Motor Efficiency Measurement

Understanding, accuracy and safety

AMRE Safety Seminar
19 July 2011

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Background

Mining Safety

From a layman's or non-miner's perspective:

- The last 25 years
- 1986 – Kinross 177 miners
- The last 5 years – personal
- Driving versus shaft / cage?

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Background – 25 years ago

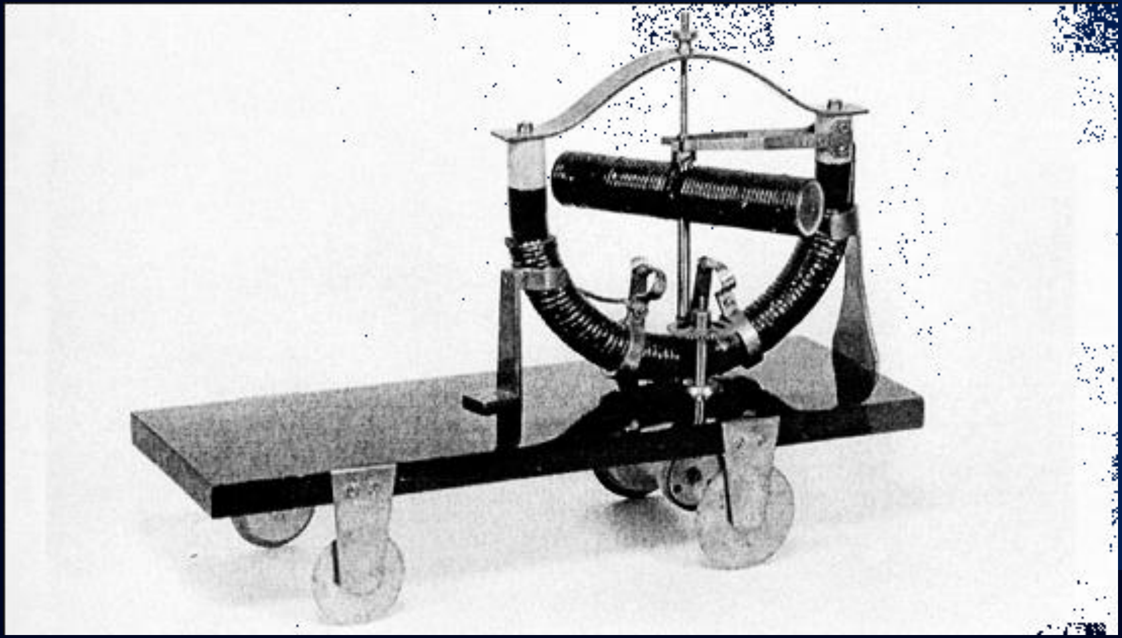
1986 Global

- Nuclear safety
- Chernobyl disaster

Today: Fukushima

Efficiency – The last 200 years

1828: Jedek’s Electric Car



What is more efficient?

1: Steam driven car

What is more efficient?

2: 1970's "Gas Guzzler"

What is more efficient?

3: Modern Electric Concept Car

What is more efficient?

4: South Africa's Electric Car

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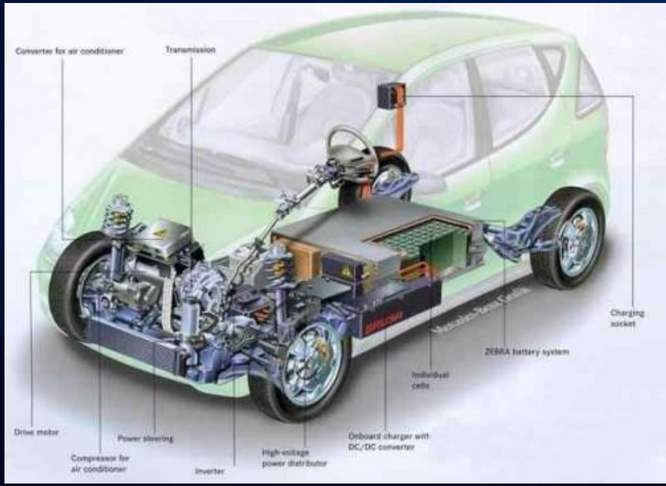
Efficiency – The last 200 years

Easy question:

Which is more efficient in the South African context?

