Score Stove[1]

Generating electricity in developing countries using thermo-acoustics powered by burning wood

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Background

In Poor Rural areas

- >2 Billion are without electricity and cook on an open fire [2]
- Smoke is a real hazard

Score

- Stove cooks, generates electricity and cooling
- €3M project
    - » 3 years research
    - » 2 years exploitation
- Large volume manufacture after 2012
- Extended partnerships

Technical Challenges

Cost

- Low cost is the main driver
- Target = €30 per household delivered to capital city of country
- 2 billion units at €30
- 60 million units at €90

Weight

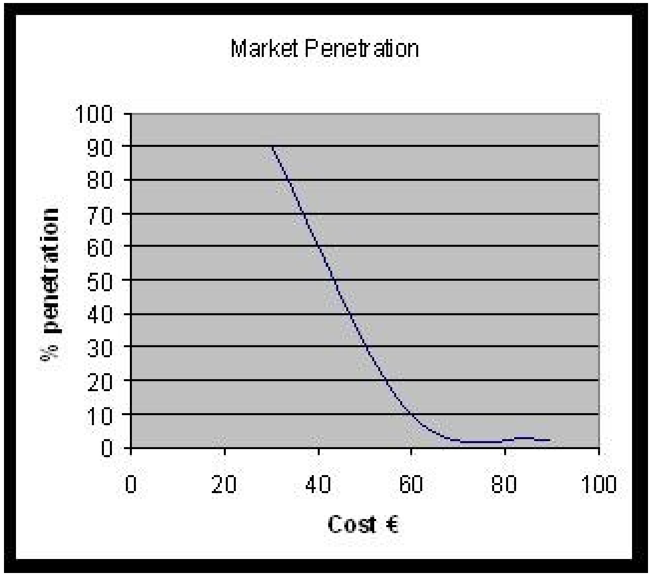
- In many areas hand carrying is the only option
- Target = 10 – 20 kg

Power output

- Electrical = $100W_e$ (from battery)
- Cooking = $1.6kW_{th}$ full power 0.75 kW for simmering

Fuel

- Consumption < 0.3 g/s (<2 logs per hour)
- Material initially wood. Looking at Dung and other bio-mass, LPG.



Options

Internal combustion engine with bio-gasifier

- Expensive, high maintenance requirement

Thermo-piles with wood burning stove

- Expensive, low efficiency, lack of robustness

Bio-Fuel fed Stirling engine

- Expensive, maintenance may be an issue

Thermo-acoustic engine

- Travelling wave
  - » Currently expensive, but options for cost reduction
  - » Units have been developed in power range
  - » Reasonable efficiency
- Standing wave
  - » Potentially the lowest cost
  - » Predicted efficiencies just acceptable.
  - » Lack of experimental data at the output power required.

NB: Only low/ zero CO_2 options are shown

Standing Wave TAE

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Fractional wavelength design

- Frequency determined by alternator, not duct length.
- Complex acoustic - LA matching

Combustor

- Initially wood burning
- High efficiency
- Low emissions
- Waste heat used for cooking

Hot Heat Exchanger (HHX) (1)

