Fibonacci Series White Paper

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Wilson Benesch Ltd.
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Sheffield
England

Relevant Products discussed: Discovery 3zero, A.C.T. 3zero, Endeavour 3zero, Resolution 3zero, Omnium and Eminence.

Celebrating 30-Years of Audio Innovation and Excellence

What is a dynamic loudspeaker?
In its purest form, a dynamic loudspeaker is a system comprised of dynamic drive units or woofers that convert electromagnetic energy into acoustic energy. In the process of this energy conversion, some of the acoustic energy that is produced should heard by the listener, but some of that acoustic energy is unwanted and will diminish the performance of the loudspeaker.

In practice for a loudspeaker designer to aspire to become a master of the art of loudspeaker design in this field, he/she must become an expert in the many difference sciences and also the engineering and manufacturing capabilities that must all work in harmony to create the ultimate reference loudspeaker within the realms of what is currently possible, or what is often referred to as the State-of-the-Art.

When considering the challenge of creating a dynamic loudspeaker such as those in the Fibonacci Series, which house multiple dynamic drive units within an enclosure, the challenges are many and varied. Through three decades of research and development (R&D), in the fields of science, engineering and manufacturing, Wilson Benesch have arrived at the latest reference, Fibonacci Series.

“one third dynamic, two thirds electrostatic”

An early review on the first Wilson Benesch loudspeaker attempted to characterise the sound as being “one third dynamic, two thirds electrostatic”. The reviewer had arrived at a summation of a product whole that was in fact a harmony of multiple parts borne of an extensive 5-year R&D project to create a whole system approach to loudspeaker design.

Analogy: The Art of Dance

Figure 1: Fred Astair and Ginger Rodgers – Dancing Cheek to Cheek

When considering a whole system approach, the art of dance is an interesting visual representation of a common goal. Dancers possess a high power to weight ratio. Dance partners are similar in size and share a passion, drive and determination to create temporal accuracy in movement as an interpretation often of a musical score. In fact "Dancing Cheek to Cheek" says it all. Everything is as one together in harmony with the music.

The typical electrostatic loudspeaker does this with consummate ease, possessing as a result a transparency and coherence that is considered very natural by most who listen. This natural characteristic, honesty and faithful presentation of a music piece has remained a primary concern that has underpinned the evolution of the Wilson Benesch sound since the inception of the company. Like the constituent components from which it is made, the sound of a Wilson Benesch loudspeaker - and in particular the Fibonacci Series and its Tactic 3.0 array – is markedly different to almost, if not all its contemporaries.

Figure 2: Tactic 3.0 Array in the A.C.T. 3zero loudspeaker

Looking at figure 2 above, the important observation is the small radiating surfaces of each drive unit are controlled by very powerful NdFeB motor systems. Taken together, the small diaphragm woofer and high power motor systems deliver a very high power to weight ratio. Subsequently the behaviour of the dynamic components is very tightly controlled and precise.

Contrast this with a large woofer design and a number of compromises can be observed, large moving mass, lower power to weight ratio, stiffer surrounds and spiders to control the movement of the large diaphragm and also the inertia of the air acting upon the surface of the dynamic parts. These are the first set of design compromises to consider when adopting a large woofer.

Large diaphragms also require large cabinets which also create another set of compromises namely a significant decrease in the signal to noise ratio of the loudspeaker. This is due in part to the large surface area of the loudspeaker enclosure which resonates as the loudspeaker is in use. But also due to the large holes within the loudspeaker baffle that mount the woofers, which are virtually transparent to the out of phase energy that exists within the chamber directly behind the slender diaphragm membrane affording a relatively easy path for this energy to energy directly into the listening space.

In sharp contrast, the Tactic Multirole Drive Unit array affords,
- a much smaller aperture into the loudspeaker enclosure.
- a harmonious fit within a relatively compact front baffle and loudspeaker enclosure.
- the concomitant air load which is inevitably far more significant in large diaphragm designs, is both reduced and distributed across multiple units.

With additional benefits in,
- smaller less stiff rubber surrounds which store less energy.
- smaller less stiff spiders which store less energy.
- together the cumulative effect is a smaller delay signature of the high hysteresis spider and rubber surrounds that are unavoidable in large woofer systems.

These differences are not insignificant and naturally provide for superior step response characteristics. But one of the most important key benefits of the Tactic Multirole Drive Unit array is the alignment and proximity of each driver. Every drive unit is either within millimetres or exactly the same alignment which legislates for class leading time alignment, whilst at the same time enabling high integrity structures and elegant baffle to be created.

These are some of the more important, but by no means all of the factors that provide a cumulative benefits that translates directly into a more vivid stereo reproduction that is capable of conjuring up in a three dimensional space both the artist and venue ambience in a way that is lifelike and tangible, even at low listening levels.

A.C.T. One: Where the Story Begins

The first Wilson Benesch loudspeaker was launched in 1994. The name A.C.T. is an acronym of 'Advanced Composite Technology' and is a direct reference to the carbon fibre composite materials technology that formed the large panels at the rear of the A.C.T. One enclosure.

History and heritage are important components in the advance of a design. It is only by looking to the past and learning from what has come before that design can evolve and improve. In this respect the A.C.T. heritage serves as an elegant timeline of evolution within loudspeaker design; the Fibonacci Series 'A.C.T. 3zero' is the sixth A.C.T. loudspeaker that Wilson Benesch has created in three decades. It is the reason why the 3zero is named so – a reference to the 30+ years of loudspeaker development that Wilson Benesch has conducted.

The materials science behind the original A.C.T. was borne from 5-years of R&D. The foundation was formed by the development of the turntable sub-chassis materials that formed the Wilson Benesch Turntable. This body of work indicated a clear benefit to using stiffer, lighter materials. The Wilson Benesch Turntable was innovative in a number of ways including several examples of hybrid structures, but this research gave rise to the world's first carbon fibre composite sub chassis.

The sub-chassis was formed from two skins of Carbon Fibre either side of a honeycomb Nomex core.

The sub-chassis was formed from two skins of Carbon Fibre either side of a honeycomb Nomex core, developed in the late 1980s. The subsequent work on the tonearms was also critical to the development of our early understanding of just how significant this materials science was. Looking back more than 30-years at this development in isolation, it is quite remarkable that Wilson Benesch was creating composite sandwich structures in the sub-platter back in 1989 – similar structures using aluminium honeycomb structures with carbon fibre skins is the sub-platter is a very similar structure to those that are starting to be seen in other products within the high-end audio industry only in recent years.

The original A.C.T. One was a tour de force of design. It was in the words of Wilfried Kress a speaker that "sparked a small revolution" in design. At the point when the A.C.T. One was launched, loudspeaker design had not evolved beyond the square box form. Following Ken Kessler's review of the Wilson Benesch Turntable, Ken asked "so what's going to be your next product?" to which Wilson Benesch Design Director Craig retorted "a loudspeaker". Ken's response? "The last thing the world needs is another loudspeaker!". Ken's statement was a valid one. There was only one designer that was doing anything that wasn't based on a square box and that was the late great Franco Serblin. But the Wilson Benesch design ethos was driven by innovation and materials science, the Wilson Benesch Turntable had been a testament to this and the preliminary design work had already begun on a revolutionary new Wilson Benesch loudspeaker.

Looking back at the pages of Craig Milnes's sketch book from the time, the blueprints of the original A.C.T. One design can be seen. Not only was the new loudspeaker not a square box, but it also introduced the sloping sculptured top. Whilst at the other end of the elegant enclosure was another feature that redefined the concept of the foot. The A.C.T. One featured a complex collection of shapes made from various alloys that stabilised the structure with menacing looking 14mm spikes similar to those used today. The structural importance of this design underlined the attention to detail that could be seen throughout the design. The alloy baffle – itself a another new concept in loudspeaker design - presented a collection of Scan derived drive units that were filtered by a very simple 2.5 way crossover network. Internally, a novel internal wiring loom consisted of solid silver conductors and an oversize Teflon jacket that was assembled in house.

As important as each of these innovative elements were to the design, the A.C.T. One's defining innovation was of course the curved carbon fibre Advanced Composite Technology structures from which the loudspeaker took its name.

The A.C.T. One was developed in the prototyping workshop of the now closed Greaves Cabinet Works of Sheffield, which was at that time the centre of UK audio cabinet production. The Director of Greaves had no desire to even try to build a curved speaker but was kind enough to allow the experience and expertise of Greaves best craftsmen to work on the prototypes and subsequent first products to be manufactured.

The A.C.T. structures were made from aerospace pre-preg disposed either side of a Nomex core. Each panel was assembled by hand and the carbon fibre formed a distinctive four by four twill. The engineering expertise required to manufacture such a component was incredibly rare at the time and was confined to aerospace and Formula 1. One of the Engineers behind the development of the A.C.T. panel was the same engineer who had met the challenge of the A.C.T. One Tonearm in 1992. His experience was pivotal to the forward momentum of Wilson Benesch at this time. One of his many notable projects included being part of the Rolls Royce engineering team that had worked on the experimental carbon fibre fan blades of the RB 211 jet engine. The image in figure 1 shows the relative stress concentration across two tonearm geometries when subject to bending. This image was produced in 1998, it serves to demonstrate the depth of understanding and knowledge about materials science and geometry within component design that Wilson Benesch has attained.