- Steam driven car
- Modern Electric vehicle



Electric Motor Efficiency

Background:

- Basic definition and principles
- Mechanical: Pumps, fans, turbines
- Motors and generators
- Complete drive systems
- Pumped storage schemes
- Combustion engines, boilers etc.
- Understand but without too much maths

$$P_{addit} = (P_{in} - P_{out}) - (P_{Fe} + P_{stator} + P_{rotor} + P_{fr,w}) \quad (1)$$

Maths and Formulas

Words of wisdom:

In mathematics you don't understand things, you just get used to them.
J. von Neumann

I have had my results for a long time, but I do not yet know how I am to arrive at them.
Karl Friedrich Gauss

Definition of Efficiency - 1

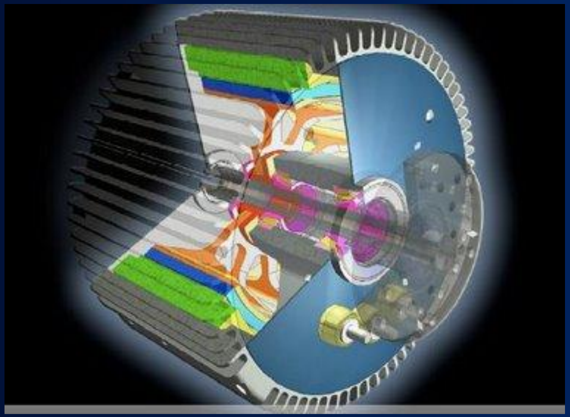
Input, Output and Losses

Efficiency = Output / Input

Output = Input – Losses

Efficiency = (Input – Losses)
Input

(We only need Input and Losses



Definition of Efficiency - 2

Fans and Pumps

Efficiency = Output / Input

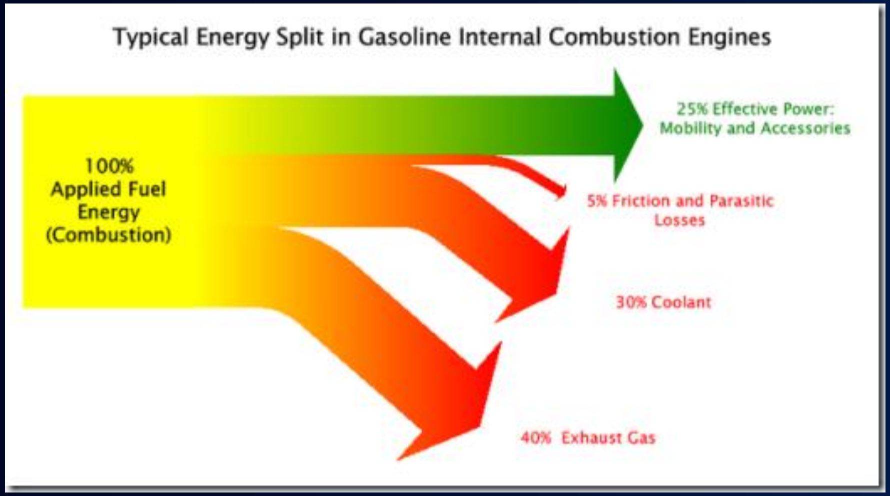
Output = Work done
(head x flow)

Input = Shaft (drive) power

Losses = friction / heat (increase in air or fluid temperature)

Definition of Efficiency - 3

Combustion Engines (boilers)



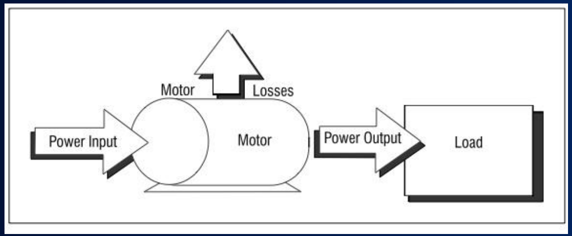
Outside scope but also about Input, output and losses…and “Calorific value”

Electric Motor Efficiency - 1

Input, output and losses

Input: Electric Power In

Output: Shaft Output Power



Losses:

- Core losses (Magnetic or Iron losses)
- Conductor resistance losses ($I^2 R$ losses)
- Friction and Windage losses
- Stray Load (Additional load losses)

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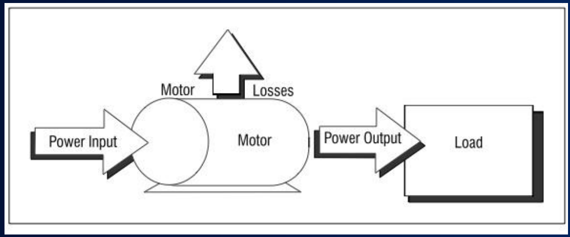
Electric Motor Efficiency - 2

How are quantities measured?