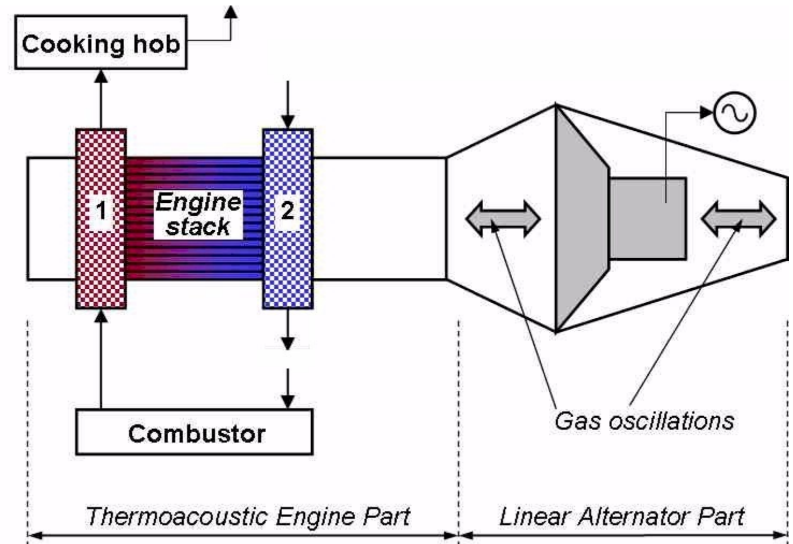
- 500°C gas temperature

Stack

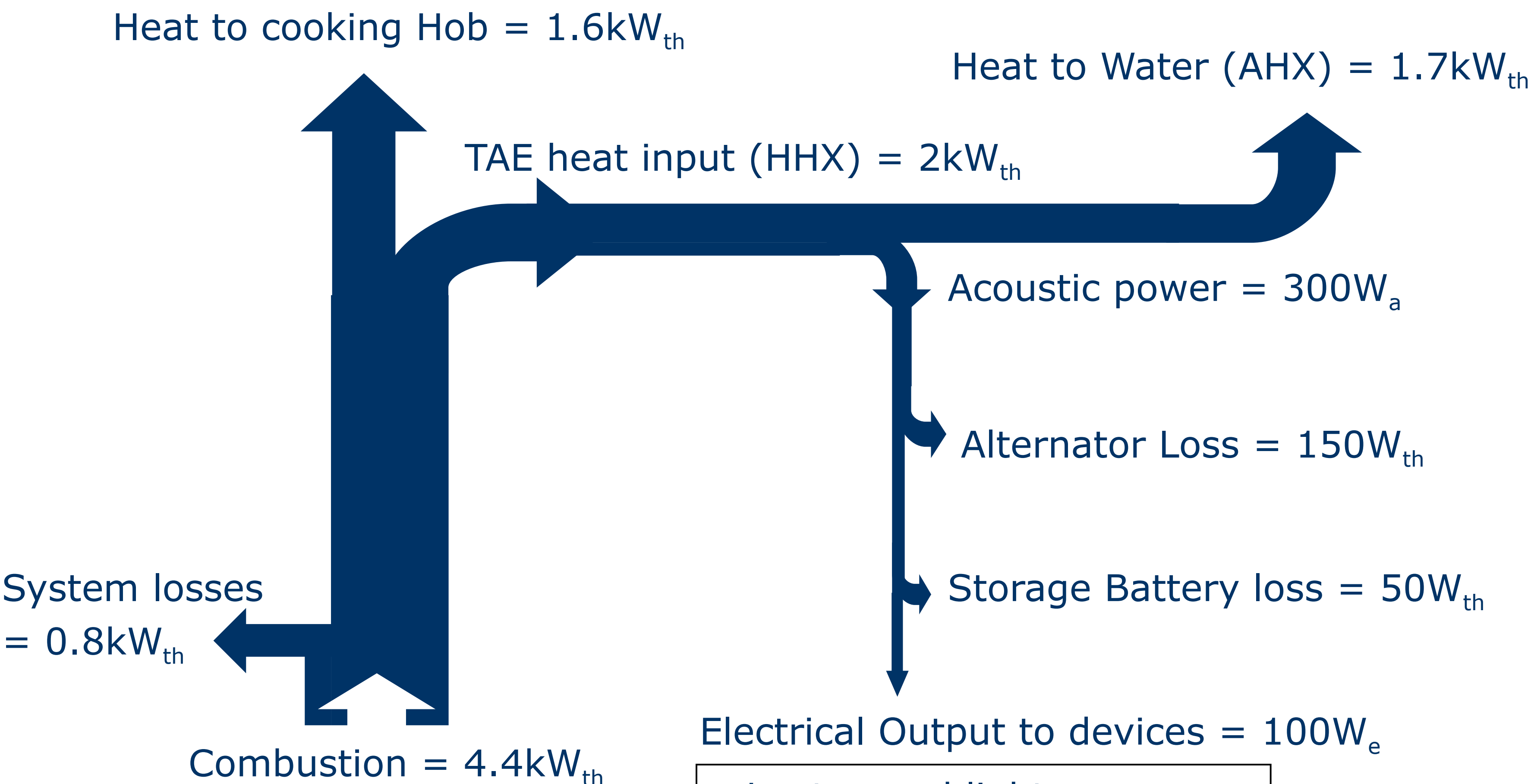
- Heats and cools gas packets
- Provides time lag at required frequency, eliminates displacer.

Ambient Heat Exchanger (AHX) (2)

- 80°C gas temperature
- Ambient heat exchanger Water cooled, also used for cooking.



