The Extraordinary Design of the Bombardier Beetle

Andy McIntosh, Leeds, UK

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Bombardier beetles

The extraordinary bombardier beetle emits a hot spray to ward off any would be predator — and usually wins. The spray is a mixture of caustic chemicals, hot water and steam and is blasted out of a special nozzle which can be pointed in any direction!

Special defence system with moveable tank turret!

Bombardier beetles (Carabidae: Brachinini) are found mainly in warm countries such as parts of Asia, Africa, Australia, USA (Florida, California). But they are also found in Europe and small colonies have even been observed in the southern part of England. They are usually not far from water and hide during the day under rocks.

The bombardier beetle (figure 1, 2) ejects a mixture of chemically heated steam and noxious chemicals out of its back end through a special turret which can be moved in any direction (even twisting over its back and pointing forwards – see figure 3). The whole system is used to ward off predators such as ants, birds, spiders and frogs (figure 2). The beetle generally wins and the opponent is stunned!

How does it do this? The chemicals do not come out as a continuous stream. Professor Tom Eisner in 1999 produced a seminal paper on the beetle and showed that a series of explosions is produced by the two chemicals hydroquinone and hydrogen peroxide in the presence of two catalysts: catalase and peroxidase. (A catalyst makes the reaction go much faster but does not actually undergo chemical change itself.) In a clever experiment, Eisner filmed a firing tethered African bombardier beetle, and then played it back in slow motion. Through this he showed that about 500 explosions were given off per second and that repeated blasts, each lasting 2–3 seconds, were emitted from the beetle (figure 3).

This is like firing an automatic machine gun with repeated bursts.

The author (Andy McIntosh), inspired by the beetle, realised there was a clever design to be discovered, and work began at Leeds University UK in collaboration with Eisner. We showed that these blasts were controlled by a unique valve system, where not only was there an inlet valve that closed under high pressure, but that there was also an outlet valve which opened at high pressure (figure 4). As explained on page 86, this leads to a violent flash evaporation event where almost instantaneously the liquid (mostly water) expands to steam.

This then shocked the opponent and stunned it.


This is from a book titled "Wonders of Creation" by Stuart Burgess and Andy McIntosh - Editor : Brian Edwards
Maybe Burgess and McIntosh are right and all the rest of us — biologists, geologists, archeologists, historians, chemists, physicists, cosmologists and, yes, thermodynamicists and respectable theologians, the vast majority of Nobel Prizewinners, Fellows of the Royal Society and of the National Academies of the world — are wrong …

https://www.theguardian.com/commentisfree/2006/dec/27/post845
…. Not just slightly wrong but catastrophically, appallingly, devastatingly wrong.

It is possible …. 

…. if Burgess and Mcintosh are right, the scientific establishment has fallen.

Richard Dawkins Dec 27th 2006

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The extraordinary design of the Bombardier Beetle
African Bombardier Beetle

Found in:

- Asia 2 cms
- North America 1-2 cms
- South America 1-2 cms
- Africa - approx 2-3 cms
- Europe 1 cm
- South of England 1 cm

Under rocks
Close to water
It ejects a mixture of chemically heated steam and noxious chemicals out of its back end...

This is a separate system to its digestive tract.

This wards off predators such as ants, birds, spiders and frogs.

The beetle generally wins and.stuns its opponent.
It ejects a mixture of chemically heated steam and noxious chemicals out of its back end...

This is a separate system to its digestive tract.

The beetle generally wins and stuns its opponent.

Moveable exhaust turret...

In any direction!

This wards off predators such as ants, birds, spiders and frogs.
More versatile than a tank turret!
From the film ‘Alien Empire’, BBC
From the film ‘Secret Weapons’, BBC

Professor Tom Eisner, Cornell University
Bombardier Beetle – Pulse combustion par excellence.

Fuel-inlet valve opened at low pressure, closed at high pressure.

Exhaust-outlet at high pressure.

.....then finding of a sophisticated pressure release valve at outlet

Approx 1mm
V1 - Doodlebug
Explosion Chamber of Bombardier Beetle

Hydrogen Peroxide

Hydroquinone

Enzymes – Catalase and Peroxidase

Catalytic combustion carefully timed

\[ \text{C}_6\text{H}_6\text{O}_2 + \text{H}_2\text{O}_2 \xrightarrow{\text{Catalase}} \text{C}_6\text{H}_4\text{O}_2 + 2\text{H}_2\text{O} \]
“In fact the Hydroquinone does nothing at all. We can put that on one side … “
Chemical Reactions within Bombardier Beetle

Catalysts Catalase and Peroxidase may be in crystalline form in fibres within the combustion chamber.
Chemical Reactions within Bombardier Beetle

