DESIGN AND ANALYSIS OF A STIRLING ENGINE FUELED BY NEGLECTED HEAT

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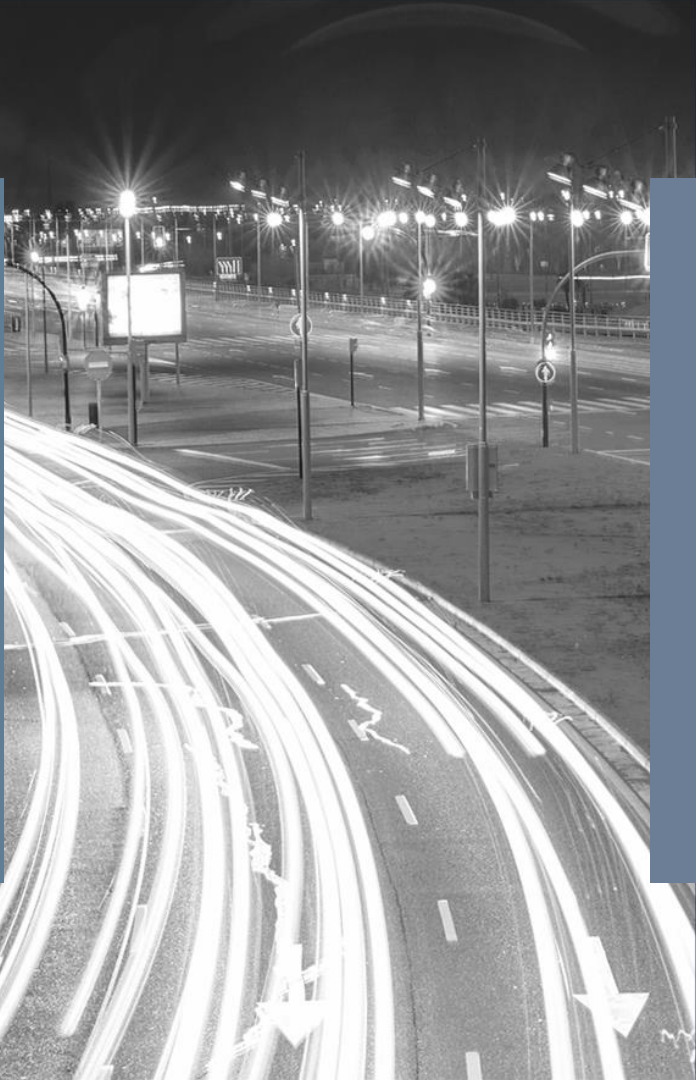


Duke UNIVERSITY | BASS CONNECTIONS

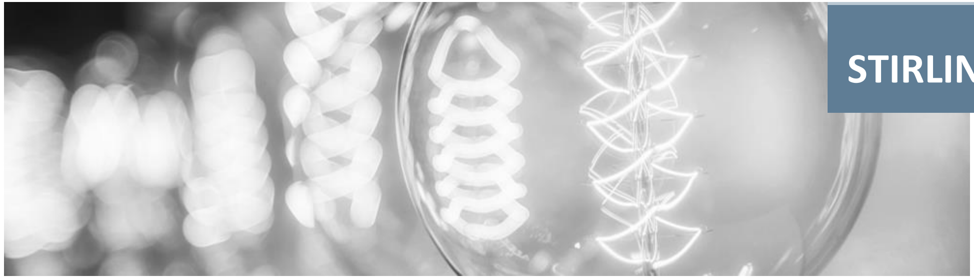
MOTIVATION

ENERGY WASTE

Every process that has energy input produces energy waste

LOW GRADE HEAT

Makes up a significant portion of wasted energy, is difficult to capture and use



STIRLING ENGINE

Provides a possible engineering solution that can generate electricity from low grade waste heat

PROJECT STAGES

01

CONFIGURATION SELECTION

Reviewed existing literature to determine optimal stirling engine configuration

02

COMPUTATIONAL MODEL

Modelled system thermodynamics and kinematics in Matlab to define design parameters

