Drone Compatible Medical Transportation Pod Design, Development and Testing

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Self-Conceived Product Development
Final Year Undergraduate Capstone Project

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SYNOPSIS

The student self-conceived product Medical Transportation Pod - Medi-Pod™ - is an aerodynamic self-cooling pod for transporting medical supplies via aerial drone. The rapid safe delivery of critical medical supplies between medical facilities and to remote, inaccessible and war torn areas is addressed by the developing device. The design, build, testing and optimisation of the Medi-Pod™ prototype has been comprehensively undertaken - yielding the finished functional conforming prototype. All testing has been successful in proving the validity of the Medi-Pod™ concept and optimised design. Validation has been achieved by both computer simulation and physical model testing.

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Essay Word Count Main Body Excluding Tables, Figures and Appendices - 1,967

1. Introduction and Inspiration

The self-conceived product Medical Transportation Pod - Medi-Pod™ - is an aerodynamic self-cooling pod for transporting medical supplies via aerial drone or personal transportation methods. The rapid safe delivery of critical medical supplies between medical facilities and to remote, inaccessible and war torn areas is addressed by the developing device.

Inspiration for this product arose from a number of sources. The author developed a strong interest in model making / product design from a very early age. The author's Father, who works in the ambulance service in central London, spoke of the great difficulties, delays and equipment / personnel costs in the current practise of transporting blood and organs between medical centres / hospitals by ambulance often during peak traffic times. Research into transport of medical supplies brought to light some shocking figures and statistics and strongly indicated an urgent need for an alternative effective medical supplies transportation mode in both civilian and military applications. The concept of the medical transportation pod was developed by the author after discovering two alarming facts - how blood and organs are transported between facilities - the number of potential lives a device like this could save when used in military life-saving applications.

Between 2001-2011, 4,596 US combat related fatalities occurred in Iraq and Afghanistan. A military medical study (Eastridge, 2012), stated that 26.3% of these combat deaths were potentially survivable - it was suggested that if the ideal conditions, i.e. if the equipment and expertise were available, these troops would have had a stronger chance of survival and the percentage of combat deaths could have been significantly lowered. The study also states that a staggering 88.9% of the deaths had occurred before the injured reached a medical facility. 4,090 troops suffered mortal wounds on the battlefield, 1,391 troops died instantly and 2,699 troops succumbed before arriving at a treatment centre. Just 506 service members made it to a field hospital before succumbing to their injuries. These numbers provide a startling indication that there is a serious need to improve the on field treatment capability for the troops. This point has also been stated by trauma surgeon Col. Brian Eastridge with the U.S Army Institute of Surgical Research (Eastridge, 2012).

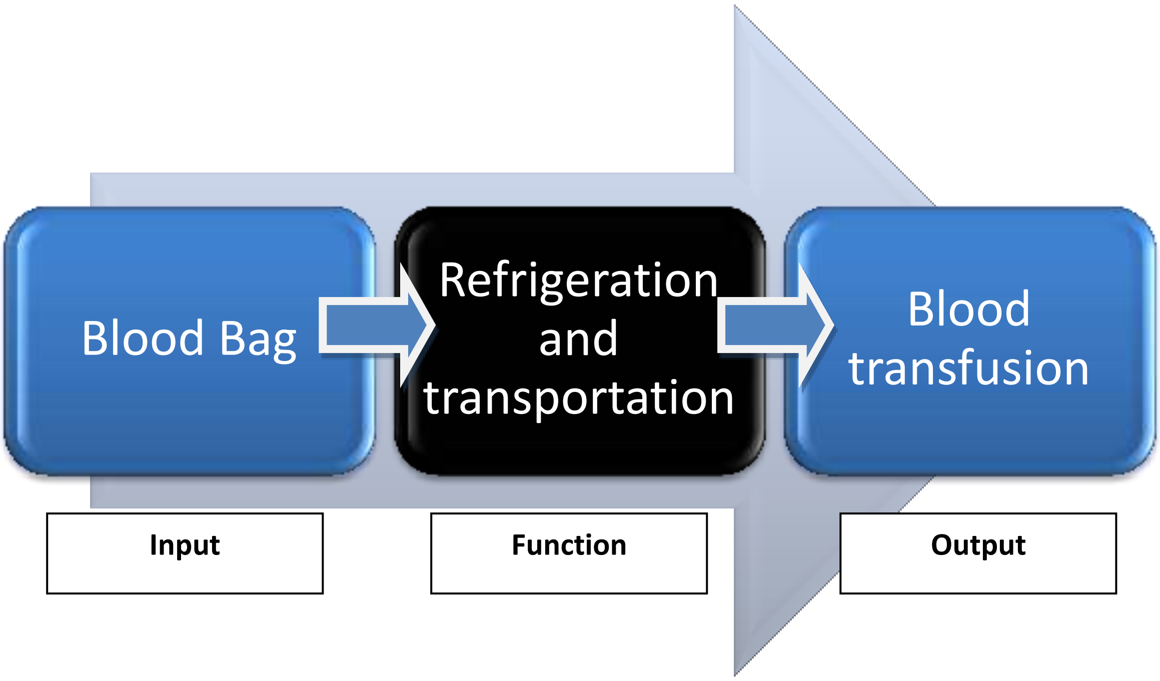
In general medical transportation, ad hoc deliveries (used to transport emergency blood supplies between hospitals and storage facilities) are not planned in the weekly schedule. Circa 120 ad hoc blood deliveries, costing on average £140 per journey, take place every week in England (Caswell, 2012). This cost can be extrapolated to many thousands of euro spent weekly for ad hoc transport purposes globally between facilities. A solution is needed to provide rapid response medical supplies to remote, inaccessible and war torn areas and a cheaper more efficient method of transporting medical supplies between medical facilities quickly - this can be achieved via aerial drone transportation. The developing Medi-Pod™ device is designed to be attachable to aerial drones

- allowing fast and safe transportation of supplies over large distances, difficult terrain or dangerous environments without danger to personnel.

Inspiration from nature gave rise to the tear drop shape of Medi-Pod™ - this aerodynamic shape optimised and validated through undertaken computational fluid dynamics analyses, wind tunnel and full flight field testing.

2. Systematic Design

A systematic design approach and methodologies, informed by the Irish Medicines Board (IMB) guidelines and support, is adopted in the iterative development of the transportation device.



High Level Objectives	Lower Level Objectives
Safety of transported product and end user	Shock absorbent
Temperature Control	Lightweight
Ease of Use	Cost effective
Cost	Material properties
Meets IMB standards	Practical for all users
Aerodynamic	Simple mechanisms

Figure 1 Determination of High and Low Level Objectives - J.King 2014

The determination of user requirements was driven by extensive consultations with the Irish Medicines board (IMB), the medical staff of the South Infirmary Hospital Cork and Skytech™ Drone Technologies.

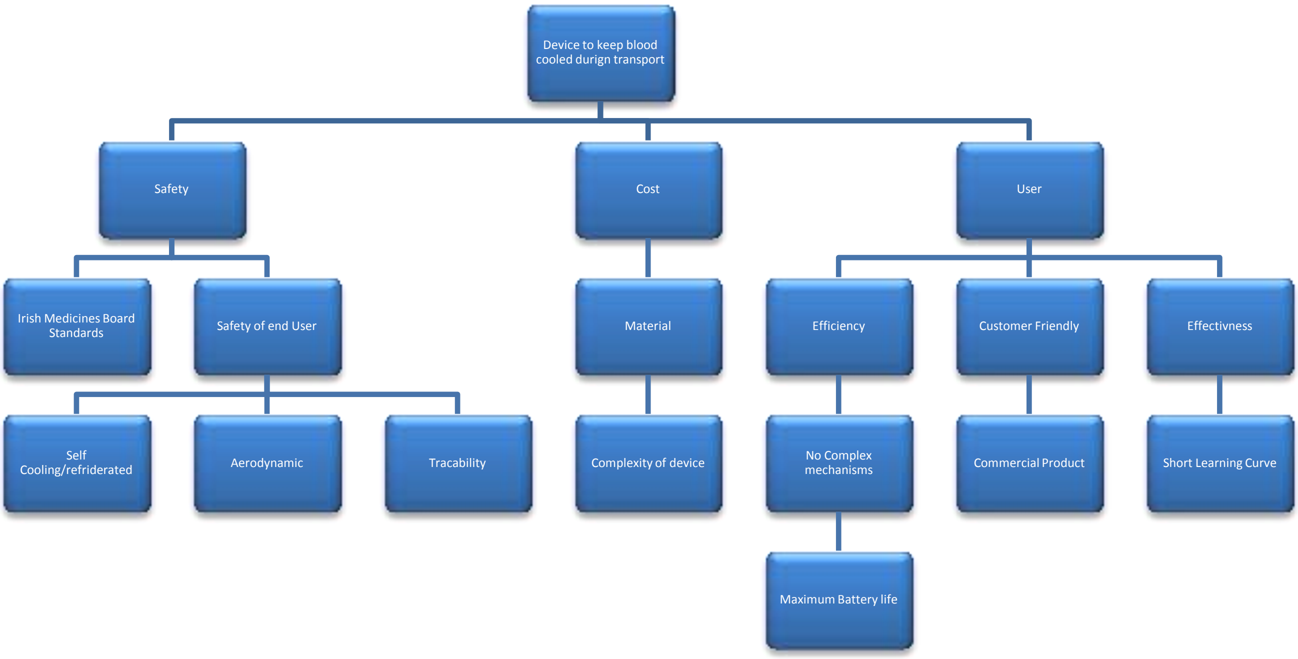


Figure 2 Medi-Pod Systematic Design Criteria Chart - J.King 2014

Drone compatibility requirements determined are:

- Operation
- Efficiency
- Safety
- Robust External Shell
- Aerodynamic Shape
- Temperature Stabilisation at Extreme Temperature Ranges
- Ease of Attachment
- Low Materials Coefficient of Friction
- Versatility
- Drone Attachment Universality

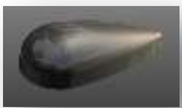


Table 1 (Ratings: 1-4) Morphological Chart - J.King 2014

Functions	Solutions				
Cooling blood	Insulation	Ice	Refrigeration cycle	Thermo electric cooling	Combination
Monitoring temp	LED screen + CPU monitor	Thermometer	Thermal strips	-	-
Shock reducing	Material	Shock absorber built in	springs	-	-
To hold blood bag	Inner plastic lining	Zip lock bag	-	-	-
Power the Device	Rechargeable battery	Li-ion (phone) battery	Solar	Miniature turbine	-

Table 2 (Corresponding Values) Morphological Ratings - J.King 2014

Functions	Corresponding Solution Ratings				
Cooling blood	3	1	1	3	4
Monitoring temp	4	1	2	-	-
Shock reducing	3	1	4	-	-
To hold blood bag	3	1	-	-	-
Power the Device	3	4	3	1	-

Morphological Charts were developed by the author to assess concept design solutions and enable selection of the optimal combination of practical solution to the identified design requirements and customer needs.

3. Commercial Research

Market research highlighted a number of blood bag transportation devices. However, none of the competitors are suitable for use with aerial drones. The Cryostenz Medi-Pod^{TM} developing device also has significant further advantages being much more lightweight and easy to transport than competitors.

Central to the device marketability is the large number of military casualties across the globe and growing costs to transport blood between hospitals and storage facilities. It is believed a significant number of fatalities could be prevented through the implementation of the Medi-Pod device. Current delivery methods for blood include delivery van, motorcycle or helicopter. These methods are all high cost and can be affected by numerous external factors such as traffic, flight restrictions and personnel issues. The Medi-Pod has been designed to be transported via aerial drone - allowing rapid, low cost and safe transportation across vast distances.

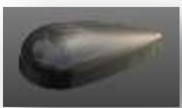
A number of competing products exist on the commercial market - Dison, Minnesota Thermal Science Credo Cube and Avatherm Military. To analyse product success and market viability, these companies were investigated.

Table 3 Tabular Assessment of Commercially Available Competitors

Competitor	Strengths	Weaknesses
Dison	Durable Case Large storage capability	Not Drone Compatible Total weight- Cost $270
Minnesota Thermal Science Credo Cube	Low Market Price Lightweight	Not Drone Compatible Styrofoam case is easily damaged
Avatherm Military	Hard, durable case Large storage capability No power required	Not Drone Compatible Total weight is 6.6kg No cooling device (insulation only)

Market research highlighted a number of blood bag transportation devices. However, none of the competitors are suitable for use with aerial drones. The Medi-Pod^{TM} developing device also has significant further advantages being much more lightweight **(at 1.454kg fully loaded – one fifth of weight of nearest competitor)** and easier to transport than competitors.

It was concluded that a major and growing market opportunity exists for a lightweight, drone compatible, self cooling transportation device, which is inexpensive and can be used repeatedly.



4. The Cryostenz™ Solution

Figure 3 Developed Medi-Pod™ Cross Section Solid Model - J.King 2014

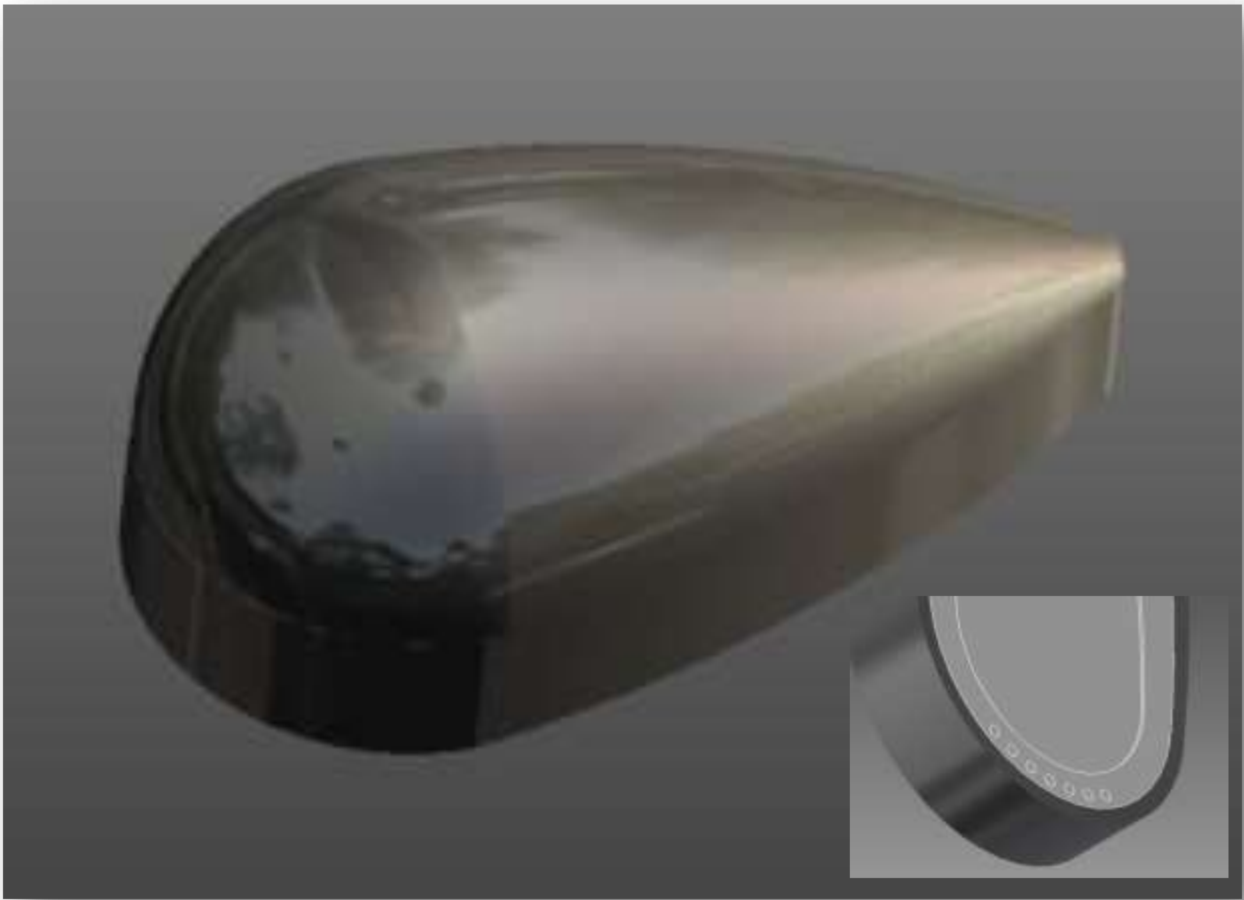


Figure 4 Medi-Pod™ 3D Solid Model and Heat Release Mechanism - J.King 2014

5. Aerodynamic Design Principles

The optimisation of the aerodynamic properties of the Cryostenz Medi-Pod™ developing device is crucial and central to drone use for rapid transportation over long distances. The two main attributes which affect the aerodynamics of the device are shape and surface finish.

