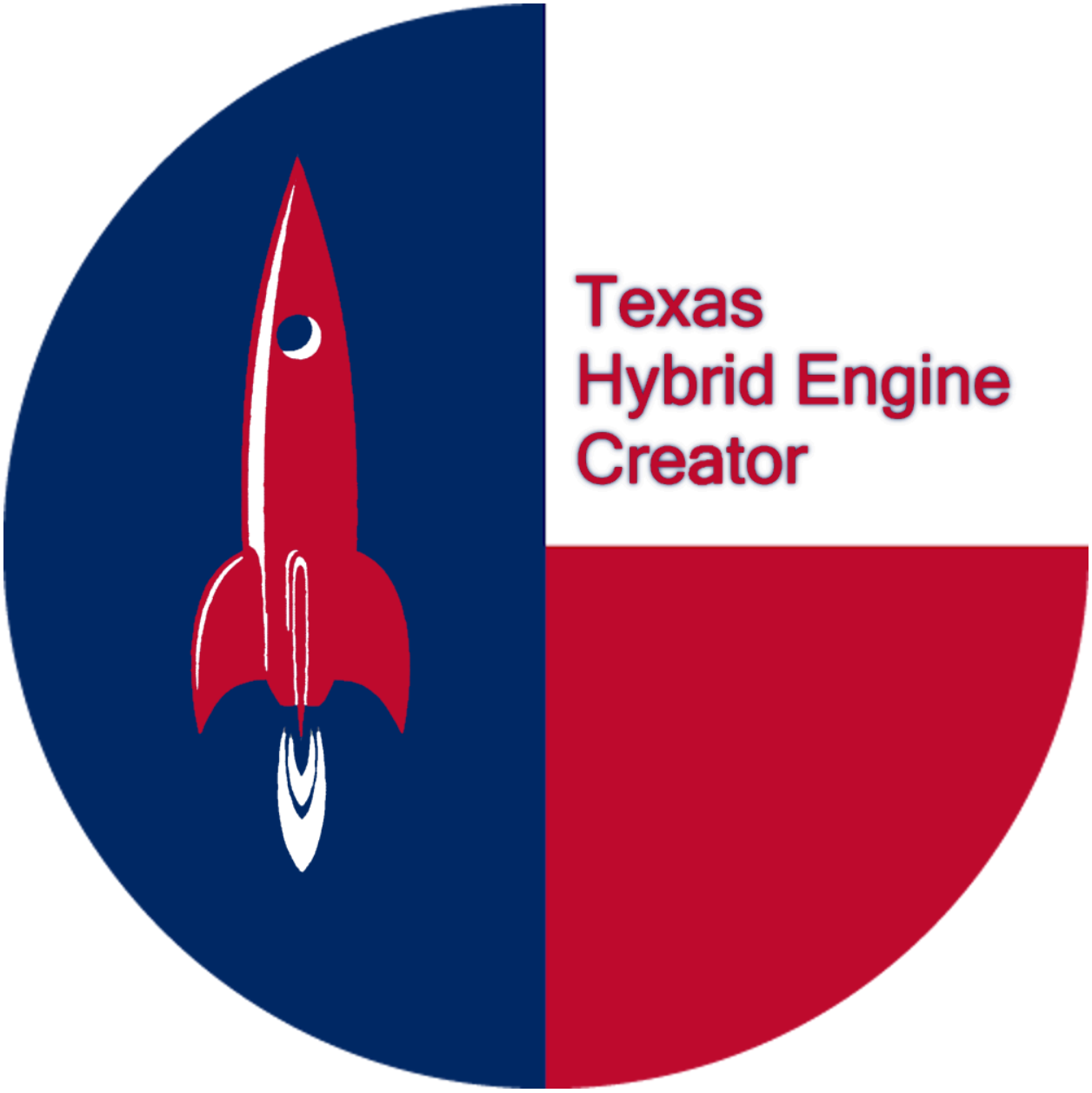

Manual for the Texas Hybrid Engine Creator

Version 0.5

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Features and Author's Notes

Program's Features:

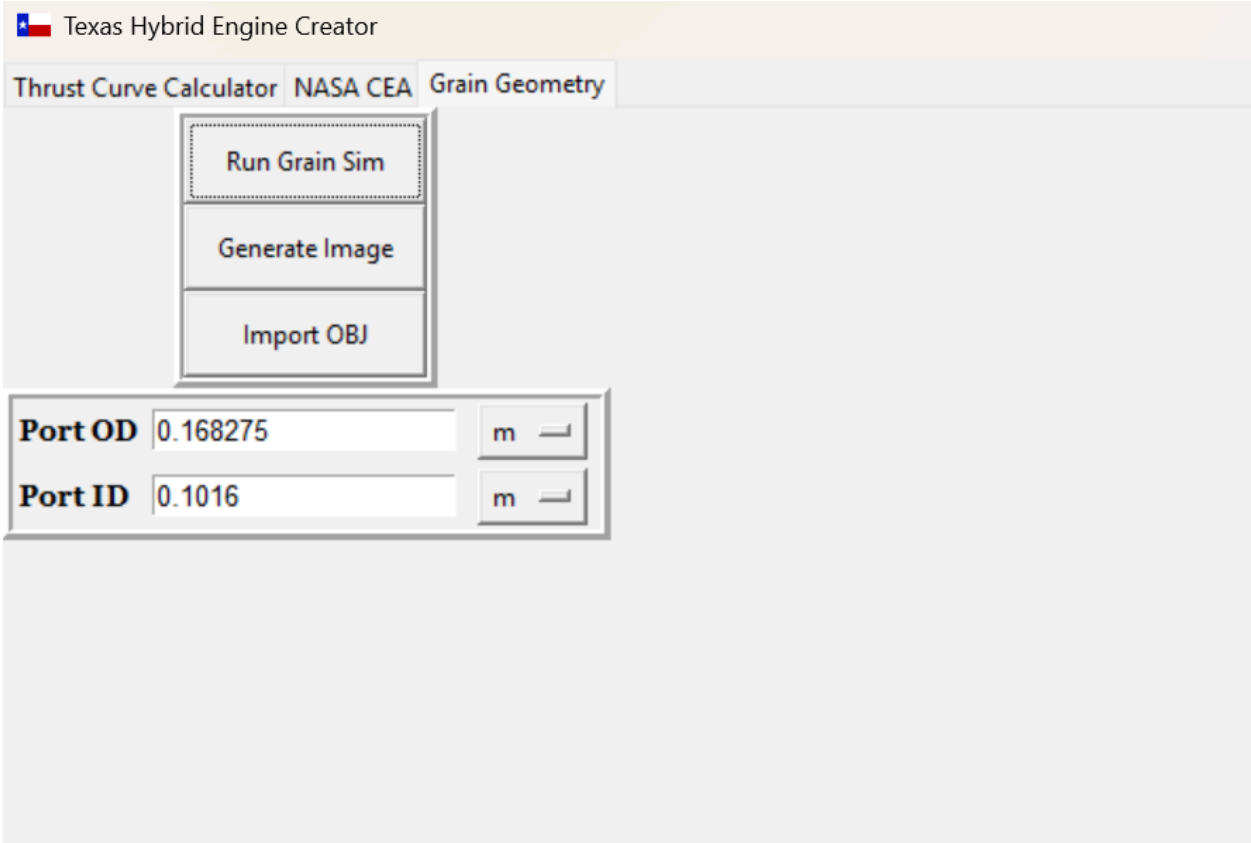
- Non-cylindrical port geometry
- Export thrust curve as a .eng file for use in OpenRocket
- Integrated NASA CEA
- Oxidizer Tank Creator
- Vapor Phase Modeling
- Ballistic Coefficient Calculator

The purpose of the program is to provide a space for experimenting with various configurations of a hybrid rocket. The current model uses nitrous oxide as the oxidizer.

How to Run a Simulation

Grain Simulation

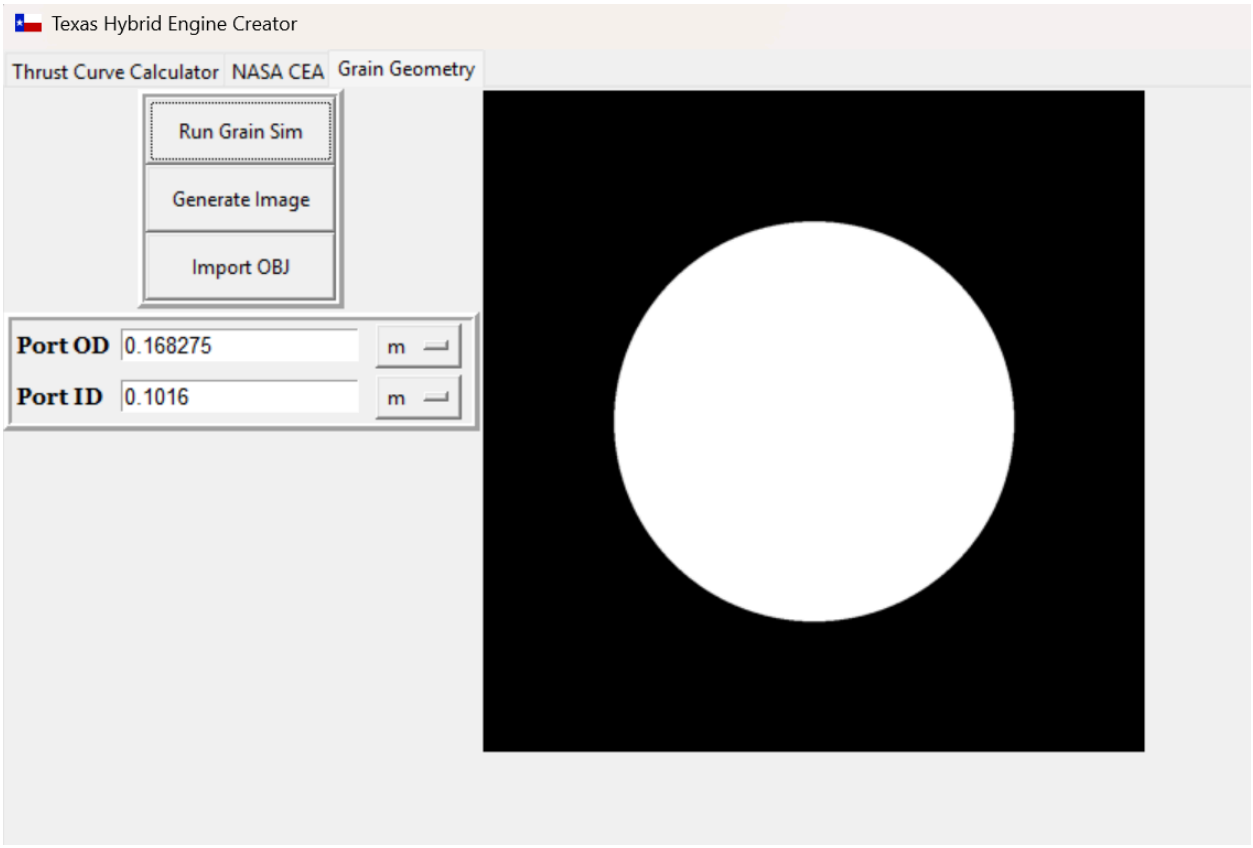
Grain Simulation occurs in the “Grain Geometry” tab.