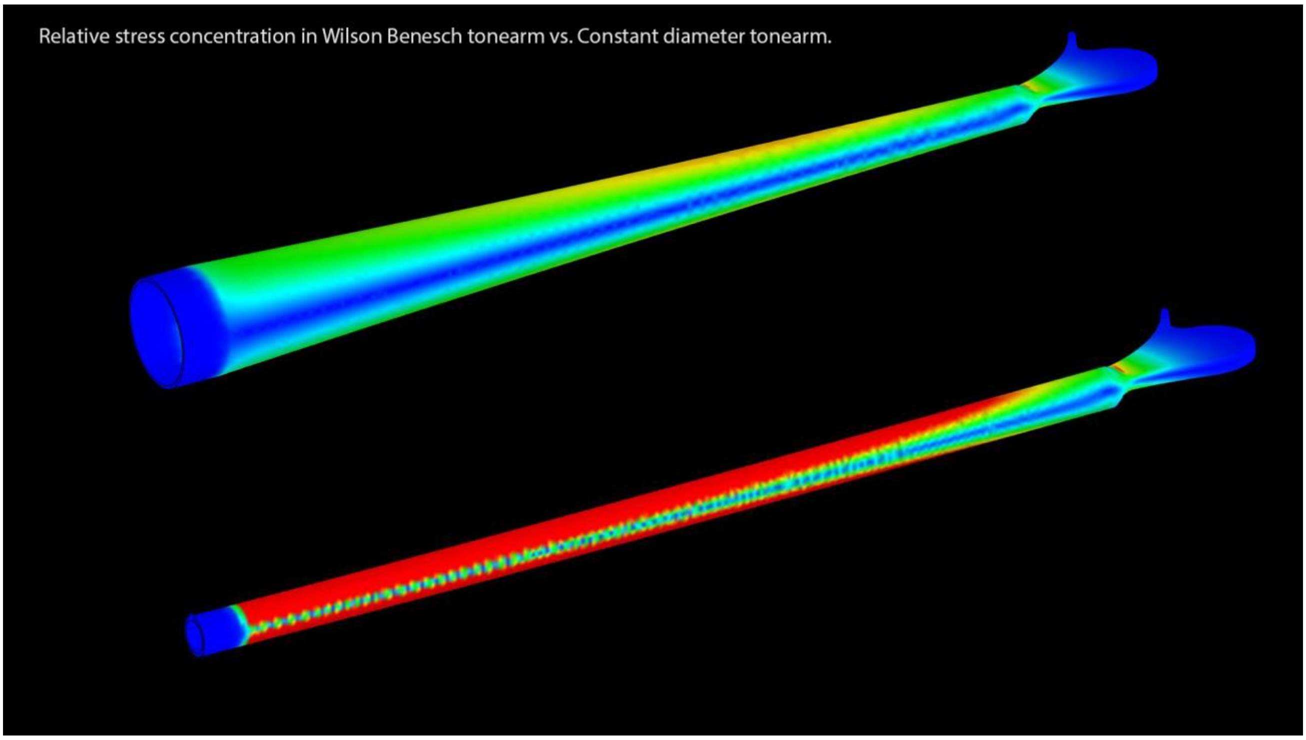


Figure 3: Finite Element Analysis shows the Relative Stress concentration across the curved and tapered geometry of the Wilson Benesch A.C.T. Tonearm at the top and the Constrant diameter tonearm below

Notable though all these elements were, perhaps more impressive was the fact that they had all been introduced in one product, but most impressive of all was the fact that such technology had all emanated from one small company. The genesis of the A.C.T One can be traced to the turntable, however the ambition that drove the design laid also laid the foundations for a unique development path, a path that was diametrically opposite to the "build em’ and spray em’" approach of the traditional square box loudspeaker industry.

The modular design of the A.C.T. One not only legislated for the introduction of mutual self-damping within the cabinet through hybrid construction techniques, it also created a framework for a design that could evolve over decades with each new design building upon the strengths and weaknesses of its predecessor. As new technologies enabled better solutions to be realised these could in turn be introduced without sacrificing the achievements seen in the previous designs.

The Evolution of the Advanced Composite Technology ‘A.C.T.’ 3zero Monocoque through Pan European Collaboration under SSUCHY

The A.C.T. Carbon Composite Monocoque was developed incrementally over 20 years. The original RTM (Resin Transfer Mould) system of manufacture was introduced into Wilson Benesch’s manufacturing facility in the late 1990s. It was a radical step to introduce such manufacturing technology at this time. Wilson Benesch was one of four organisations that committed to this new manufacturing technology, the others being Lotus cars and two M.O.D. contractors. Wilson Benesch was able to achieve this through grant aid by Her Majesty’s Government via the agency PERA.

The SSUCHY Project

In September 2017 In September 2017, Wilson Benesch commenced a collaborative research and development project entitled, “Sustainable Structural and Multifunctional Biocomposites from Hybrid Natural Fibres and bio-based polymers” – SSUCHY. The SSUCHY Project gathered 17 European partners (figure 2). Working collaboratively for 4-years to develop composite constituents, based on renewable resources (i.e. bio-based polymers and natural fibre reinforcements). The project was conducted over 48 months, from September 2017 to August 2021, with a total budget of €7.4-million, including €4.45-million of BBI JU contribution.

This project has received funding from the Bio-Based Industries Joint Undertaking under the European Union's Horizon 2020 research and innovation program under grant agreement No 744349.

Figure 4: The Collaborative partners of the SSUCHY Project from across Europe under the Horizon 2020 Fund

The A.C.T. 3zero Monocoque in the Fibonacci Series features a variety of novel materials that are derived from sustainable and renewable sources. The new A.C.T. 3zero Biocomposite Monocoque is several orders of magnitude superior to its predecessor whilst also being almost as stiff.

In depth research - Femto and Bristol University studied the function of composites at both the micro and macro level. As such it represents the most comprehensive, in-depth study ever carried out into how oil based and natural materials based composites behave when subject to structural borne vibration.

The balance between stiffness & damping - the complex interplay between damping and stiffness is critical to achieving the highest levels of optimisation. All materials including the stiffest, resonate well within the audio band. It is this intellectual property that has been acquired during SSUCHY that has enabled Wilson Benesch to adapt its manufacturing capability and unique materials processing systems in order to take advantage of this emerging science. The A.C.T. 3zero Monocoque is completely novel, next generation materials science that redefines the State-of-The-Art.

The same article also alludes to the significance of the “Modular Approach” that WB invented in the A.C.T. One. The foresight and significance of this approach is borne out of recognition of the complexity of loudspeaker design. It became the intellectual foundation of WB approach to loudspeaker design. The A.C.T. One evolved the realisation of the Odyssey Series in 2001. This evolved with identical sub-systems into the Geometry Series in 2012. In 2023 The Fibonacci Series stood on the shoulders of its predecessors and moved the technology forward with lessons learned over decades.

Real improvements in any sphere of engineering are more often than not based on huge investment of both time and money. The investment made by WB's Modular Approach is now one of the companies most valuable assets.

In much the same way as the Porsche 911 continues to evolve and improve over decades the uniqueness and pedigree of the resulting design totally contrasts with that of the monolithic design. A monolithic design is a single, highly constrained, one off. Without any doubt then, one of the major strengths of The Fibonacci Series is it's pedigree. Another significant stage in the on-going development that is now entering it's thirtieth year. Fibonacci is not only a life times work it is also a celebration of collaboration. Without the input of a huge number of engineers and scientists none of this would have been possible. Fibonacci is above all else, testimony to the benefits of collaborative research and development. There is no disputing the uniqueness of the outcome.

Figure 5: The Fibonacci Series in 2022 at its launch - from Discovery 3zero on the left to the Eminence on the right

Resonance and Sound

In a loudspeaker cabinet design, the aim of the audio engineer is to produce a cabinet that is silent whilst the loudspeakers drive units reproduce the sound of music. Figure 4 and Figure 5 below that were generated during testing and development through the SSUCHY Project show the A.C.T. Monocoque being subjected a wide spectrum of audio frequencies, with a series of sensors across the monocoque to study the resonant frequencies and behaviour of the structure when subject to acoustic energy. This kind of analysis has allowed Wilson Benesch to continually refine the design and improve it. When a loudspeaker cabinet vibrates or resonates it is creating sound waves and therefore additional sound to that which was originally reproduced by the drive unit and thus an unwanted addition to the music. Audio engineers adopt many different traditional methods of reducing resonance within the loudspeaker chassis, a common example is internal bracing, but the most commonly accepted approach to controlling the resonance of the cabinet it to create it from stiff materials that resist resonance. It is in the second respect, that carbon fibre can be seen to push the performance envelope further than any other material currently used in loudspeaker chassis design.

Figure 6: Image produced courtesy of Femto_ST Research under SSUCHY. Extract from Masters Paper by Aymen Barhoumi.