Extensive Computational Fluid Dynamics (CFD) Analysis of the device shape was undertaken by the author to achieve an optimal solution for aerodynamic stability and efficiency in drone flight operation conditions. (See Figures 5 and 6)

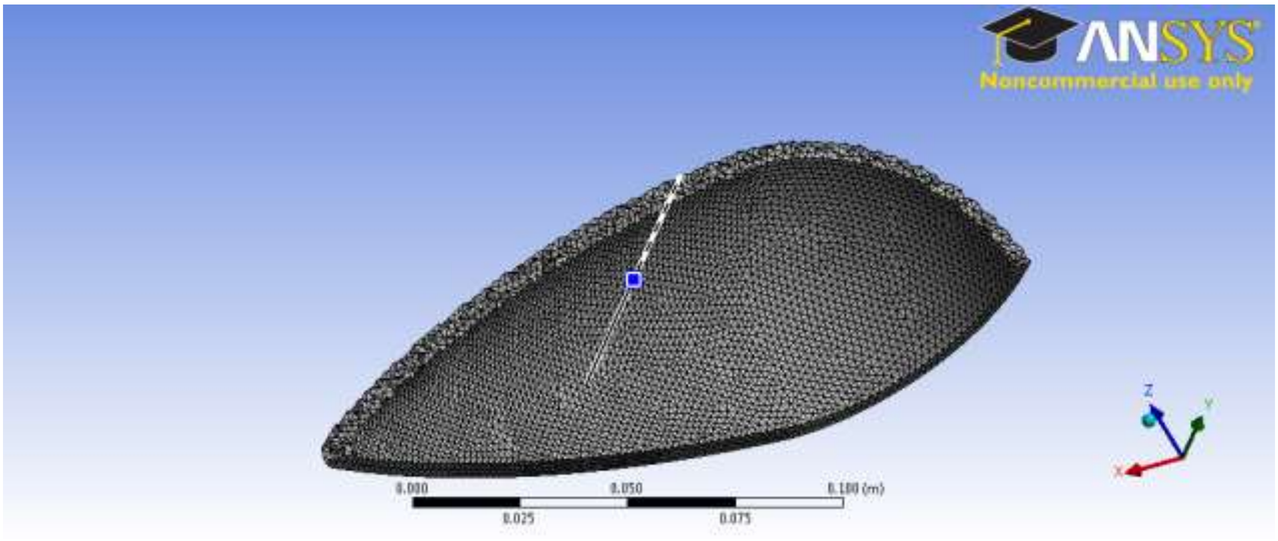


Figure 5 Developed Computational Fluid Dynamics Model Mesh of Medi-Pod™ - J.King 2014

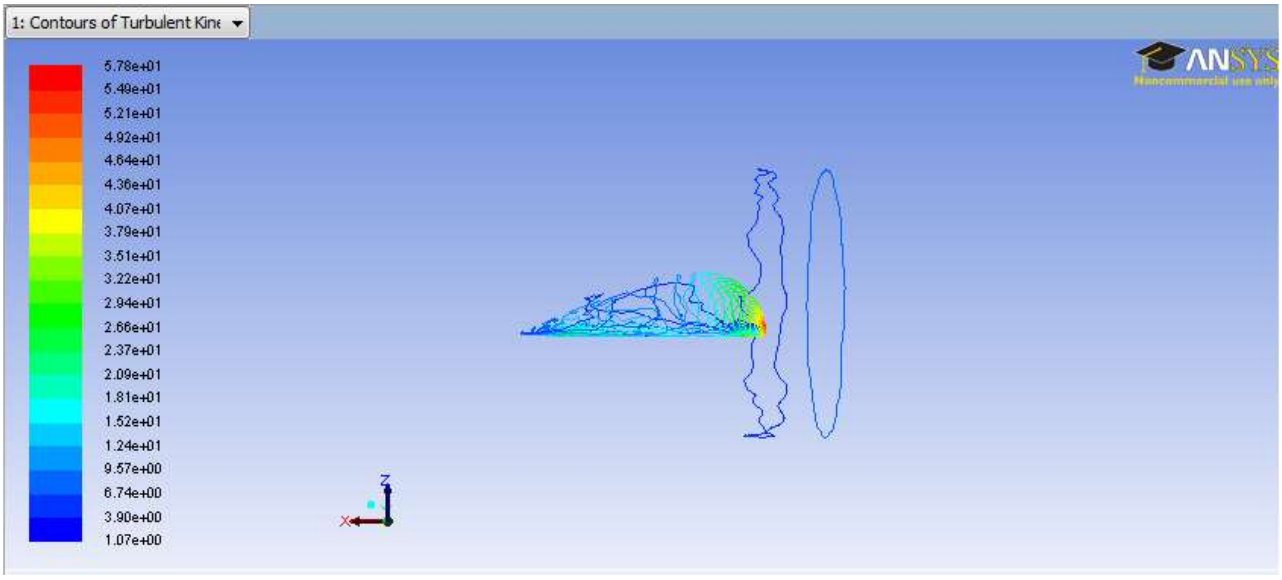


Figure 6 Turbulent Flow over Medi-Pod™ at 22m/s (Max Commercial Drone Speed) - J.King 2014

6. Medi-Pod™ Prototype Manufacture

Production of the device was split into two sections; moulded shell and interior insulation.

Shell Manufacture

The shell is a series of woven Carbon Fibre and Kevlar Fibres. Using an epoxy resin the layers of material were fastened together. This Kevlar weave can be seen in Figure 7 before the application of epoxy resin.

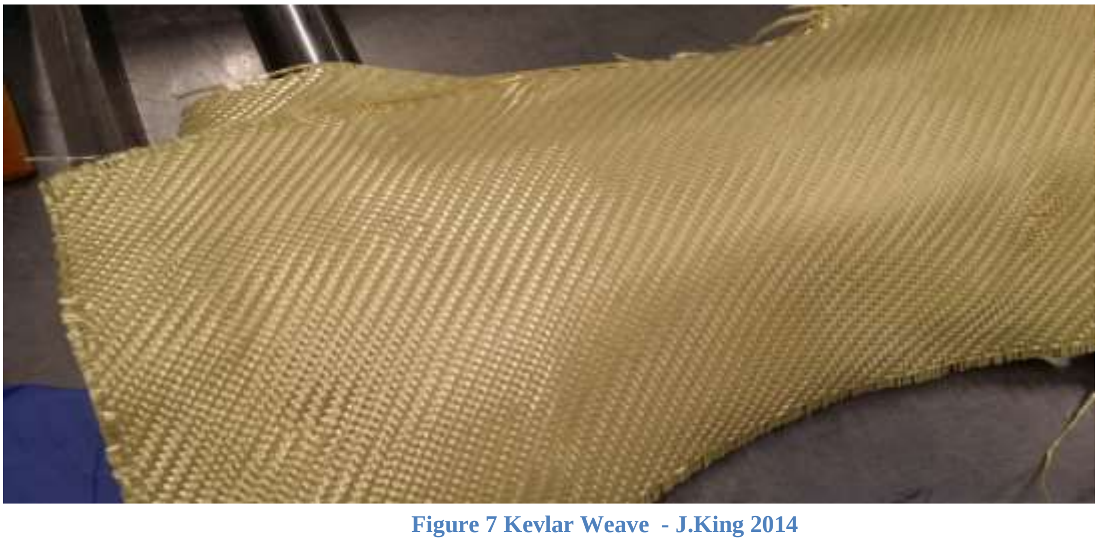


Figure 7 Kevlar Weave - J.King 2014

The process requires five layers, three Carbon Fibre and two Kevlar to finish the shell. Each layer was applied and a coating of epoxy resin was coated gently onto the surface to ensure bondage, see Figure 8 for the five layers over the shell mould which was printed on the college 3D rapid prototype printer from advanced solid model design drawings developed by the author.

Figure 8 Carbon Fibre and Kevlar Application on Developed Mould - J.King 2014

The mould was removed from the semi hardened fibre/resin mix. The weave was placed into a vacuum autoclave bag - see Figure 9 - and placed in the college autoclave.

Figure 9 Pieces ready for Autoclave in Vacuum Bag - J.King 2014

Once hardened, the shell was cut into the correct shape - see Figure 10.

Figure 10 Trimming Excess of Hardened Piece - J.King 2014

Insulation Manufacture

The insulation has been formed from a roll of high density sheet cork - see Figure 11

Figure 11 Cork Roll Top View - J.King 2014

The cork roll had to be made into a solid block to allow machining. This was achieved using a high temperature set glue and a veneer compressing unit - see Figure 12.

Figure 12 Viner Pressing the Layers of Cork - J.King 2014

Once a solid block was made, a comprehensive machining program was developed by the author on Alphacam to allow the CNC machine to cut the insulation to the correct shape - see Figure 13. A four fluted solid carbide ball nose cutter was used to create the angles surface of the part.