Input: Power Meter

Output: Torque (or power) Transducer

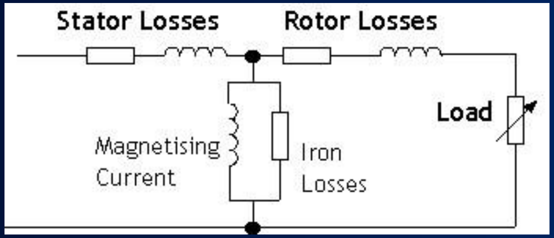


(Output can be measured with the driven load if it has been calibrated or is suitable for torque or power measurement. E.g.: Dynamometer)

Losses are the most difficult to measure

Electric Motor Efficiency - 3

How are losses measured?



- Calorimetric method/s
- Tests: Separation of losses

(No-load and locked-rotor tests)

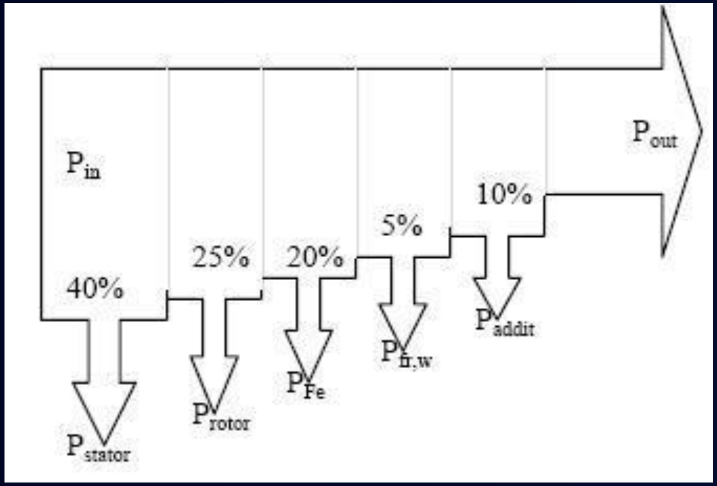
- Direct load testing: Losses = Input - Output

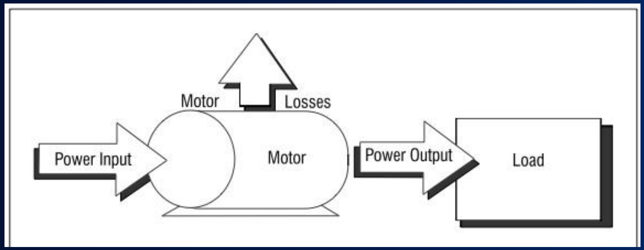
FOR MOTORS: LOSSES = HEAT

How are these tests performed in practice?

Electric Motor Efficiency - 4

Calorimetric method:





Seal motor enclosure and measure heat output.
- Water cooled motor: H²O Flow & Delta Temp.
- Impractical and almost impossible on-site

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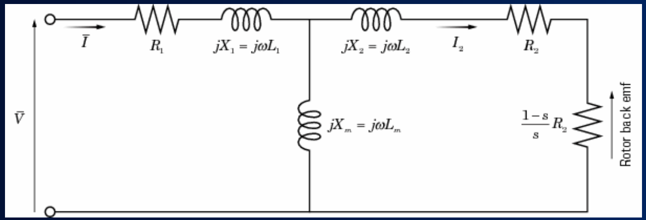
Electric Motor Efficiency - 5

Separation of Losses Test:

No-load test determines:
- Core / Iron losses
- Friction and Windage



Locked-rotor determines (with calculation):
- Stator I^2R losses
- Rotor I^2R losses (Rotor power = Input x slip)

Stray load losses are by IEC or IEEE approx.