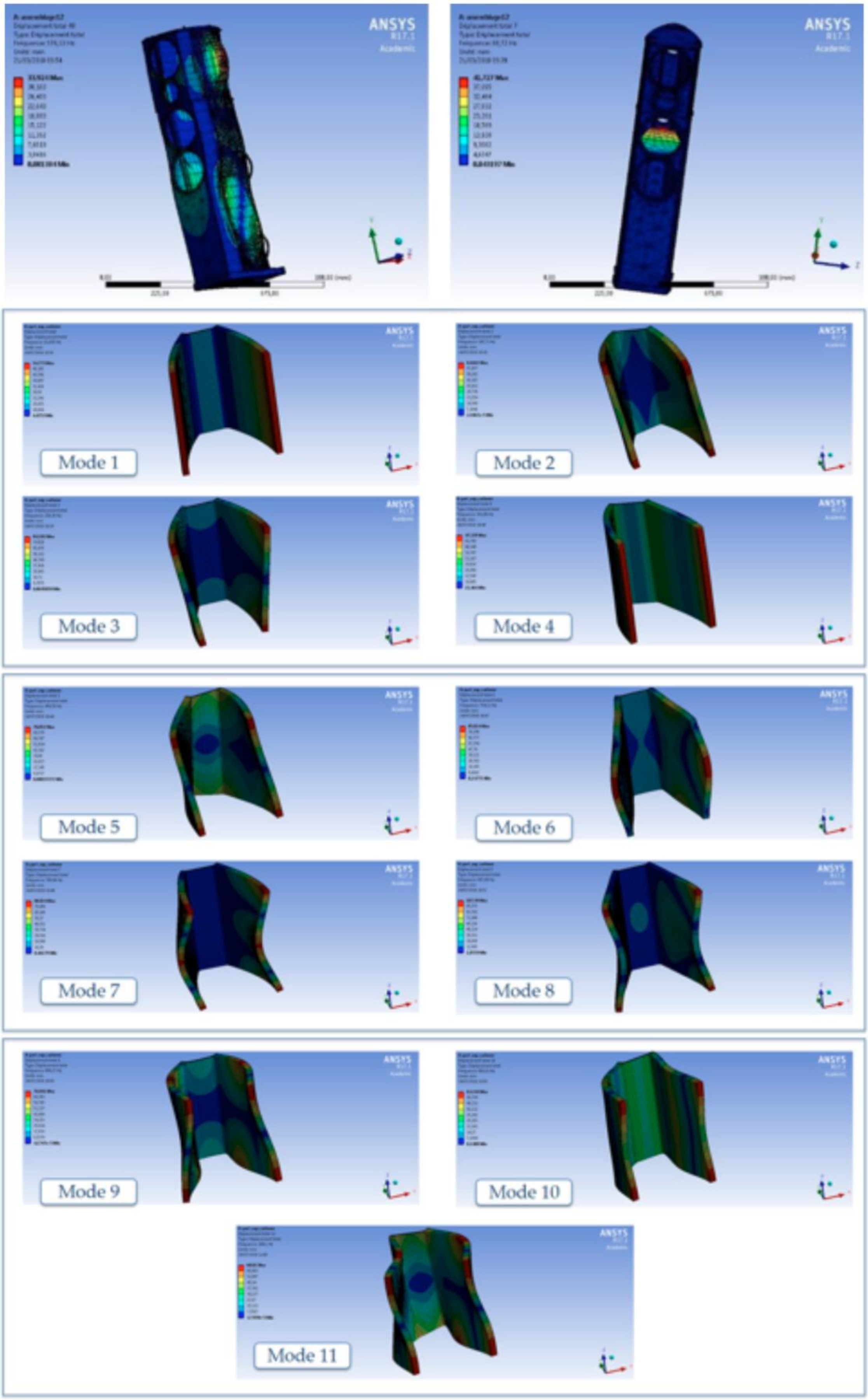


Figure 7: Image produced courtesy of Femto_ST Research under SSUCHY. Extract from Masters Paper by Aymen Barhoumi.

So how does a composite fibrous monocoque improve performance in a loudspeaker?

The A.C.T. 3zero Monocoque is a complex composite structure with a fibrous material at its core. The fibrous material that is comprised of billions of single fibres which when infused with a resin and cured, creates a stiff, lightweight material. The orientation of the fibres is key to the stiffness of the material and can be manipulated by the designer to create highly optimised structures and components with stiffness in specified areas where strength is required.

As an example of the remarkable properties of fibrous materials, Carbon fibre which Wilson Benesch still use within certain components within the Fibonacci Series, is known to be 10x stiffer than steel, whilst also having a significantly lower mass than aluminium. Perhaps the numbers are hard to grasp and put into perspective, but watching the video via this link, Top Gear's Richard Hammond demonstrates nicely the remarkable stiffness and strength of a carbon fibre crankshaft compared to a steel crankshaft at Lotus F1 Test facility:
https://www.youtube.com/watch?v=hjErH4_1fks.

In a loudspeaker the balance of stiffness and energy damping within the enclosure is important. But to draw on the concepts introduced above via the crankshaft, when you turn up the volume and the amount of energy inside the loudspeaker cabinet increases, at its most basic level the fibrous A.C.T. 3zero Monocoque resists resonance better than any other known material. However, as can be appreciated by studying the illustrated diagram below, the Wilson Benesch A.C.T. 3zero Monocoque is a composite construction which combines the stiffness of hemp fibres with the damping properties of a naturally sourced core material. Now exists a structure that is able to not only resist resonance, but also absorb kinetic energy and dissipate it as a heat exchange with the environment rather than produce cabinet resonances that are audible in the listening environment.

Geometry in A.C.T.

It is widely recognised that highly optimised structures exhibit geometrically optimal elements. In pursuit of performance nature has already rejected less than optimal designs and by looking at forms found in nature one can learn many lessons in design. The Wilson Benesch font was designed on pure geometrical forms and it's the ethos that has underpinned every design for three decades.

The shell shown in figure 6 is one of the finest examples of such a structure. The mollusc shell provides protection to the soft flesh of the mollusc residing inside, therefore this structure needs to be strong. The shell has evolved into a curved shape since this geometric form is one of the strongest forms, distributing weight and pressure evenly to the entire structure. The A.C.T. 3zero Monocoque uses the a curved form to add to the phenomenal stiffness of the composite structure and optimise its form and function.

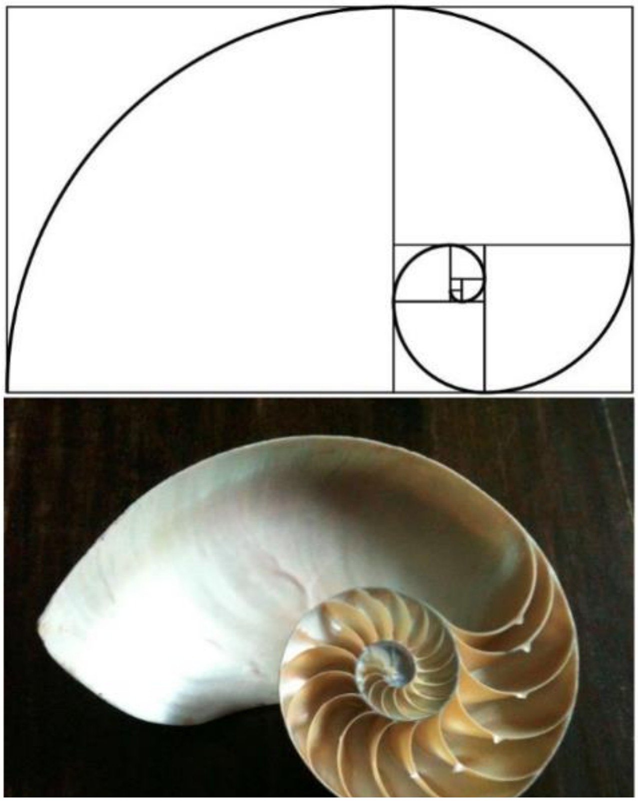


Figure 8: The Fibonacci Spiral generated by mathematics and shell of a Mollusc showing this Golden Ratio in Nature

But the curved form also plays a second crucial role in dictating both how the loudspeaker interacts with sound frequencies that are reflecting around the listening room and also how the small acoustic signature of the loudspeaker cabinet is dissipated.

Jodrell Bank telescope uses a curve to focus radio waves onto one point. It can receive signals from deep space millions of miles away from earth. The curved form of the A.C.T. monocoque acts in the opposite manner – by creating curves on the exterior surface the enclosure of the loudspeaker disperses sound waves and reduces their energy.

Figure 9: Jodrell Bank Observatory

If you observe how your voice reflects from a flat wall compared with a curved wall, it is easy to appreciate that the volume of your reflected voice is much lower when reflected from a curved wall compared with a flat wall. This is because the sound energy is dispersed across a wide angle, rather than focused in a direct line back toward you. This is critically important to a loudspeaker, which should disappear within the listening space leaving only the sound of the music.

A.C.T. 3zero Monocoque Advanced Composite Technology

If the sophisticated A.C.T. 3zero Monocoque structure was judged by purely engineering function, it would lay claim to being one of the worlds lightest, stiffest and most highly damped structures ever manufactured. In terms of energy damping and therefore signal-to-noise ratio, it would exceed with consummate ease the traditional conventional materials typically seen in loudspeaker design to date.

Regular carbon fibre weave ⟶ 50,000 Fibres per toll; Millions of fibres in a single structure ⟶ Single fibre 1:50,000th the diameter of a human hair

The A.C.T. 3zero Monocoque has been engineered and optimised for its critical role in audio reproduction:

1. **Composite Structure;** Its composite structure vastly improves the damping property of Hemp Fibres. The combination of the core material and other materials that are protected under intellectual property creates a biocomposite composite monocoque with optimised stiffness and damping properties for use within the Fibonacci Series enclosure.
2. **Fibre orientation;** a single toll of hemp fibre consists of hundreds of thousands of microscopic fibres. Each fibre presents a boundary between escaping energy inside the loudspeaker cabinet and the listening environment. Furthermore, these fibres are arranged in a regular fashion. The discernible fibrous weave in the monocoque allows the energy being absorbed by the structure to flow directionally along the weave into the viscoelastic seals which bond the aluminium structures in the speaker.
3. **Sound transmission;** because of the directional flow of energy down the regular weave and fibres in a hemp fibre composite structure, the velocity of transmission of this energy is greater than any conventional material. This provides the designer with a significant advantage, allowing the small amount of unwanted sound energy escaping from the loudspeaker cabinet to occur as close as possible to the original sound made by the drive units in the loudspeaker. This avoids unpleasant smearing of the sound from cabinet resonance during playback.
4. **Geometrically optimised;** the perfect curvature disperses sound energy both internally and externally evenly across its surface. This is critically important in loudspeaker cabinet design. It eradicates what audio engineers term *standing waves*. This inhibits the ability of the listener to easily locate one point of diffraction, so the loudspeaker cabinet remains silent.
5. **High Resonant Frequency;** every object has a natural resonant frequency. Stiff - light structures naturally have a high resonant frequency, where compliant - heavy structures have a low resonant frequency. High frequencies are easily damped, where low frequencies are very problematic and cannot easily be damped. In the Fibonacci Series, structures with a high resonant frequency such as the A.C.T. 3zero Monocoque and the aluminium structures are damped using visco-elastic seals, which can easily absorb any high resonant frequencies.