Aqueous solution of reactants is stored in a reservoir, and is composed of hydroquinone $C_6H_6O_2$ at a concentration of 25% and hydrogen peroxide at concentration of 10% - Holoubek and Schildknecht

Important steps

$$C_6H_6O_2(aq) \rightarrow C_6H_4O_2(aq) + H_2(g)$$ \hspace{1cm} \Delta H_2 = +177.232 \text{ J mol}^{-1}

$$H_2O_2(aq) \rightarrow H_2O(l) + \frac{1}{2}O_2(g)$$ \hspace{1cm} \Delta H_3 = -94.5 \text{ J mol}^{-1}

$$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l)$$ \hspace{1cm} \Delta H_4 = -285.5 \text{ J mol}^{-1}

Overall Reaction

$$C_6H_6O_2(aq) + H_2O(aq) \rightarrow C_6H_4O_2(aq) + 2H_2O(l)$$ \hspace{1cm} \Delta H_1 = -202.8 \text{ J mol}^{-1}

Total heat release for one kilogram of solution is then 794.2 kJ/kg solution
Chemical Reactions within Bombardier Beetle

Aqueous solution of reactants is stored in a reservoir, and is composed of hydroquinone $C_6H_6O_2$ at a concentration of 25% and hydrogen peroxide at concentration of 10% - Holoubek and Schildknecht

- **Benzoquinone**

  Important steps:

  \[
  C_6H_6O_2(aq) \rightarrow C_6H_4O_2(aq) + H_2(g) \]
  \[
  H_2O_2(aq) \rightarrow H_2O(l) + \frac{1}{2}O_2(g) \]
  \[
  H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l) \]

  Where:
  \[
  \Delta H_2 = +177.232 \text{ Jmol}^{-1} \\
  \Delta H_3 = -94.5 \text{ Jmol}^{-1} \\
  \Delta H_4 = -285.5 \text{ J mol}^{-1} \\
  \Delta H_1 = -202.8 \text{ Jmol}^{-1} 
  
  Overall Reaction:

  \[
  C_6H_6O_2(aq) + H_2O(aq) \rightarrow C_6H_4O_2(aq) + 2H_2O(l) 
  \]

  Total heat release for one kilogram of solution is then 794.2 kJ/kg solution

Dawkins missed!
And it is not simple to produce H₂O₂!

Extremely narrow diameter tubes in which it is believed the chemicals C₆H₆O₂ and H₂O₂ are made.

Combustion chamber.
Valve system of Combustion Chambers

Combustion chambers.
Note the boxing glove like arrangement of the combustion chambers.
These pinch the inlet tubes under pressure.
“LIGHT BULB MOMENT!”

Important discovery of *two* valve system

Inlet and *outlet* valves
End on view of Outlet Valve:

- **Closed**
- **Open**

**Membrane**

**Hard cuticle**
Christine Ortiz at MIT using laser tomography has shown that both combustion chambers usually operate together.

Twin carburettors!
Mimicking the valve system...
CFD used for modelling the Bombardier Beetle combustion chamber as a cylinder.

CFD used for modelling the experimental rig.
Modelling using steam explosion

Main cylinder held at 1.1 bar until release at time $t = 0$ secs.

1.1 bar is the saturation vapour pressure for vapour at 378K.

The dividing membrane is then released.

Laminar flow with zero slip boundary conditions at wall of nozzle outlet.

Dimensions of main cylinder made so that volume is identical to Beetle combustion chamber.
Modelling using steam explosion

Steps of 0.060 msecs
Steam volume fraction

Ejected water and steam
Ejected water and steam
An experimental rig mimicking the valve system of the Bombardier Beetle

First platform experimental rig built and tested to mimic the physics of the Bombardier Beetle chamber – approx 20 times the 1mm combustion chamber of the Beetle.
An experimental rig mimicking the valve system of the Bombardier Beetle

First experimental rig in action with large droplets and near maximum mass ejection.
● It has a sophisticated inlet and exhaust valve.
● It emits a mixture of water and steam under pressure.
● Mixed with the steam and water is a noxious quinone.
● The heating is by a chemical reaction involving hydrogen peroxide and hydroquinone.
● It can direct the blast in any direction it wishes.
● It can blast at 400 - 500 times per sec.
● It can maintain a burst for about 2-3 secs, and carry on doing many bursts…
It is an example of pulsing (oscillating) combustion in nature
It is a classic example of biomimetics
The core technology copied is the combustion chamber design (valves) and the nozzle
There are applications to a number of areas including:
- Nebulisers – (Aqueous and Organic),
- Fire extinguishers,
- Fuel Injector
- Aerosols and air fresheners
The extraordinary aiming and throw of the bombardier beetle spray.

