Bao.

Manufacturing Report

Bao. Technologies

A comprehensive design for manufacture report.

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Team Bao
2020/2021

Our team.

We are a motivated group of 7 product designers, designing a small, desk top electrical speaker prepared for mass manufacture (50-100K units) utilising Carefully selected; plastic, metal and glass manufacturing processes in-order to produce a sleek, contemporary designed, competitive product to compete with those already in the current desk-top speaker market.

Manufacture report
Index

£79.0 23.4% 70%

£79.00
in 20 Countries

Bao is priced at just £79.00 and sold across twenty countries globally, a direct amazon competitor.

Growing
in 20 Countries

Bao is a smart speaker, designed for a lucrative market currently growing at a gross CAGR of 23.4%

Recyclable
Recycleable materials

Bao isnt just a smart speaker, its also eco friendly, with 70% of parts being recyclable.

Bao.
Complete sound

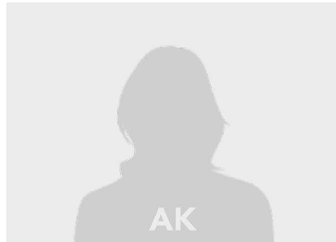
Team Bao
Meet the team...

Our Designers
From across the UK

The Team Bao, design team consists of seven, under-graduate products designers, Paz, Ava, Hugo, Jack, Michael, Jack and Theodora each specialising in different areas of our smart speakers design, as-well as two experienced design consultants helping to provide focus and direction to the Team Bao: Marco Cavallero and Timothy Minton.

Paz Blacher-Moore
CAD and Graphics design

Extravert, sensing, feeling,perceiving
Paz is a positive, entertainer member of our team, ready to work.



Ava Kenning
Marketing and finance

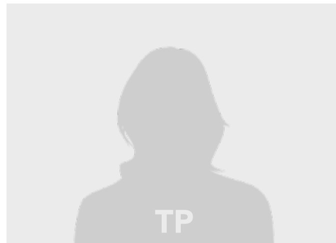
Introverted, sensing, thinking, perceiving
Ava a serious, reliable, hard working member of our team.

Hugo Burns
Glass manufacturing

Extravert, intuitive, thinking, judging
A positive influence, hugo is a great critical thinker for the team.

Michael Riberio
Plastics manufacturing

Extravert, sensing, feeling, perceiving
Michal is a perceptive, level headed member of team Bao.



Theodora Powell
Metal manufacturing

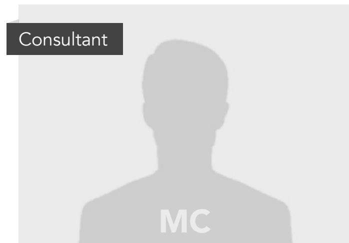
Extravert, intuitive, thinking, judging
Theodora is a, colourful, intuitive and critical member of team Bao.

Jack Nash
Manufacturing Assembly

Introvert, sensing, feeling, judging
Jack is a great judge, a vital thinker behind the Bao team.

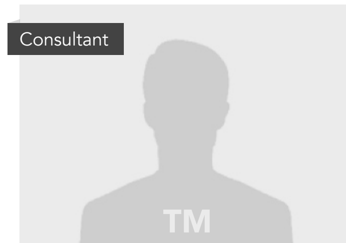
Jack Robson
Electromechanical design

Introvert, intuitive, feeling, judging
Jack is the intuition, the driving force behind team Bao's cohesion.



Marco Cavallero
Design consultant

Marco Cavalero: a design consultant providing, valuable information to our design team.



Timonthy Minton
Design consultant

Timothy Minton: a design consultant providing, valuable information to our design team.

Market research
Smart speakers

The smart speaker market is valued at £4 million in 2018 and projected to reach £23 million by 2024 at a CAGR of 23.4%.

Smart speakers are the latest innovation dominating the tech-market speakers, activated by a voice command to perform different tasks such as listening to music, ordering food, and online shopping. Marketfuture.com, 2019

Market overveiw.
An increase in the demand for smart home devices is the significant factor that drives the growth of the smart speakers market. Other factors, which influence the market growth are increase in consumer readiness to invest on trending technologies and rise in usage of smart devices among the younger generation.Marketfuture.com, 2019

The key share-holders in the smart speaker market include Amazon, Apple, Alibaba, Alphabet, Sonos, Bose, Xiaomi, Samsung and Plantronics. Amongst these technology companies, Amazon holds the highest market share in the smart speaker market, with its Alexa-series products sold through the web-site amazon.co.uk, followed by Alphabet. Marketfuture.com, 2019

Key information

- » purchasing power of the consumers has increased due to rise in global disposable income. Total Increase of 2.5% in 2018.
- » Increased demand for multi-function devices. controlling devices through voice commands offers more utility to the consumer.
- » Increase in the usage of smart home devices drives the net sales of smart speakers. Traditional devices, being replaced by smart devices.
- » Partnerships between smart home manufacturers and smart speakers allows integration of home devices with smart speakers.
- » The exploitation of user data by manufacturers invade privacy restricts the demand for smart speakers from consumers.
- » Key players in the smart speaker market are: Amazon, Apple, Alibaba, Alphabet, Sonos, Bose, Xiaomi, Samsung and Plantronics.

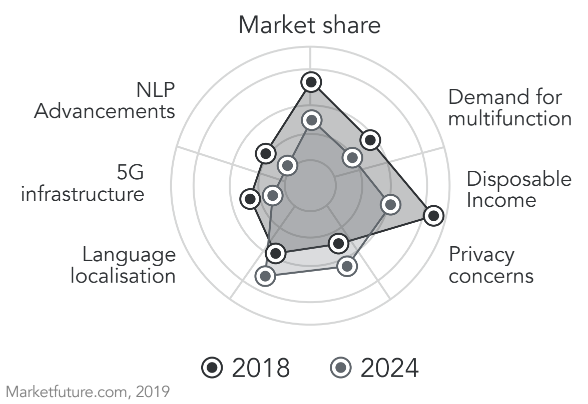
The Market: Smart speaker market information and statistics.

The three most well-known smart speakers brands include the Amazon Echo, Apple homepod and Google Nest (which used to be called the Google Home) ranges of products – and more devices are being added all the time, including the new Amazon Echo (2020). Amazon still commands the global smart speakers users, but its lead continues to decline. The Google Homepod is the fastest-growing competitor. Marketfuture.com, 2019

Mainland China, which has the COVID-19 pandemic under control, will lead, growing 16%, while the rest of the market is expected to grow 3% as countries continue to battle the coronavirus. With demand for stay-home entertainment expected to increase, companies have released new smart speakers and displays, ensuring value and availability. This is critical ahead of the 2020 year-end shopping season.Marketfuture.com, 2019

Smart speaker market

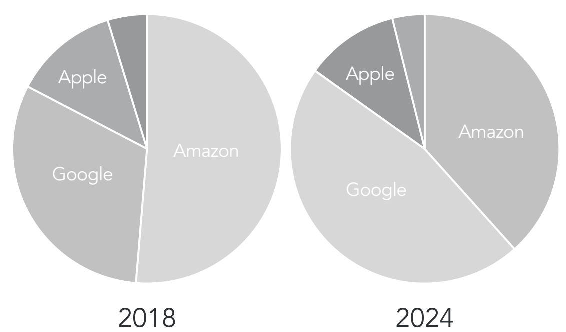
Illustration shows the development of key factors in the smart speaker market between 2018 and 2024.



Marketfuture.com, 2019

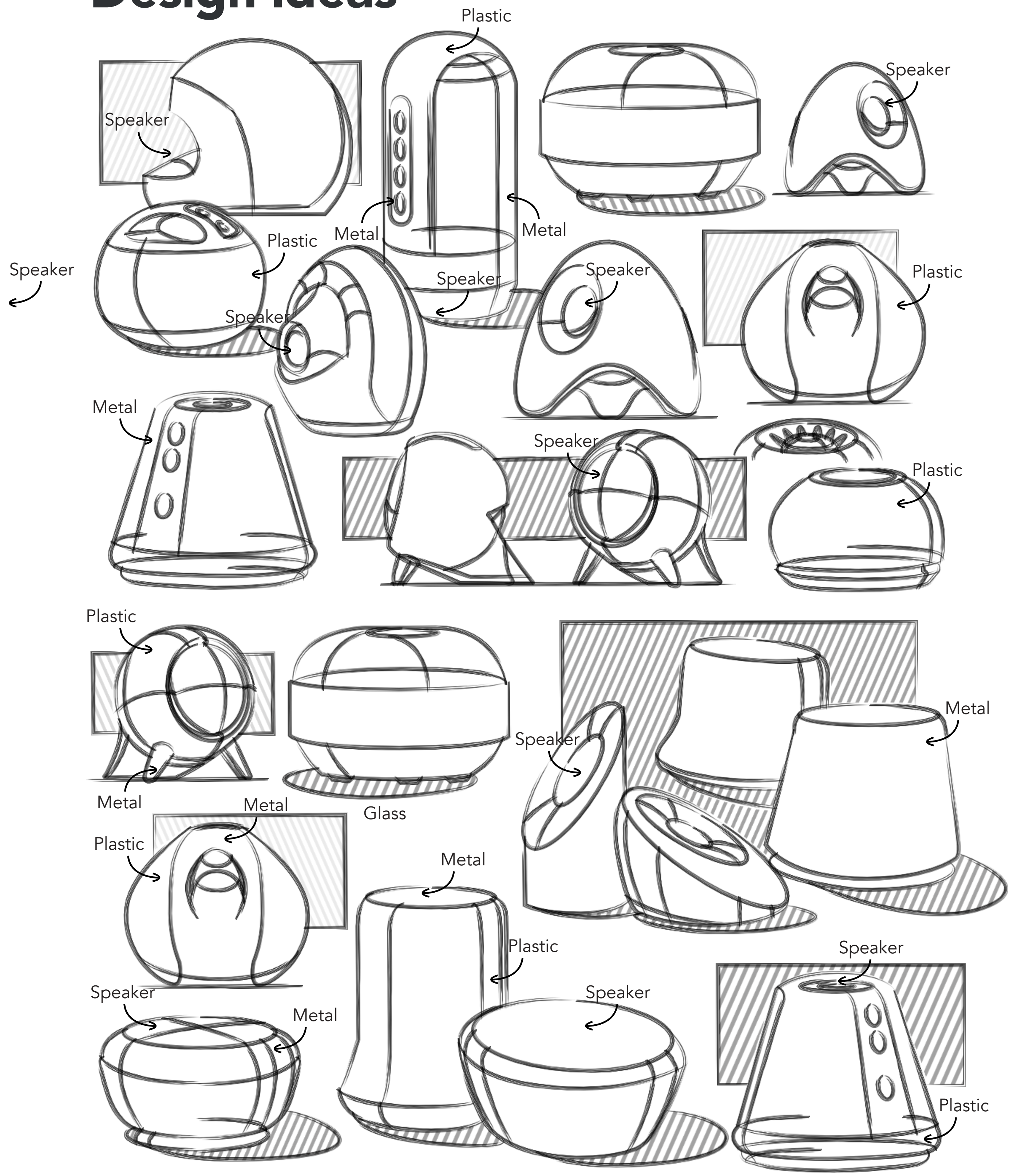
Global market share

The market share of key businesses in the smart speaker market, showing the change in shares from 2018 to 2024.