Cabinet Design in the 21st Century

The image below (figure 8) provides a simple comparison between two structures with the same air volume and the same stiffness. The image illustrates the huge difference in the relative size and weight of the two structures in order for each to achieve the same design goal.

Figure 10:

The design limitations of MDF indicate that they are inappropriate for use in loudspeaker cabinets aspiring to be the ultimate solution.

Replacing MDF with aluminium improves stiffness, however aluminium exhibits very poor self damping, the result would be a highly resonant structure. In order to control resonance in designs based around aluminium, elaborate and complex bracing is deployed, which in turn subtracts from the air volume of the internal cabinet, a major loudspeaker design compromise.

Key Concepts

All cabinet structures resonate and emit sound.

Mass

High Mass = Low Resonant Frequency = High Cabinet Noise Low Mass = High Resonant Frequency = Low Cabinet Noise

Resonant Frequencies

High Resonant Frequencies are easily damped. Low Resonant Frequencies are difficult to damp.

Surface Area

If a loudspeaker cabinet has 100 times the surface area of the drive unit diaphragm it only has to move (resonate) 100th the amount of that diaphragm to produce the same output.
So it follows, large cabinets are inherently less stealth like and silent.

The Biocomposites Age

Wilson Benesch pioneered the use of carbon fibre composite structures in audio design. The company now has more than 30-years experience and intellectual property, relating to the exploitation of this important field of engineering.

It goes without saying that this wonder material has revolutionised the automobile industry, aerospace industry and sports equipment industry to name a few. Countless examples can be seen from the McLaren P1, to the Boeing 787 Dreamliner, or to Sir Bradley Wiggins's incredibly stiff, lightweight carbon fibre bicycle used to win the Tour de France. But in 2023, the composite age is now moving from petrochemically derived plastic carbon fibres into a sustainably sourced natural fibre biocomposite age.

In each case the unrivalled stiffness, strength and the phenomenal weight advantage that fibre composites have provided has allowed these designs to become a reality. But of course, the inherent property of fibre composites, which is key to Wilson Benesch designs such as the A.C.T. 3zero, is the phenomenal damping properties of these composite structures and the ability to channel and manage energy flow in one single structure.

Perhaps the best 'real world' example of this property is in Formula 1 car design. Here carbon fibre structures have been subjected to the most public demonstrations of the phenomenal capacity of this material to absorb huge amounts of energy, whilst remaining largely intact in order to protect the driver in the car. Today there are countless drivers who owe their life to this material. They are the stiffest most highly damped structures known to man.

Figure 11: The Red Bull RB18- the F1 Championship winning car in the 2021-22 Season

However the future of composite materials use within engineering is now being redefined. Research and development projects just like SSUCHY are emerging now globally as the push to eliminate petrochemical based composite structures is growing. The composite structures of the future are already being seen across high performance engineering products and structures (see Figure 10 and 11). The Wilson Benesch Fibonacci Series is just one example and it demonstrates the pioneering developments that continue at Wilson Benesch.

Figure 12: Hemp Fibre Biocomposite body panels used in the chassis of the new Porsche Cayman 718 GT4 CS MR: https://www.bcomp.ch/news/porsche-full-natural-fibre-bodykit/

Figure 13: The Tesla Electric GT P100D: https://www.bcomp.ch/news/racing-egt-tesla-and-building-sustainable-racetrack/

Mutual Self Damping: Aerospace Engineering Materials

The concept of mutual self damping is central to any high performance engineering system, especially those where a high degree of control over the structures behaviour is concerned. A rudimentary example would be the use of the fingers in stringed instruments to control the vibration in strings and so changing the sound the instrument makes.

damp·ing

noun *Physics.*
1. *a decreasing of the amplitude of an electrical or mechanical wave.*
2. *an energy-absorbing mechanism or resistance circuit causing this decrease.*
3. *a reduction in the amplitude of an oscillation or vibration as a result of energy being dissipated as heat.*

Mutual self damping is based on the energy absorbing potential (damping ratio), of two quite different materials which are brought together. When the materials are disturbed from their static equilibrium, the resonant frequencies of each material act upon each other and reduce or stop completely, one and the others resonance – the mutually self damp one another.

The image below shows one such example of a resonating glass, being damped by the finger. This is identical to the percussionist, damping the cymbal by grabbing it.

Wilson Benesch exploit mutual self damping through the use of aerospace engineering materials. The A.C.T. 3zero Bicomposite structure, which is mutually self damped in its own right, is combined with the aluminium baffle, spine and bass board. The biocomposite structure legislates for the use of aluminium, a (relatively) poor damping material, by damping the aluminium before it is excited by the energy born from the loudspeakers drive units.

Wilson Benesch: The History of Mutual Self Damping

In 1994 Wilson Benesch announced the A.C.T. One Loudspeaker. At the time the design was radically different from anything that had been seen before in the high end audio market.

Unlike the single material, recti-linear MDF box designs of the day, the A.C.T. One consisted of a curved carbon composite chassis. But the success of the design was based on the use of no fewer than five different materials, including hard wood, MDF, aluminium, steel and of course the A.C.T. composite.

3D Parametric Design

With the exception of the Discovery 3zero, all the models in the Fibonacci Series feature a beautifully sculptural carbon composite top. Whilst a very natural, organic form, based on curves and free flowing lines, the shape is an extremely complex 3D structure that has been optimised using powerful 3D Parametric Computer Design software.

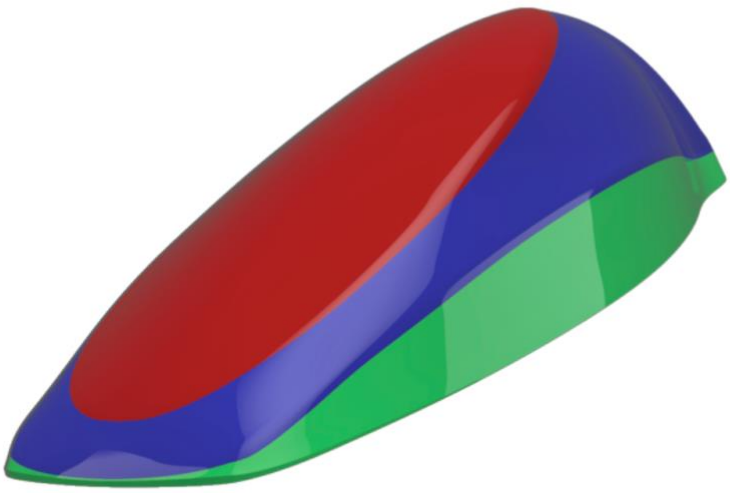


Figure 14: The Complex Geometry of the Eminence Loudspeaker Top

All of the carbon fibre tops evolved from sketches to full sized clay and wax sculptured forms. The wax model are then extensively modelled in a digital 3D space using a 3D laser scanner. The data is placed into a 3D design package and the complex forms are then refined further, creating a symmetrical structure down medial plane.

This method is akin to reverse engineering, but the advanced engineering software available to Wilson Benesch provides a unique and highly efficient workflow. Were it not for the 3D laser scanner and the engineering excellence that exists within the Wilson Benesch design team, the complex forms found within the tops of each loudspeaker in the Fibonacci Series would not be conceivable.

Such highly engineered, sculptural structures are exclusively the preserve of high-performance products or architectural forms. The top of a Fibonacci Series loudspeaker is therefore a testament to the significant design and engineering excellence that pertains at Wilson Benesch, it is the hallmark of a true high end audio product.

Stealth;
Mastering Reflection, Refraction and Diffraction

Stealth Structure

Stealth

n
1. (Aeronautics) (*modifier*) denoting or referring to technology that aims to reduce the radar, thermal, and acoustic recognisability of aircraft and missiles.

Figure 15: The Royal Albert Hall, London: Large fiberglass acoustic diffusing discs in the roof remove the echo from the Albert Hall. Prior to their installation in 1969, it was said that the hall was the only place where a British composer could be heard twice.

When a longitudinal sound wave strikes a flat surface, sound is reflected in a coherent manner provided that the dimension of the reflective surface is large compared to the wavelength of the sound. However, the reflective nature of a structure varies according to the shape of the surface. Uneven surfaces will tend to scatter energy, rather than reflect it coherently.

In good design, form always follows function. So whilst the loudspeaker tops form a beautiful structure, the complex 'stealth like' form is critical to the performance of the loudspeaker. By removing any flat, reflective surfaces and creating a highly complex structure, any reflective sound energy is scattered. This diminishes its energy and also avoids standing wave patterns within the listening space that are easily detected by the human ear as distortion or colouration.

The Fibonacci Series owes much of its phenomenal capacity to present a spatial soundstage and transparent imaging, to the curved carbon composite forms of the top and the A.C.T. 3zero Monocoque. The loudspeaker stealthily disappears within the listening space, leaving an ethereal soundstage and lifelike presentation.

The Evolution of the Tactic Multirole Drive Unit

When Wilson Benesch introduced the original multirole *Tactic Drive Unit* in 2001, it was the first drive unit in the market to utilise the incredible magnetic power of NdFeB or rare earth magnet. Now more widely used in high end drive unit designs, but by no means industry standard owing to the very high cost of the material, NdFeB is the most powerful commercially available magnet available.