03

CAD MODEL

Designed engine in Solidworks based off of computational parameters

04

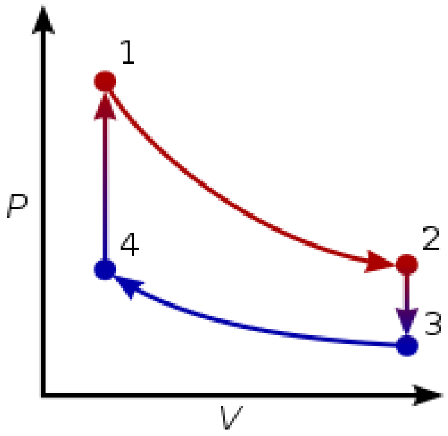
APPLICATIONS

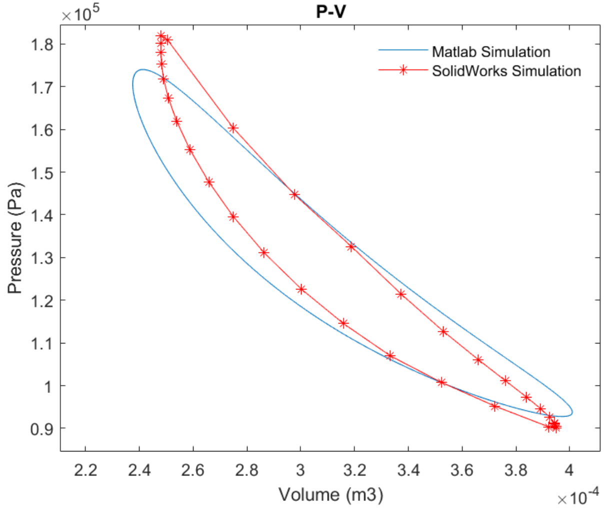
Determine real world applications where the engine could successfully achieve goal of energy reclamation

05

MANUFACTURE AND TESTING

Plan to construct and test an engine prototype to verify and evaluate functionality

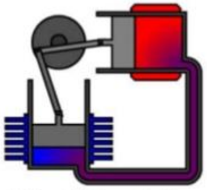




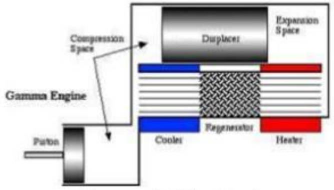
THERMODYNAMIC MODEL

Stirling Cycle

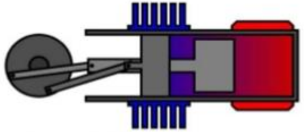
- Thermal Energy→ Mechanical Energy
- Types of Stirling Engines
  - **Free-piston Stirling engine**