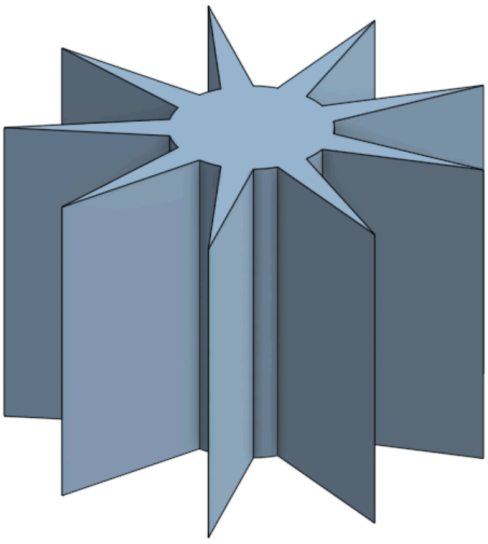
Before selecting the “Run Grain Sim” button, you have 2 options:

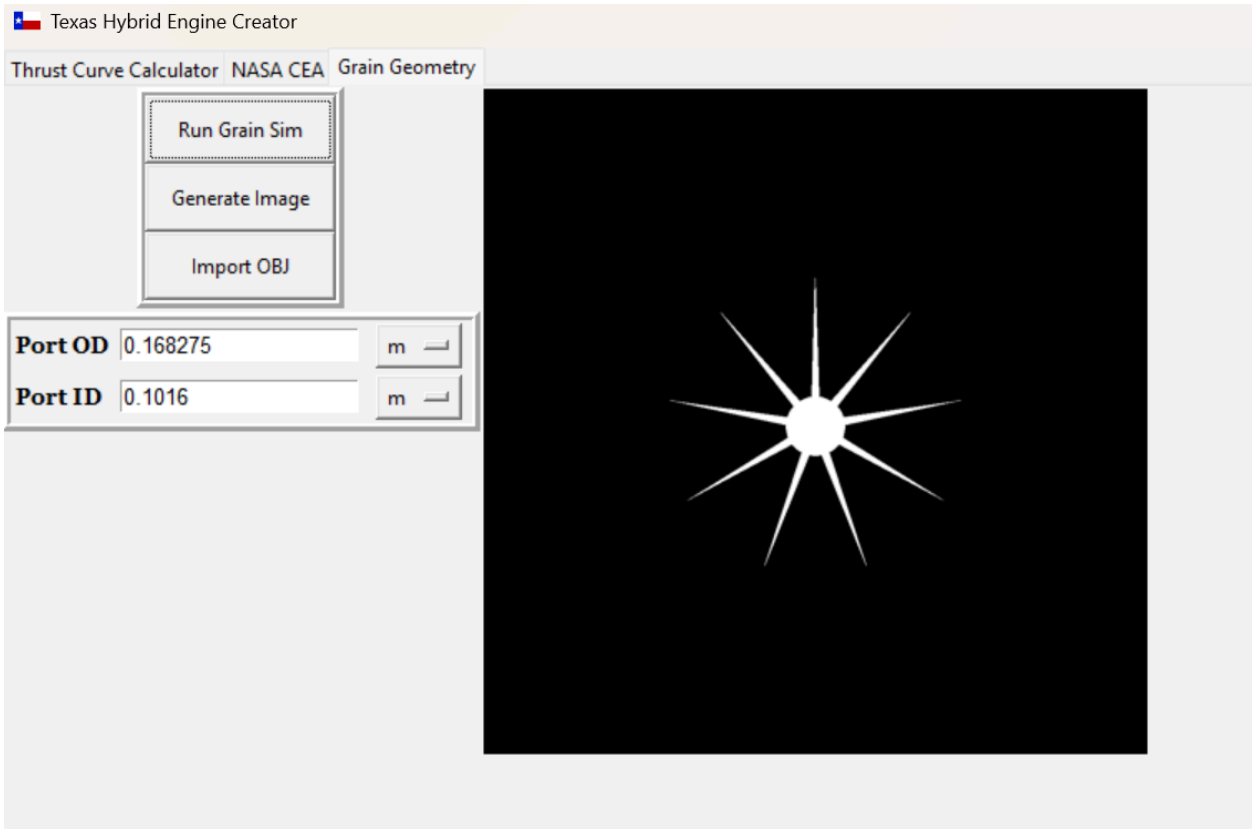
- Generate Image
- Import OBJ

After using each option, you should see a cross-section of the fuel grain. Currently, TXHEC does not support 3-dimensional complex fuel grains; only fuel grains with a port shape that remains constant throughout the grain length can be modeled.



Generate Image: This is useful for circular port geometries. The Port OD and Port ID text boxes will be used to create a circular port.