Power flow (pre-optimisation)



- Laptop and light or
- TV, Radio and lights
- Charge mobile phones

Optimisation of the design

A non-trivial, multi- variable problem

Optimisation: Cost

Paradox

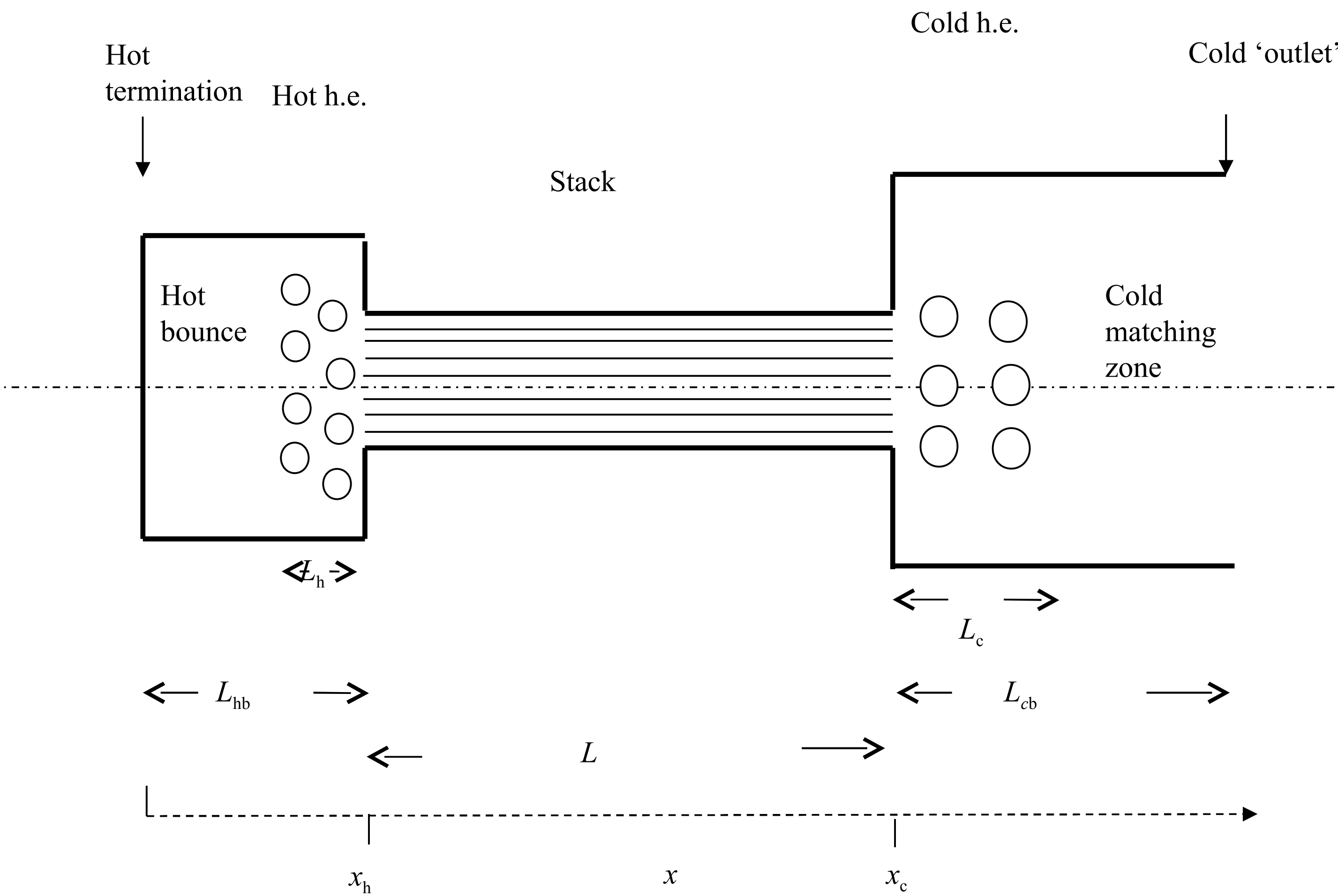
- Smoke free stove Nepalese manufacture ~ £25
  - Low labour costs
  - Excludes profit and transport
- Gas stove (LPG) in UK
  - £14.99 includes:
  - Local tax and transport
  - Profit (manufacturer and retailer)

Low material content is key

- Thin sections
- Strengthened by geometric shape

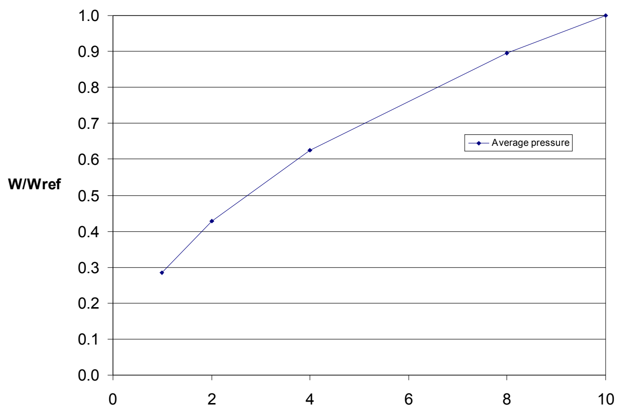
Leads to low weight design

Optimising the TA Geometry
(Standing wave model)