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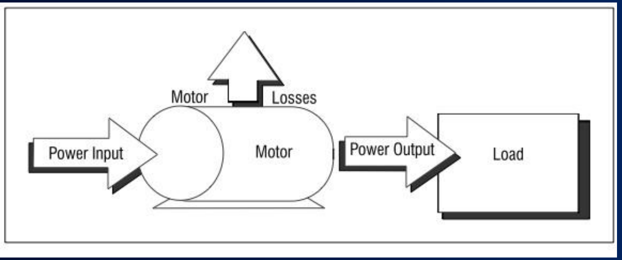
Direct Load Test:

Electrical Power Input:
- Current Transformers
- Voltage Transformers



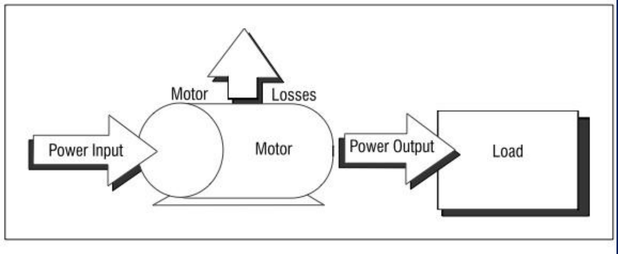
Mechanical Power Output:
- Torque Transducer (highly accurate)
- Speed measurement / Tachometer
- Power = Torque x Speed

- Measures Stray Losses
- BUT very accurate equipment required (site?)

Electric Motor Efficiency - 7

Direct Load Test On-site:

Electrical Power Input:
- Current Transformers
- Voltage Transformers

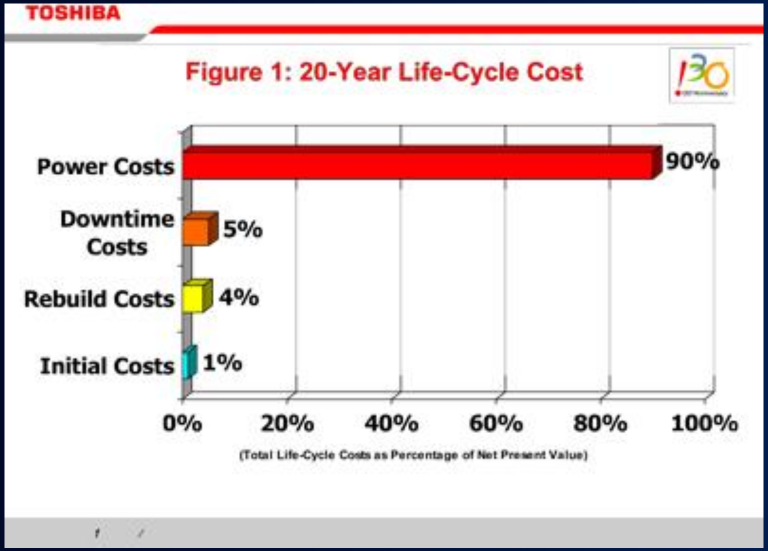


Mechanical Power Output:
- Torque Transducer - If possible (not often)
- Strain gauges on shaft (accuracy limited)
- Speed measurement / Tachometer

- Okay for inefficient motors and mechanical loads BUT not for large efficient motors

Why is Efficiency so important?

Life-cycle cost of motors:



Energy (Power) cost overshadows all other costs of motors (running and capital cost)

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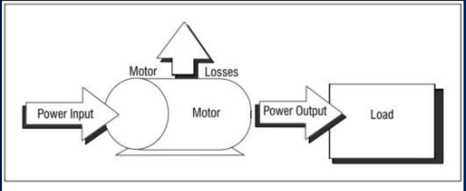
Direct Load Test Accuracy:



Example motor:
- 900 kW rated output
- 50 %, 90 % and 99 % Efficiency

Efficiency	Power In	Power Out	Losses
50 %	1800 kW	900 kW	900 kW
90 %	1000 kW	900 kW	100 kW
99%	910 kW	900 kW	10 kW

Electric Motor Efficiency - 9

Direct Load Test Accuracy:

Example motor Efficiency errors:
- With 1 % error on Mech. Power
- Assume 0 % error on Elec. Power