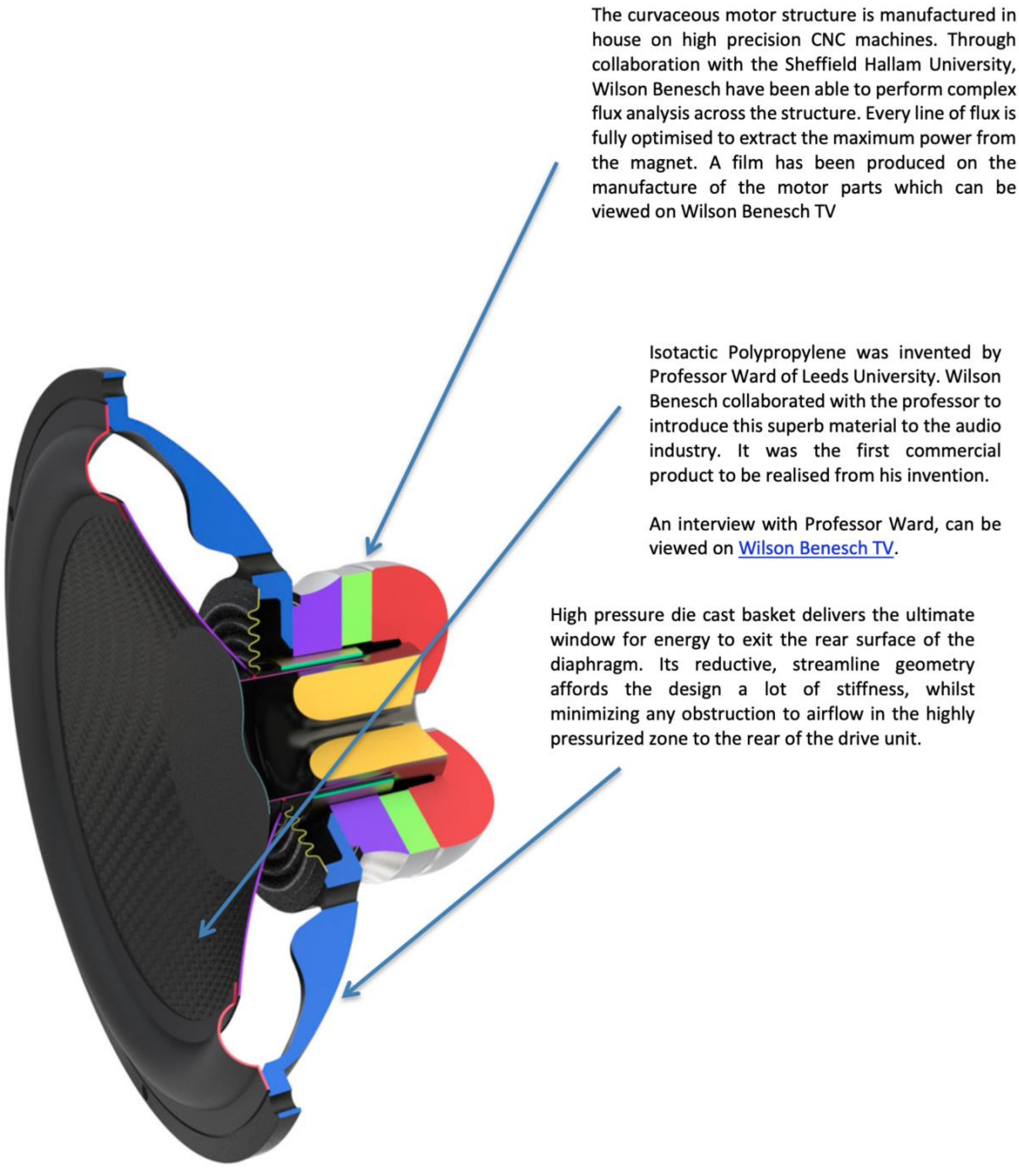


Figure 16: A Cross Section of the Tactic Multirole Drive Unit

An interview with Professor Ward, can be viewed on Wilson Benesch TV.

Isotactic Polypropylene (IPP)

Underpinning the Wilson Benesch design philosophy is science; in engineering and the application of the basic physical laws that govern the universe. Since the foundation of the company in 1989, advanced materials technology has consistently led our extensive R&D programmes and much of our product development has hinged around one wonder material or another.

No where can the concerns for balance in both stiffness and damping be better seen than in the material used in the diaphragm. Wilson Benesch rejected carbon fibre for this application in the early nineties and instead chose a material called Isotactic Polypropylene. IPP was developed by Professor Ian Ward. Isotactic literally means, “of equal inclination” and refers to the repeating, regularly spaced methyl group on the backbone of the chain within IPP chemical structure allowing the macromolecules to coil into a helical shape. It is this chemical property that makes IPP the most suitable choice for a high end drive unit design.

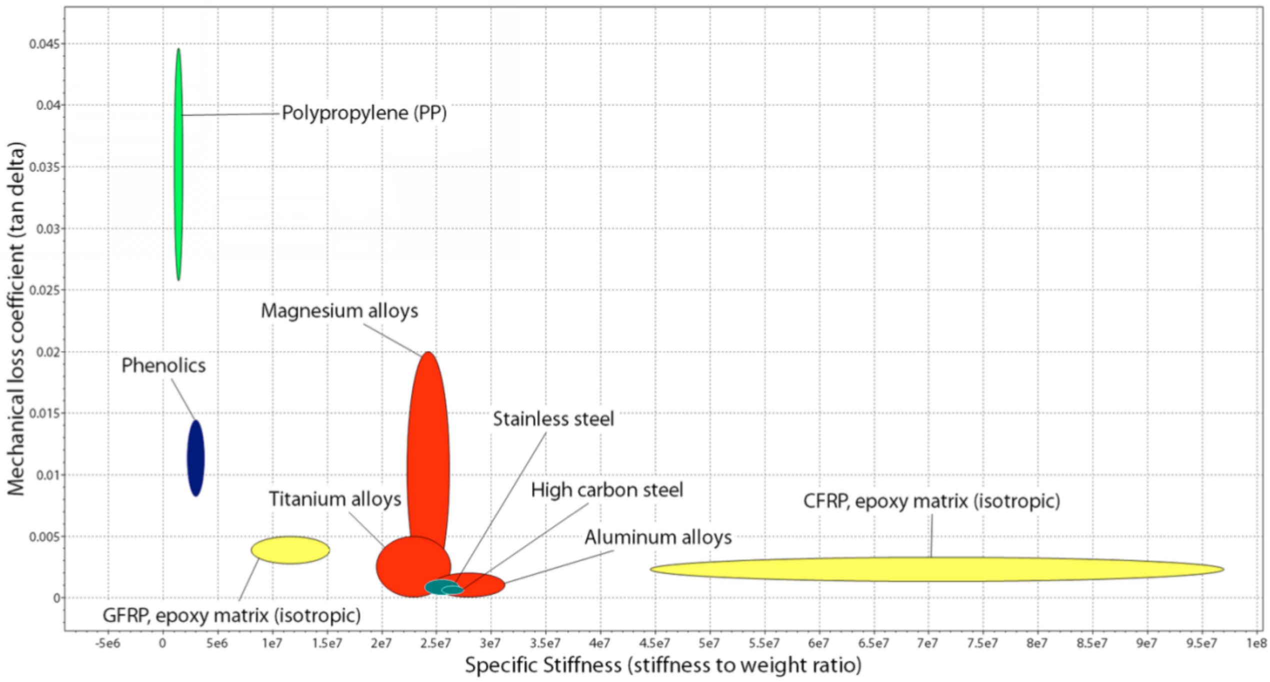


Figure 17: Specific Stiffness vs Mechanical Loss Coefficient of Various Materials

The graph above compares the degree to which a material damps vibrational energy (mechanical loss coefficient) and its stiffness to weight ratio. Whilst polypropylene has a relatively low stiffness to weight ratio, it has excellent ability to damp vibrational energy. Woven Isotactic Polypropylene is in fact five times stiffer and better damped than the homogenous polypropylene shown in the graph above.

When subjected to audio frequencies a drive unit diaphragm moves in and out to create sound waves at different frequencies that produce a musical piece. However the timbre, quality and clarity of the sound produced has a direct relationship to the material used to create the sound.

Wilson Benesch rejected carbon fibre diaphragms made from a carbon fibre / epoxy matrix, after trials undertaken in 1995. Further research has been conducted using alternative hard dome materials. Without exception the highly engineered, highly optimised Tactic Drive Unit accompanied by IPP was chosen for its natural sound and none sibilant sound character.