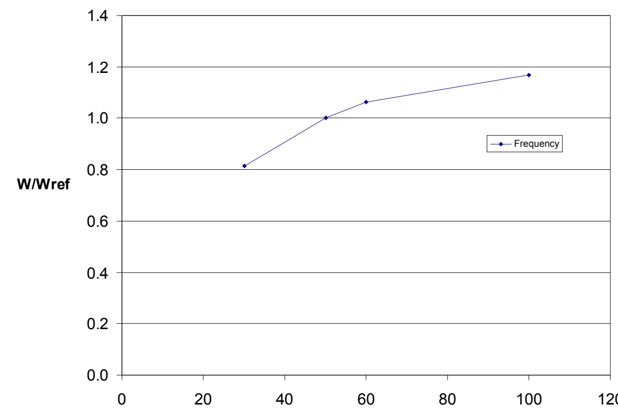
Sensitivities in the TA model

(for single set of base conditions)

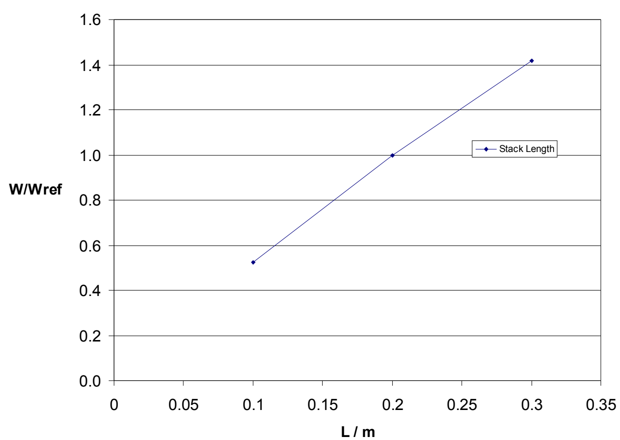


Pressure

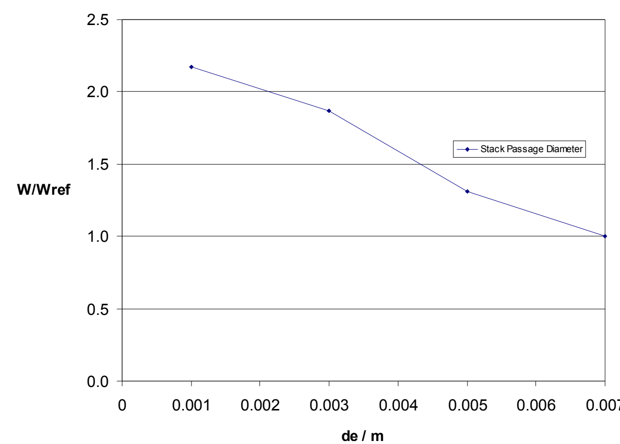
(at fixed drive ratio)



Frequency



Stack Length

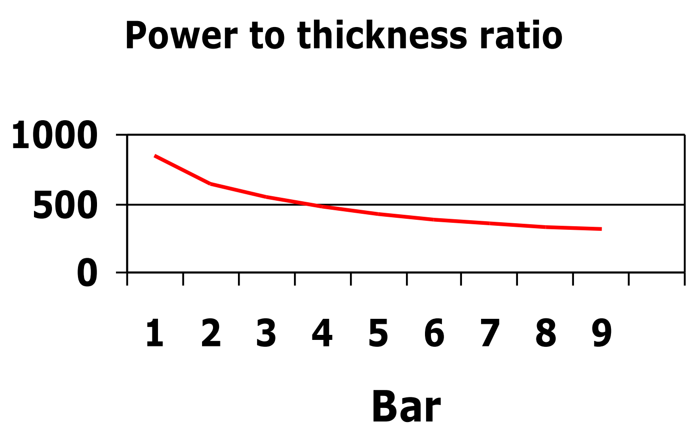


Stack Passage dia.