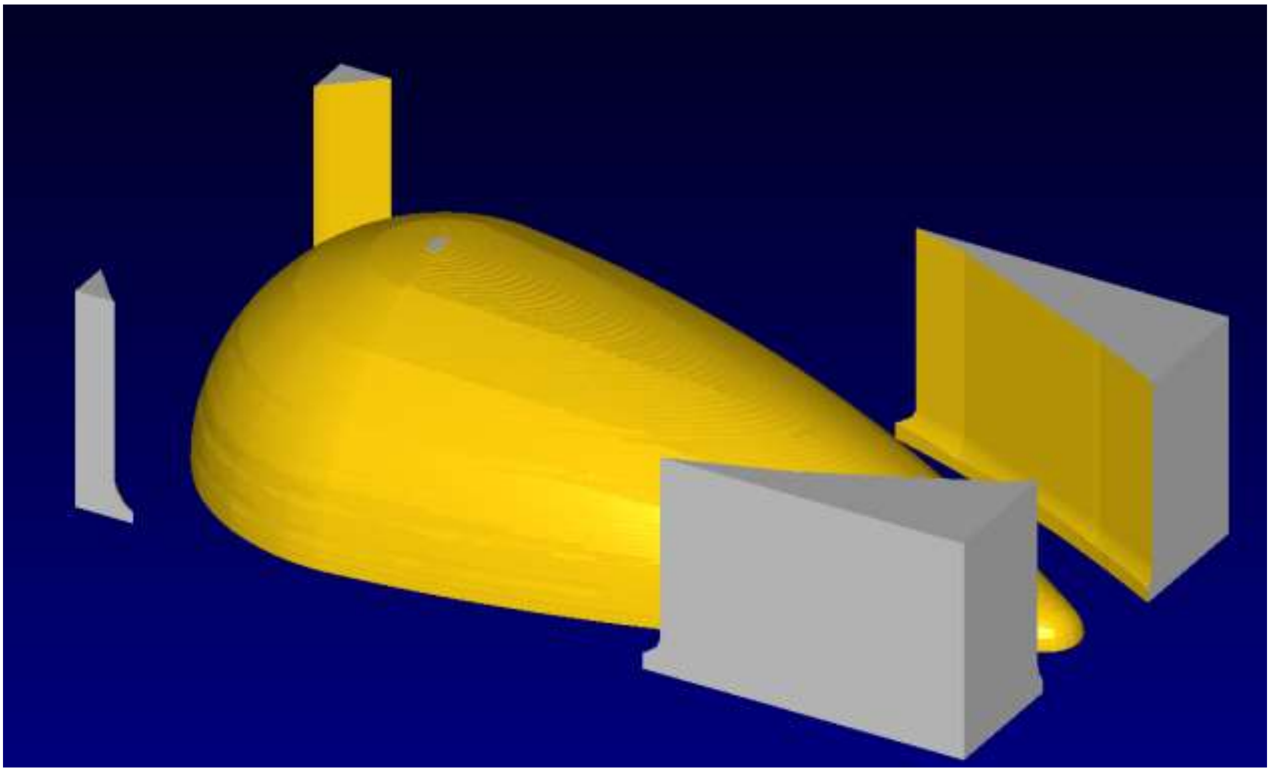


Figure 13   Alphacam Model   - J.King 2014

Final Product

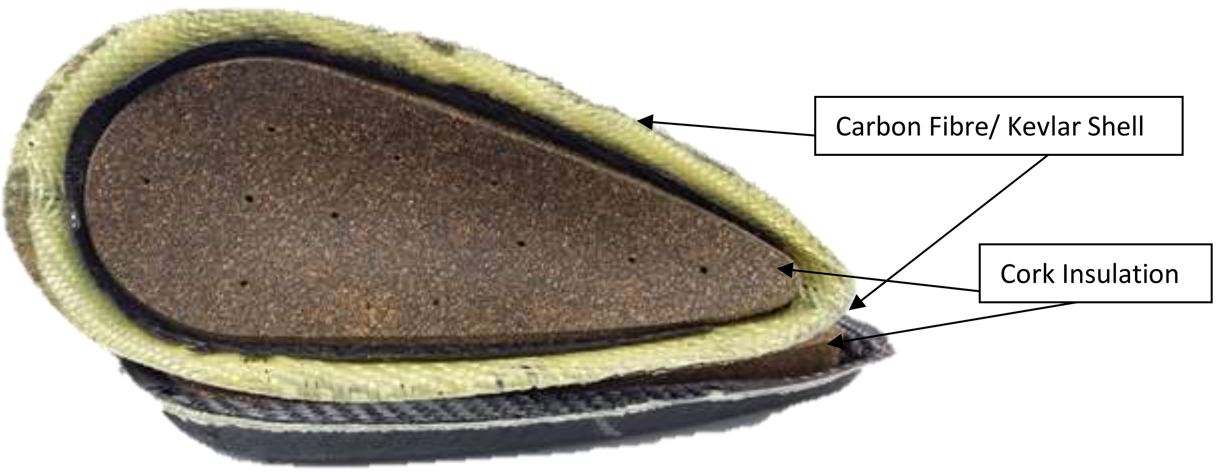
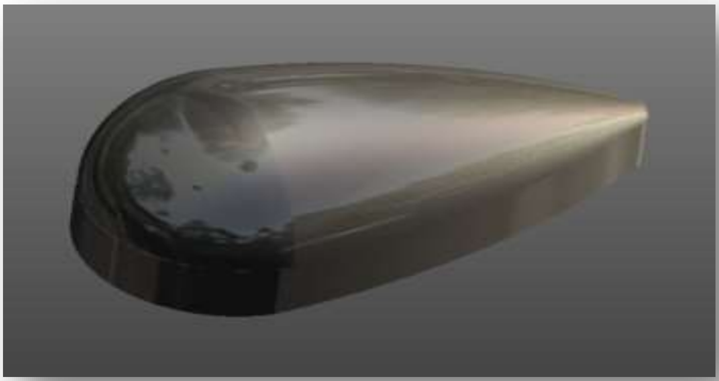


Figure 14   Insulated Shell - J.King 2014

The manufacture and assembly of the Medi-Pod™ Mark 1 prototype was undertaken and carried out by the enthusiastic technicians at my college and myself. The assembled device was used for all subsequent testing.

Figure 15 Manufactured Medi-Pod™ Prototype Mark 1



7. Wind Tunnel Testing of Developing Device

Experimental Wind Tunnel Testing was undertaken by the author to validate and optimise the drone compatible device.

A test rig was designed, constructed and commissioned in the college wind tunnel.

The speed of the wind tunnel was varied to simulate the flight of a drone to a maximum velocity of 22m/s.

Significant challenges were encountered and overcome by the author in achieving this experimental validation of the aerodynamics of the developing device.

For example, no test equipment was available to measure the low drag forces induced in the developed prototype, thereby requiring the author to develop a test utilising a modified force gauge to measure the drag force on the device. (See Figure 16)

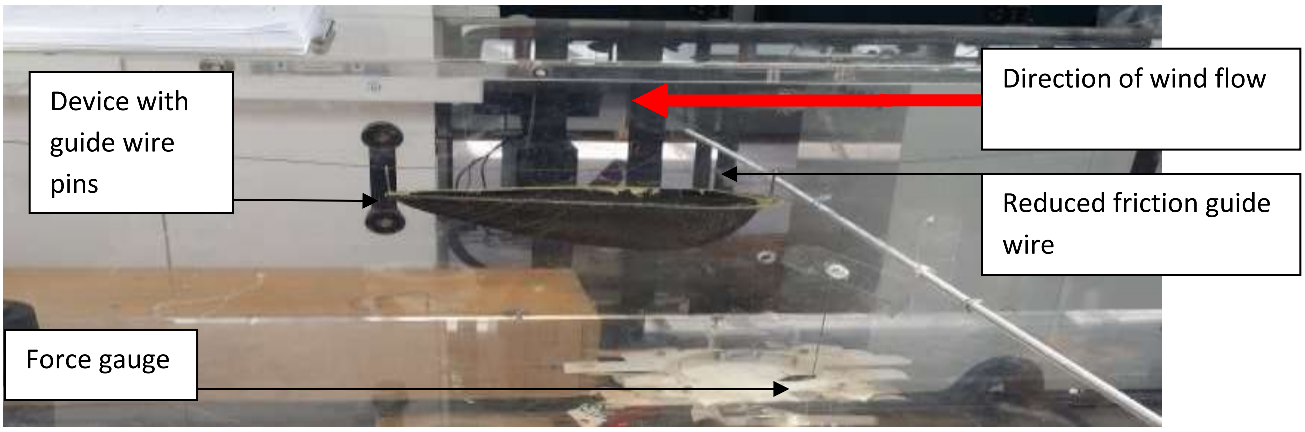


Figure 16 Medi-Pod^{TM} Prototype Wind Tunnel Aerodynamic Optimisation Experimental Test Set Up - J.King 2014

The surface finish of the device is a polished finish, reducing material coefficient of friction of near zero.