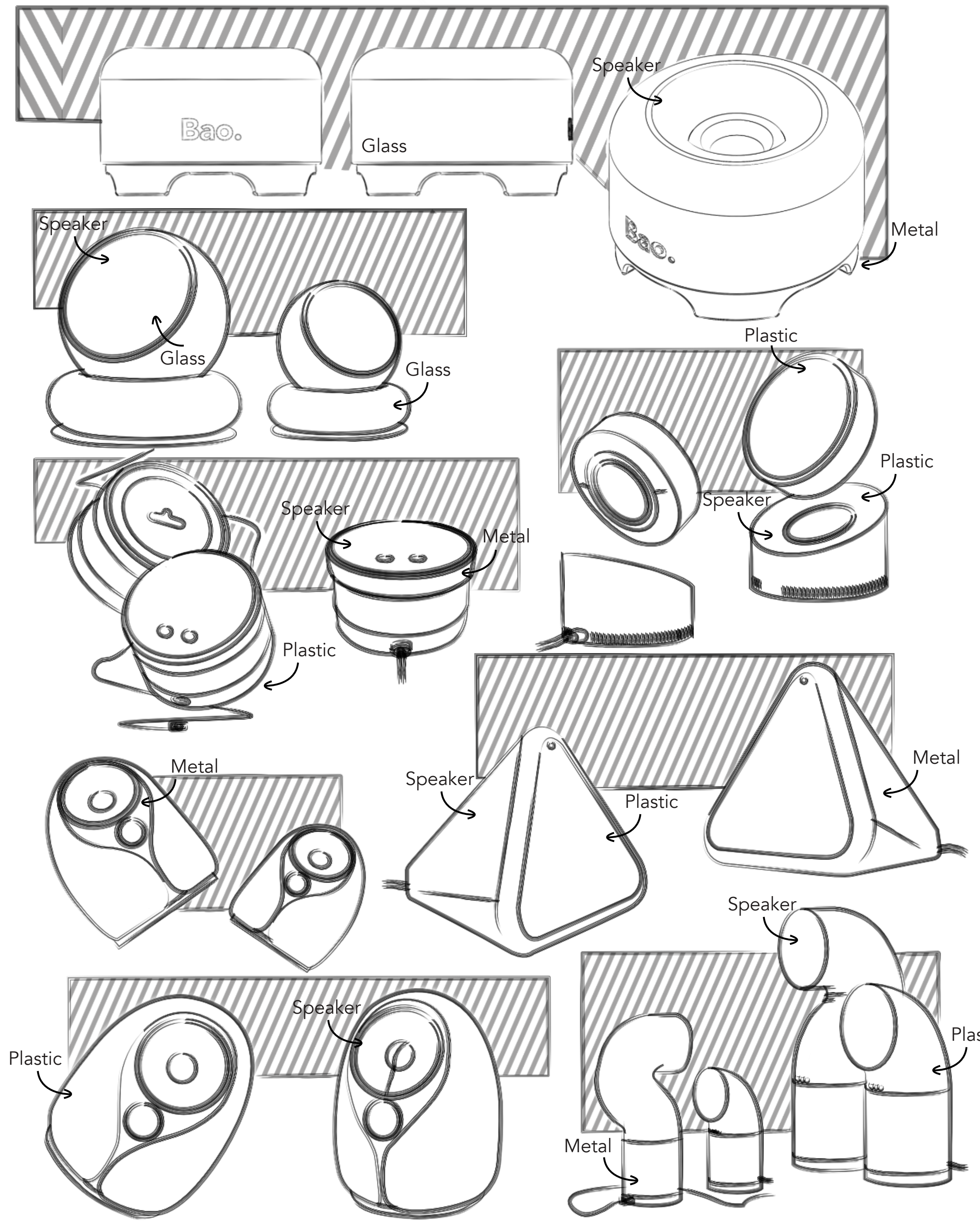


Marketfuture.com, 2019

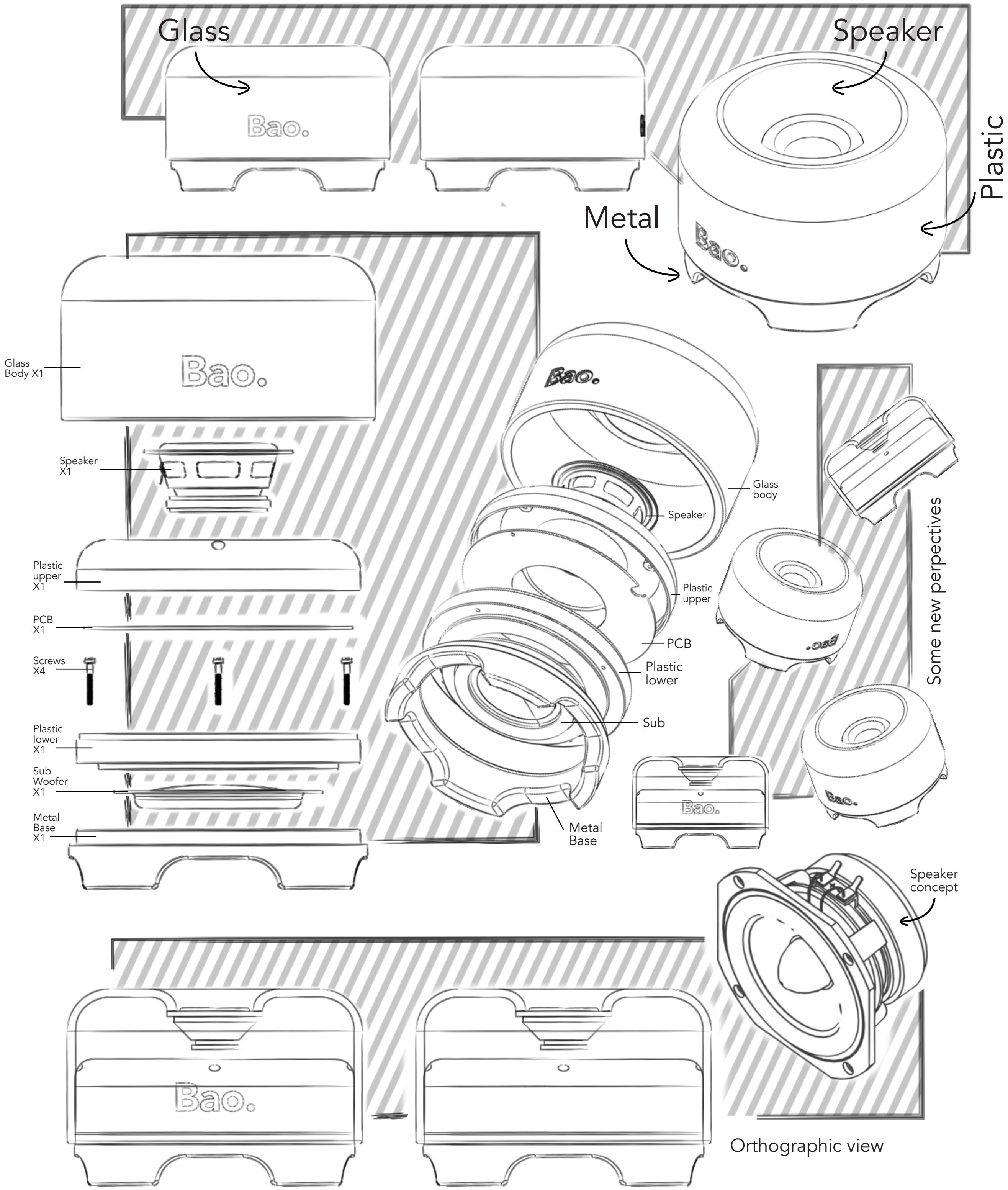
Bao. Ideation
Design ideas



Bao. Ideation
Design ideas



Bao. Ideation
Final concept



Bao.
Final concept

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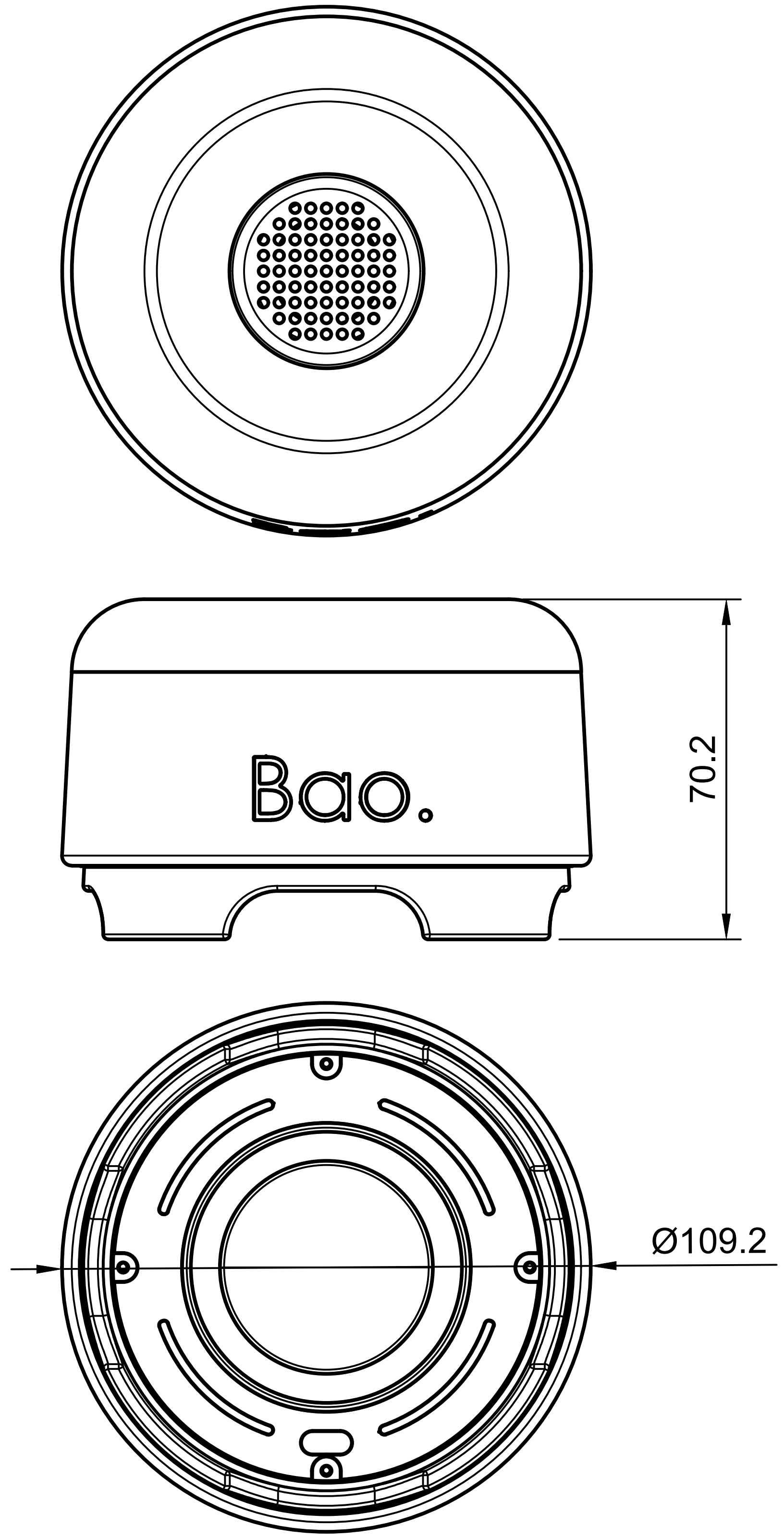


TOLERANCES
WHOLE NUMBERS +-0.5
1Dec 0.0+-0.25
2Dec 0.00+-0.1
3Dec 0.000+-0.01
Angles +-0.5deg

THIRDANGLE PROJECTION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH: Gloss 0.06-0.10Ra

DEBURR AND BREAK SHARP EDGES

DO NOTSCALE DRAWING

REVISION: Version 1

	NAME	SIGNATURE	DATE
DRAWN	PBM		06/03/21
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:
MANUFACTURE:
FINISH:

WEIGHT:

TITLE:

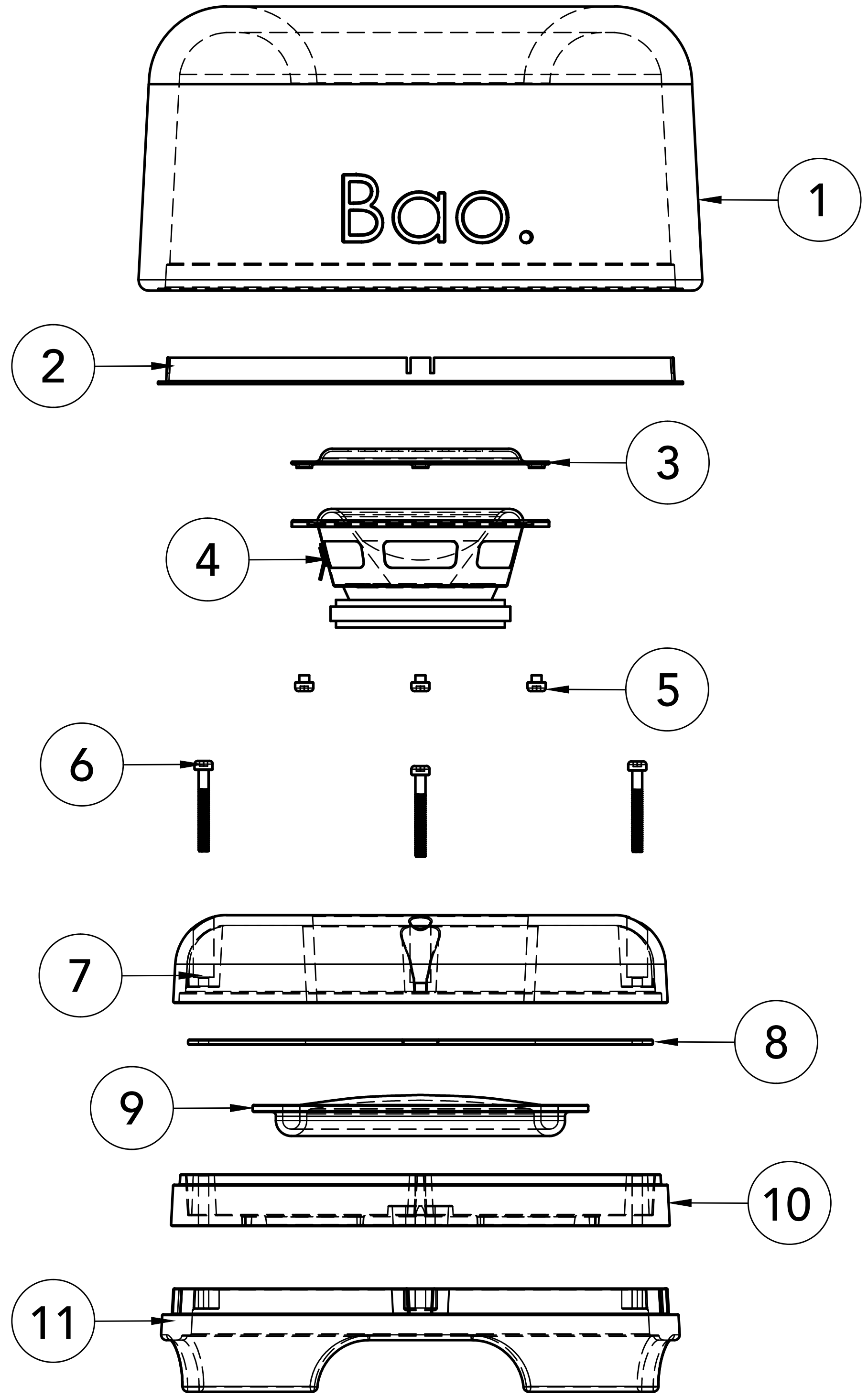
Product drawing

DWG NO. BAOFA01

A4

SCALE:1:1.5

SHEET1 OF 1



11	1	BAOMB01	Cast aluminium base	Aluminium A380
10	1	BAOPL01	Lower plastic molding	ABS Polylac 717C
9	1	BAOSW01	Passive, low frequency sub woofer	Rubber / Steel plate
8	1	BAOPCB01	USB-C powered PCB	Fibre glass
7	1	BAOPU01	Upper plastic molding	ABS Polylac 717C
6	4	BAOPB01	M1.8 Steel fixing bolts for plastic moulding	Plated mild steel
5	4	BAOSB01	M1.8 Steel fixing bolts for speaker	Plated mild steel
4	1	BAOSP01	Speaker	N/A
3	1	BAOSG01	Sheet steel speaker grill	Stainless steel sheet 304
2	1	BAOSR01	Sheet steel fixing ring	Stainless steel sheet 304
1	1	BAOGU01	Upper glass dome cover	Tempered glass
Item	Qty	Part Number	Description	Material