Throw of 20 cms from 1mm chamber

Throw ratio ~ 200

From BBC Life series
Single exhaust of large droplets from 2 cm chamber

Throw of 4m from 20 cm chamber

Throw ratio ~ 200

Fire extinguisher application
Wide spray angle

Fig. 9. Two single frames of the ejection taken by the high speed digital video camera at 1500 frames per second. The first frame (top) is taken at 93ms and the second one (bottom) at 123ms after opening the exhaust valve. In this experiment it was intended to measure the exit velocities from the nozzle. For this purpose a ruler is installed behind the nozzle in line with its axis to allow keeping track of some individual droplets positions in time for velocity measurements.
Three major patents for these applications - Fuel injector, Fire extinguisher and Pharmaceutical Spray

What was said by one of the patent agents advising our project ....

May be we should try and patent the beetle?
Later rigs

Now able to reach 100 - 200 Hz.

Applications to fuel injectors, medical sprays, fragrancers etc.
Applications for the Bombardier Beetle technology

Bombardier Beetle

Physics of chamber and valve system

- Inlet valve
- Timing
- Pressure relief exit valve
- Temperature of chamber
- Repetitive pulse combustion
- Modality
- Droplet size
Control and Applications for the Bombardier Beetle technology

Bombardier Beetle

Physics of chamber and valve system

- Inlet valve
- Timing
- Pressure relief exit valve
- Temperature of chamber
- Repetitive pulse combustion
- Modality
- Droplet size

Applications to:

- Pharmaceutical - Nebuliser – (Aqueous and Organic)
- Needleless injector
- Fire extinguishers
- Fuel Injector
- Aerosols
- Aeroponics

Droplet size:
- 1-10 µm
- ~100 µm
- 10-50 µm
- 10-20 µm

Applications to:

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- 1-10 µm
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Featured on many programmes

THE ONE SHOW - THURSDAY 12TH MAY 7PM ON BBC1

Mike Dilger discovers how the Bombardier Beetle is going to help fire safety

BBC 1 One Show – May 12th 2011
Featured on many programmes

Featured in:

**BBC Look North, Sept 2007**
‘Beetle could be life saver - Leeds scientists believe the beetle’s unique spraying technique could be a clue to saving lives.’

**Discovery Channel News, Oct 2007**

**BBC Material World, Nov 2007**

**Der Spiegel, January 2008**

**Industrial Pharmacy, March 2008**
‘Bio-inspiration for new pharmaceutical sprays’, Vol 17, pp12-14

**Physics World, April 2008**

**Science Daily, April 2008**

**Scientific American, April 2008**
3rd April 2008 60 second science

**MSNBC News, May 2008**
‘Beetle’s toxic blasts trigger Innovation; Scientists inspired by creature’s unusual defense mechanism’

**The Naked scientist show, May 2009**
‘Bioengineering - Engineering Inspired By Nature’

[http://nakeddiscovery.com/downloads/split_podcasts/09.05.31/Naked_Scientists_Show_09.05.02_3984.mp3](http://nakeddiscovery.com/downloads/split_podcasts/09.05.31/Naked_Scientists_Show_09.05.02_3984.mp3)

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Additional resources:
- [BBC Look North, Sept 2007](http://www.bbc.co.uk/mediaselector/check/player/nol/newsid_7000000/newsid_7001600?redirect=7001696.stm&news=1&bbwm=1&bbram=1&nbwm=1)
- [Der Spiegel, January 2008](https://www.spiegel.de/spiegel/print/d/144.html)
- [Industrial Pharmacy, March 2008](http://www.hindawi.com/journals/indph/2008/914602/)
- [Physics World, April 2008](http://physicsworld.com/cws/article/print/33577)
- [Science Daily, April 2008](http://www.sciencedaily.com/releases/2008/04/080401170543.htm)
- [Scientific American, April 2008](http://www.sciam.com/podcast/episode.cfm?id=14B29E60-974B-1718-3B3079783FEBA6E9&mp=1)
- [MSNBC News, May 2008](http://www.msnbc.msn.com/id/24637825/)
- [The Naked scientist show, May 2009](http://www.thenakedscientists.com/HTML/podcasts/show/2009.05.31/)
The design features of the bombardier beetle....

- Precise catalytic chemistry to heat mixture that is ejected
- Precisely timed inlet valve
- Precisely timed exhaust valve
- Controlled vapour explosion
- Sensory mechanism as to location of attack
- Moveable turret to direct exhaust fluid
- Production of $\text{H}_2\text{O}_2$ and Hydroquinone
- 400-500 explosions per sec
- It can maintain a burst for about 2-3 secs
Richard Dawkins Dec 27th 2006

.... Not just slightly wrong but catastrophically, appallingly, devastatingly wrong.