The shape of the Cryostenz Medi-Pod^{TM} developing device has been significantly modified from the original concept to allow more optimal air flow over the device and drone stability under flight operational conditions.

8. Temperature Control

Blood has to be stored between 2-5 degrees Celsius - at this temperature the blood can be stored for 24 hours. The IMB also requires a factor of safety of 1.6 for all medical devices used for transporting blood in respect to maximum operating time.

Maximum average drone flight 3 hours - the device has to be tested for 5 hours.

Mathematical modelling of Medi-Pod™ was first undertaken - this mathematical model is a simplified image of a real system. The developed mathematical model maps the heat flow through the device and determines the temperature of the interior of the Medi-Pod™ developing device at any given time t in seconds – sample governing equation for temperature calculation listed hereafter:

$$T_{inside}(\mathrm{t}) = \frac{\frac{kA}{l}\left(T_{outside}(t-1) - T_{inside}(t-1)\right) - Q_{cooler}(t-1)}{Mc} + T_{inside}(\mathrm{t}-1)$$

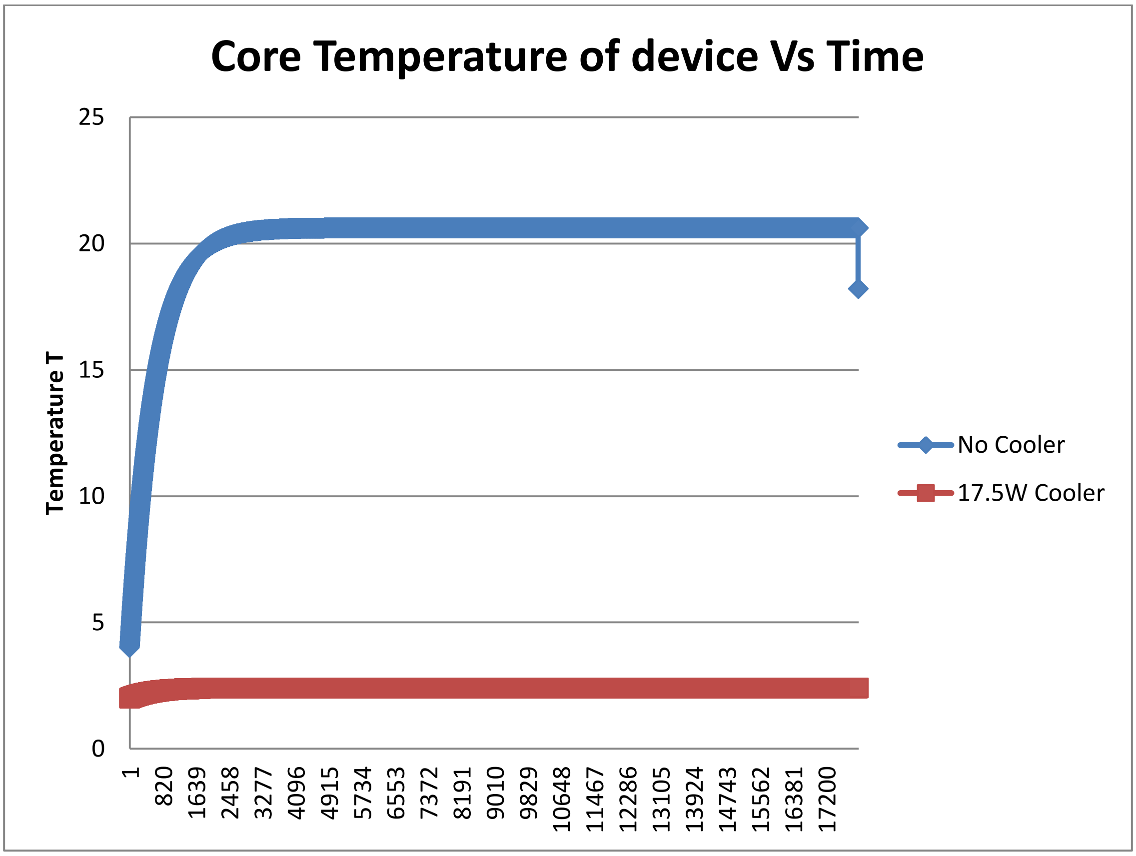


Figure 17 Time (seconds) Vs Temperature (degree Celsius) Output Plot for Developed Thermal Mathematical Model of the Device Heat Flow J.King 2014

Physical tests were then carried out on the device in accordance with IMB standards for devices - utilizing the same parameters as the developed mathematical model and performance assessed during the application and non-application of a sourced thermo-electric cooler.

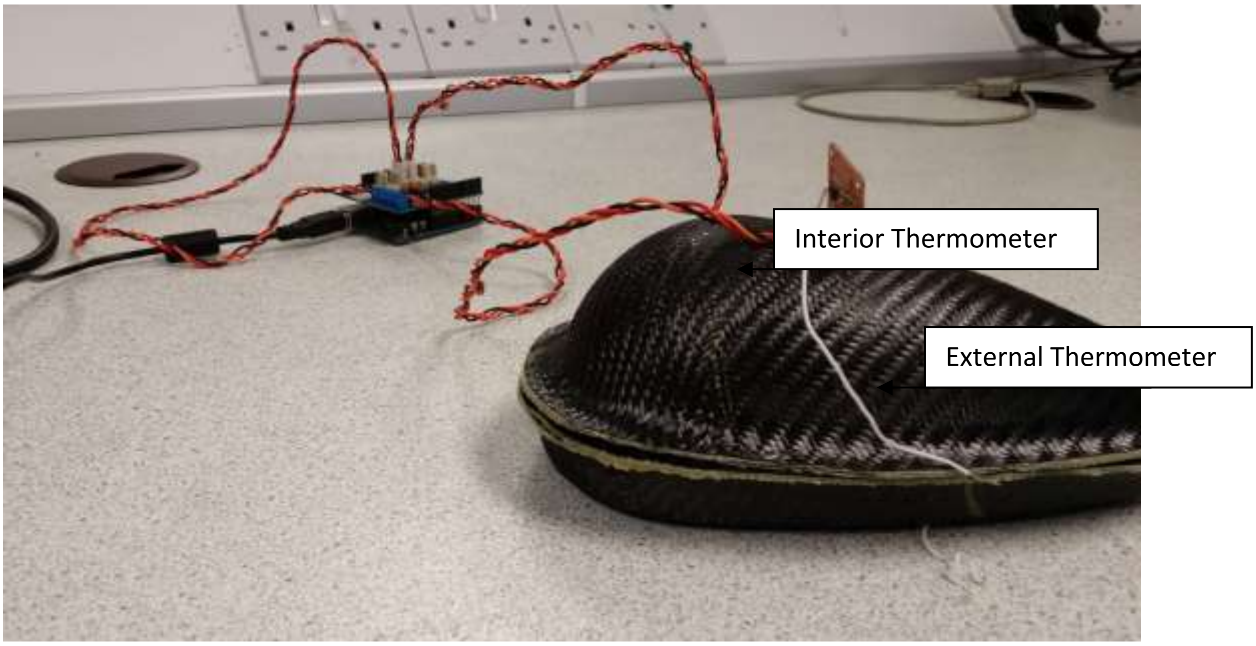
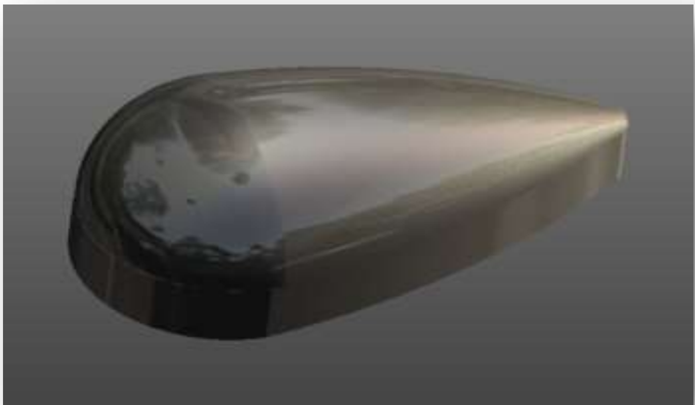


Figure 18 Thermal Conductivity Test Set Up - J.King 2014

Results:

The external temperature of the developed device does not fluctuate from its set point providing the determined 17.5W capacity thermoelectric cooler configuration system is applied.