Tactic 3.0 Drive Unit

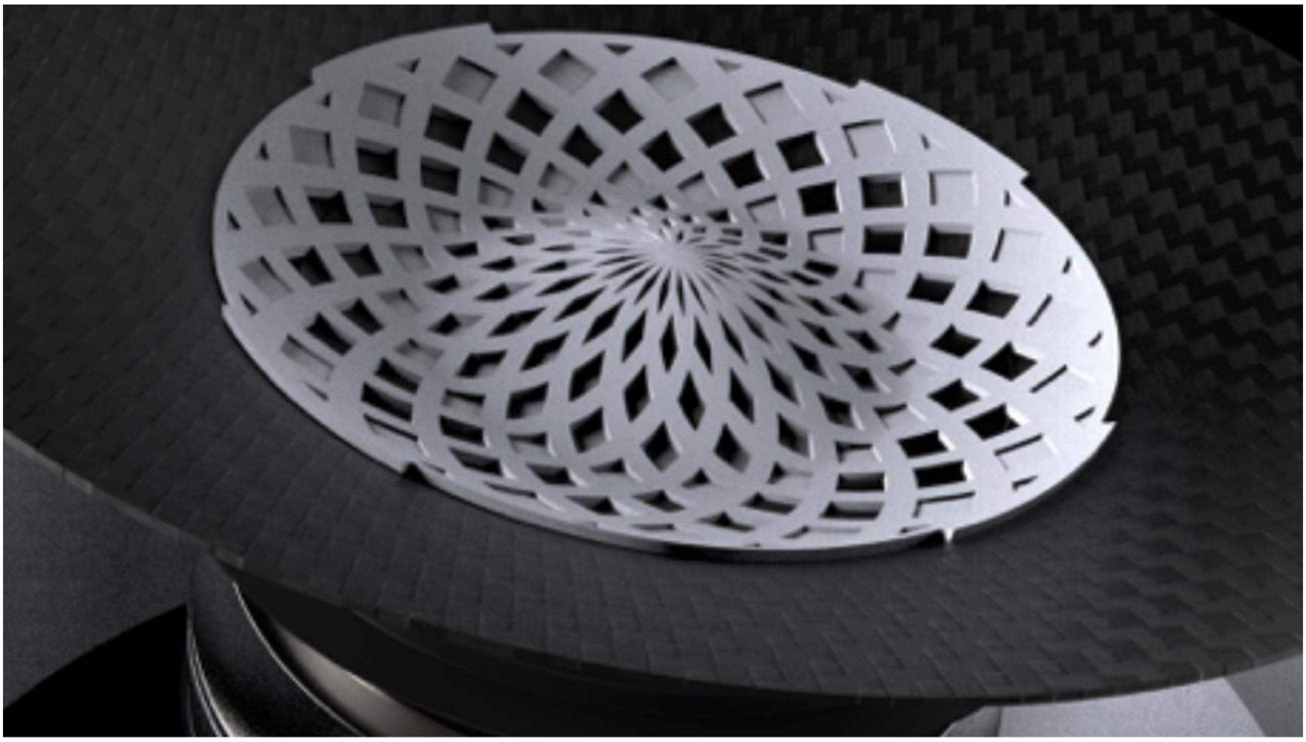


Figure 18: The image above shows the latest version of the ever evolving Tactic technology represented by Tactic 3.0.

The "dustcap" plays a critical function in the behaviour of this system. Different materials are deployed to provide the optimal behaviour for the different frequency bands that the driver is required to reproduce. The structure at the centre of the diaphragm plays a critical role in providing damping as well as influencing and to some extent depending on the materials and geometry actually shaping the upper section of frequencies output of the diaphragm. This is a critical aspect of the relationship between the drive unit and its ability to blend and be in harmony with the roll off of the tweeter. In the past, several materials have been drawn upon to enable the fine tuning of this marriage. Additive Manufacturing has opened up a new chapter in the pursuit of this subtle but extremely important aspect of loudspeaker design. For the first time the principle aspects of this structure can all be adjusted in a way that was previously impossible. The result is a new geometrical form that is comprised of a double curvature with both open and closed aspects in the form of a lattice structure again borrowed from natural geometry. 5 different materials and adhesives provide significant improvements in the both the accuracy of the frequency response and the reduction of distortion.

Tactic 3.0 Isobaric Drive

Figure 19: The A.C.T. 3zero with the monocoque removed to show all of the main dynamic drive units

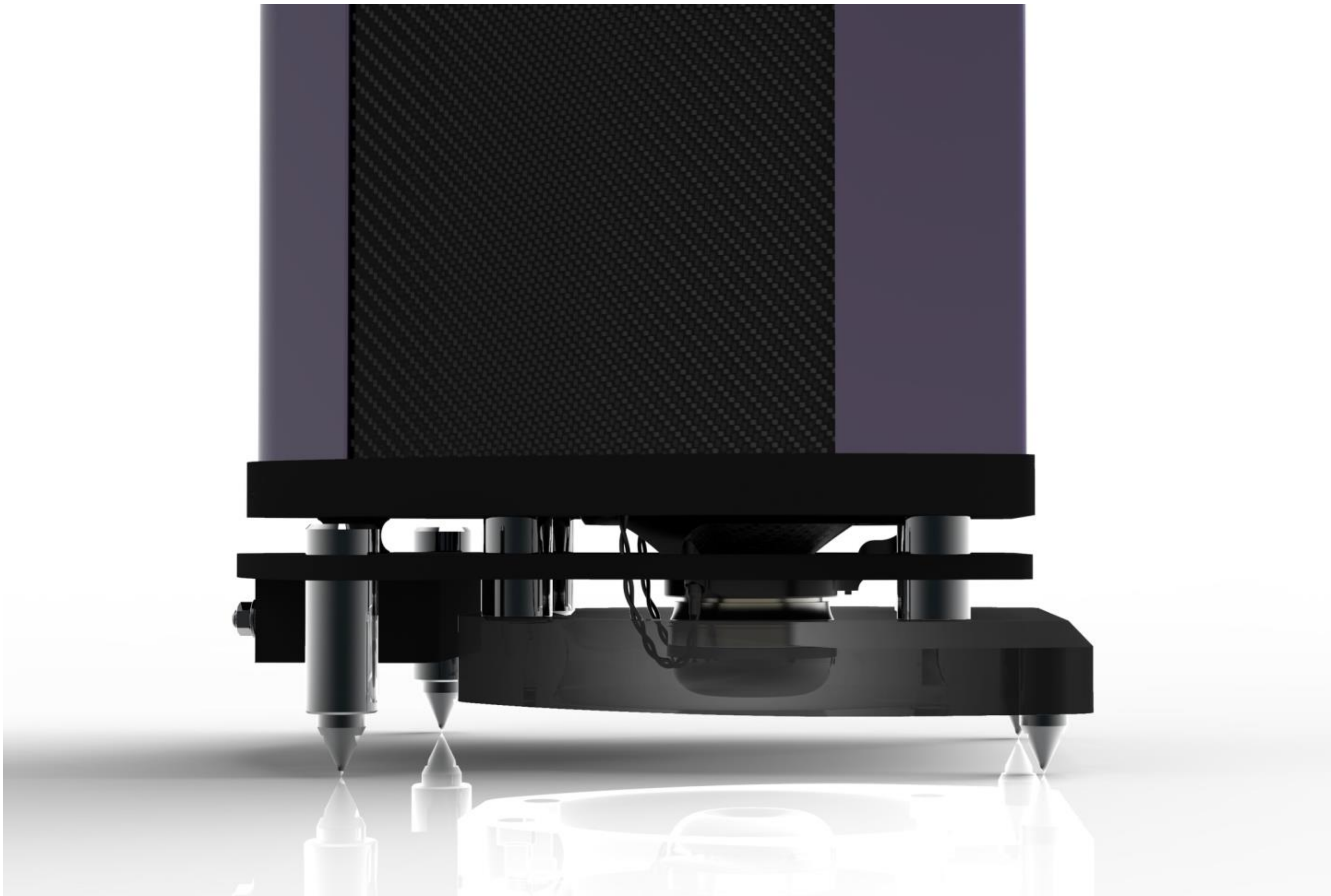


Figure 20: The A.C.T. 3zero Loudspeaker foot with a see through foot plate to show the Isobaric Drive System

The principle low frequency load of the Fibonacci Series is delivered by a series of Tactic 3.0 Isobaric Drive Systems. Here two Tactic 3.0 Drive Units combine to create an Isobaric Drive System.

The Isotactic Drive System is responsible for reproducing incredibly tight and controlled bass response that is perfectly integrated with the midrange Tactic 3.0 drive unit.

There are no transient delays in nature. So it should come as no surprise, that transducers that exhibit the fastest transient response come closer to reproducing natural sound more accurately. This has been a guiding principle in all Wilson Benesch drive unit development.

The basic Laws of Physics dictate that a large woofer will never function with the speed and dynamics of a small drive unit. It is for this reason that Wilson Benesch ruled out the idea of using large, slow woofers in loudspeaker design.

Such drive units cannot accelerate or decelerate quickly enough to reproduce the sound and energy of a musical performance faithfully. To accept such a compromise would be to accept energy propagation that could never be described as integrated. With large woofers, the foundations of the entire sound scape are compromised by retarded dynamic response both in terms of step response and system recovery.

The key facts about exactly why the isobaric is the ultimate solution for generating bass might be obvious from the adjacent image. However, for your scrutiny, the next page contains a summary.

• Super stiff / super low mass diaphragm. The air link between the two diaphragms can be seen as a composite structure with outstanding stiffness to weight ratios. No other known drive unit diaphragm can aspire to possess such properties.

• The complexity of the isobaric virtually eliminates cabinet noise. First of all imagine a conventional large cone loudspeaker design. Now remove from the design the diaphragm and imagine now what you see. A hole that looks more like a washing machine! So after working so hard to build a massive structure we are asked to ignore this huge hole, this window to noise. Even complex membranes pose little or no barrier to noise that has a direct path to the listener. This simple physical fact is why Wilson Benesch has never used a conventional diaphragm or large drive unit.

• To achieve the same bass extension, a conventional design would require double the air volume. A larger box means more noise. No one can argue with this. The ability of the enclosure to achieve any Stealth qualities is also severely undermined.

• The drive unit that you hear, has no spring effect on it. The drive unit inside the enclosure moves all aspects of the air volume and so the spring effect. The drive unit you hear sees only a single pressure the same as free space. The resonant frequency is as a result, very low. This low resonant frequency could only be achieved in a conventional system by adding mass, at least double. The consequence is a total loss of dynamics and transient performance. Much has been written about the integration of sound between drive units. Conventional design admits defeat at the outset. With the isobaric design, the bass is in fact faster in terms of its step response than the midrange.

• Large drive units are inherently unresponsive. You cannot accelerate and decelerate a large heavy car, like you can a small nimble car. Basic physics tells us this. In large woofers, it is only convenience and cost that are the main benefits. For this you pay the price of poor step response and overhang. You also suffer a character of sound that is completely different to the other dive units that it is expected to integrate with.