Parts List

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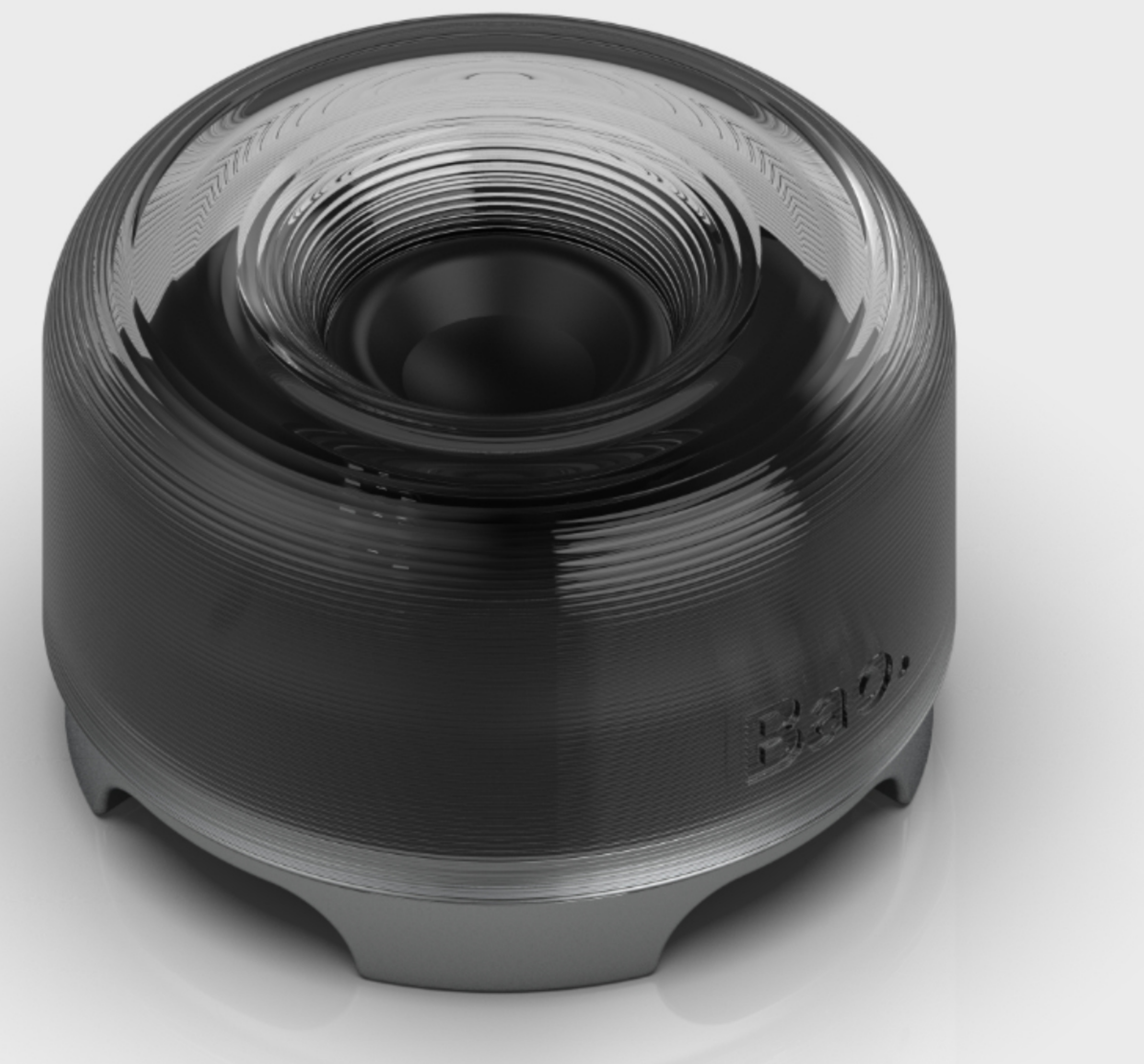


SOLIDWORKS
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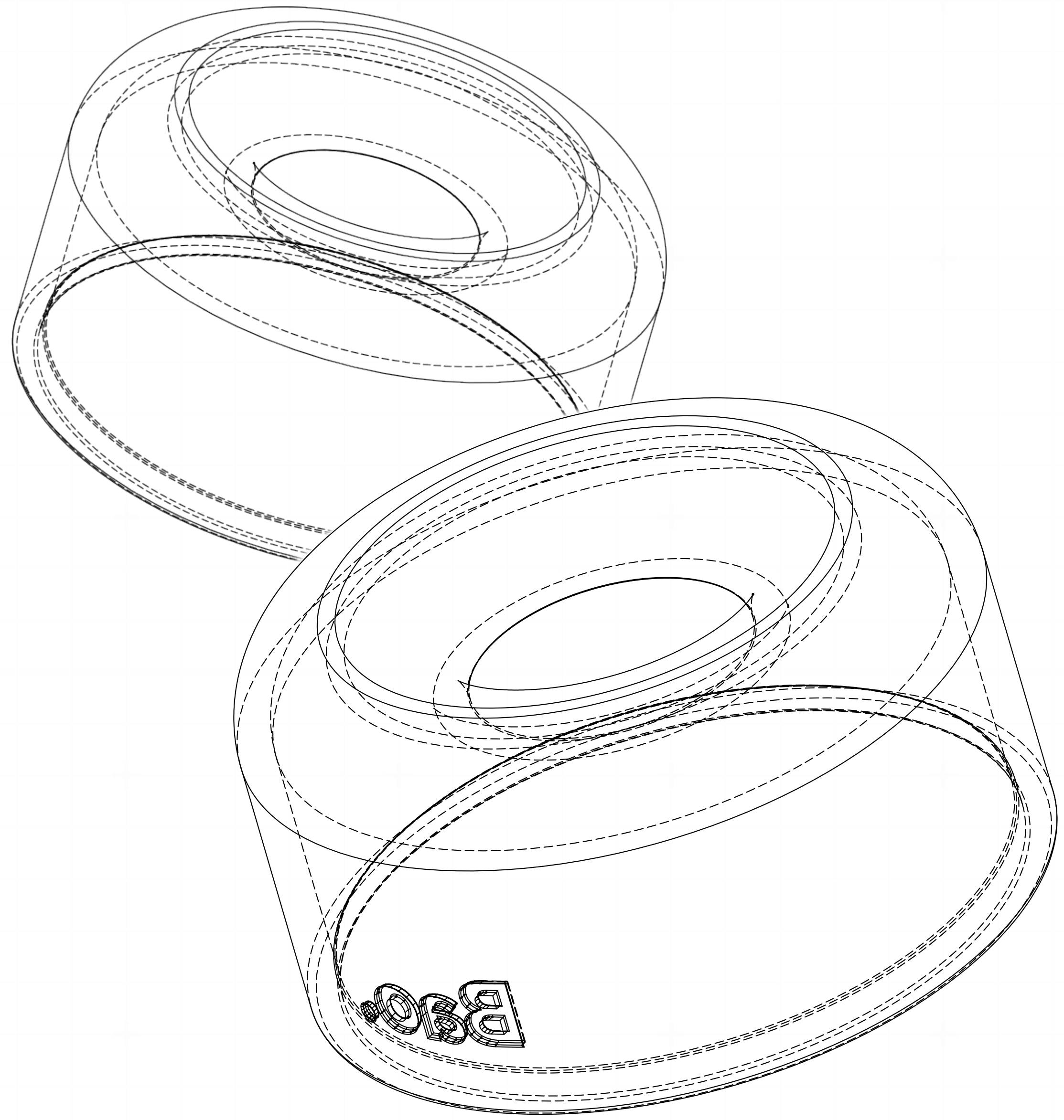
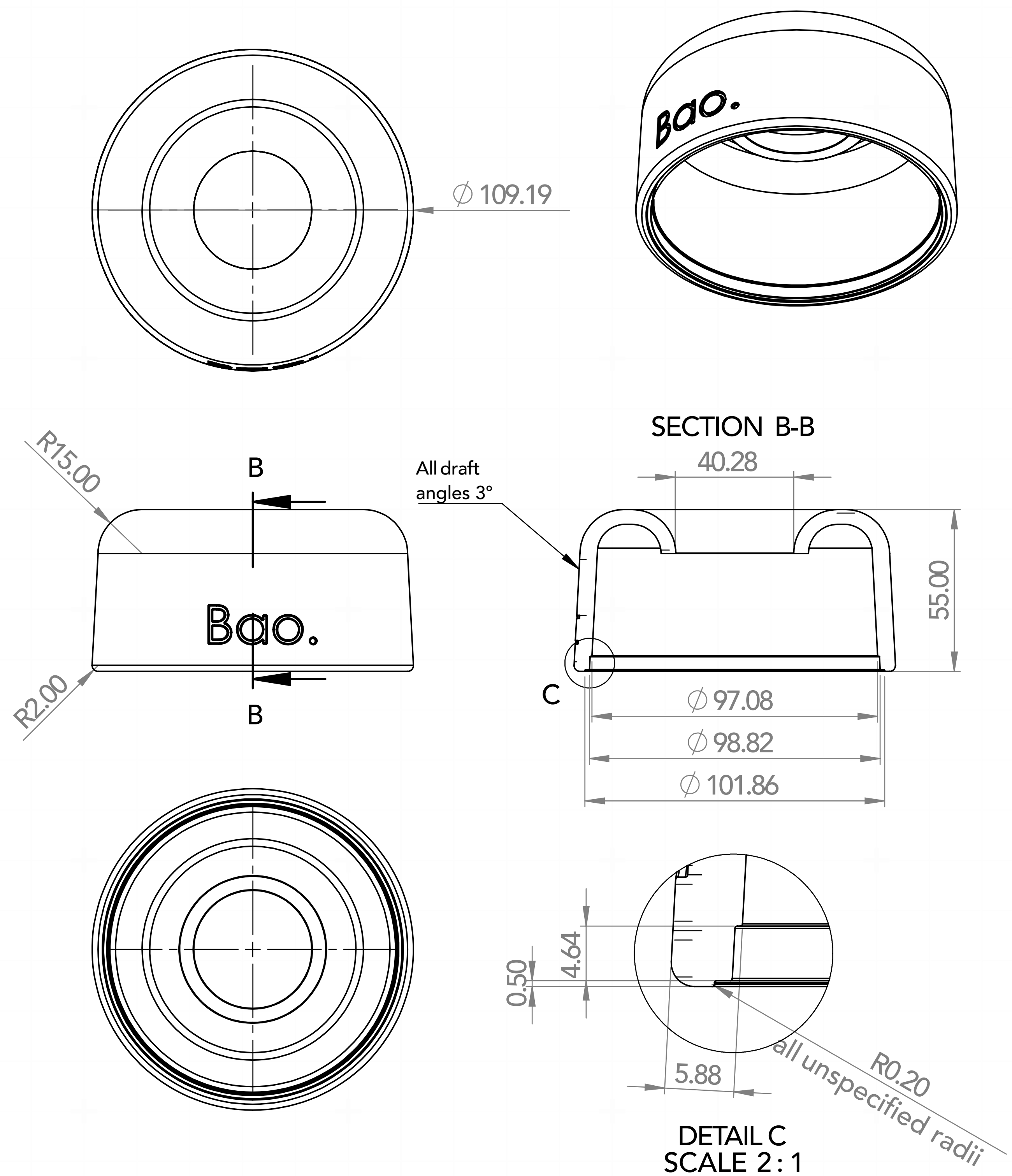
Manufacture guide
Glass body





THIRDANGLE PROJECTION UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: Gloss 0.06-0.10Ra	TOLERANCES WHOLE NUMBERS +-0.5 1Dec 0.0 +-0.25 2Dec 0.00 +-0.1 3Dec 0.000 +-0.01 Angles +-0.5deg	DEBURR AND BREAK SHARP EDGES	DO NOTSCALE DRAWING
			REVISION: Version 1

	NAME	SIGNATURE	DATE
DRAWN	PBM		06/03/21
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: **Glass upper**

MATERIAL: Tempered glass

MANUFACTURING: Compression moulding

WEIGHT:

DWG NO. **BAOGU01** A4

SCALE:1:2 SHEET1 OF 1

Material
Tempered glass

"Tempered glass is considered to be four times stronger than regular annealed glass"

Ny-engineer.com, 2019

Tempered glass was selected for its high strength and impact-resistant properties. Tempered glass is manufactured in the same way that annealed glass is apart from the final tempering process. Unlike annealed glass, which is heated and cooled slowly, tempered glass is heated and then rapidly cooled with compressed air, while the inner surface is left to cool at a slower rate. This results in the two surfaces being in tension, giving the glass its strength Tooley Fay, 1984.

Sand	72.6%
Soda ash	13%
Limestone	8.4%
Dolomite	4%
Alumina	1%
Other	1%

Ny-engineer.com, 2019

The Tempered glass used by Bao is a composite glass material comprised of 72.6% sand, 13% soda ash, 8.4% limestone, 4% dolomite, 1% alumina and 1% other (unspecified material). Tooley Fay, 1984.

The main component of glass, sand is heated at high temperatures to become viscous. Sand is mixed with flux: Soda ash to melt at lower temperatures. Calcium oxide keeps the glass from forming unwanted impurities. These dry ingredients are mixed together and melted by a furnace to form a liquid compound. Cullet is also added to help it melt.

Physical properties

Tempered glass is four times stronger than regular annealed glass. Tempered glass is transparent, chemical and heat resistant as well as greater strength and impact resistance compared to standard glass. When broken, tempered glass breaks into small rounded pieces instead off large shards Tooley Fay, 1984.

Density	Melting Point (Average +/- 50)	Thermal Conductivity	Coefficient of Thermal Expansion	Poissons Ratio	Process
(Kg/m3)	°C	(kN/mm2)	(K-1)	(.0)	
2.41	1500	70	8.8x10-6	0.22	Glass pressing

Ny-engineer.com, 2019

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Mechanical properties

The tempered glass we use must have a minimum surface compression of 90MPa or a minimum edge compression of 90MPa. Tempered glass has a hardness of 9h (Moh scale), close to the 10h hardness of diamonds Lyons, William C, 2006.