This extremely promising operational finding holds true for external temperatures up to 40 degrees Celsius – the upper limit of required medical container operation.



9. Shell Structure Design and Testing

Advanced finite element computer aided analyses and methodologies were applied by the author to show how the device acts during flight. Pressure caused by airflow over the device has been applied to key locations on the device (see Figure 19).

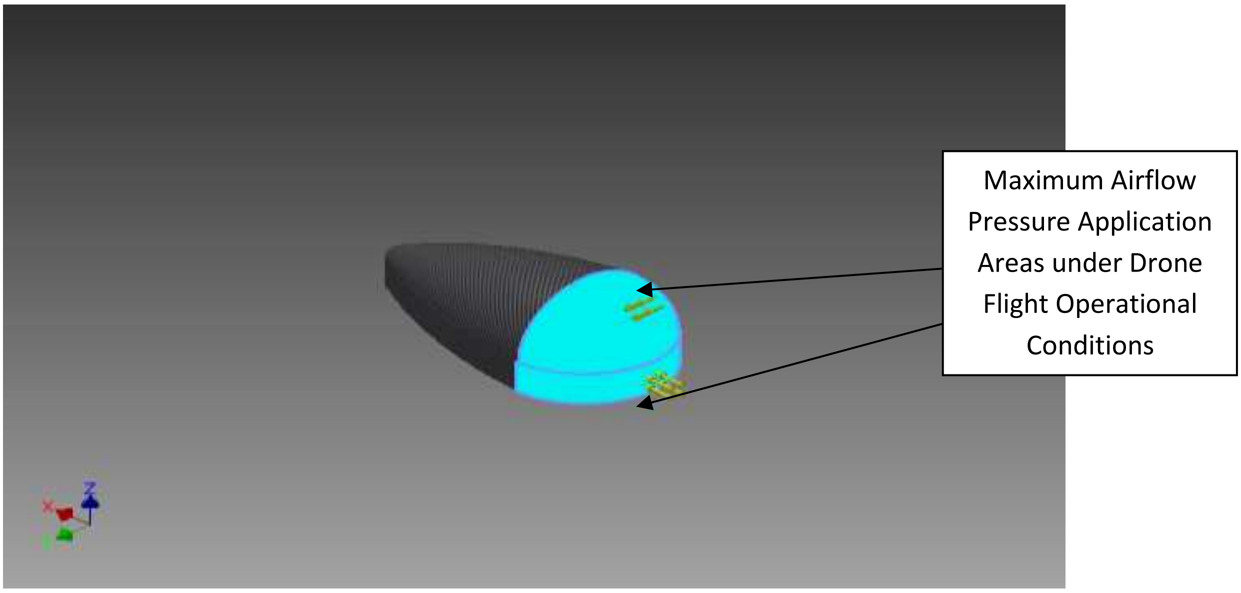


Figure 19 Max Pressure applied to Critical Locations on Developing Device Device - J.King 2014

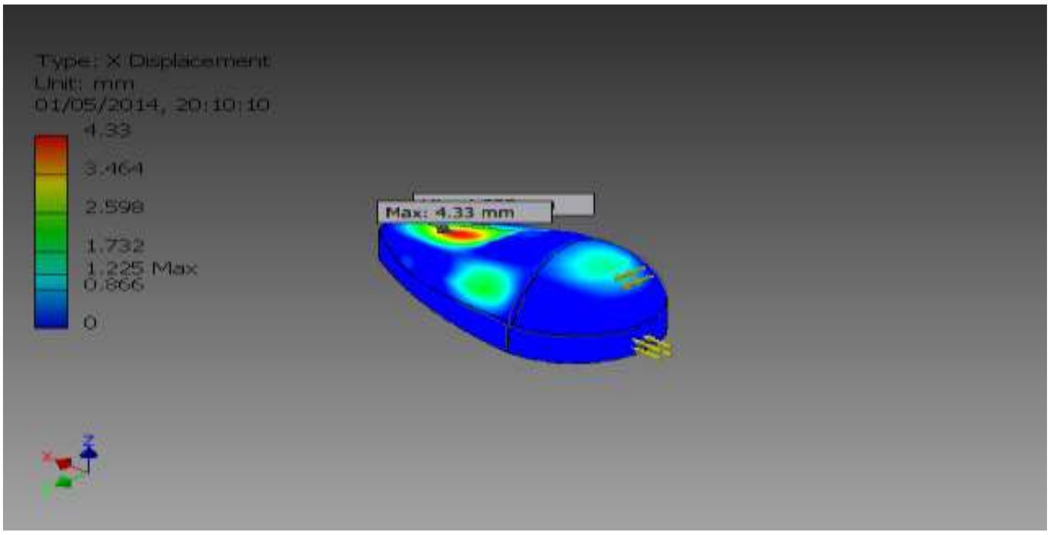


Figure 20 Shell Deformation (mm) under Maximum Applied Pressure - J.King 2014

The undertaken analyses confirmed that the shell performed well and critical stresses and deformations well below acceptable limits.

Experimental Charpy toughness and Brinnell hardness tests were also undertaken on the shell structure material and confirmed robustness of the device under drone flight operational conditions.

Carbon Fibre combined with Kevlar makes an excellent shell material, providing strength while not adding weight, providing a smooth surface finish and high energy absorption.

10. Drone Field Testing of Medi-Pod™

Successful Field Testing of MediPod™ has been undertaken with both fixed wing and quad copter drones - this testing undertaken under controlled conditions at the internationally renowned Cork Model Aero Club dedicated facility in Brinny, Inishannon, Co.Cork.

Cork Model Aero Club is widely regarded as one of the most innovative and ground-breaking developmental model aeronautic clubs, centrally involved in the successful landing in Galway (mirroring the historical flight of British aviators Alcock and Brown in 1919) of the first trans-atlantic drone flight in 2003 and host (2001) and winner of many honours at the F3A World Model Aircraft Aerobatics Championships.

Figure 21 Fixed Wing and Quad Copter Drone Field Testing of Medi-Pod™ - J.King 2014

Feedback from Cork Model Aero Club has been very positive in relation to manoeuvrability and aeronautical response / performance of the MediPod™ fitted drones in take off / lift off, landing / set down, full flight and advanced aeronautical manoeuvers. Members were particularly impressed by and very laudatory of the high stability (as indeed predicted by CFD and wind tunnel testing) and control achieved by the tear drop shaped pod fitted drones both in normal flight and complex aerobatic manoeuvers.