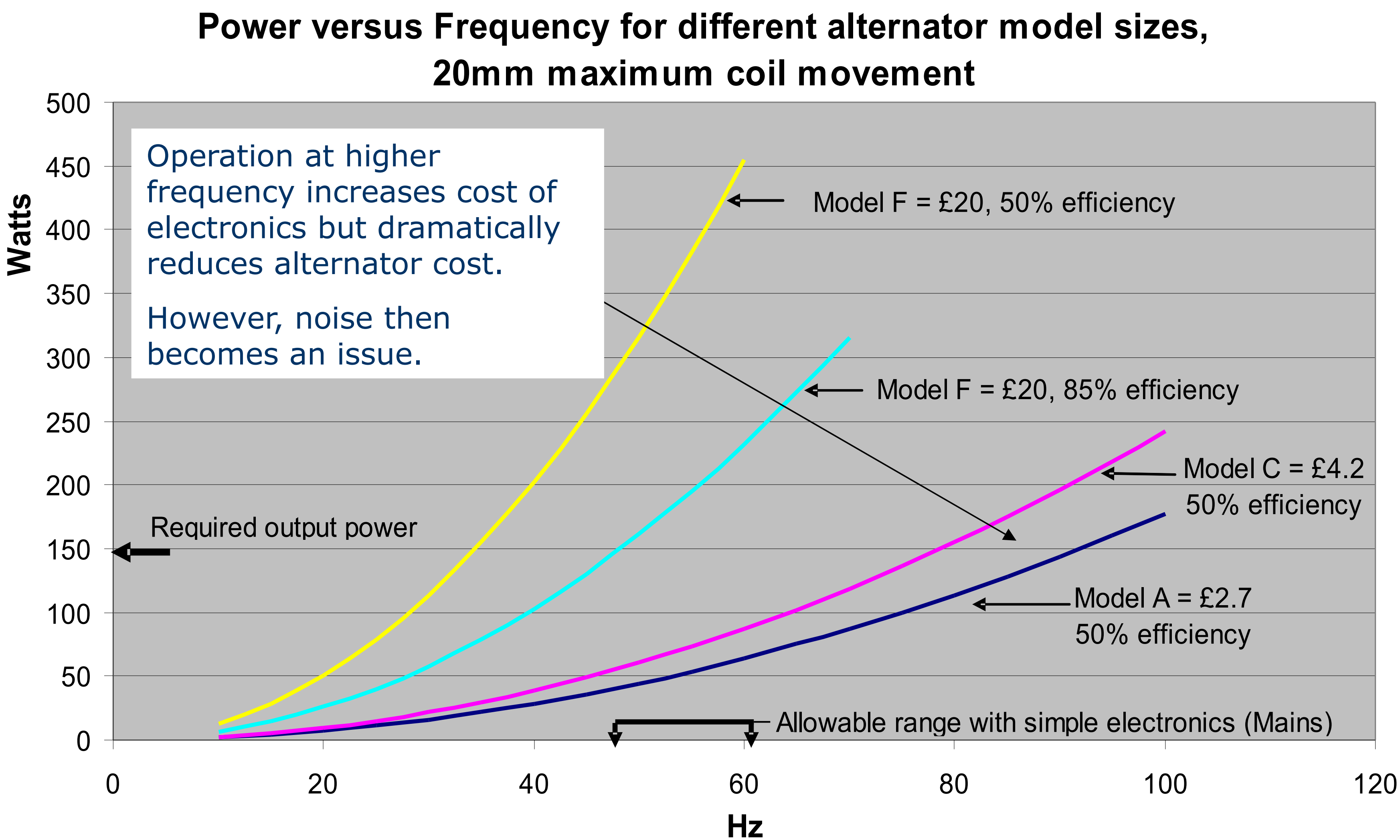
Optimisation: Cost Issues

Optimisation examples

- Increased frequency
  - » Alternator efficiency ↑
  - » Thermo-acoustic efficiency ↓
- Increased pressure
  - » Mass of containment ↑
  - » Power output per volume ↑
- TAE topology
  - » Standing wave less complex, (Hence lighter for given efficiency)
  - » Travelling wave more efficient (Hence less weight per Watt)
- Working gas
  - » Air is cheapest
  - » Helium allows higher frequency (hence lighter alternator and TAE)



Optimisation: Alternator



Operation at higher frequency increases cost of electronics but dramatically reduces alternator cost.