From Semisphere to Fibonacci

The Semisphere was developed entirely by Wilson Benesch and continues to form one of the most focused areas of research in the company. The Semispehere was borne of two completely different technologies, the soft dome tweeter and the Murata ceramic piezo super tweeter. These two systems gave rise to the need for a third direction. The outcome led to the world's first hybrid dome tweeter structure.

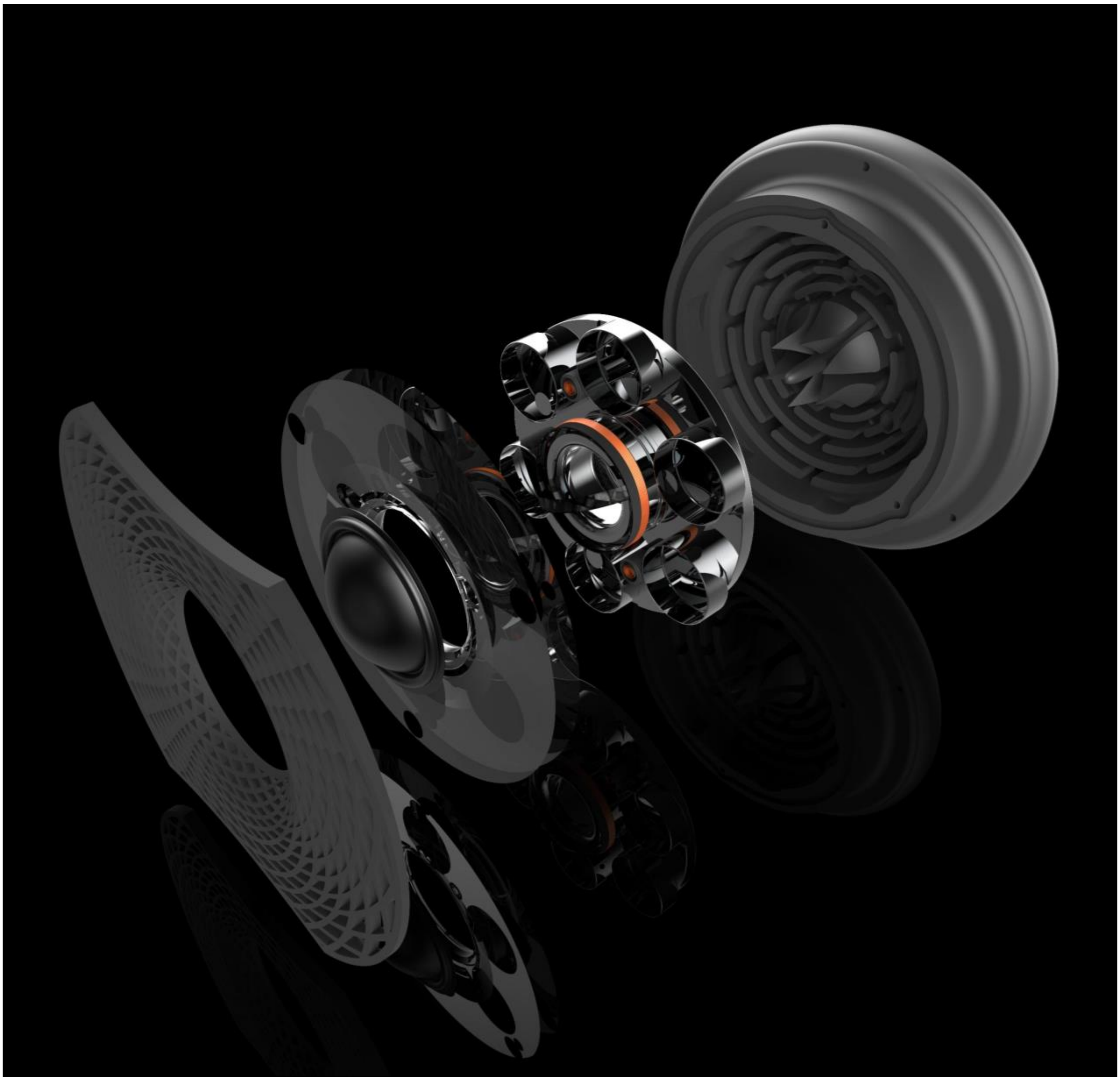


Figure 21: The Fibonacci Tweeter

The sound of the Semisphere and in turn the Fibonacci tweeter was unique and remains distinctively different even today, almost ten years since it was first conceived. Being neither wholly soft nor completely hard the system presents virtues of both these classes of tweeter that are valued in today's high definition systems. Significantly it does not suffer from the principle weaknesses. Fibonacci achieves an extended frequency response that is beyond that of any soft dome achieving an output beyond 30KHz. The absence of any perceptible hard dome characteristics is however the major achievement.

How was this achieved?

A tow of carbon fibre provides for a beam of 3,000 fibres that run across the axis of the dome effectively sub dividing the weakest axis. In addition the voice coil is elevated in stiffness using the same approach. The added mass is so low that the acceleration and deceleration is only marginally impacted. Another significant advantage provided by the fibrous nature of the structure is the level of damping that exists naturally within the anisotropic nature of carbon fibre which also presents acoustic energy with one of the fastest transfer functions known to man.

Fibonacci Tweeter

Like its predecessor the Fibonacci tweeter was developed in parallel with the principle drive unit being used in the loudspeaker design, in this case the Tactic 3.0 midrange drive unit.

Common to both the Fibonacci tweeter and Tactic 3.0 are the Fibonacci Elements that mimic and exploit the benefits of natural geometry that has evolved over millennia. Additive manufacturing is set to transform the manufacture of all products and Wilson Benesch has been involved in developments in this field at the outset thanks to its collaborations with Sheffield University and the AMRC (Advanced Manufacturing Research Centre) where Craig Milnes was recently invited to make a presentation on the potential of this emerging materials science.

Wilson Benesch added additive manufacturing systems to the company's manufacturing capability in 2017. Since then a broad range of applications have been realised. The Fibonacci elements pay homage to the Italian 12th-century mathematician.

A 20KHz sound wave is 17mm long. The structures adjacent to the tweeter dome subsequently play a critical function in the constructive and destructive interactions of the sound waves propagated from the dome of the tweeter. One of the major issues of all tweeter faceplates is the output response cancellation effects of uncontrolled energy. Adding to this complexity, each tweeter dome has its own unique signature and therefore requires its own unique faceplate to arrive at the optimal results. Through painstaking iterative design the resulting faceplate known as the Fibonacci Element has been found to deliver the optimal performance exceeding

Figure 22: The Tactic 3.0 with its Fibonacci Element at its centre, with a Fibonacci Tweeter in the middle of the A.C.T. 3zero Loudspeaker Baffle

the basic geometry of the original Semisphere by delivering more control and as a result a flatter response.

The result sees a highly optimised structure that has been made possible through very recent advances in manufacturing technology, known as Additive Manufacturing. Wilson Benesch has been working on many structures and numerous materials in this field with both Sheffield University and the AMRC. The company already manufactures many components in both metal and carbon reinforced polymer. However it is the design process behind this work that has been critical to the development of these structures, essentially mimicking nature. The lattice structure is as you would expect a hybrid. The principle “seen component” is built from a carbon reinforced polymer that is extremely low mass and extremely high in damping. Significantly this structure is completely decoupled from the main baffle by the sub structure that is visible through the lattice. The damping properties of felt are well known and have been used in pianos, tweeters and a broad variety of engineering applications. This absorbing substructure adds to the damping ensuring the absorption rather than reflection. The resulting flat response of the Fibonacci tweeter owes much to this perfectly adapted system that represents the State-of-The-Art in tweeter face plate design.

Highly Optimised Motor Design

Figure 23: The Fibonacci Tweeter Motor

Looking figure 23 above, it can be observed that the Fibonacci Tweeter features a ring of six high power NdFeB magnets. The magnets are held captive by a steel front and backplate. This design optimises airflow across the tweeter motor which is critical for cooling to maintain optimal performance of the voice coil. The steel used is selected for its high iron content which maximises the power of the NdFeB magnets to create a high power motor with the copper voice coil at its centre.

Labyrinth Sealed Tweeter Backplate

Looking at figure 22 and 23, it can be observed that there is a hole at the centre of the Fibonacci Tweeter. This allows the energy generated at by the Silk-Carbon hybrid dome to escape into the rear chamber of the tweeter. It is critical that the energy that passes into this rear chamber is managed and controlled to ensure that it does not reflect a back wave into the voice coil and out into the listening environment. Wilson Benesch created the new Labyrinth Chamber to control this energy. When looking closely at its structure it can be observed that the Labyrinth Chamber features structures that form troughs with curved tapered shapes. The chamber traps sound waves as they travel into the back of the tweeter and attenuate the sound wave, dissipating the energy as heat. Again Wilson Benesch use additive manufacturing technologies to grow the Labyrinth Chamber in our factory.

This type of development would have been impossible until only very recently. Additive manufacturing has opened up a new arena of design opportunities that Wilson Benesch has been exploring for over seven years and is now exploiting in a broad range of new developments. The unique acoustic signature of the Fibonacci tweeter is clearly quite unique in character. It's success owes much to the innovation of the original Semisphere. It is these small steps that Wilson Benesch will continue to take as an innovator and advanced materials manufacturer that will enable the small but significant accumulative benefits of on-going research and development.

Optimising Air Volume: The Endeavour 3zero Carbon-Nanotech Enclosure

Whilst the Endeavour is ground breaking in many respects, its crowning achievement might well lay directly behind the midrange drive unit. The Endeavour introduces the world's first Carbon-Nanotube enhanced carbon composite midrange bell housing. Born from research carried out in partnership with the Advanced Manufacturing Research Centre in Sheffield. The Carbon-Nanotech Enclosure is a huge breakthrough in high performance loudspeaker design.