11. Unique Market Features of Medi-Pod™

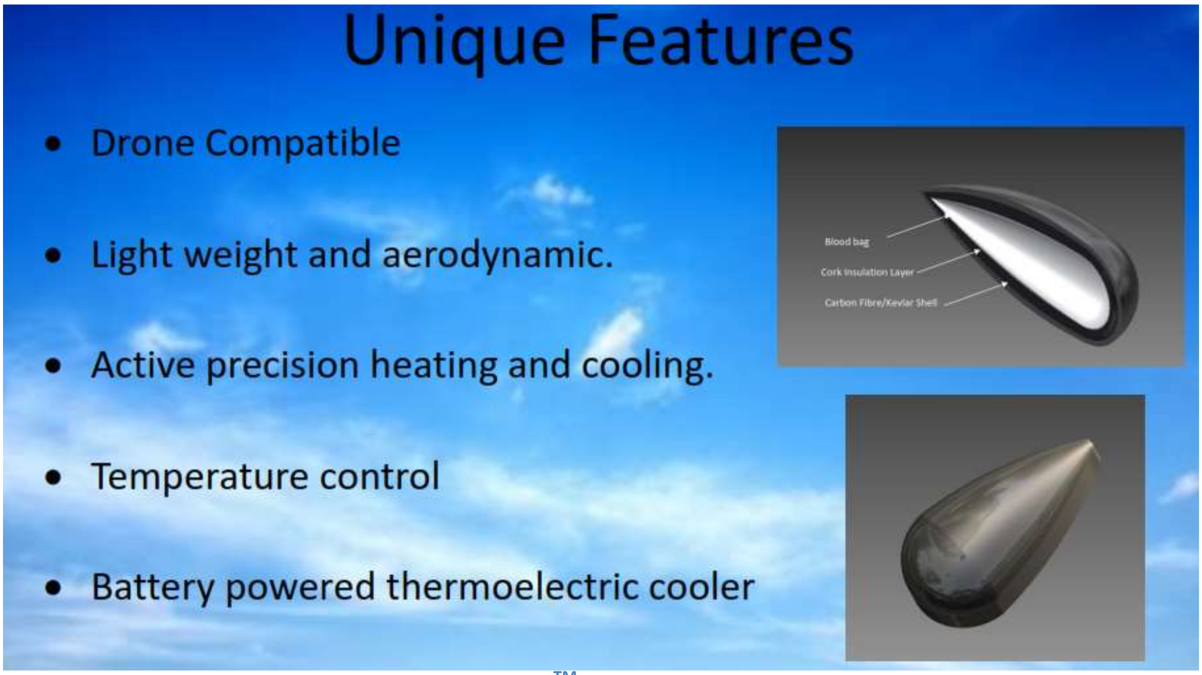


Figure 22 Medi-Pod™ Unique Features - J.King 2014

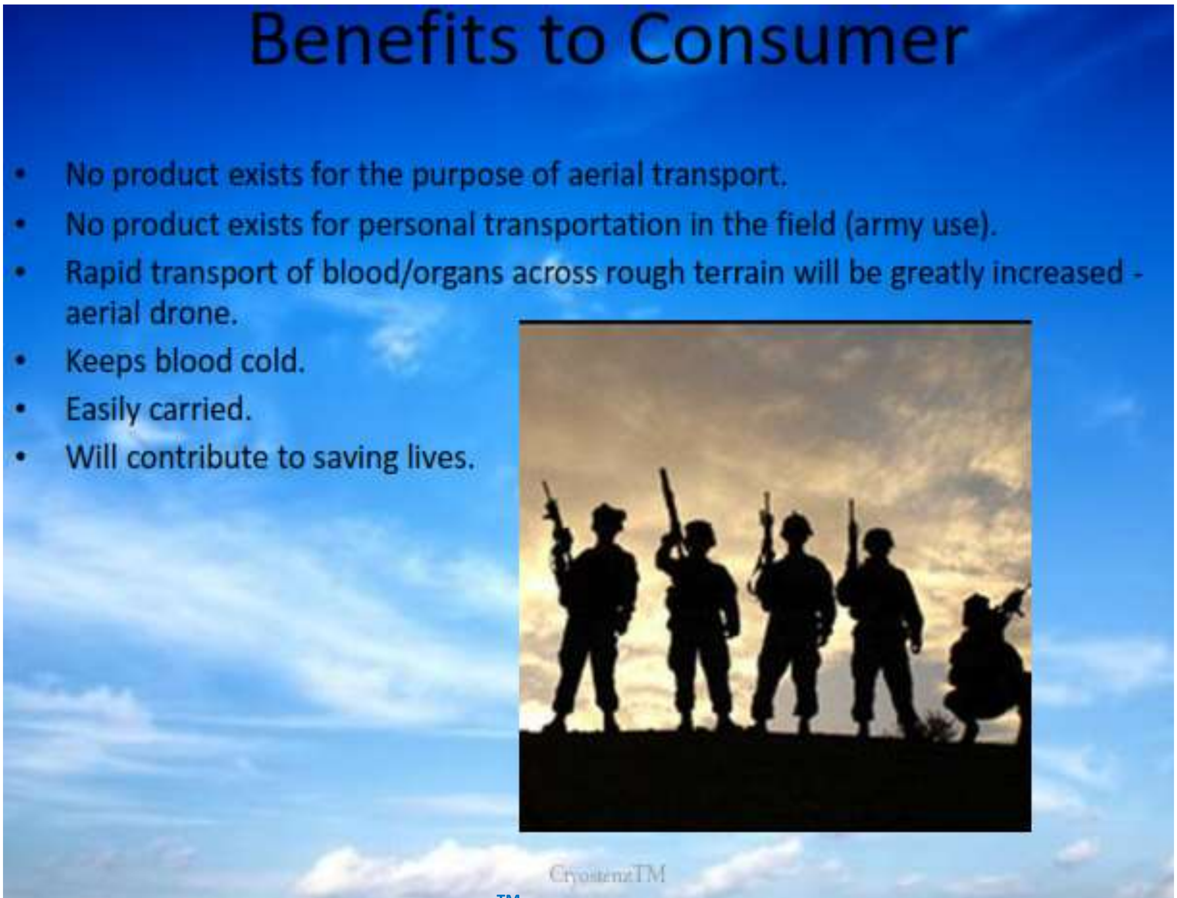


Figure 23 Medi-Pod™ Benefits to Customers - J.King 2014

12. Conclusion

The design, testing and build of the self-conceived product Medical Transportation Pod - Medi-Pod™ - prototype has been comprehensively undertaken yielding the finished functional conforming prototype.

All laboratory and fixed wing / quad copter drone field testing has been successful in proving the validity of the Medi-Pod™ concept and optimised design. Validation has been achieved by both computer simulations and physical model testing.

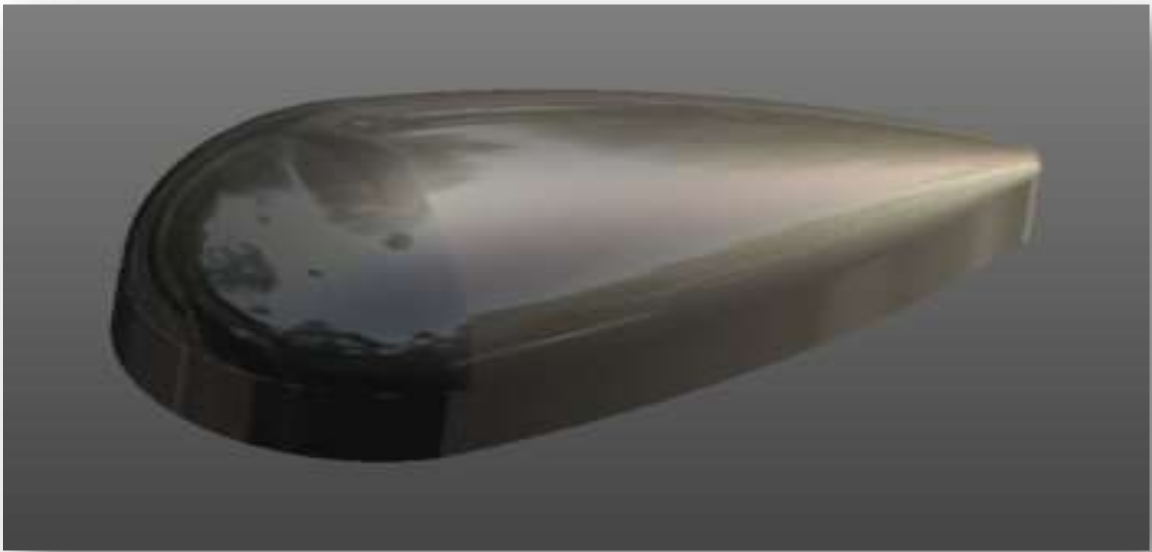
The next aim for the device is to devise a cost and time effective method for mass production of the device. Currently, the build method for each device takes roughly 8 hours of manual labour and a further two hours of machine time. This production time can be greatly reduced by a number of mass manufacture techniques used in industry.

Finding the most efficient method of production is key to making the Medi-Pod™ into a viable product and competing with industry leaders such as Avatherm and Dison.

The core drone compatibility and capability of the Medi-Pod™ product is also a critical distinguishing factor in the medical transportation market. None of the identified competitors are suitable for use with aerial drones and, at 1.454kg fully loaded, Medi-Pod™ is one fifth of weight of nearest competitor.

The device is currently fully functional. However, the addition of sensors to allow the device to self regulate rather than to operate at a predefined constant temperature would greatly benefit the device in future use.

As part of college innovation week 2014 activities, the author presented the developing project to a distinguished panel of entrepreneurs and commercialization experts through an in house “Dragons Den” competition and was awarded first place. The author is also enrolled in the Hatchery (student start-up product) program in the college and in the initial stages of marketing the Medi-Pod™ and establishing a business base.



13. References

A.Jahangirian & A.Shahrokhi, 2011. Aerodynamic shape optimization using efficient evolutionary algorithms and unstructured CFD solver. *Computers and Fluids,* Issue 46, pp. 270-276.

Akay, M., Mud, S. K. A. & Stanley, A., 1997. Influence of moisture on the thermal and mechanical properties of autoclaved andoven-cured Kevlar-49/Epoxy Laminates. *Composite Science and Technology,* Issue 57, pp. 565-571.

Alagar, M., Kumar, A. A., Mahesh, K. & Dinakaran, K., 2000. Studies on thermal and morphological characteristics of E-glass/Kevlar 49 reinforced siliconized epoxy composites. *European Polymer Journal,* pp. 2449-2454.

Army-Technologies, 2012. *Army-Technology.* [Online]
Available at: http://www.army-technology.com/projects/mq-8b-fire-scout/mq-8b-fire-scout3.html
[Accessed October 2013].