Alpha Stirling Engine



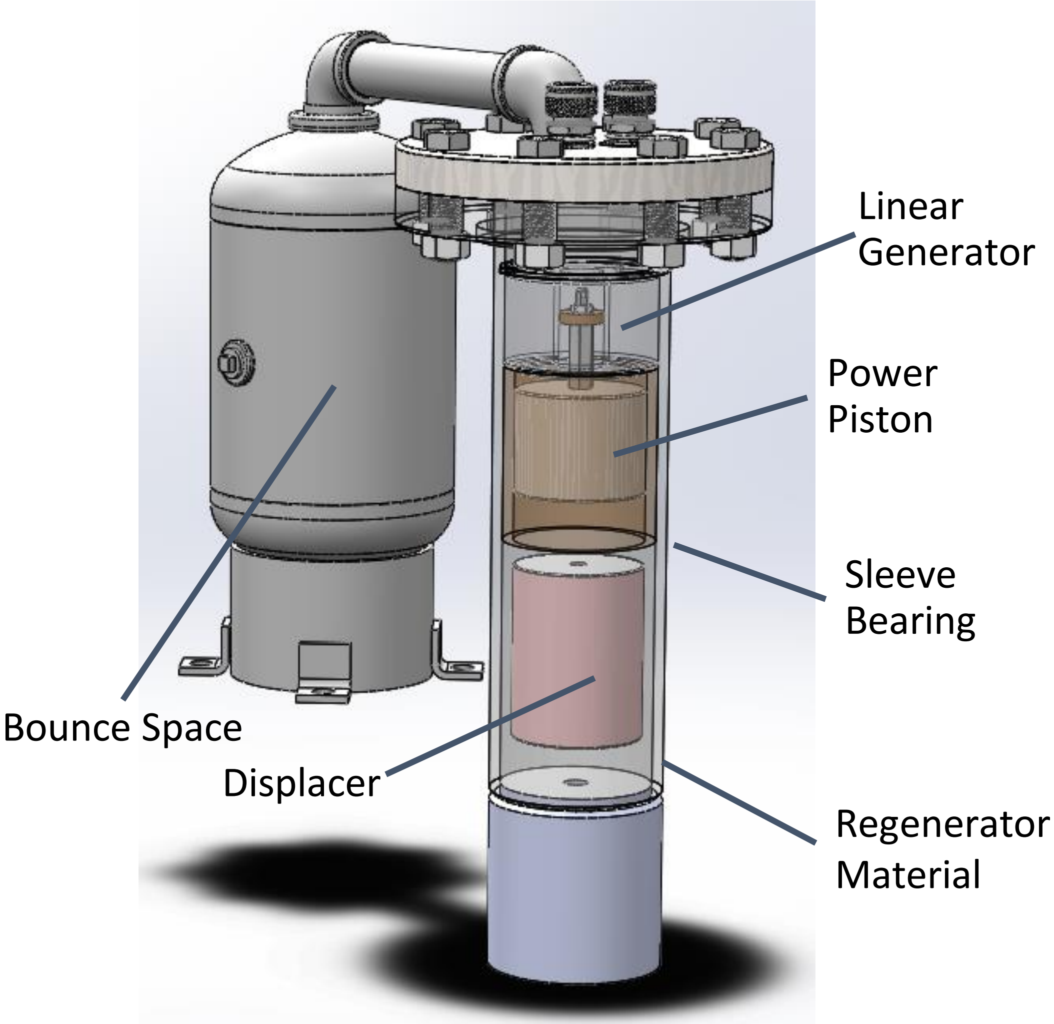
Gamma Stirling Engine



Beta Stirling Engine

Model Results

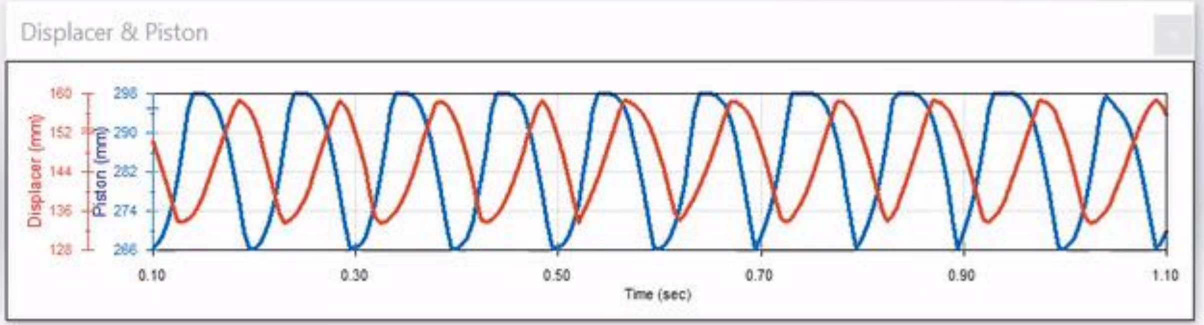
- More conservative estimate: **23 W** from a 200K temperature difference