Mechanical strength	Thermal Shocking	Surface compression	Mechanical fragmentation	Spontaneous breakage	Thermal breakage	Process
(Mpa)	(Degc)	(Mpa)	(Angle)	(Y/N)	(Y/N)	
120	200c	>90	Obtuse	Yes	No	Glass pressing

Ny-engineer.com, 2019

Our glass exhibits a mech-strength of 120 Mpa and surface compression >90 Mpa. The material exhibits no thermal breakage and fragments obtusely under mechanical stress.

Processing
Glass pressing

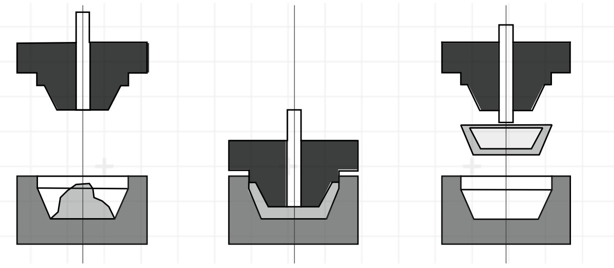
Our process

We use glass press molding to form our Bao glass parts. This process was chosen as it is suitable for the accurate mass production of small and simple shaped glass parts.

Our raw mixture is heated and mixed in a furnace at 1500°C. This molten glass is then passed through a feeder, where it is sheared to uniform pieces, called "gobs" Tooley Fay, 1984.

A two part mould is required to form the part. Gobs are loaded into the female mould. The male mould compresses the molten glass to fill the shape. The male mould releases the pressure, and the female mould splits, releasing the part.

The formed part is then tempered. Passing through a long oven, before the outer surfaces are rapid air cooled (inside surfaces are left to cool naturally). Press is the fastest, most accurate way to manufacture the part Tooley Fay, 1984.



Blow moulding is not an option as the part has two holes in it which, would prevent pressurisation. All part features are incorporated into the mould design features cannot be machined as surface tension would cause it to shatter.

Casting pressure

The Bao base is cast into a tool steel mould at a calibrated pressure of 1400kg / cm³, reducing the alloys grain size diameter to 5mm². This calibrated pressure of 1400 kg/cm2 gives the base a relative yield strength of 76 MPa and impact strength of 3.938Pa improving the components relative factor of safety (finite element analysis) Lyons, 2006..

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Mould design

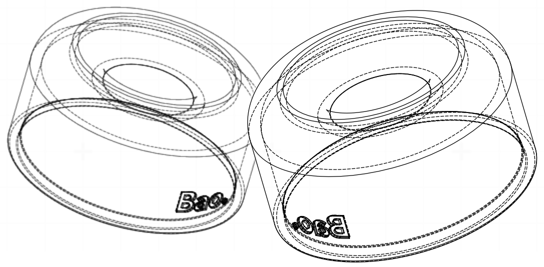
Our two part mould is made from A48 grade grey cast iron (C3.4, Si1.8, Mn0.5). The preferred choice as it has a hardness of 260 Brinell and a tensile strength of 50Ksi, required to prevent glass particles from eroding the mould surface Lyons, 2006.

Cast iron has excellent thermal resistance properties. The constant heating and cooling moulds causes thermal stress and can cause the mould to deform or fail completely. These stresses are usually the dictating factor of a mould's lifespan. Our mould is expected to last 10,000-12,000 cycles before requiring repair or replacement Lyons, 2006..

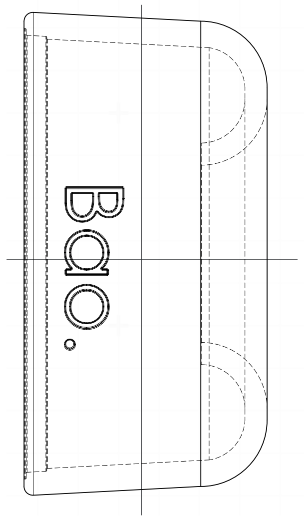
The female mould half will have a split case design. This allows the bottom mould to hinge open to allow easier releasing of the part. Tooley Fay, 1984.

Design
Our design

Rules



Our glass part exhibits uniform wall thicknesses to prevent weak points where less material is present. Wall thickness should be a minimum of 3mm to prevent cracking. It is recommended to have a minimum material thickness of 6mm when tempering the glass to prevent the surfaces from cooling at the same rate. This results in weaker glass as the surfaces are not in a high tension ratio to each other. Draft angles for all surfaces are > 3° for mould release Formlabs, 2019.

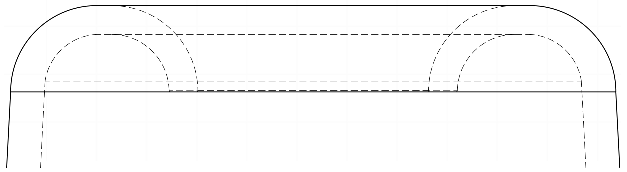


The curvature and shape of the part provides added strength. All corners are rounded with radii for added structural integrity.

The curvature, aswell as the radii ensure that the molten glass is able to fill both part of the mould cavities and prevents excessively tight geometry in the mould might inhibit the glass forming process Formlabs, 2019.

Finishing processes

The manufacturing process leaves a high quality surface finish doubling up as a polishing process. The heated surfaces act similar to a fire polishing process causing the glass to soften sealing surface imperfections, preventing cracks from forming. Formlabs, 2019



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Structural design

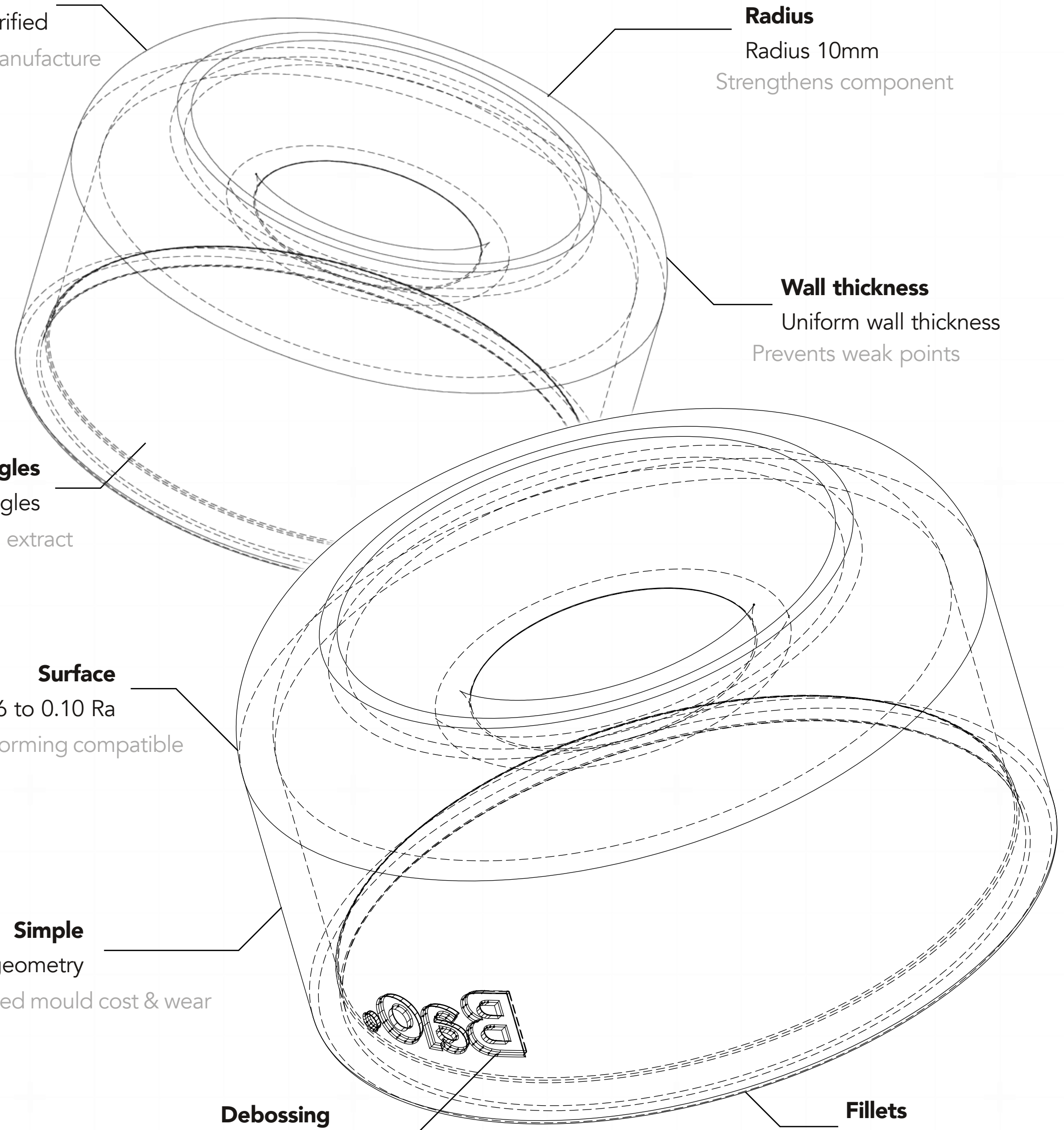
Similar to how glass bottle manufacturers operate we are able to 3D scan our parts as they are removed from the mould as a final quality control step. If the glass domes are defined as out of tolerance, they are processed for recycling.

The part has been engineered to exhibit a factor of safety of two, making it twice as strong as the max load it is expected to take. This is due to the material properties of tempered glass as-well curved, compact design eliminating features which could cause the part to break under load Formlabs, 2019.

Intentionally designing our parts stronger than needed allows us to compensate for unexpected loads and miss-usages.

Design
Closer look

John Moncrief ltd.
- Verified part for manufacture



Production
Manufacturing cost

John moncrief ltd.
- Provided this quote

General Information

Name:	BAOGP01
Description:	Bao upper glass part (Tempered glass)

Part information

Quantity:	50,000.00
Material:	Tempered glass: pressed
X-Y-Z (mm):	100.00 x 100.00 x 55.00
Weight (kg)	0.5.00 kg
Tolerance:	High precision (<= 0.125)
Surfacing:	High quality (Gloss shiny)

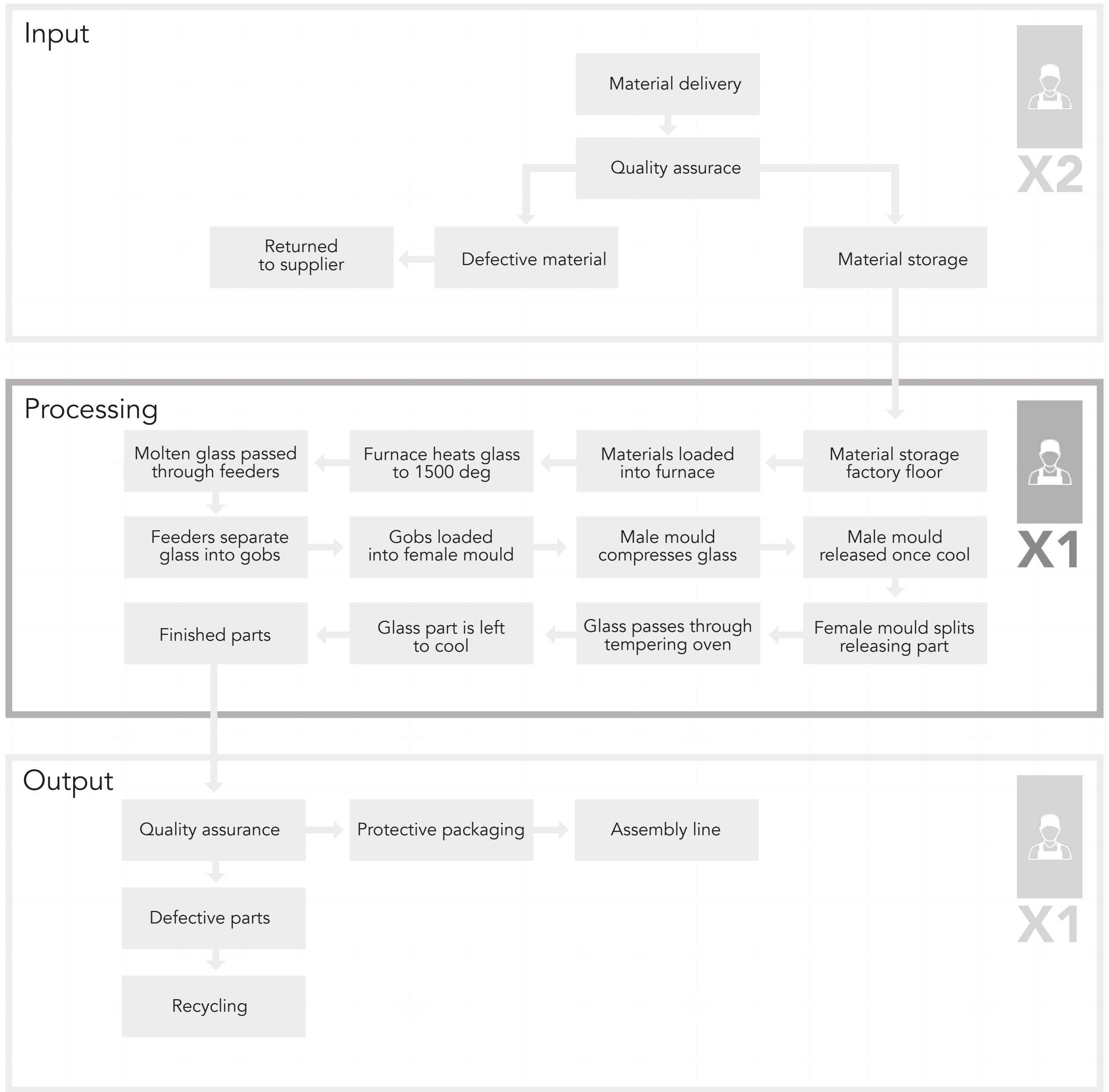
Processing paramaters

Material	
Weight (kg):	0.50.00
Price (£/kg):	2.16.00
Markup (%):	25.00
Production	
Machine:	Glass pressing
Clamp force (kpa):	700.00
Setup time (hrs):	8.00
Up-time (%):	95.00
Post-processing (hrs):	0.00
Defect rate (%):	3.00
Production rate (p/hr):	116.00
Hourly rate (£/hr):	17.95
Production markup (%):	10.00
Tooling	
Number of cavities:	1.00
Number of dies:	2.00
Die making rate (£/hr):	90.00

Cost summary:

Glass pressing	£63,858 (£1.277 per part)
Material cost	£12,963 (£0.259 per part)
Production cost	£9,550 (£0.191 per part)
Tooling cost	£55,000 (£1.100 per part)
Total cost	£77.500 (£1.550 per part)

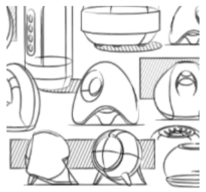
Production
System diagram



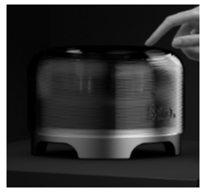
Change log
Design revisions

Stage 1
Conceptualisation

We initially worked to produce a range of ideation sketches defining the desired aesthetic shape / feel of the product. After a final shape was chosen this design was further explored with materials and design features more clearly defined.