Barnes, B. & Fulford, G. R., 2009. *Mathematical Modeling with case studies; a differential equations approach using Maple and Matlab.* Boca Raton, FL: Chapman & Hall.

Caswell, J., 2012. *National Transport and Logistics Resource Plannign Manager at NHS Blood and Transport* [Interview] (28 February 2012).

Colman, D. N. & Friedman, D. M., 2002. *PBS.* [Online]
Available at: http://www.pbs.org/wnet/redgold/basics/bloodcollection.html
[Accessed 25 November 2013].

Donald F. Young, B. R. M. T. H. O. W. W. H., 2010. *introduction to fluid mechanics, Coefficient of drag on immersed bodies.* 5th ed. s.l.:John Wiley & Sons; 5th Edition edition .

Duell, J. M., 2004. Impact Testing of Advanced Composites. In: *Advanced Topics in Characterization of Composites.* Trafford: Trafford Publishing, pp. 97 - 111.

Dwyer, 2013. *Dwyer-inst.* [Online]
Available at: http://www.dwyer-inst.com/Product/Pressure/Manometers/FluidFilled/Series250-AF
[Accessed 2014].

Eastridge, D. B., 2012. *Death on the Battlefield, Implications for Prevention Training and Medical Care,* s.l.: United States Armed Forces.

Gong, J., Wu, J. & Guan, Z., 1999. Examination of the Indentation Size Effect in low-load Vickers Hardness Testing of Ceramics. *Journal of the European Ceramic Society,* pp. 2625-2631.

Gustin, J., Joneson, A., Mahinfalah, M. & Stone, J., 2005. Low velocity impact of combination Kevlar/carbon fiber sandwich composites. *Composite Structures,* Issue 69, pp. 396-406.

Heamotronic, 2013. *Heamotronics.* [Online]
Available at:
http://www.haemotronic.it/index.php?option=com_content&task=view&id=51&Itemid=31
[Accessed November 2013].

IMB, 2012. *Medical Devices.* [Online]
Available at: http://www.imb.ie/EN/Medical-Devices.aspx

Imboden, D. M. & Pfenninger, S., 2013. *Introduction to Systems Analysis; Mathematically Modeling Natural Systems.* New York: Springer Heidelberg.

ISPE, 2008. *Good Engineering Practice.* s.l.:ISPE.

Jacobson, M. Z., 2005. *Fundamentals of Atmospheric Modeling.* 2nd ed. s.l.:Cambridge University.

Joepan, 2010. *joepan.* [Online]
Available at: http://joepan.org/2013/02/20/ode-to-the-mq-9-reaper-a-poem-by-joe-pan/
[Accessed October 2013].

John D Anderson, J., 2007. *Fundementals of Aerodynamics.* 4th ed. s.l.:McGrew-Hill.

Kang, T. J. & Kim, C., 2000. Energy-absorption mechanisms in Kevlar multiaxial warp knit fabric composites under impact loading. *Composite Science and Technology,* Issue 60, pp. 773-784.

Lagutin, V., Lapygin, V. & Trusov, S., 2008. *STRESS ANALYSIS OF STRAIN-GAUGE BALANCE FOR «LIFTING BODY» MODELS AERODYNAMIC TESTS,* Korolev: 1Central Research Institute of Moscow.

Lawrence J. Broutman, e. a., 1972. *IMPACT STRENGTH AND TOUGHNESS OF FIBER,* Springfield: NTIS.

Met Eireann, 2013. *Met Eireann.* [Online]
Available at: http://www.met.ie/climate/cork.asp
[Accessed March 2014].

MHRA, 2013. *Recommendations on the control and monitoring of storage and transportation temperatures of medicinal products.* [Online]
Available at: http://www.mhra.gov.uk/home/groups/comms-ic/documents/publication/con007569.pdf
[Accessed November 2013].

Mouritza, A., Bannisterb, M., Falzonb, P. & Leongb, K., 1999. Review of applications for advanced three-dimensional fibre textile composites. *Composite Part B Engineering,* Issue 30, pp. 1445-1461.

Munson, B. R., Rothmayer, A. P., Okiishi, T. H. & Huebsch, W. W., 2012. *Fundamentals of Fluid Mechanics.* 7th ed. s.l.:Wiley.

Nasa, 1997. *Geometry for Aerodynamicists.* s.l.:Nasa.

National Aeronautics and Space Administration, 2010. *Nasa.* [Online]
Available at: http://www.grc.nasa.gov/WWW/k-12/airplane/drag1.html
[Accessed 14 Novenmber 2013].

National Health Service, 2013. *Guidance Document for cold storage temperature monitoring and mapping for blood products,* Swindon: The Pharmaceutical and Healthcare Sciences Society.

National Health Service, 2013. *Guidance Document for Cold Storage Temperature Monitoring and Mapping for Blood Products.* Wiltshire: The Pharmaceutical and healthcare Sciences Society.

P. Krishna Vagdevi, B. R. O. R., 2013. Experimental Test on Carbon Fiber/Epoxy and Glass Fiber. *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE),* 8(5), pp. 56-61.

Parker, W. J., Jenkins, R., Butler, C. & Abbott, G. L., 1960. *Flash Method of Detennining Thennal Diffusivity, Heat Capacity, and Thennal Conductivity*, California: U.S Navel Defense Laboratory.

Perry, R. G. D., 1997. *Perry's CHemical Engineers' Handbook.* 7th ed. s.l.:McGraw-Hill.

Predoi, D., 2008. *Calcium phosphate ceramics for biomedical aplications,* Bucharest: University of Bucharest.

Queesland Health, 2011. *Guideline for the Storage, Transportation and Handling of refridgerated Medicines, vaccines and blood in Queesland health Facilities,* Queensland: Queensland Health.

Rathore, M. M. & Kapuno, R. R., 2011. *Engineering Heat Transfer.* 1st ed. s.l.:Jones & Bartlett Learning.

Rosa, I. M. D., Sarasini, F., Sarto, M. S. & Tamburrano, A., 2008. EMC Impact of Advanced Carbon Fiber/Carbon Nanotube Reinforced Composites for Next-Generation Aerospace Applications. *IEEE TRANSACTIONS ON ELECTROMAGNETIC COMPATIBILITY,* 50(3), pp. 556-563.

Salehi-Khojin, A., Bashirzadeh, R., Mahinfalah, M. & Nakhaei-Jazar, R., 2006. The role of temperature on impact properties of Kevlar/fiberglass composite laminates. *Composite Part B Engineering,* Issue 37, pp. 593-602.

Salehi-Khojin, A., Mahinfalah, M., Bashirzadeh, R. & Freeman, B., 2005. Temperature effects on Kevlar/hybrid and carbon fiber composite sandwiches under impact loading. *Composite Structures,* Issue 78, pp. 197-206.

Savage, G., Bomphray, I. & Oxley, M., 2004. Exploiting the fracture properties of carbon fibre composites to design lightweight energy absorbing structures. *Engineering Failure Analysis,* Issue 11, pp. 677-694.

Schillings, C., Schmidt, S. & Schulz, V., 2011. Efficient shape optimization for certain and uncertain aerodynamic design. *Computers and Fluids* , Issue 46, pp. 78-87.

Smith, J., Van Ness, N. & Abbott, M., 2005. *Introduction to Chemical Engineering Thermodynamics.* s.l.:McGraw Hill.

Tarpani, J. R., Maluf, O. & Gatti, M. C. A., 2009. *Charpy impact toughness of conventional and advanced composite laminates for aircraft construction,* s.l.: SciFlow Brazil.

Tomasi, C., 2004. *Mathematical Modelling of Continuous Systems,* s.l.: Duke University.

Tronskar, J., b, M. M. & b, M. L., 2001. *Measurement of fracture initiation toughness andcrack resistance in instrumented Charpy impact testing,* Singapore: National University of Singapore.

Troy Built Models, 2013. *Troy built Models.* [Online]
Available at: http://www.troybuiltmodels.com/items/UAV2-ENG.html
[Accessed November 2013].

V.A.Bokil, 2009. Introduction to Mathmatical Modeling. In: *Introduction to Mathmatical Modeling.* Oregon: University of Oregon, pp. 1-24.

V.R.Mehta & Kumar, S., 1994. Temperature dependant torsional properties of high performance fibres and their relevance to compressive strength. *Journal of Material Science* , Issue 29, pp. 3658-3664.

Wu, C.-H., 2006. *Chemical Vapor Deposition of Carbon Naostructures and Carbon Naotubes-Reinforced Composite*, new York: University of Rocherester.

Yadav, S., Kumar, V. & Verma, S. K., 2006. Fracture toughness behaviour of carbon fibre epoxy composite with Kevlar reinforced interleave. *Material Science and Engineering*, B(132), pp. 108-112.