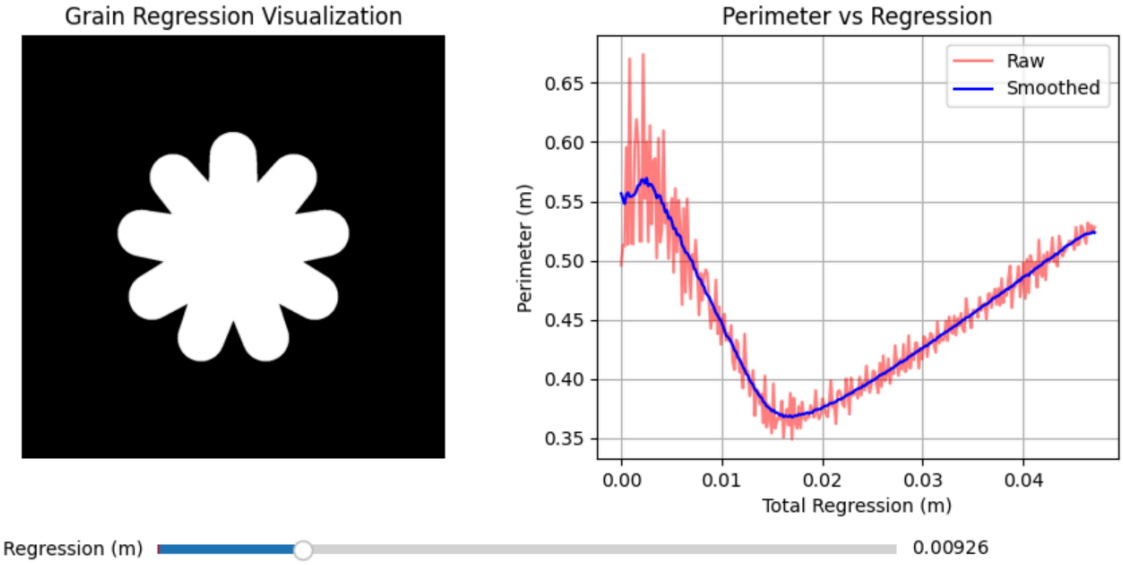




Import OBJ: This allows the user to input complex grain geometries into TXHEC. In CAD software, model the grain's port; Do NOT model the

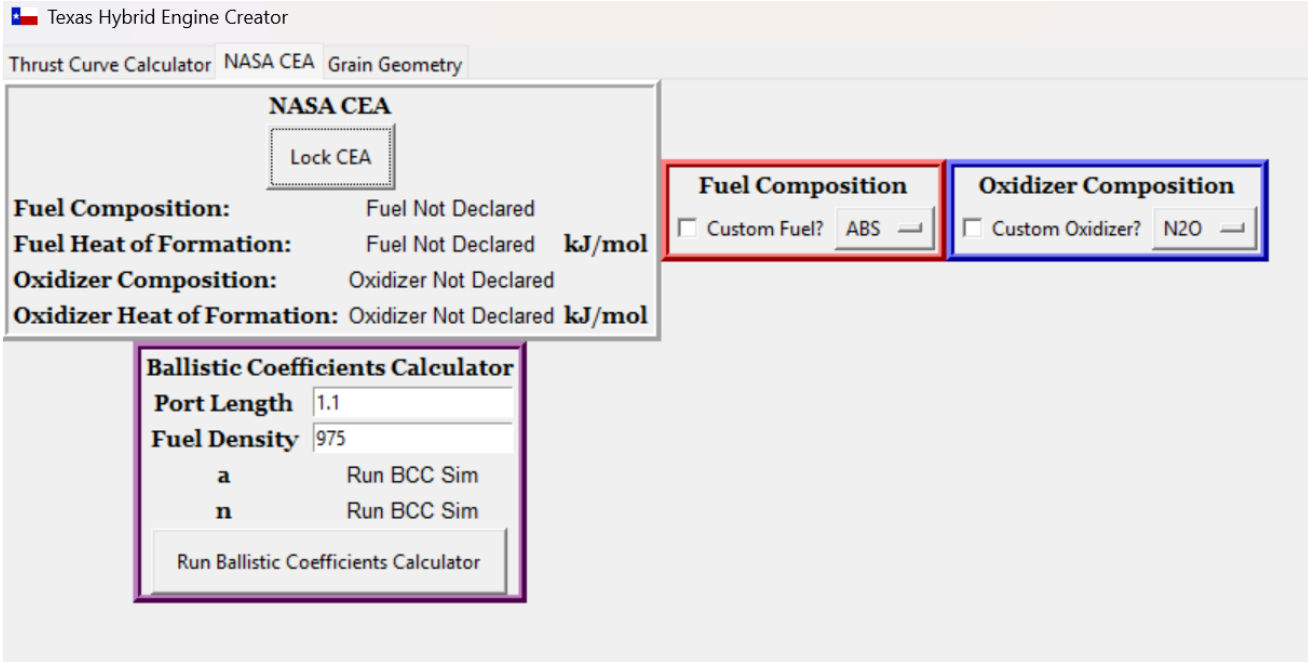
entire fuel grain. Once you have an OBJ file, you can import it into TXHEC. NOTE: You still must define the Port OD in the software before importing your OBJ. The only thing importing an OBJ does is capture a cross-section of your fuel grain.

Once your grain is loaded, select “Run Grain Sim” to run the grain sim. This process might take a few seconds.



After running a grain sim, you can now view information in the window that pops up. You can use the slider to visualize how the grain is projected to burn.