Stage 2
Aesthetic concept

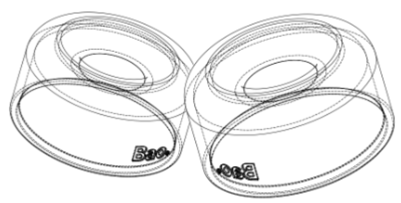


Initially developing a looks like model gave us the ability to refine the aesthetic features of our products design. Glass was chosen as a possible material for the cover because of its ‘natural’ and distinctive aesthetic properties e.g. weight, transparency and hardness etc.

Stage 3
Manufacturing

Initial research into manufacturing processes showed that it would be practical to make a glass top that would function as necessary within the cost constraints. However, the complexity of the shape would need to be limited and the fixing methods carefully considered.

Stage 4
Part development

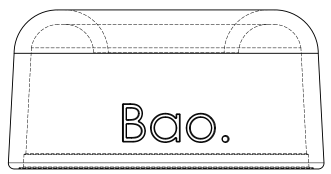


Research into glass materials showed that tempering would increase the strength and durability of the component improving resistance to impact. Investigation into fixings showed the need for methods that spread load, in areas where points of localised high stress are created during assembly

Stage 5
Part development

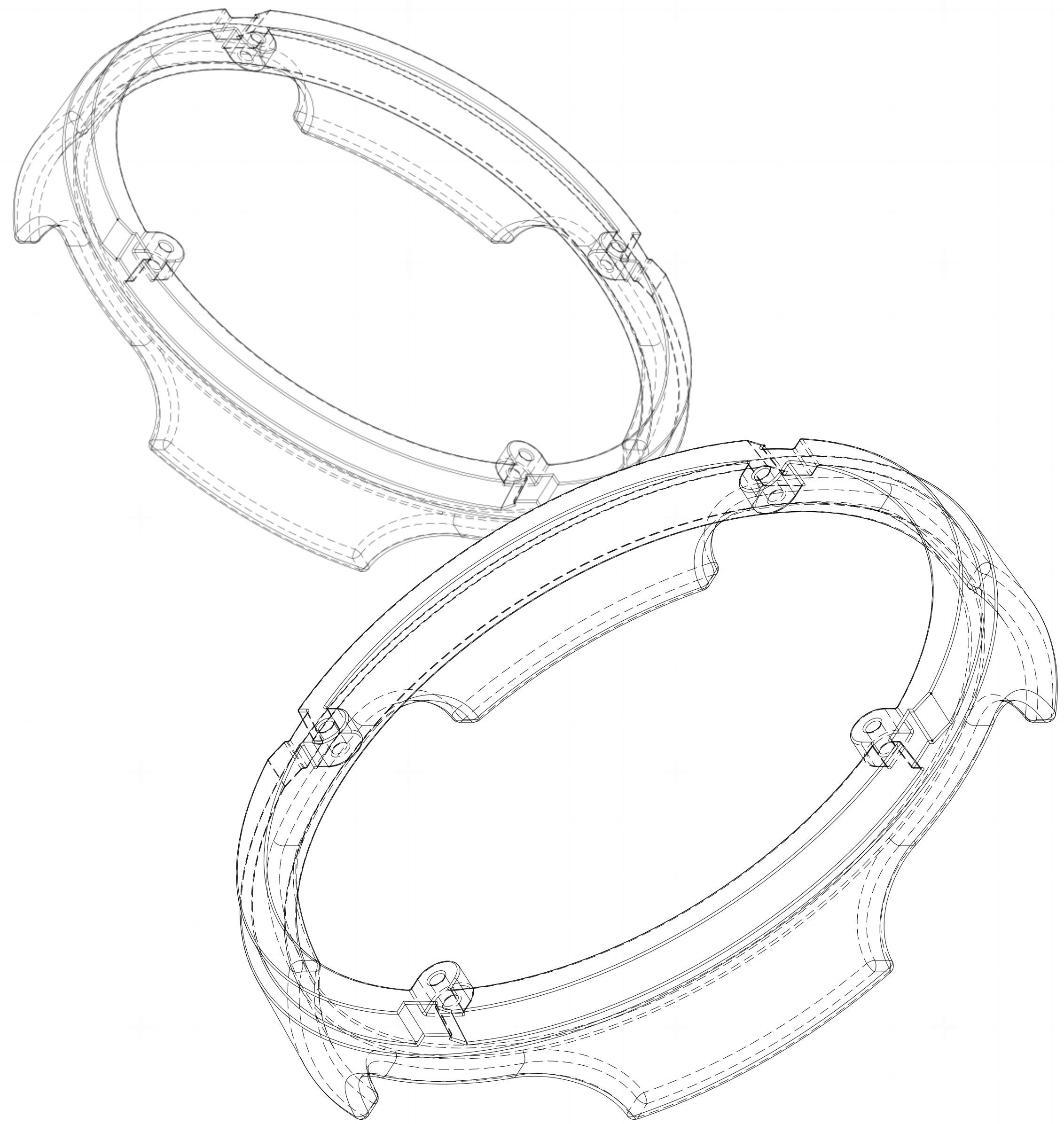
The fixing method chosen for attaching both the Speaker Grill and Fixing Ring was bonding with a specialist electronics adhesives typically used for smart phone screens (e.g. 3M™ VHB™ 4914 family). This can be produced as a flat gasket to make it easy to apply evenly and ensure a good bond.

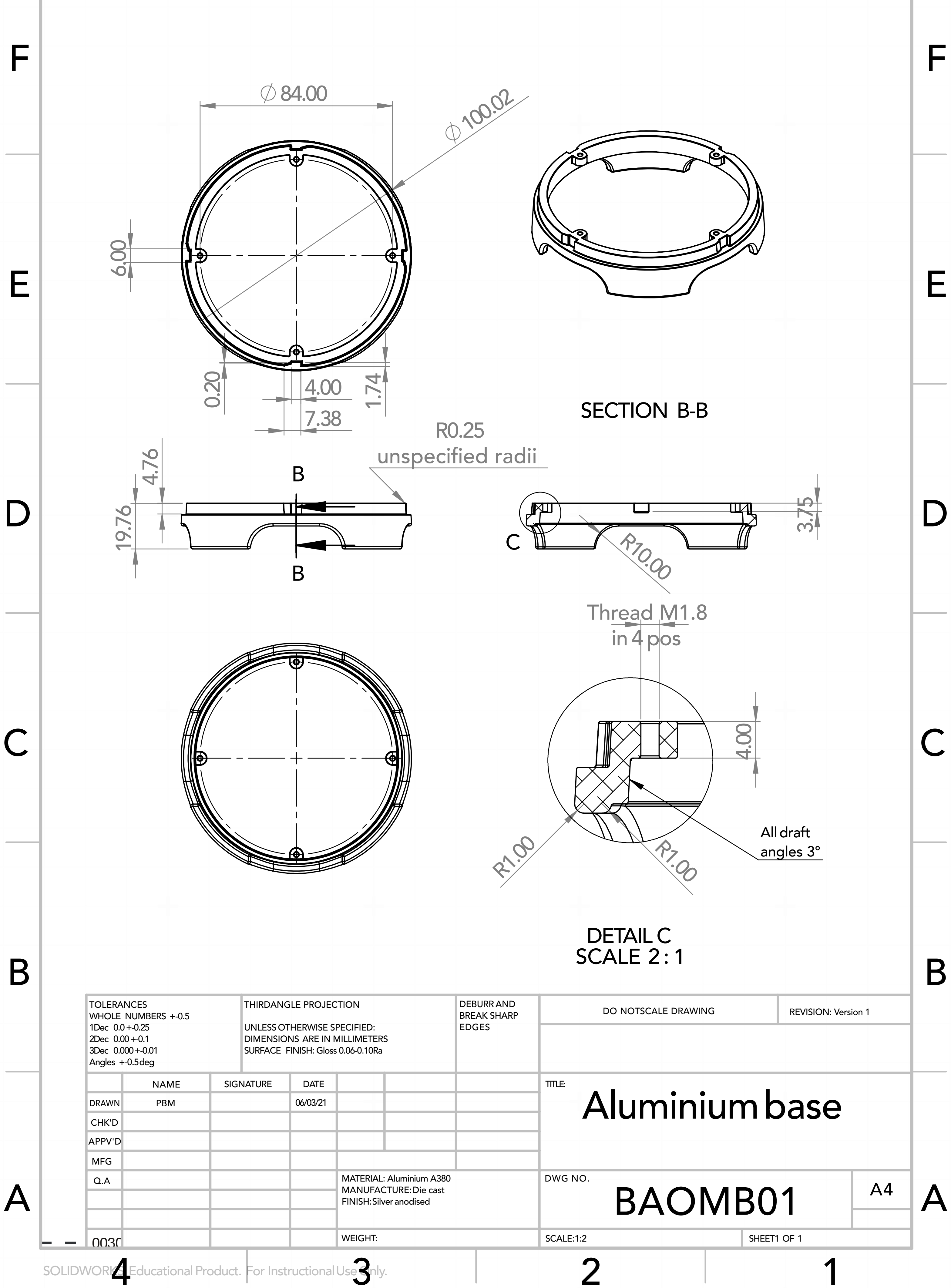
Stage 6
Manufacturer selection



Potential glass manufacturers were researched and John Moncrieff was chosen because of the suitability of their production facilities. John Moncrieff confirmed that they could manufacture the part without revisions and the cost.

Manufacturing guide
Aluminium base





Material
A380.0

"The most commonly used alloy in die casting and the least expensive in terms of cost per pound"

CNM Tech, 2018

We chose A380.0, a metal used in products from power tools to furniture, given its ability to create light parts with various surface finishing options compared with other die-cast alloys like copper or tin. A380.0 can withstand high operating temperatures, as-well-as being versatile, corrosion-resistant. Other aluminium alloys: A6061 and A383, were considered; however, A380.0 was chosen due to its favourable strength-to-weight characteristics, as-well-as overall cost CNM Tech, 2018.

Aluminum	Bal.
Copper	3.0-4.0
Magnesium	0.1
Iron (max)	1.3
Tin (max)	0.35
Nickel (max)	0.5
Zinc	3.0
Manganese	0.5
Silicon	7.5-9.5
Other-Metallic	0.5
RoHS Compliant	✓

OEFORM, 2019

Our A380.0 is mixed with metals: magnesium, iron, copper, silicon, zinc, and manganese to Improve the aluminium characteristics, bringing added strength and durability to the material. The addition of silicon and magnesium in A380.0 improves the aluminium's resistance to corrosion—a favourable characteristic for the design of our product.

Physical properties

Alloy A380 is the most widely cast alloy, offering the best combination of physical properties and production. A380 has good die filling characteristics due to its thermal properties and melt point. The material has good thermal and electrical conductivity, with a low thermal expansion coefficient ADAMS (2013).

Density	Melting Point (Average +/- 50)	Thermal Conductivity	Coefficient of Thermal Expansion	Electrical Conductivity	Process
g/cm^3	°C	W / m K	µm/m°K	% IACS	
2.71	566	96	21.8	23.0	Cold Chamber Die Casting

OEFORM, 2019

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Mechanical properties

A380 Exhibits a range of positive mechanical properties, High tensile, Impact and shear strengths contribute to a yield strength rating of 160MPa. The material also exhibits a hardness of 80HB (Brinell) ADAMS (2013).

Elongation	Tensile Strength	Yield Strength (0.2%)	Impact Strength	Shear Strength	Hardness	Process
% in 50mm	MPa	MPa	J	MPa	Brinell (HB)	
3.5	324	160	4	190	80	Cold Chamber Die Casting

OEFORM, 2019

A380 is the most economical aluminium alloy featuring a positive combination of casting properties compared to other aluminium alloys like A404 / 6061 ADAMS (2013).

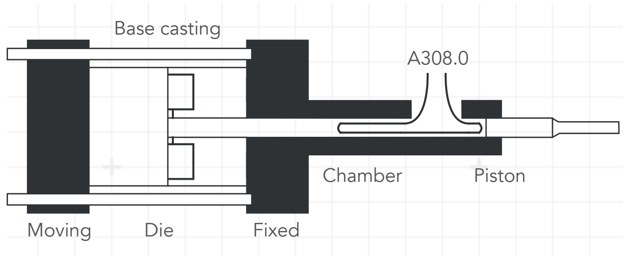
Processing
Die casting

Our process

High pressure die casting is used to form the A380.0 aluminium base. The process is suited for the high-volume production of omplex near-net shape parts like speaker base.

A metal die cavity with the negative geometry of the base part is created for a simple die consisting of two matching halves. This die is mounted to the machine which injects molten metal at high velocities. The die closes as molten metal is poured to a shot sleeve, the sleeve opening closes and a ram forces the metal into the die (10–100 ms), generating high levels of pressure. CNM Tech.

This pressure is maintained for a short time; active cooling occurs in the die cooling the mould. The ram is then relseased to releave the pressure as the die opens and ejector pins push out the base part. The process has a cycle time of approximately 90 seconds. CNM Tech.