Efficiency	Power In	Losses	Abs. Eff. Error	Rel. Error
50 %	1800 kW	900 kW	9/1800 = 0.5 %	9/900 = 1 %
90 %	1000 kW	100 kW	9/1000 = 0.9 %	**9/100 = 9 %**
99%	910 kW	10 kW	9/910 = 0.99 %	**9/10 = 90 %**

N.B.: Even with highly accurate torque measurement – Relative error is unacceptable

Electric Motor Efficiency - 10

Direct Load Test Accuracy (cont.):

Example motor Efficiency errors:
- With 5 % error on Mech. Power
- Assume 0 % error on Elec. Power

Efficiency	Power In	Losses	Abs. Eff. Error	Rel. Error
50 %	1800 kW	900 kW	45/1800 = 2.5 %	**45/900 = 5 %**
90 %	1000 kW	100 kW	45/1000 = 4.5 %	**45/100 = 45 %**
99%	910 kW	10 kW	45/910 = 4.9 %	**45/10 = 450 %**

Result for 50 % Efficient Load is acceptable IF load testing a pump or compressor with low efficiency – but not for any motors!

Electric Motor Efficiency - 11

Direct Load Test Accuracy (cont.):

Direct load testing is even sensitive to Power In:
- With 0 % error on Mech. Power
- Assume 1 % error on Elec. Power

Efficiency	Power In	Losses	Abs. Eff. Error	Rel. Error
50 %	1800 kW	900 kW	18/1800 = 1 %	**18/900 = 2 %**
90 %	1000 kW	100 kW	10/1000 = 1 %	**10/100 = 10 %**
99%	910 kW	10 kW	9.1/910 = 1 %	**9.1/10 = 91 %**

Despite perfect Mechanical load / torque / power measurement – the relative error for motors of realistic efficiencies is unacceptable UNLESS very accurate Input Power measurement is possible.

Why do only men do this?

Because women can't think of such brilliant ideas…

Electric Motor Efficiency - 12

Separation of Losses Test:

No-load testing with 1 % Input Power:
- With 0 % error on Mech. Power
- Now error is only on (1 % of) the LOSSES!

Efficiency	Power In	Losses	Abs. Eff. Error	Rel. Error
50 %	1800 kW	900 kW	9/1800 = 0.5 %	**9/900 = 1 %**
90 %	1000 kW	100 kW	1/1000 = 0.1 %	**1/100 = 1 %**
99%	910 kW	10 kW	0.1/910 = 0.01 %	**0.1/10 = 1 %**

One may argue (correctly) that Stray Load Losses are not measured, but let us extend this example to a 50 % error in the Stray Load losses (between IEC / IEEE approx. and actuals...

Electric Motor Efficiency - 13

Separation of Losses Test (cont.):

No-load testing with 1 % Input Power:

- With 0 % error on Mech. Power
- Assume 50 % error in 1 % Stray Load Losses!

Effic.	Power In	Losses	Rel. SL Error	Rel. Error
50 %	1800 kW	900 kW	9/1800 kW = 0.5 %	**18/900 = 2 %**
90 %	1000 kW	100 kW	5/1000 kW= 0.5 %	**6/100 = 6 %**
99%	910 kW	10 kW	4.05/910 kW = 0.5 %	**4.15/10 = 41.5 %**

Error is constant because it is 50 % of 1 % across the full example range. Therefore additional Relative Stray Load loss error is 0.5 %. Note that the error is still acceptable for up to 95 % efficiency, even with an unrealistically bad accuracy and Stray Load error.

What does this mean?

Conclusion of previous examples:

Unless laboratory quality instrumentation is available the Separation of Losses test produces considerably better accuracy – On-site or in a test facility

A test facility can implement the required accuracy

It is always better to implement this accuracy and test using the direct load test – if possible, practical and cost-effective

What about on site? Separation of Losses of course!

What load does test look like?