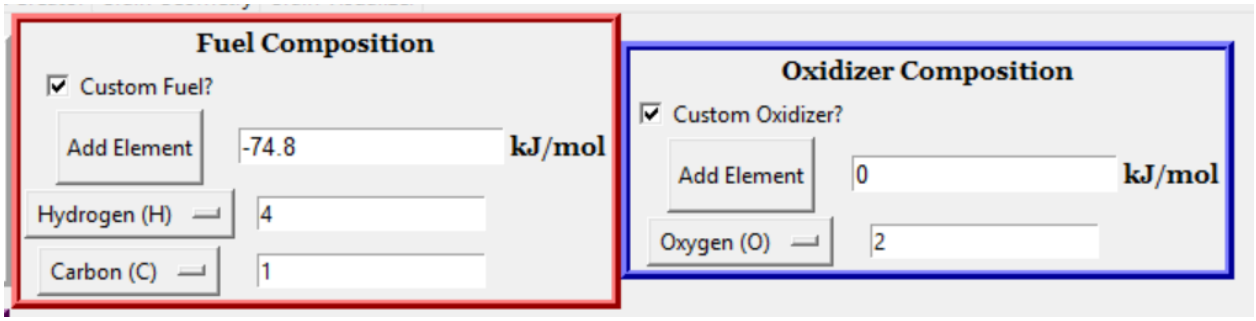
Integrated NASA CEA



This tab handles the CEA data by running NASA CEA. The NASA CEA tab also handles fuel-specific properties. TXHEC allows any fuel and oxidizer to be used in the CEA tab, but keep in mind that the actual thrust curve software is hard-coded for nitrous oxide. There are presets for common fuels and oxidizers to select from in the composition boxes.

While the Ballistic Coefficients Calculator is contained in the NASA CEA tab, it is not a required part of running a simulation.

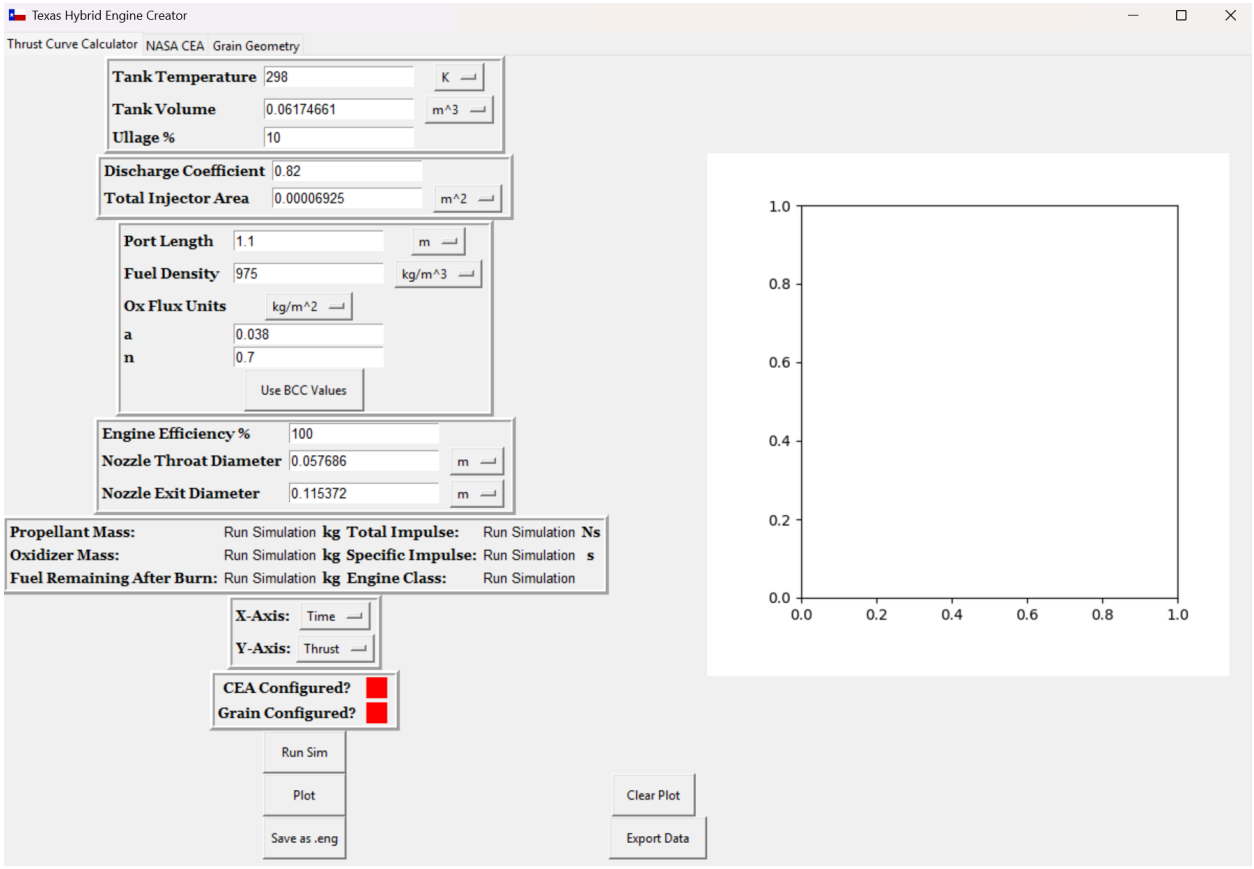
Alternatively, you can input a custom composition into the program for CEA to run.



After selecting the checkbox, you can input the Heat of Formation and the mole ratios of the reactants.