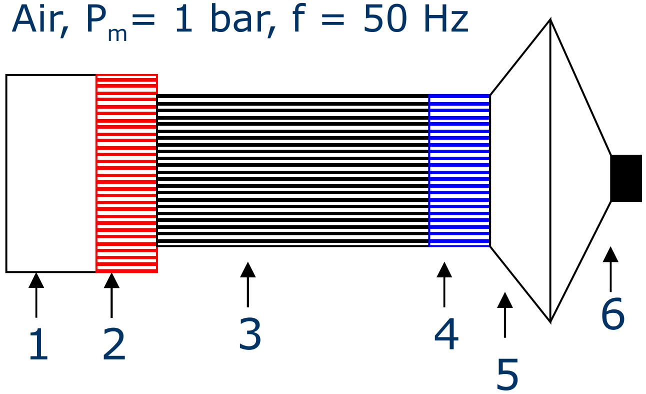
However, noise then becomes an issue.

Demo#0 DeltaEC Simulation

-based on the commercially available parts

Segments in DeltaEC simulation

Air, P_m= 1 bar, f = 50 Hz



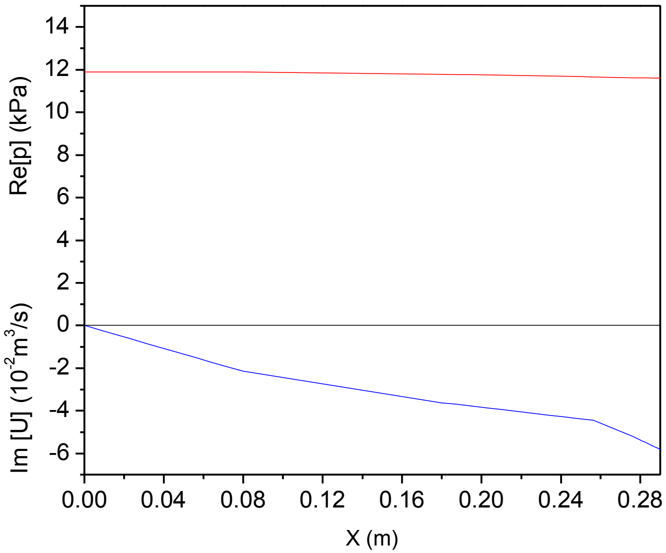
1. Bounce volume : 0.175m x 0.175m square, length=8cm
2. Hot heat exchange: HX, Porosity=0.4, Length=10 cm
3. Stack: Honeycomb, Pore D=3.2 mm, L=8 cm
4. Ambient heat exchange: AHX, Porosity=0.4, Length=2 cm
5. Transition Cone, S1=0.01 m^2 S2=0.0167 m2, L=1.5 cm
6. Loudspeaker

   Diaphragm D: 15 cm; E-Resistance R: 5.5 ohms;

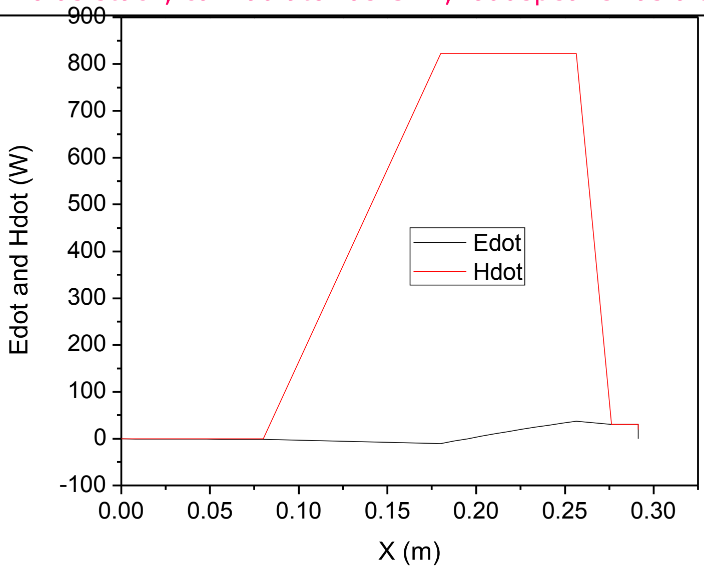
   BL: 23.8 T-m; Force factor K: 3850 N/m

   Mechanical resistance: 3.07N-s/m

This "design" is based on the commercially available parts: metal honeycomb as stack, car radiator as CHX, loudspeaker as alternator.