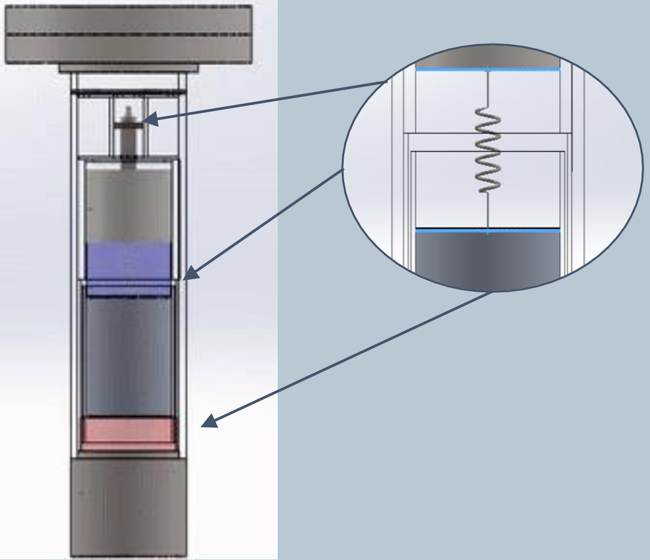


CAD MODEL

Current Unit Total Price for Duke ME Lab:
$971.05

Anticipated External Machining Costs (Weldment and Precision Machining):
$100-$200



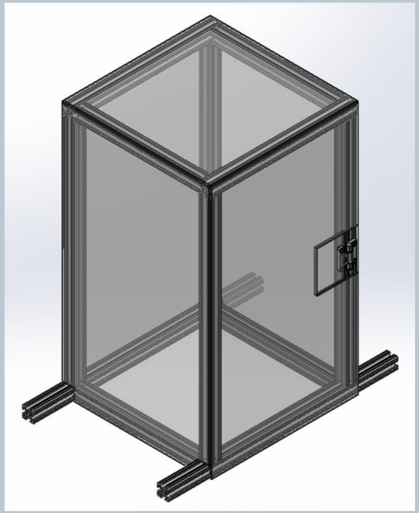


DYNAMIC MODEL

Parameter	*MATLAB Model*	*SolidWorks Model*
Piston Amplitude	1.62 cm	1.61 cm
Displacer Amplitude	1.25 cm	1.22 cm
Phase Shift	85°	108°

TESTING

ENCLOSURE



EXPERIMENTATION

Air: at 1.01 bar, 2 bar

Helium: at 1.01 bar, 2 bar

MEASUREMENT

Output: generator wired to load resistor, DAQ

Heating: thermocouple control loop

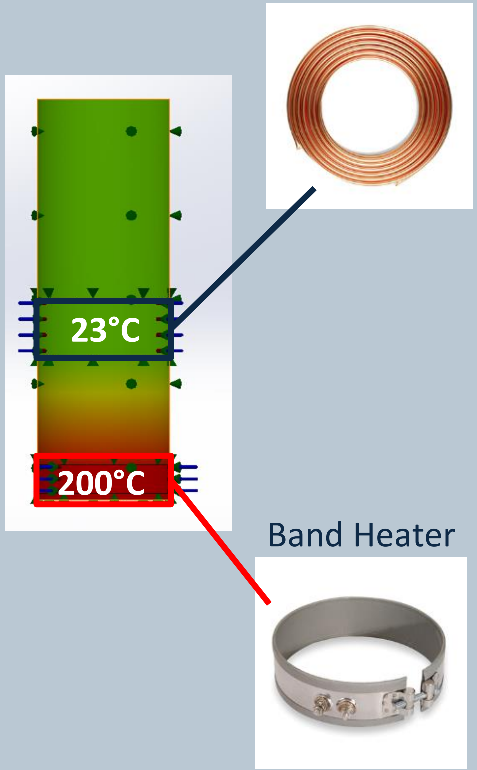
SAFETY

Enclosure: ⅛" acrylic shield

Protection: eyewear, safe areas

Budget:

TEMPERATURE



PROCESS FAILURE MODES AND EFFECTS ANALYSIS (PFMEA)