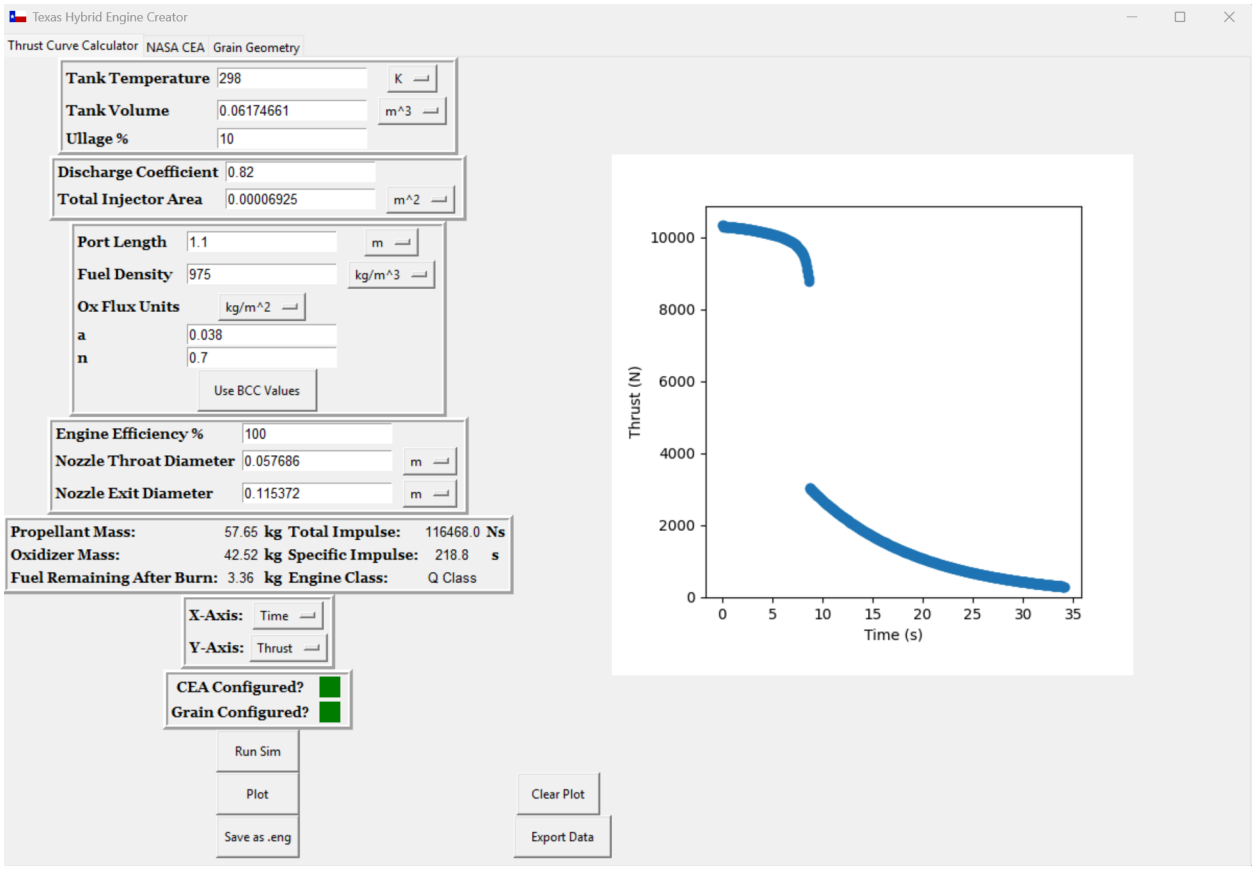
Selecting “Lock CEA” will set your fuel and oxidizer that will be used in the thrust curve simulation. Note: Even though you can set any oxidizer that you want, the model is only accurate for Nitrous Oxide.

Thrust Curve Calculator

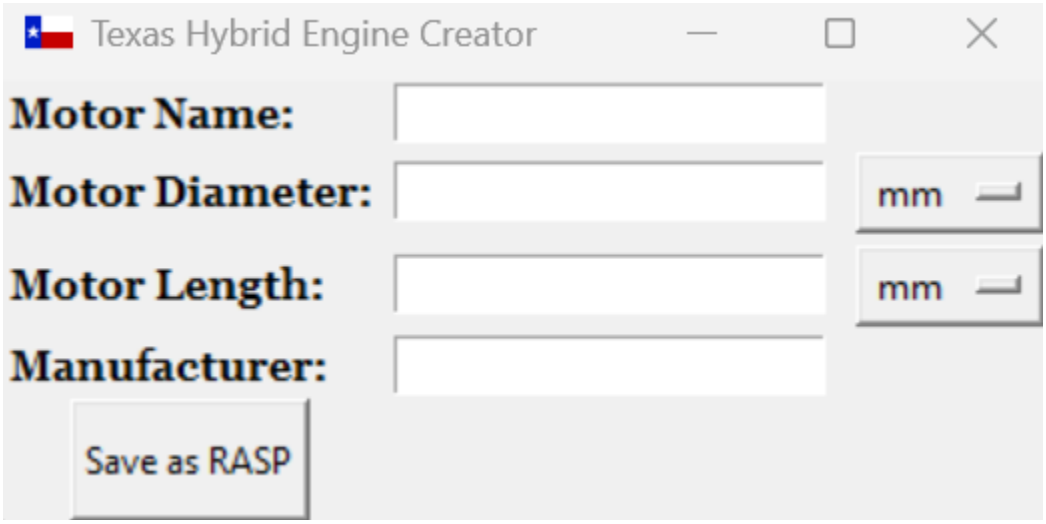


This is the main tab of the software.

Put the rest of the inputs required for a simulation here. Once everything is configured, select “Run Sim”.