Distribution of Re[p] and Im[U]



Distribution of Edot and Hdot

Optimisation Issues:

-Cross sectional area & Bounce volume

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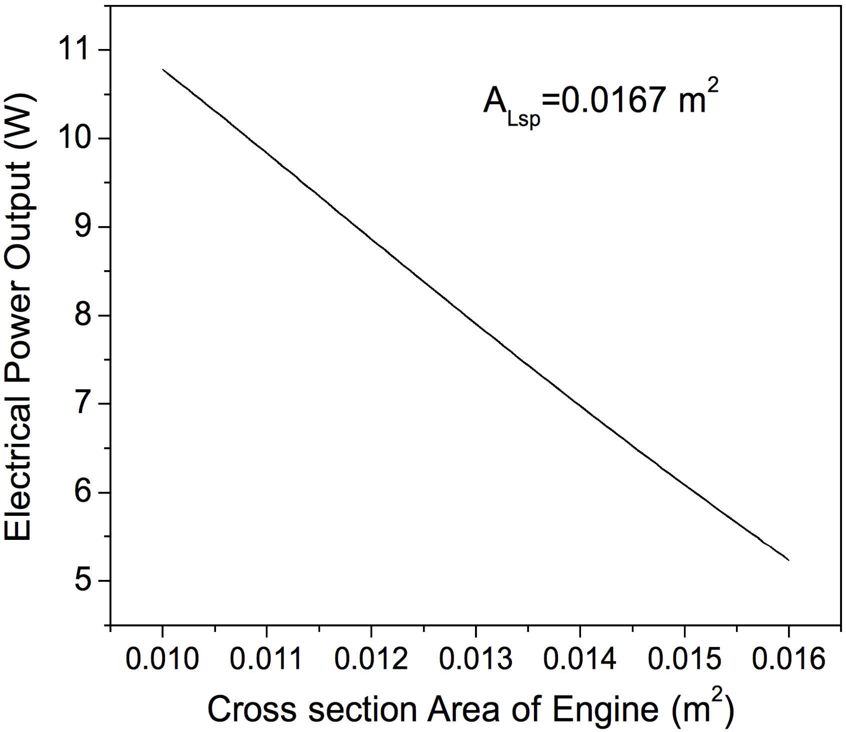
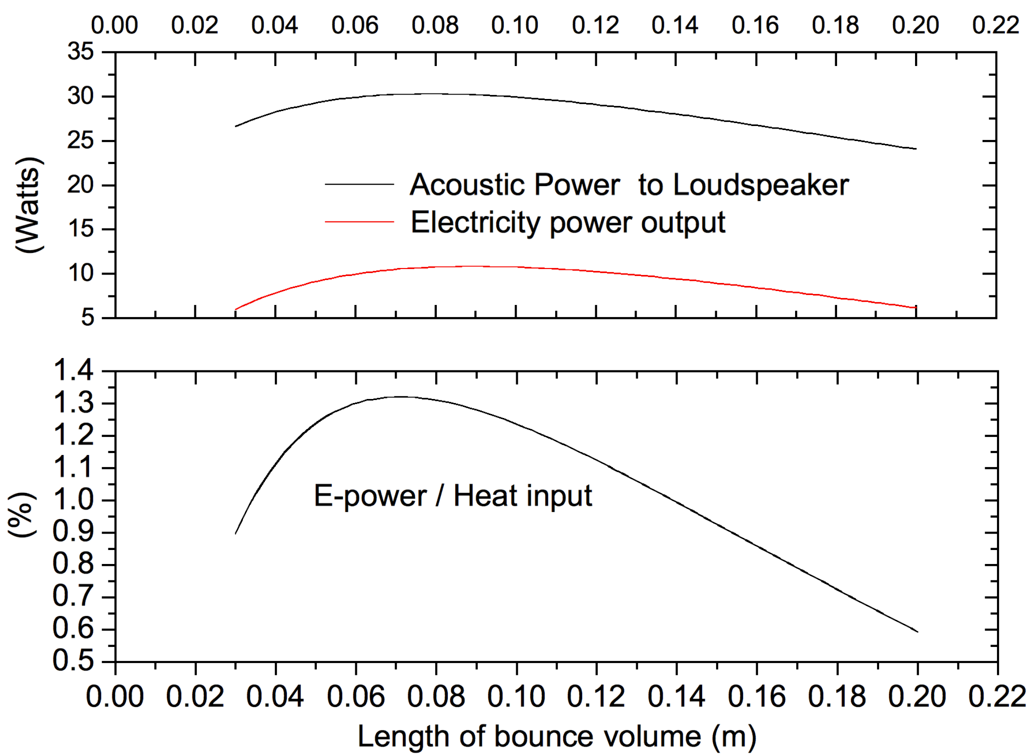


The volumetric velocity |U1| at the diaphragm of LA is decided by its stroke and the area. To transport sufficient acoustic power to the LA, a high pressure amplitude |p1| is required. Therefore, a smaller (but still big enough for HHXs) cross sectional area if required for the engine. As shown in the left figure: 0.01 m2 is chosen for this Demo #0.