It is possible ....

.... if Burgess and McIntosh are right, the scientific establishment has fallen.”
Consortium of University of Leeds and Swedish Biomimetics 3000® for developing innovative spray technology based on the bombardier beetle.
For since the creation of the world His invisible attributes are clearly seen, being understood by the things that are made, even His eternal power and Godhead, so that they are without excuse.
...brilliant engineering...

...by the brilliant Engineer...

“...without Him nothing was made that was made...” John 1:3
Bombardier beetles

The extraordinary bombardier beetle emits a hot spray to ward off any would-be predator— and usually with success. The spray is a mixture of caustic chemicals, hot water and steam and is blasted out of a special nozzle which can be pointed in any direction!

This is like firing an automatic machine gun with repeated bursts.

The author (Andy McIntosh), inspired by the beetle, realised there was a clever design to be discovered, and work began at Leeds University UK in collaboration with Eisner. We showed that these blasts were controlled by a unique valve system, which can be turned in any direction (figure 4). As explained on page 86, this leads to a violent flash evaporation event where almost instantaneously the liquid (mostly water) expands to steam. Because

- A spectacular spray of steam and chemicals is expelled from the beetle (figure 1).
- A special valve system is used to control the high-pressure liquid stream (figure 2).
- The valve system is controlled by a unique trigger mechanism, which can be turned in any direction (figure 3).

Special defence system with moveable tank turret!

Bombardier beetles (Carabidae: Brachinini) are found mainly in warm countries such as parts of Asia, Africa, Australia, USA (Florida, California), but they are also found in Europe and rarely in parts of England. They are usually not far from water and hide during the day under rocks. The bombardier beetle (figures 1, 2) ejects a mixture of chemically heated steam and noxious chemicals out of its back end through a special turret which can be moved in any direction (even twisting over its back and pointing forwards – see figure 3). The whole system is used to ward off predators such as ants, birds, spiders and frogs (figure 2). The beetle generally wins and the opponent is stunned!

How does it do this? The chemicals do not come out as a continuous stream. Professor Tom Eisner in 1999 produced a seminal paper on the beetle and showed that a series of explosions is produced by the two chemicals hydroquinone and hydrogen peroxide in the presence of two catalysts: catalase and peroxidase. (A catalyst makes the reaction go much faster but does not undergo chemical change itself.) In a clever experiment, Eisner filmed a firing tethered African bombardier beetle, and then played it back in slow motion. Through this he showed that about 500 explosions were given off per second and that repeated blasts, each lasting 2–3 seconds, were emitted from the beetle (figure 3). A. African bombardier beetle (Brachinus species)

B. Bombardier beetle spraying an ant attacker

C. Bombardier beetle demonstrating the turret which enables it to fire over its back

D. Bombardier beetle valve system

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Diagram reproduced from original in Physics World, 21(4), 30, April 2008

This is the first biological system to be designed with a moveable tank turret!
Summary of potential applications of the Bombardier Beetle technology

More on Fire Extinguisher Application

- It is an example of pulsing (oscillating) combustion in nature
- It is a classic example of biomimetics
- The core technology copied is the combustion chamber design (valves) and the nozzle
- There are applications to a number of areas including: Nebulisers – (Aqueous and Organic), **Fire extinguishers**, Fuel Injector, Aerosols and air fresheners
Santa Barbara Fires in California
Dec 2017, some of worst in living memory…..

1.2. Wild Fires

Even though property loss is small compared to the overall Fire loss, nevertheless the problem of wildfires is significant in the US.
Carr Fire going on now July / Aug 2018 in California - Fire Tornados have killed two firefighters....
Fire whirls, also known as fire "tornados", are spinning vortexes of air, ash and fire. They form when rising hot air begins to rotate and forms a vortex that picks up flammable gases and burning debris vegetation. Fire whirls typically only last a few minutes but can be very dangerous because they can move quickly. They can reach dozens of metres in height, with core temperatures as high as 1,090°C.
There is a great need to protect the firefighter him or herself from getting trapped and overcome by the fire or fumes. This is particularly true in forest fires where a number of fire kernels need to be tackled at one time and where individual fire fighters can be in extreme danger.

The Beetle inspired fire extinguisher has the advantage that it can shoot a vapour and water jet a great distance and thus protect a firefighter.

With a larger chamber of typical length 5 cms, the distance reached should be approximately 10 metres.

At Mississippi State University we are actively looking for funding to support the building of such a bigger prototype.


More information on Bombardier Beetle web site:
www.bombardierbeetle.org
The defense mechanism not only requires sophisticated chemistry but also a valve system such that an inlet valve cuts off more fuel while an exhaust valve opens out and shoots boiling caustic liquid at the attacker.
QUESTIONS