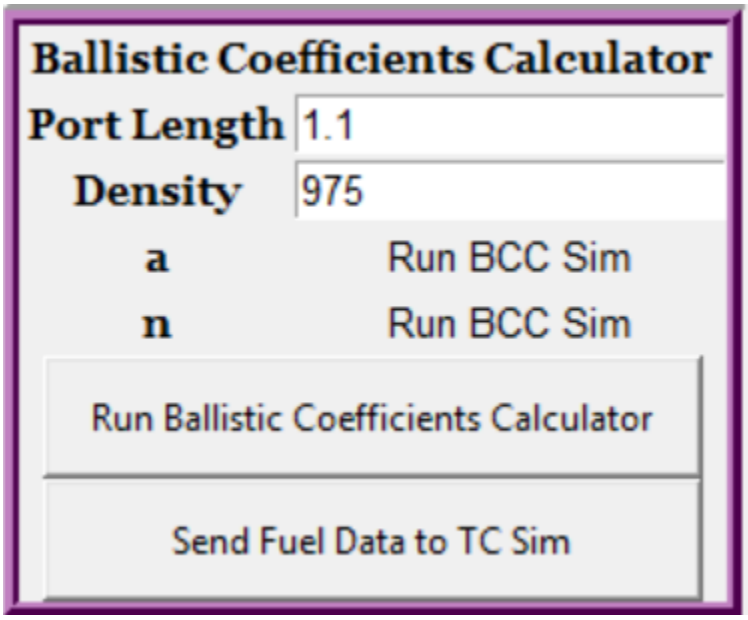
After running the sim, select “Plot” to plot the thrust curve. You can configure what is being plotted on each axis. “Export Data” exports the simulation as a CSV file.



Select “Save” to save the thrust curve as an ENG file. You can then use this file in another program such as OpenRocket.

Auxiliary Programs

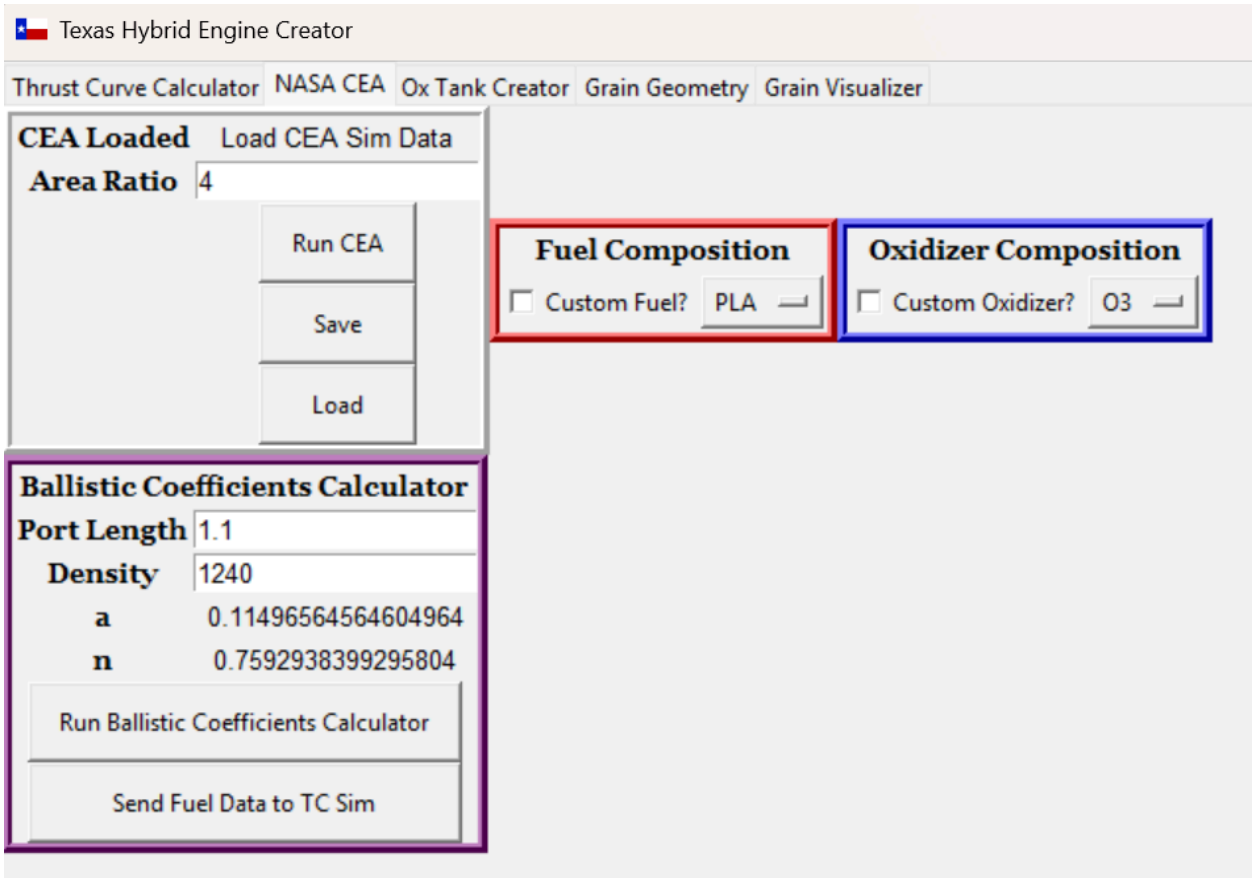
Ballistic Coefficients Calculator



One of the most frustrating things about hybrid rockets is that you must have empirical data to get ballistic coefficients. TXHEC offers a limited model to predict the ballistic coefficients of some fuels. Any oxidizer can be used. The fuel must be a non-liquifying polymer with no additives to increase regression. Examples of suitable fuels for this include ABS and

HTPB. Fuels that would not work include Paraffin and fuels with aluminum. The main purpose of the BCC is to explore unique propellant combinations that would otherwise not be tested.

Port Length and Density are in SI units (meters and kg/m^3). You must run a grain simulation before running the BCC. This is because the ballistic coefficients are affected by grain geometry.



You do not need to run NASA CEA for the BCC to work. However, the BCC uses the same inputs as NASA CEA. Utilizing this auxiliary program, we can find the Ballistic Coefficients for a novel propellant mix: PLA and Ozone.