Process Step/Input	Potential Failure Mode	Potential Failure Effects	SEVERITY (1 - 10)	Potential Causes	OCCURRENCE (1 - 10)	Current Controls	DETECTION (1 - 10)	RPN	Action Recommended
What is the process step, change or feature under investigation?	In what ways could the step, change or feature go wrong?	What is the impact on the customer if this failure is not prevented or corrected?		What causes the step, change or feature to go wrong? (how could it occur?)		What controls exist that either prevent or detect the failure?			What are the recommended actions for reducing the occurrence of the cause or improving detection?
Regenerator Housing	Manufacture produces unexpected ID/OD	Inability to assemble; Piston Jamming	8	Warping during 3D printing process	5	Account for documented warping effects in model	2	80	3D print the housing first, measure real dimensions to bore cylinder/machine displacer

SCALING UP: 1 kW ENGINE

Size:

- Beale equation
- Piston swept volume increase
- Diameter & height increase

Cost:

- Larger parts (+)
- Bulk purchasing (-)
- Production costs (+)
- Process automation (-)

PRODUCTION COST/UNIT: $2500
SELLING PRICE: $3000

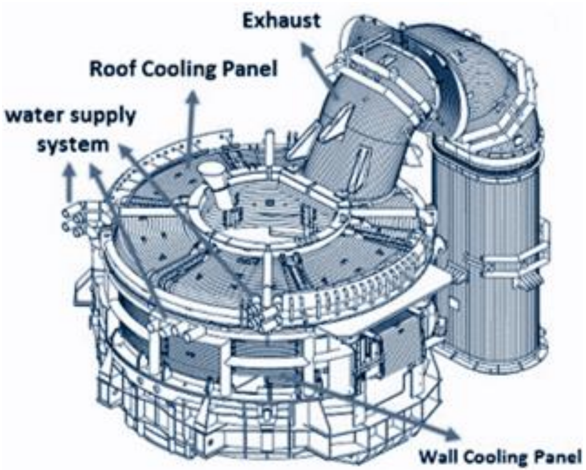
APPLICATIONS DECISION MATRIX

	INDUSTRIAL WASTE HEAT	LAUNDRO-MATS	DATA CENTERS	SOLAR PV	PAVEMENT	ROOFS AND ATTICS	KITCHENS
HEAT DIFFERENCE	**5**	**2**	1	1	1	1	2
EASE OF IMPLEMENTATION	**3**	**4**	4	3	1	1	3
DISTRIBUTION OF HEAT	**4**	**3**	4	4	2	2	3
UTILITY OF OUTPUT	**2**	**4**	3	4	3	4	3
CONSISTENCY OF HEAT	**5**	**4**	4	3	3	3	3
TOTAL	**19**	**17**	**16**	**15**	10	11	14

APPLICATION 1: INDUSTRIAL WASTE HEAT

Steel

1000 F	2,500 F	2000 F
Blast furnace	EAF	Rolling



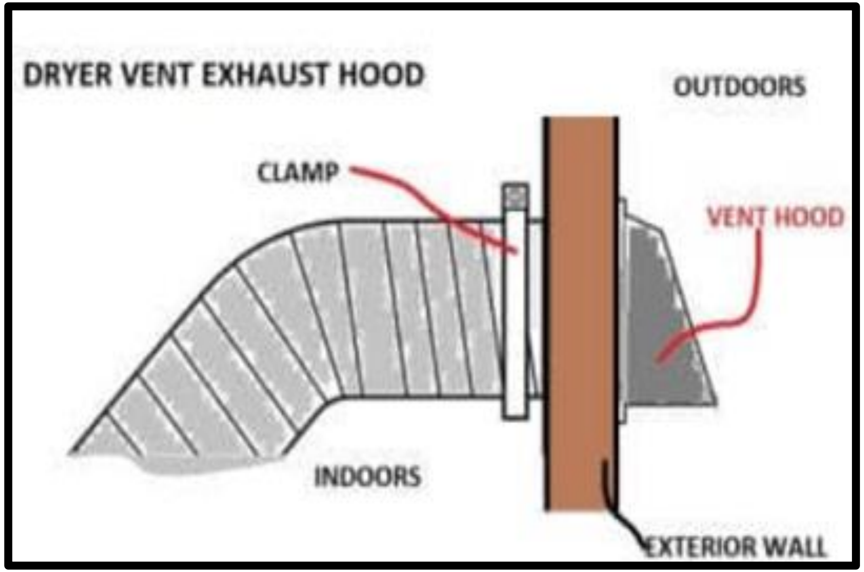
Pros:

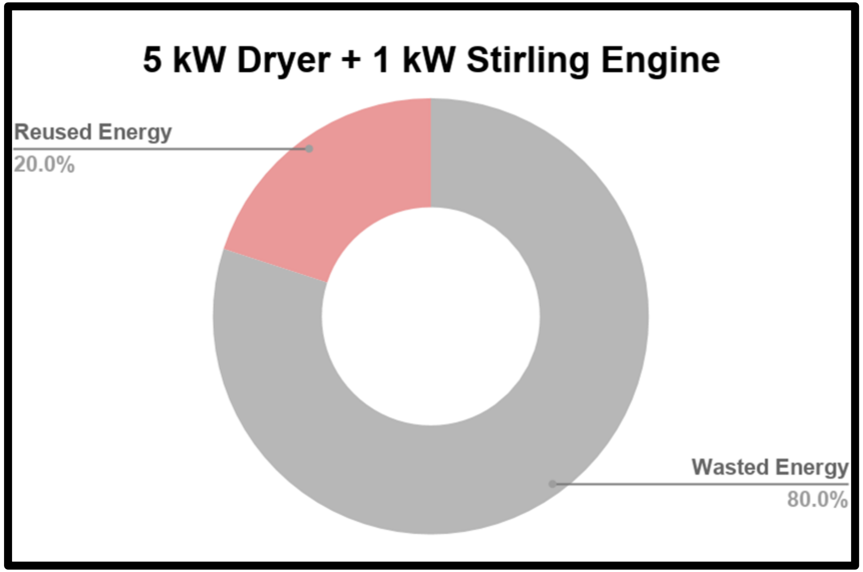
- High Waste Heat Temperatures
- Variety of Applications
- Ease of implementation

Cons:

- Difficulty in using energy produced
- Corrosivity danger of exhaust gases/water

APPLICATION 2: LAUNDROMATS

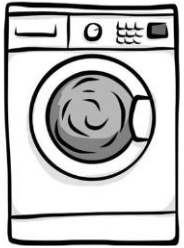




Durham Temp: 10-30^{o}C →Temp Difference: 60-80^{o}C

BUSINESS PLAN: $3000 ENGINE

Laundromats



- **Saves $500 in energy per dryer per year**
- Dryer life: 15 years
- Total savings per dryer life: $7500

Steel

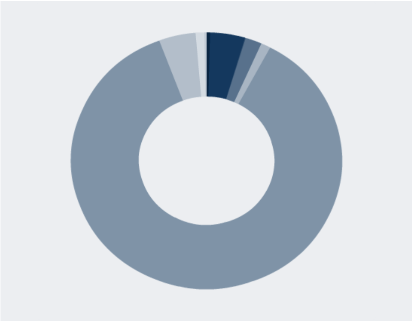
- **Saves $6.81 per year per factory (assume 4 EAF)**
- REC
- Utility credits

ENVIRONMENTAL AND SOCIAL IMPACTS

CO2 Emissions

Emission-free substitute for electricity generation

3.2 tons of CO_2 equivalent avoided per year - Laundromats



Environmental Impacts

CO_2 Reductions versus Manufacture - Net Benefit from reduced electricity consumption

Payback period of less than three months

Potential ecotoxicity from manufacture

Social Impacts

Wellbeing: Cleaner air from reduced emissions

Human impact categories: carcinogenic byproducts

Longer social impact payback

Utilities benefit

CONCLUSION

- Capture of waste heat will be essential to solving society’s energy and decarbonization problems.
- This conceptual free piston Stirling engine is intended to demonstrate one possible solution to the issue of heat waste.
- Success of this engine concept hinges on testing results, requiring the construction of a physical prototype.
- Prototype testing will further inform estimations on scalability and real world applications.

ACKNOWLEDGEMENTS

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QUESTIONS?

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