Bao uses High pressure die casting as it allows us to create castings with high casting yield (up to 95%), high levels of surface finish, and high dimensional control. These factors minimise relative post-casting machining and finishing. CNM Tech.

Casting pressure

The Bao base is cast into a tool steel mould at a calibrated pressure of 1400kg / cm³ reducing the alloys grain size diameter to 5mm². This calibrated pressure of 1400 kg/cm2, gives the base a relative yield strength of 76 MPa and impact strength of 3.938Pa improving the components relative factor of safety (finite element analysis) ADAMS (2013).

+++

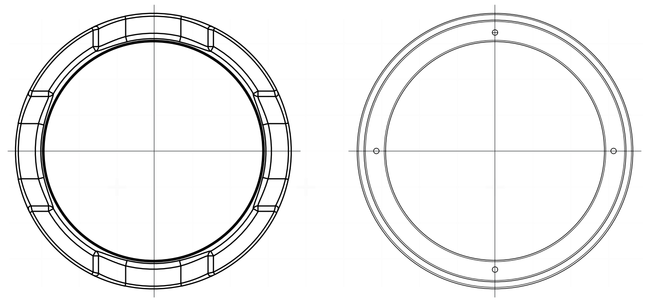
Die design

The dies are multiple cavity molds made from a pressure and heat resistant alloy tool steel (S1.2343 (X38CrMoV5-1) H11) capable of withstanding both the heat of the pre-heated injected material (660.37 °C) as-well as the pressure from the ram filling the cavity (1400kg / cm³). Die-casting steels like (S1.2343 (X38CrMoV5-1) H11) exhibit a resistance to heat-checking as-well as a high resistance to soldering and to erosion (washout) ADAMS (2013).

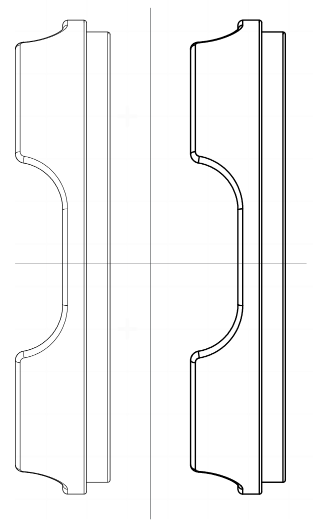
Properties of thermal fatigue determine the lifetime of steel dies (S1.2343 (X38CrMoV5-1) H11) operating at high temperatures. Thermal fatigue is the fatigue failure caused by the change in thermal stress. The washout of aluminium die-casting dies is caused by corrosive wear, erosive wear, and soldering ADAMS (2013).

Design
Our design

Rules



The walls of speaker base are roughly uniform in thickness to prevent breakage. A wall thickness above up-to 10mm is adhered to preventing the formation of internal cavities and material porosity. The greater the wall thickness, the longer it takes for the base to cool increasing risk of shrinkage. Thin wall sections like around the screw holes are atleast 2mm in thickness. preventing inconsistency leading to deformation. Holes and openings are in the direction of extraction CNM Tech.

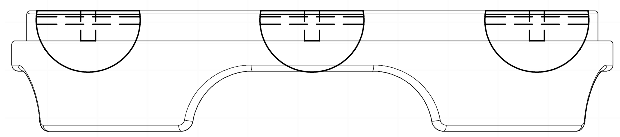


A draft angle of 3° is created on cavity surfaces perpendicular to the mould parting line so the speaker base can be removed from the mold easily.

A suffiencient number of overflow wells are created within the mould cavity to prevent shrinkage of the speaker base from any excess air being trapped inside the mold cavity

Finishing processes

The speaker bases surface finish is achieved within the mould, and doest require extra finishing. The threaded inserts are created by hand using a steel tapping screw. Excess flashing is trimmed from the sprue, with no finishing required for ejector pin marks (positioned on inside faces).



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Structural design

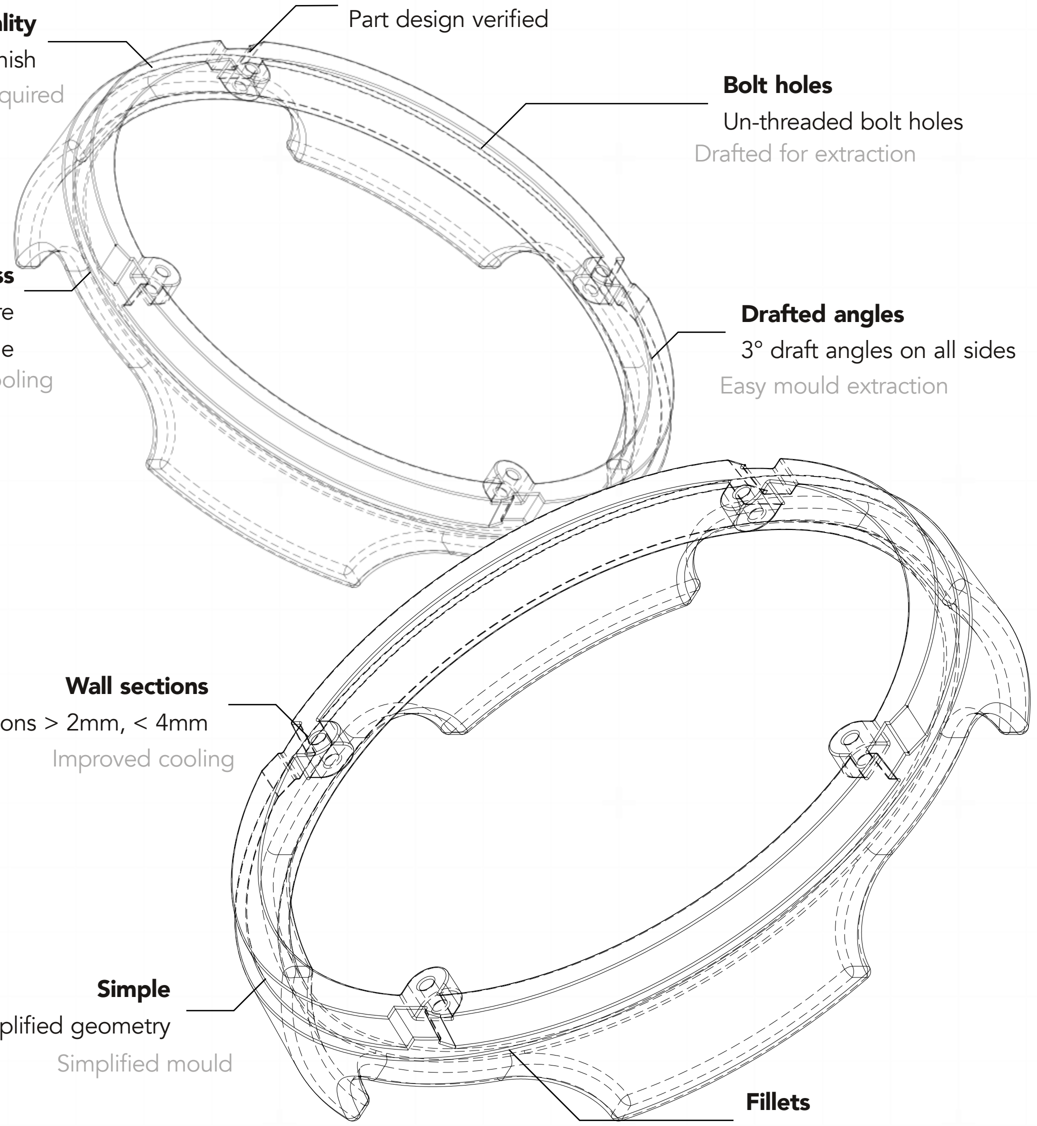
Fillets are used to improve structural integrity and metal flow. The fillets around the design's feet meet at a sharp corner or edge and help prevent high-stress concentrations at this juncture (impact from bumps/knocks) CNM Tech..

The part has been engineered to exhibit a factor of safety of two, making it twice as strong as the max load it is expected to take. This is due to the material properties of A380.0 as-well-as its thick, compact design, eliminating features that could cause the part to break under load CNM Tech.

Intentionally designing the part stronger than needed allows compensates for unexpected loads, misuse, or degradation.

Design
Closer look

proto labs
- Verified part for manufacture



Production
Manufacturing cost

Harrisoncastings.ltd
- Provided this quote

General Information

Name:	BAOMB01
Description:	Bao metal base: Aluminium A380.0

Part information

Quantity:	50,000.00
Material:	Aluminium A380.0. Die cast
X-Y-Z (mm):	100.00 x 100.00 x 20.00
Weight (kg)	0.10.00 kg
Tolerance:	High precision (<= 0.125)
Surfacing:	Medium quality (matte)

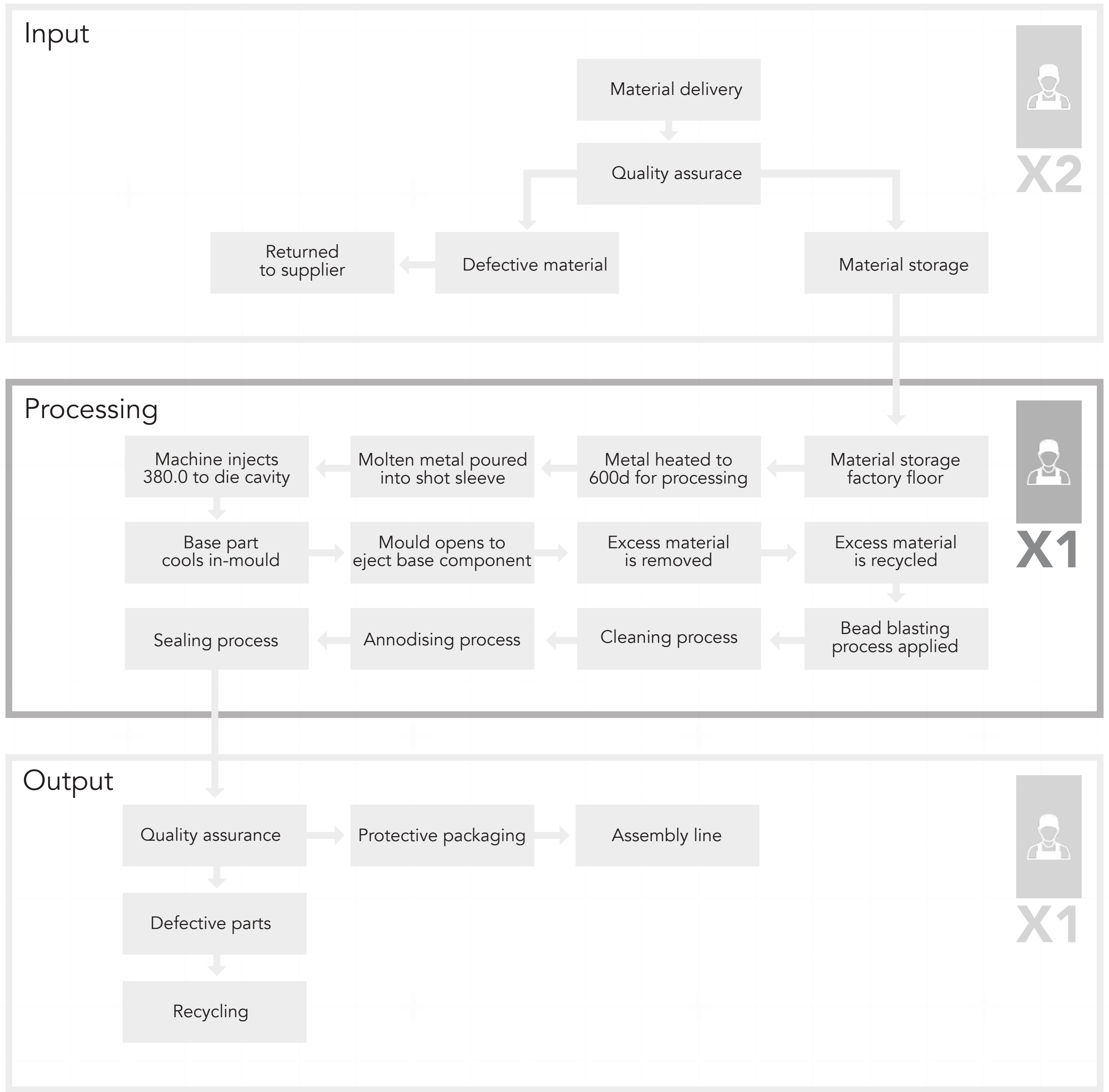
Processing paramaters

Material	
Weight (kg):	0.10.00
Price (£/kg):	2.16.00
Markup (%):	25.00
Production	
Machine:	Cold chamber
Clamp force (kN):	890.00
Setup time (hrs):	8.00
Up-time (%):	95.00
Post-processing (hrs):	0.00
Defect rate (%):	5.00
Production rate (p/hr):	116.00
Hourly rate (£/hr):	17.95
Production markup (%):	10.00
Tooling	
Number of cavities:	1.00
Number of dies:	1.00
Die making rate (£/hr):	65.00

Cost summary:

Die casting	£63,858 (£1.277 per part)
Material cost	£12,963 (£0.259 per part)
Production cost	£8,690 (£0.174 per part)
Tooling cost	£42,206 (£0.844 per part)
Total cost	£63,858 (£1.277 per part)

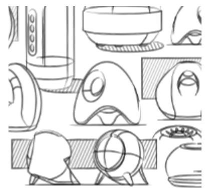
Production
System diagram



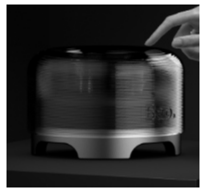
Change log
Design revisions

Stage 1
Conceptualisation

We initially worked to produce a range of ideation sketches defining the desired aesthetic shape / feel of the product. After a final shape was chosen this design was further explored with materials and design features more clearly defined.