Methodology

Methodology of Grain Simulation

The main purpose of the grain simulation is to provide a cross-sectional area to calculate ox flux and the perimeter of the cross-section for fuel mass calculations.

To characterize the port geometry of the fuel grain, a binary image of the grain cross-section is used as the primary input. This image is thresholded to create a binary mask, where pixels corresponding to the hollow port region are identified distinctly from those representing solid fuel.

Following this, the cropped and filled binary image is placed at the center of a square computational grid whose physical dimensions correspond to the grain's outer diameter. The resolution of the grid is determined by a dynamic pixel-to-meter scaling factor, allowing all further computations to be directly related to real-world units.

To simulate the fuel regression process, a distance field is computed over the domain using the Euclidean distance transform. This field assigns to each pixel in the solid fuel region the shortest distance to the nearest port

boundary. Conceptually, this field represents how far each point within the fuel is from being consumed, assuming uniform regression in the normal direction from the port surface. Distances in the distance field that exceed the physical radius of the grain are clamped. This ensures that the modeled regression cannot extend beyond the grain's outer diameter and that no part of the distance field lies outside the physical domain. Simply, the grain cannot burn outside of its outer diameter. The resulting distance field provides a continuous, scalar representation of how the grain would evolve under progressive radial regression.

The regression process is modeled by sweeping a threshold across the distance field. At each increment, a binary mask is created to represent the region of the port that would exist after a certain amount of radial regression. This simulates a fuel burnback profile where material is removed from the interior outward, in uniform steps. For each thresholded region, the corresponding port geometry is analyzed. The perimeter of the regressed shape is calculated using morphological edge-detection techniques, identifying pixels that lie on the boundary of the evolving port. Additionally, the area of the port is estimated by counting the number of pixels within the thresholded region and converting this to square meters using the known pixel resolution.

Methodology of Ballistic Coefficients Calculator

Developed using *Hybrid Rocket Fuel Regression Rate Data and Modeling* by Zilliac and Karabeyoglu.

This is one of the more experimental things in TXHEC. I will skip the derivation and just explain how the program works.

$$\hat{\dot{r}} = a\hat{\overline{G}}_{ox}^{\,n}\hat{x}^{m}$$

In hybrid rockets, the above equation is used to find the regression rate using Oxidizer flux. Oxidizer flux is simple to get; you need the ox flow rate and the port cross-sectional area. The exponent *m* is often assumed to be zero to simplify this equation. In reality, it is not zero, but for thrust modeling purposes, it's fine to assume that it is. That leaves us with two constants to find: *a* and *n*.

For clarification, the subscript *c* means chamber and *s* means surface. You may ask, what is the difference? Chamber refers to

combustion/combusted materials, usually located in the center of the chamber. Surface refers to the burning surface of the fuel, which is extremely fuel-rich.

$$\Delta h = h_c - h_s = c_{p_c}\left(T_c - T_o\right) - c_{p_s}\left(T_s - T_o\right)$$

This first equation is the difference in enthalpy between the chamber and the surface of the fuel. The subscript *o* means ambient. The information that we will need for this equation is: the specific heat capacity of both surface and chamber, the temperature of both surface and chamber, and the ambient temperature.

Now, the chamber is easy; you just run NASA CEA at stoichiometric to collect data. The paper relies on empirical data for the surface. However, that would limit the fuels that we could use, so I found a workaround. By running CEA extremely fuel-rich (example: .001 O/F), we can simulate the surface conditions of an arbitrary fuel.

$$\phi_c = \frac{1.22(O/F)\dfrac{\Delta h}{h_g}}{K_{ox_e} + (O/F + K_{ox_e})\dfrac{\Delta h}{h_g}}$$

K_{oxe} = 1 for this equation. For O/F, use the stoichiometric ratio of your reactants. h_g represents the heat of gasification. This value is different for each fuel, but I chose an average value of 2314 J/g, which was found from averaging several polymers.

$$k = -0.005\left(\frac{E_a}{R_u T_s}\right) - 0.08$$

A similar approach was used for E_a, where an average activation energy was used. I chose 200 kJ/mol for this value. The accuracy of this model can be increased if custom values are used for these fields. However, this would require real-world measurement or complex chemical analysis out of the scope of this program.

$$\mu_e = \left(26.69 \sqrt{\frac{MT_b}{\sigma^2}} \right) \times 10^{-7}$$

This is an equation for the viscosity of the port gas. M is the average molecular weight of the fuel and oxidizer. σ is the hard-sphere diameter in Angstroms (5). $T_b = T_s$ and also $\mu_e = \mu_m$.

$$A = \frac{0.022}{\mu_m{}^k (T_s / T_m)^l} \Pr^{-0.6} \left(\frac{\Delta h}{h_g} \right)^{0.23} \phi_c{}^{0.77}$$

$$\dot{\hat{r}} \approx \frac{A}{\rho_f} \left[1 + 2.5 C_1 \left(\frac{\hat{G}_{ox} \hat{D}}{\mu_m} \right)^{-0.22} \frac{\hat{D}}{L} + 4A(k+1) \left(\hat{G}_{ox} \hat{D} \right)^k \frac{L}{\hat{D}} \right] \hat{G}_{ox}{}^{k+1} \hat{D}^k$$

Now, it is just a matter of plugging in the formulas. The remaining constants are: Pr = 1, l = .29, C_1 = 2. Now, for developing the a and n values, it is simple. For a, use the regression rate equation with ox flux set to 1. For n, $n = k + 1$. You may note that the flux exponent is only dependent on the reactant choice, not the grain geometry.