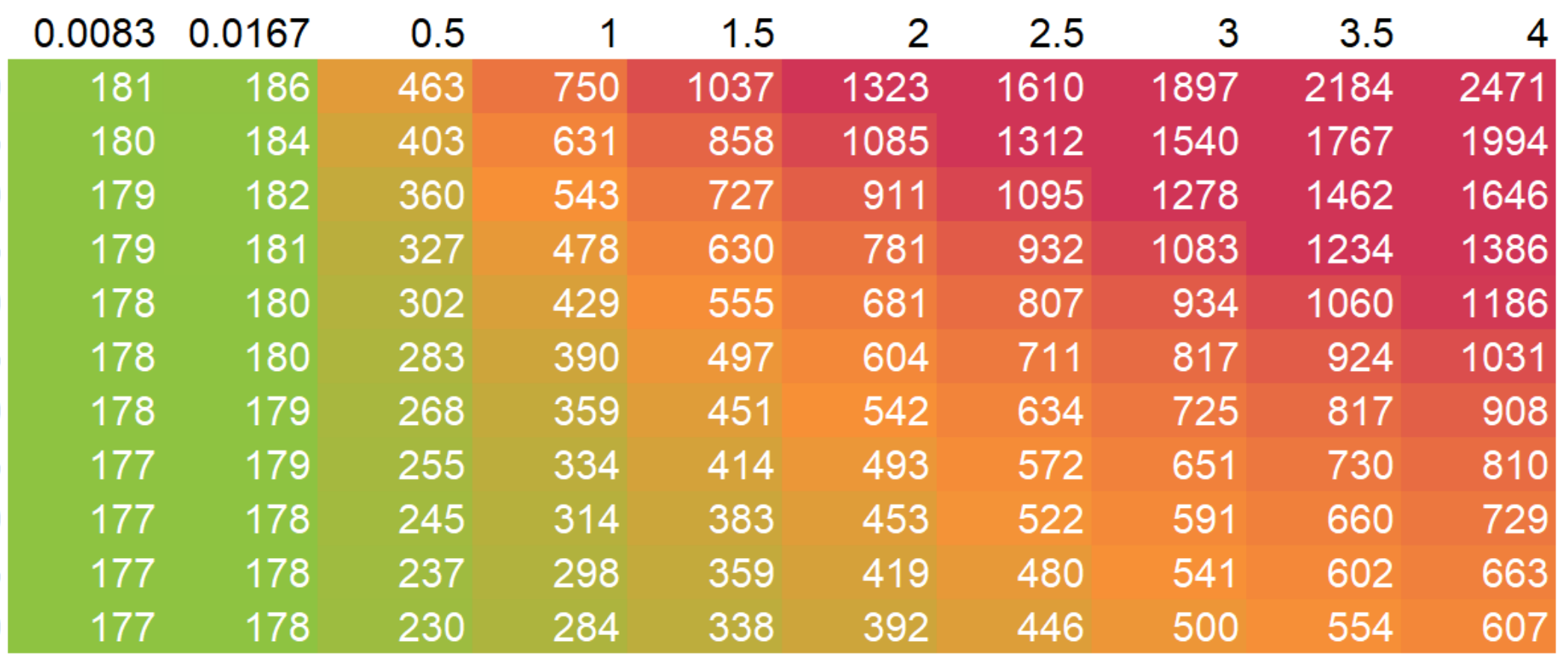
$$I_B = H_{c,eff}\, m_c^{''} r$$

4. Flame Height (l_f)

$$l_f = 0.0775 I_B^{0.46}$$

PREDICTED IMPACT ON CONDUCTOR

Finney's data combined with fuel calculations reveal that wildland fires' flame residence time lie anywhere from 30 seconds to 3+ hours. Combining this data with cable height and material properties, with fire heat flux data in a heat transfer model yields the following results:



	0.0083	0.0167	0.5	1	1.5	2	2.5	3	3.5	4
30	181	186	463	750	1037	1323	1610	1897	2184	2471
35	180	184	403	631	858	1085	1312	1540	1767	1994
40	179	182	360	543	727	911	1095	1278	1462	1646
45	179	181	327	478	630	781	932	1083	1234	1386
50	178	180	302	429	555	681	807	934	1060	1186
55	178	180	283	390	497	604	711	817	924	1031
60	178	179	268	359	451	542	634	725	817	908
65	177	179	255	334	414	493	572	651	730	810
70	177	178	245	314	383	453	522	591	660	729
75	177	178	237	298	359	419	480	541	602	663
80	177	178	230	284	338	392	446	500	554	607

***Table 2**: Final temperatures of overhead conductor as function of height and time. Green=some heat gained, Orange=aluminum melting point, Red=failure*

***Equation**: $T_f = \frac{q^{''}(t)}{mc_p} + T_i$; T_f=final temperature, $q^{''}$=flame heat flux, t=time, m=mass of conductor (200'), c_p=specific heat of aluminum, T_i=initial conductor temperature*

CONCLUSION AND NEXT STEPS

Flame time and cable height are crucial variables to consider when conducting fire tests. Moving forward, the fire table will begin construction and tests will be conducted in a laboratory fire chamber.

SOURCES AND ACKNOWLEDGEMENTS

1. "Forest Fire" by Curtis Gregory Perry is licensed under CC BY-NC-SA 4.0. https://www.flickr.com/photos/curtisperry/37055303635/in/photostream/ https://creativecommons.org/licenses/by-nc-sa/2.0/ Image was cropped.
2. The author sincerely thanks Mark Finney, Ph.D., and the USDA Forest Service - Missoula Fire Sciences Lab team for their expertise and tour of their facilities.
3. SolidWorks design image courtesy of John 'Crash' Bell II
4. Finney, M. A., McAllister, S. S., Grumstrup, T. P., & Forthofer, J. M. (2021). Wildland Fire Behaviour: Dynamics, Principles, and Processes. Collingwood: CSIRO Publishing, 2021.

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