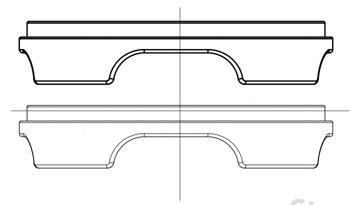
Stage 2
Aesthetic concept



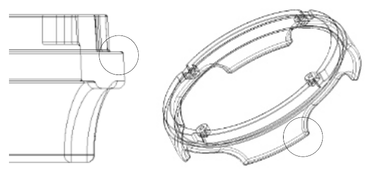
Initially developing a looks like model gave us the ability to refine the aesthetic features of our products design. Aluminium was initially selected as a possible material for the base because of its high value look and feel — adding to the product's distinctive, quality aesthetic.

Stage 3
Manufacturing

First pass research into manufacturing processes showed that it would be practical to make a component, that performs the necessary functions, in aluminium cost effectively. with viable manufacturing methods including: sand casting / machining and die casting processes.



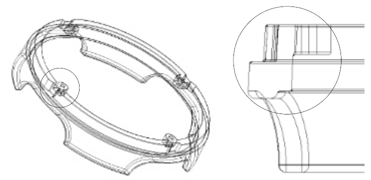
Stage 4
Part development



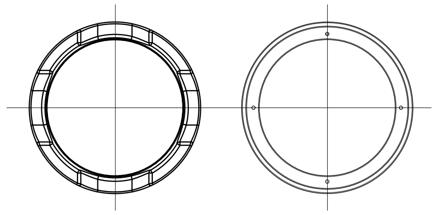
After comparison of the available manufacture methods, gravity die casting was selected as the preferred route as it offered the best compromise between cost, finish and design flexibility. The part was developed with typical die casting features such as 3° draft angles and suitable radii.

Stage 5
Part development

Initially our design featured thick base wall (10mm). After review this was adapted to a uniform 4mm wall thickness ('L' section) saving around 40% in cost & weight. Part finishing discussed with consultants, selected anodising and sealing giving the part a durable, corrosion resistant satin appearance.

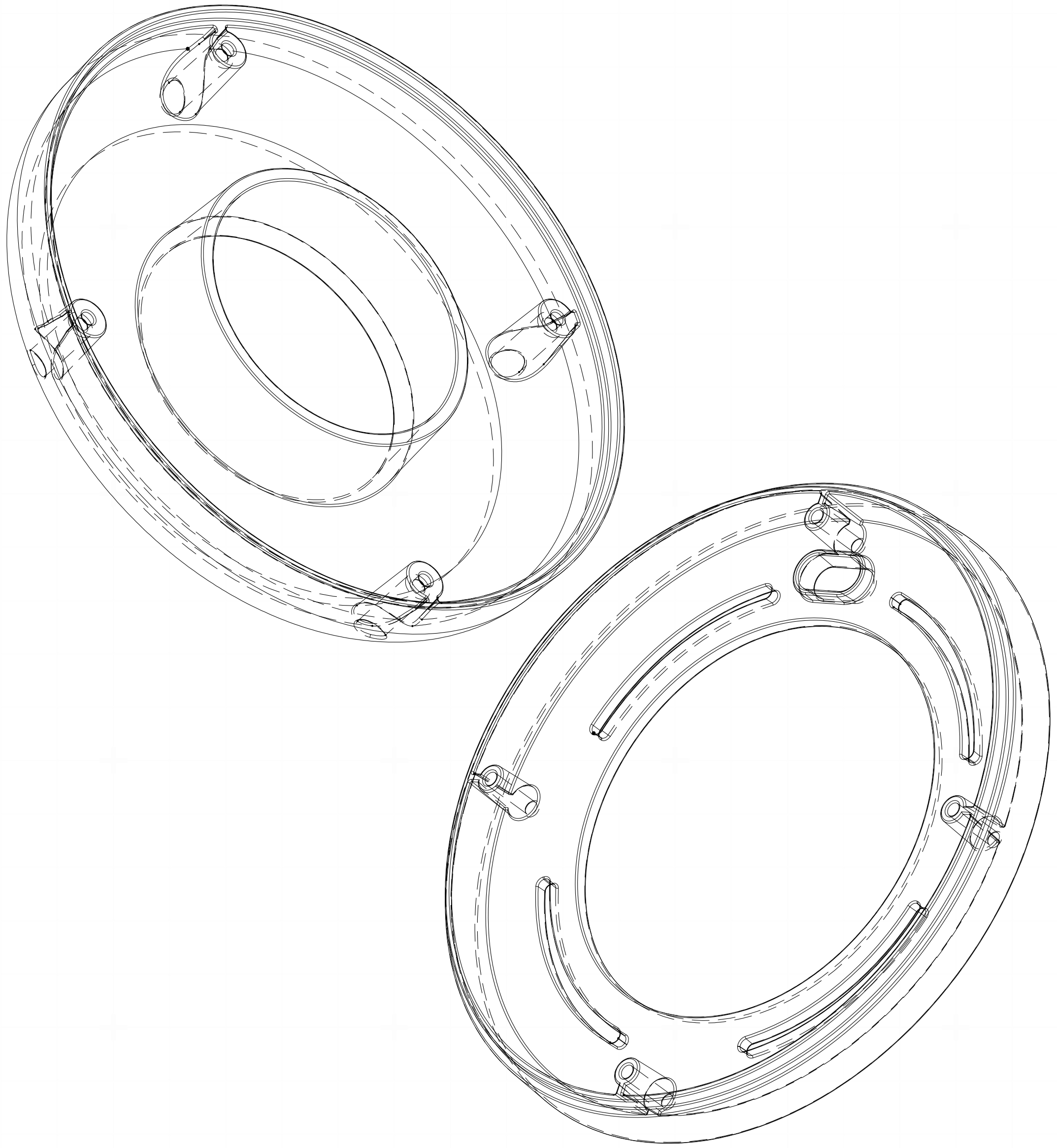


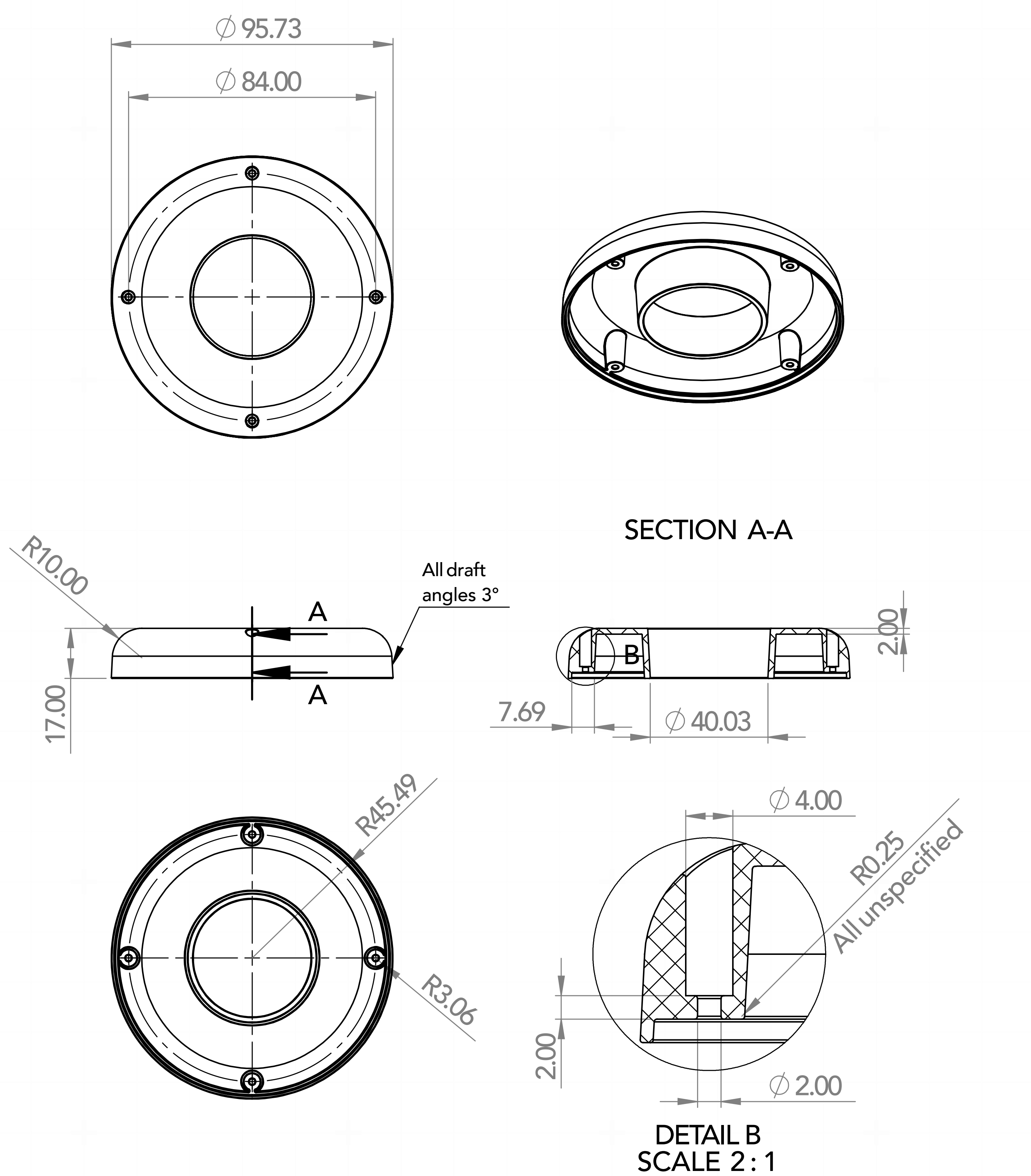
Stage 6
Manufacturer selection



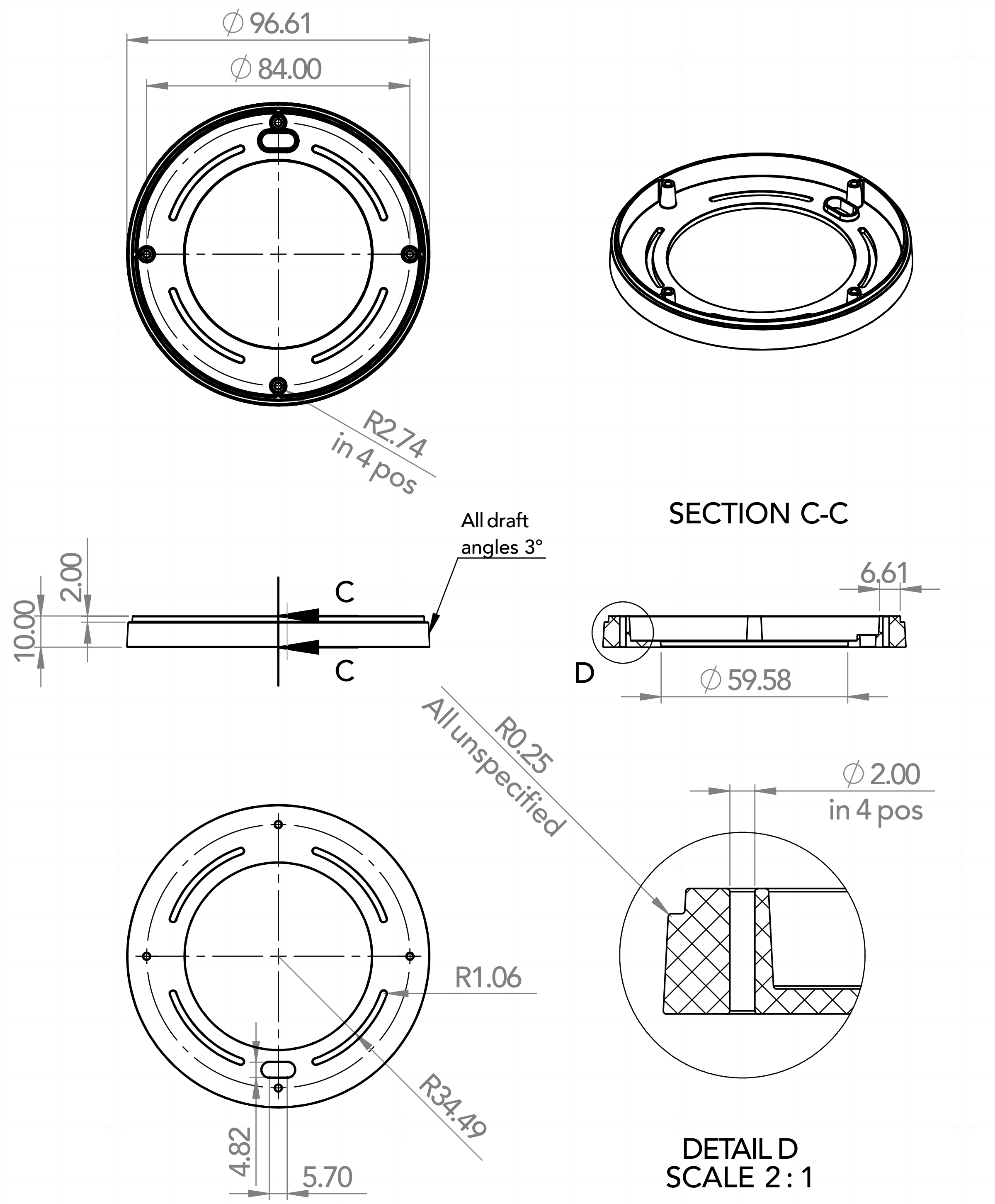
Potential casting companies were researched and Harrison Casting was chosen because of their familiarity with the scale of production as well as production facilities. Harrison Casting confirmed that they could manufacture the part without revisions to the design and the production cost.