This extra-ordinary structure bestows the following key benefits:

1. Optimal Midrange Air Volume: By partitioning the air volume available exclusively for the midrange drive unit. This critical drive unit, which produces the frequencies within the bandwidth most sensitive to the human ear, is free to work in isolation of the Isobaric Drive. Significant improvements in the midrange dynamics can be achieved as the drive unit no longer competes with the far more powerful Isobaric Drive.

2. Optimal Isobaric Air Volume: In order to achieve powerful, dynamic and low bass frequencies, the bass drive units require a large air volume within the speaker cabinet. Due to the phenomenal stiffness of the A.C.T. monocoque, Wilson Benesch loudspeakers are relatively free from complex internal bracing found in other designs which subtract from the critical internal air volume. By isolating the midrange to its own optimised enclosure, Wilson Benesch have significantly increased the air volume afforded to the Isobaric Drive even further.

The image on the right illustrates the total air volume available to the Isobaric Drive in two design options.

Looking at the illustration on the left, which is based on the conventional idea of simply dividing the cabinet in half for bass and midrange units, it can be appreciated that the total air volume afforded to the Isobaric Drive is very small.

Now looking at the right illustration, we can see that the Carbon-Nanotech Enclosure has isolated the midrange and allowed the remainder of the cabinet around the enclosure, including the space at the top of the cabinet for the Isobaric Drive.

3. Optimal Energy Control: The Carbon-Nanotech Enclosure isolates the midrange drive unit and its effective 'open window' to the listening room from the energy generated inside the cabinet. The Carbon-Nanotech Enclosure is phenomenally well damped, so by adding what is effectively a second composite structure to damp and control out of phase energy within the cabinet, the noise floor is lowered to a new level within the frequency range most sensitive to the human ear. The midrange presentation has a clarity and composure that is beyond previous benchmarks.

4. Optimal Integration: Low frequency energy is delivered by the vertically orientated Tactic II Isobaric Drive that places the voice coils in virtually the same plane as the Tactic II midrange drive unit. This configuration ensures near perfect time alignment with the lowest level of diffraction. Being vertically orientated ensures that no structural displacement occurs even at the highest levels.

5. Optimal Geometry: It is no coincidence that the geometry of the Carbon-Nanotech Enclosure closely resembles that of a classic champagne bottle. The curved structure has a proven ability to cope with enormous pressures.

6. Optimal Material Application: With the numerable critical design goals of the Carbon-Nanotech enclosure, only the most advanced materials technology could be applied to achieve these. As the structure is placed internally, the aesthetic concerns associated with the A.C.T. Monocoque are largely superfluous, so it has been possible to deploy aerospace quality pre-preg carbon fibre, combined with the strongest material known to man, carbon nanotubes. By adding carbon nanotubes to the resin matrix, it is possible to attain improvements in damping and stiffness that is almost 5x that of similar structures without carbon nanotubes. In terms of the stiffness, the Carbon-Nanotech Enclosure supersedes the A.C.T. Monocoque, however the complex multi-layer construction of the A.C.T. Monocoque remains the industry benchmark.

The Discovery 3zero & Endeavour 3zero

The Discovery 3zero
When Wilson Benesch unveiled the original Discovery loudspeaker in 2001, it defied the norms of loudspeaker design. In much the same way that the A.C.T. One loudspeaker did, the Discovery introduced a new design language. Unlike any other speaker at the time, it presented itself as a stand-mount design yet delivered bass capabilities akin to a floor-standing speaker. This innovative approach set it apart.

The Discovery 3zero loudspeaker and those before it exemplifies the Isobaric design more prominently than any other Wilson Benesch creation. The compact cabinet of the Discovery 3zero allows for the highest signal-to-noise ratio measurements achievable. Additionally, the vertical alignment of the bass driver minimises any detrimental impact from driver movement, approaching zero disturbance. By positioning all three drive units in close-proximity around the tweeter, the Discovery 3zero sets the industry standard for generating a coherent sound field. These exceptional and distinctive features culminate in an unparalleled achievement that surpasses previous limitations. The acoustic result is a level of clarity and transparency across the entire bandwidth that is unparalleled and incomparable in its precision.

The significant technological advancements incorporated into this high-performance powerhouse have propelled it to achieve a level of improvement that justifies a replacement. Years of dedicated work and innovation, as evidenced by the Fibonacci Series, demonstrate the substantial progress made. While maintaining the tried and proven form factor, every aspect of the original design has been enhanced without retaining any unchanged elements. This remarkable feat showcases the extent of evolution and innovation that has been achieved in this product.

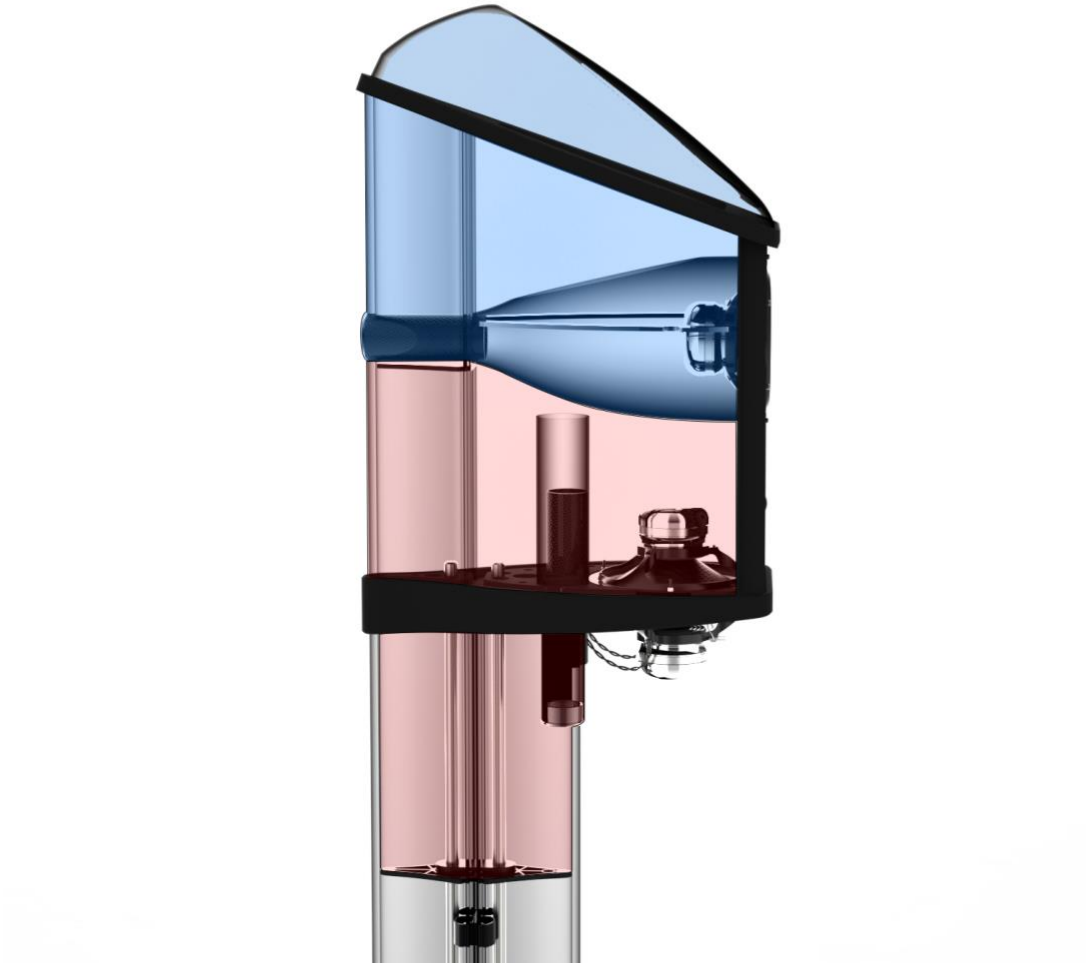
Extensive years of meticulous development and significant investments in cutting-edge manufacturing technologies have resulted in a remarkable improvement in performance across various aspects such as materials science, electromagnetic systems, dynamic elements, and assembly techniques.

These advancements were not only observed in the Discovery 3zero but also influenced the development work of the Endeavour.

The Endeavour 3zero

Concurrently, during the Endeavour's development, innovative energy-absorbing damping systems were discovered and subsequently integrated into the Discovery, showcasing the cross-pollination of advancements and technologies across projects.

The images above show the internal structures in the Endeavour 3zero using advanced composite materials and geometrically optimised structures.



The image above shows the optimisation of air volume in the Endeavour 3zero.

The midrange drive unit is an encapsulated in composite systems that avoid all possibilities of standing waves of any kind. This is achieved by exploiting the carbon top air volume as well as the volume above the centre line of the bell housing. The bell housing adds enormous stiffness by virtue of its geometry but without robbing the internal volume of vast quantities of air which would be unavoidable with conventional materials typically used in the vast majority of loudspeakers. The three fold increase in air volume reduces distortion to levels that were impossible previously whilst exploiting a more extended low frequency extension that blends seamlessly with the isobaric bass driver to achieve previously impossible levels of integration. The mid range step response is also improved due to the reduced air pressure exerted by the larger air volume.

The Isobaric bass has been enhanced also by an equally significant increase from n air volume. How is this possible? The added volume is made possible due to the high precision gaskets that have been developed by Wilson Benesch that now makes the impossible possible. The air within both the spine and the stand of the speaker has been brought into play. With 4 times the available air when compared to the previous iteration the envelope of air is now capable of freeing the isobaric to deliver low frequency levels that defy all expectations. The full range capabilities of this super monitor are an industry standard that reveals new levels of acoustic performance capable of stimulating the musical synapses like no other product in this class.