Site	Test facility
	

Torque transducer (flange) between motor and generator in test facility arrangement (right)

On-site Efficiency Testing

Separation of losses (modified):

Electrical Power Input:
- CT's and VT's in-situ

No-load test determines:
- Core / Iron, Friction and Windage

- Known or measured stator R gives I^2R
- Rotor losses from P_rotor = Input Power x slip
- Stray Load Losses from IEC or IEEE

(Very simple and sufficiently accurate)

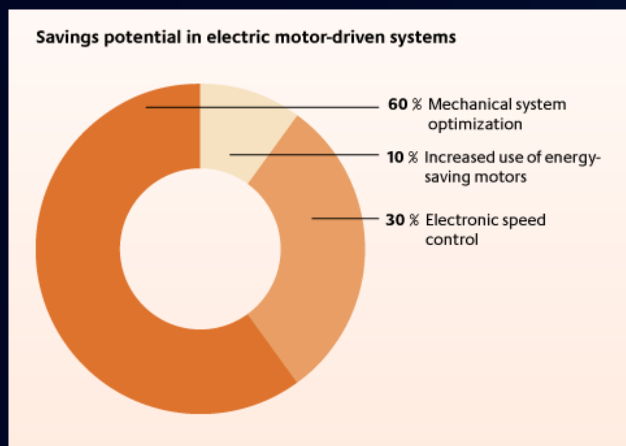
Back to Safety

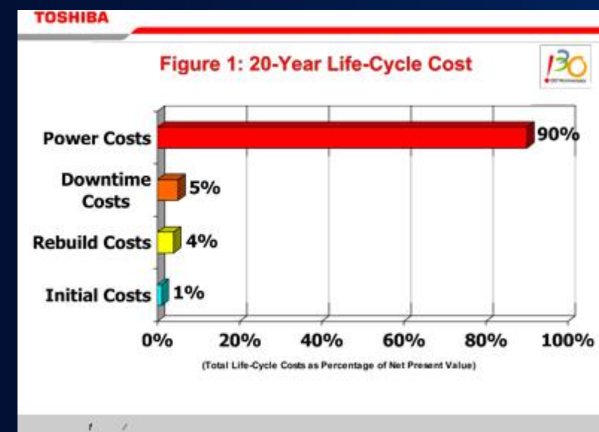
Worst safety issue of on-site test:

- Measuring stator Resistance
- Uncoupling motor

Efficiency is critical (TOC)

N.B.: Assess the Total System:





The driven load is usually the least Efficient part of the system

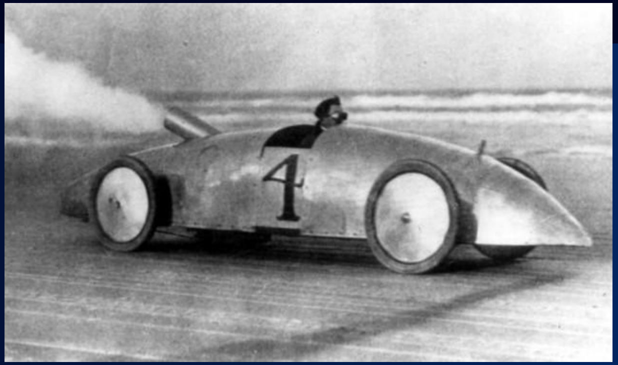
Back to the question…

The Steam driven car is more efficient (in SA)!

It relies on original electricity which is produced by a coal-fired (steam turbine) power station.

It amounts to having a small steam driven generator in the Electric vehicle for electricity!

(Will change with clean power)



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Electrically power aircraft?

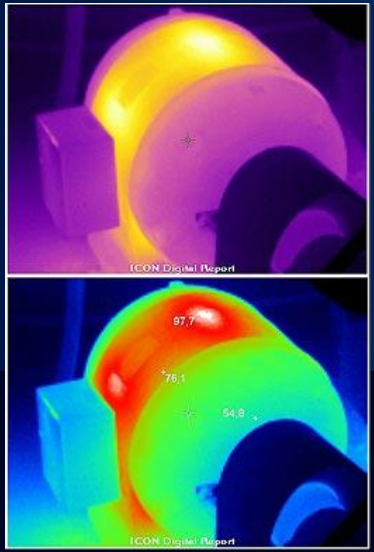
Yes – it exists – called Antarez:

- 175 km/hour cruise
- 750 km range
- Fuel cell

Thank you

Positive notes:

- Gold price over $1600 / Oz
- Even with US$ strengthening
  (for the wrong reasons!)



- It's easy to be negative
  + Back to 1986, worldwide:
- US attacked Libya
- France performed nuclear tests
- Challenger exploded in mid-air
- Wikipedia 1986 in South Africa