In the resonator, the acoustic field is approximately a standing wave. The local acoustic impedance of stack (depends on the location) plays an important role in maximizing the energy conversion in the stack. The local impedance of the stack can be determined by the length of the bounce volume. 8 cm is given by the simulation.



Early Demonstrator#0

Off the shelf parts

Ambient pressure

Powered by Propane

6kW heat in

- Tubular Hot Exchanger

Stack

- 3.2mm hole size
- 100mm square
- 120mm long

Car radiator ambient exchanger

Linear Alternator

- 17cm loudspeaker with additional mass added

Demo#0 results

Speaker electrically driven to characterise T/A duct

Mechanical Q measured

- Thiele Q_{ms} well defined
- Easy to measure
- Separates T/A effect from rig and alternator losses

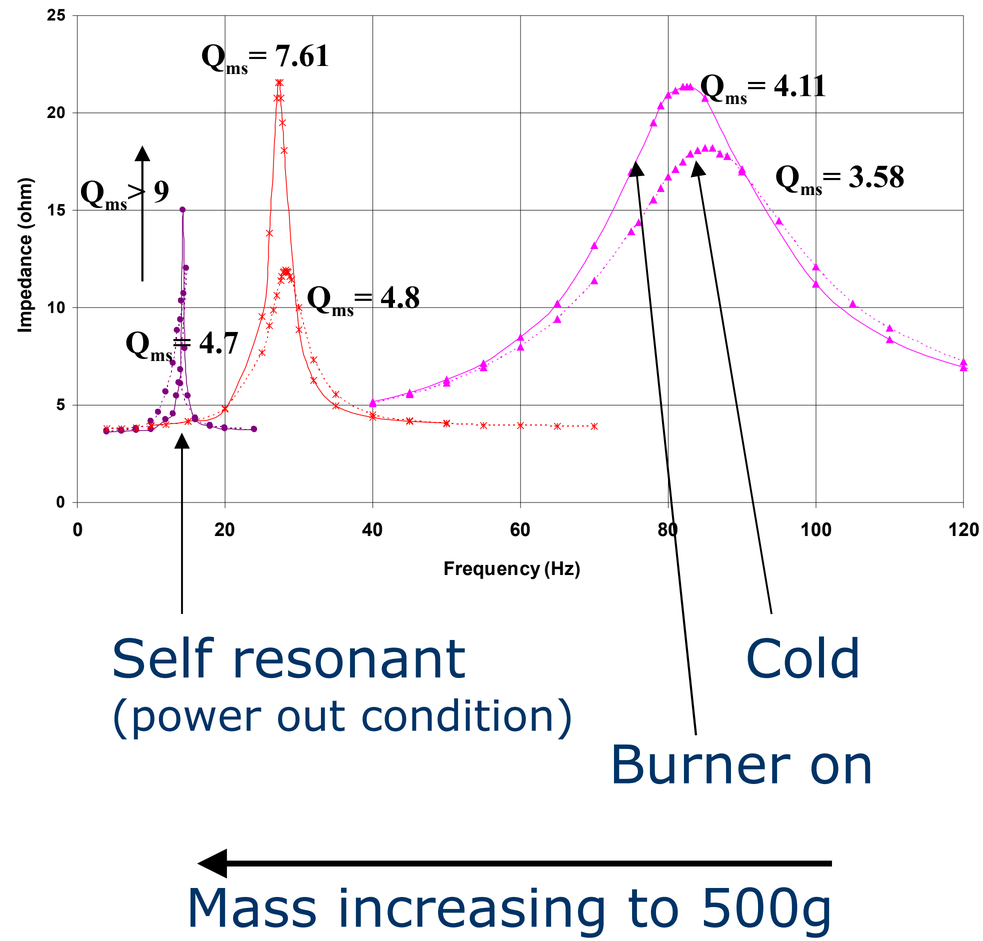
HHX

- Heat transfer mainly through radiation
- Significant loss through stack from radiation
- Large temperature profile

Perceived noise increases above 40Hz, even when back of speaker enclosed.

Mechanical issues

- HHX cracking
- Vibration



Acknowledgements

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References

[1] www.score.uk.com

[2] The World Bank 2005, “Rural energy and development for two billion people: Meeting the challenge for rural energy and development (September)” http://siteresources.worldbank.org/INTENERGY/Resources/Rural_Energy_Development_Paper_Improving_I