Manufacturing guide
Plastic housing
Upper and lower





THIRDANGLE PROJECTION UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: Satin 0.10-0.20Ra	TOLERANCES WHOLE NUMBERS +-0.5 1Dec 0.0+-0.25 2Dec 0.00+-0.1 3Dec 0.000+-0.01 Angles +-0.5deg			DEBURR AND BREAK SHARP EDGES	DO NOTSCALE DRAWING	REVISION: Version 1
	NAME	SIGNATURE	DATE		TITLE: Plasticupper	
DRAWN	PBM		06/03/21			
CHK'D						
APPV'D						
MFG						
Q.A				MATERIAL:ABS Polylac717C (Black) MANUFACTURE: Injection moulding	DWG NO. BAOPU01	A4
				WEIGHT:	SCALE:1:2	SHEET1 OF 1



THIRDANGLE PROJECTION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH: Satin 0.10-0.20Ra

TOLERANCES
WHOLE NUMBERS +-0.5
1Dec 0.0+-0.25
2Dec 0.00+-0.1
3Dec 0.000+-0.01
Angles +-0.5deg

DEBURR AND BREAK SHARP EDGES

DO NOTSCALE DRAWING

REVISION: Version 1

	NAME	SIGNATURE	DATE
DRAWN	PBM		06/03/21
CHK'D			
APPV'D			
MFG			
Q.A			

TITLE: Plastic lower

MATERIAL:ABS Polylac 717C (Black)
MANUFACTURE: Injection moulding

DWG NO. BAOPL01

A4

WEIGHT:

SCALE:1:2

SHEET1 OF 1

Material
ABS Polylac 717C

"ABS is one of the most widely used polymers in injection molding"

(Polylac 717C)

We chose ABS Polylac 717C as the material for manufacturing our internal plastic housing as the materials are low-cost thermoplastic, with well studied industrial use in injection moulding.

ABS is relatively easy to Manufacture with good resistance to heat, chemicals and general impact loads.
ABS is appropriate for designing our plastic components often used to make similar products, from kids toys to tooling handles and chassis (Dielectric Manufacturing, 2020).

Key reasons we chose ABS Polylac 717C

- Good electrical properties
- Stronger than alternative options like PP/PLA
- Impact-resistant
- Abrasion-resistant
- Chemical resistant.
- Safe, non-toxic

ABS is a material that can be recycled (Other 7). Recycled ABS is also available to us and could be used in place of/in combination with virgin plastic to reduce our overall greenhouse gasses, linked to the primary production phase.

Physical properties

ABS is a medium to lightweight polymer (0.9–1.53 g/cm3) that exhibits a range of desirable physical properties, offering us a combination of durability, abrasion resistance, and hardness ideal for general purpose injection mouldings for consumer products like our Bao speaker.

Melting Point	°C	-
Density	g mL^{-1}	1.03 - 1.14
Coefficient of Thermal Expansion	cm / (cm °C)	2.0 - 10.3
Heat Deflection Temperature, 0.5 MPa	°C	88 - 107
Heat Deflection Temperature, 1.8 MPa	°C	71 - 103
Thermal Conductivity x 10^{-5}	W / mK	0.17 - 0.23
Rockwell Hardness, R Scale	n/a	R102 - R104

Polymerdatabase.com, 2019

+++

Mechanical properties

ABS Polylac 717C exhibits good impact resistance, as-well-as mechanical strength. This once again makes it ideal for consumer products like our speaker design, requiring durability to offer a long-life in service.

Tensile Strength, Yield at 23 C	MPa	28 - 120
Tensile Strength, Break at 23 C	MPa	
Elongation, Yield	%	1.0 - 50
Elongation, Break	%	2.5 - 40
Tensile Modulus at 23 C	MPa	420 - 2500
Flexural Strength, Yield	MPa	50 - 162
Flexural Modulus	MPa	1550 - 2580
Compressive Strength	MPa	

Polymerdatabase.com, 2019

ABS Polylac 717C can also have a range of colours surface finishes applied to create desirable aesthetic outcomes, defined by the mould design and master-batch.

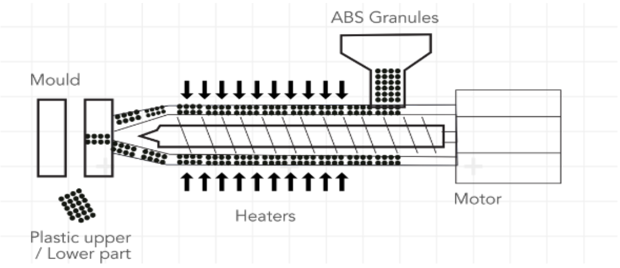
Processing
Injection moulding

Our process

We use plastic injection moulding as our chosen process to produce our ABS Polylac717C parts. Pre-purchased black ABS granules are dropped into our machine barrel through a hopper, where they are then heated by a series of heaters and forced into a tool-steel die mounted to the injection moulding machine. A ram forces the ABS into the die (10–100 ms), generating high-pressure levels.

This pressure is maintained for a short time; active cooling occurs in the die cooling the mould. At the end of our part cycle, the die opens and ejector pins positioned on the internal faces as-well-as the necessary valve gates to hide any un-sightly moulding marks that might affect the product aesthetics Dayamachinery 2020..

Each part has a process cycle time of approximately 30 seconds Protomould 2020.



Removal of the plastic part from the mould is done by gravity or by a robot arm. A robot arm is our preferred method of removal as this reduces the likelihood of component surface defects caused by free-fall from the moulding machine to bin.

Casting pressure

The plastic parts are injected at a pressure from 60 to 150 Mpa due to the 2mm wall thickness of the injection moulded parts. The holding pressure is defined between 60 to 70 MPa reducing the plastic parts' relative internal stresses. The melt injection speed is usually injected at medium and low speeds Dayamachinery, 2020.

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Mould design

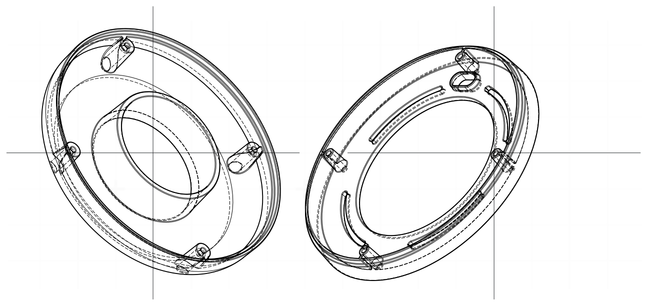
Because of our low manufacturing quantity, only a single impression aluminium tool is required to produce our plastic parts Protomoulds 2020. The choice of aluminium is also enabled in selecting ABS, which requires low injection pressures due to its high melt flow index (30g/10min).

Protomould also requested relatively high draft angles (3deg) to produce these parts to suit their preferred manufacturing platform. Protomould, 2020

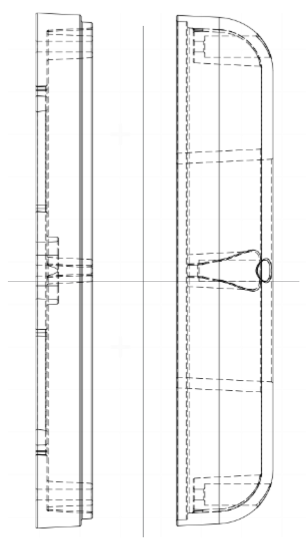
ABS has relatively low shrinkage (0.6%) compared to other polymers like HDPE (3%), simplifying our moulds' design. If higher capacity production for our parts was required, multi-cavity tools made from tool steel could be considered to reduce costs at higher production further.

Design
Our design

Rules



The walls of plastic moulding are uniform in thickness to prevent deformation and promote even cooling. A wall thickness of 2mm is adhered to. The greater the wall thickness, the longer it takes for the plastic parts to cool, increasing the shrinkage risk. Keeping the thickness relatively thin compared to extremely thick can help keep production costs low and prevent mistakes being made in the machine promoting material consistency in the parts. Protolabs, 2020.

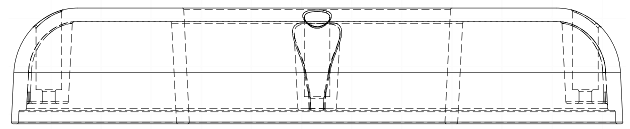


A draft angle of 3° is created on cavity surfaces perpendicular to the mould parting line so the speaker base can be removed from the mould easily. Protolabs, 2020.

Ribs around the mounting bosses add strength to the parts without exceeding the 2mm thickness. adding strength without risking shrinkage/deformation.

Finishing processes

The surface finish of the plastic parts is achieved within the mould and doest require extra finishing. Excess flashing is trimmed from the sprue, with no finishing required for ejector pin marks or sprue details as these are positioned on the inside faces of the plastic components. Protolabs, 2020.



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Structural design

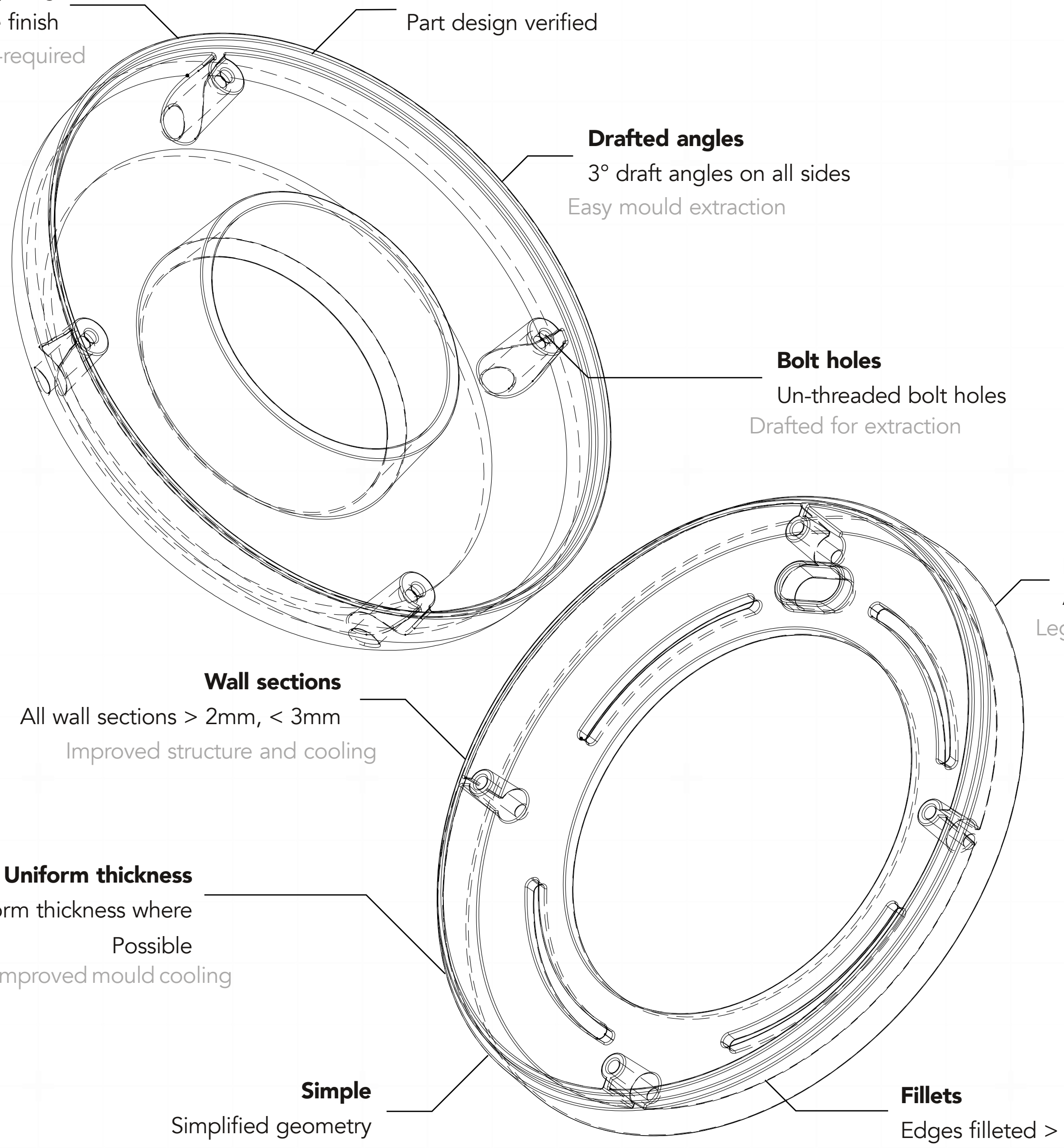
Fillets are used to improve structural integrity and in-mould plastic flow. The fillets around the design edges meet at all sharp corners/edges and help prevent high-stress concentrations at this juncture (impact from bumps/knocks).

Ribs integrated between the mounting bosses and walls of the parts add structure and rigidity to the bosses reducing their likelihood of failure under stress. This was important to our design as these are the fixing areas for the bolts and require structure and stiffness.

Curved surfaces add structure to the design walls, as-well-as the radiused upper moulding around the bosses.

Design
Closer look

proto labs
- Verified part for manufacture



Production
Manufacturing cost
Plastic lower

proto labs
- Provided this quote

General Information

Name:	BAOPL01
Description:	Plastic lower moulding

Part information

Quantity:	50,000.00
Material:	ABS PA-717C (Black)
X-Y-Z (mm):	95.00 x 95.00 x 17.00
Weight (kg)	0.10.00 kg
Tolerance:	High precision (+/- 0.076mm)
Surfacing:	Medium quality (matte)

Processing paramaters

Material	
Weight (kg):	0.10.00
Price (£/kg):	2.16.00
Markup (%):	25.00
Production	
Machine:	Injection moulding
Clamp force (kN):	750.00
Setup time (hrs):	8.00 (est)
Up-time (%):	98.00 (est)
Post-processing (hrs):	0.00
Defect rate (%):	2.00 (est)
Production rate (p/hr):	120.00 (est)
Hourly rate (£/hr):	17.95 (est)
Production markup (%):	10.00 (est)
Tooling	
Number of cavities:	1.00
Number of dies:	1.00
Die making rate (£/hr):	N/A

Cost summary:

Die casting	£39,000 (£0.78 per part)
Material cost	£30,000 (£0.60 per part)
Production cost	£9,000 (£0.18 per part)
Tooling cost	£3,355 (£0.067 per part)
Total cost	£39,000 (£0.78 per part)

Production
Manufacturing cost
Plastic upper

proto labs
- Provided this quote

General Information

Name:	BAOPU01
Description:	Plastic upper moulding

Part information

Quantity:	50,000.00
Material:	ABS PA-717C (Black)
X-Y-Z (mm):	95.00 x 95.00 x 10.00
Weight (kg)	0.10.00 kg
Tolerance:	High precision (+/- 0.076mm)
Surfacing:	Medium quality (matte)

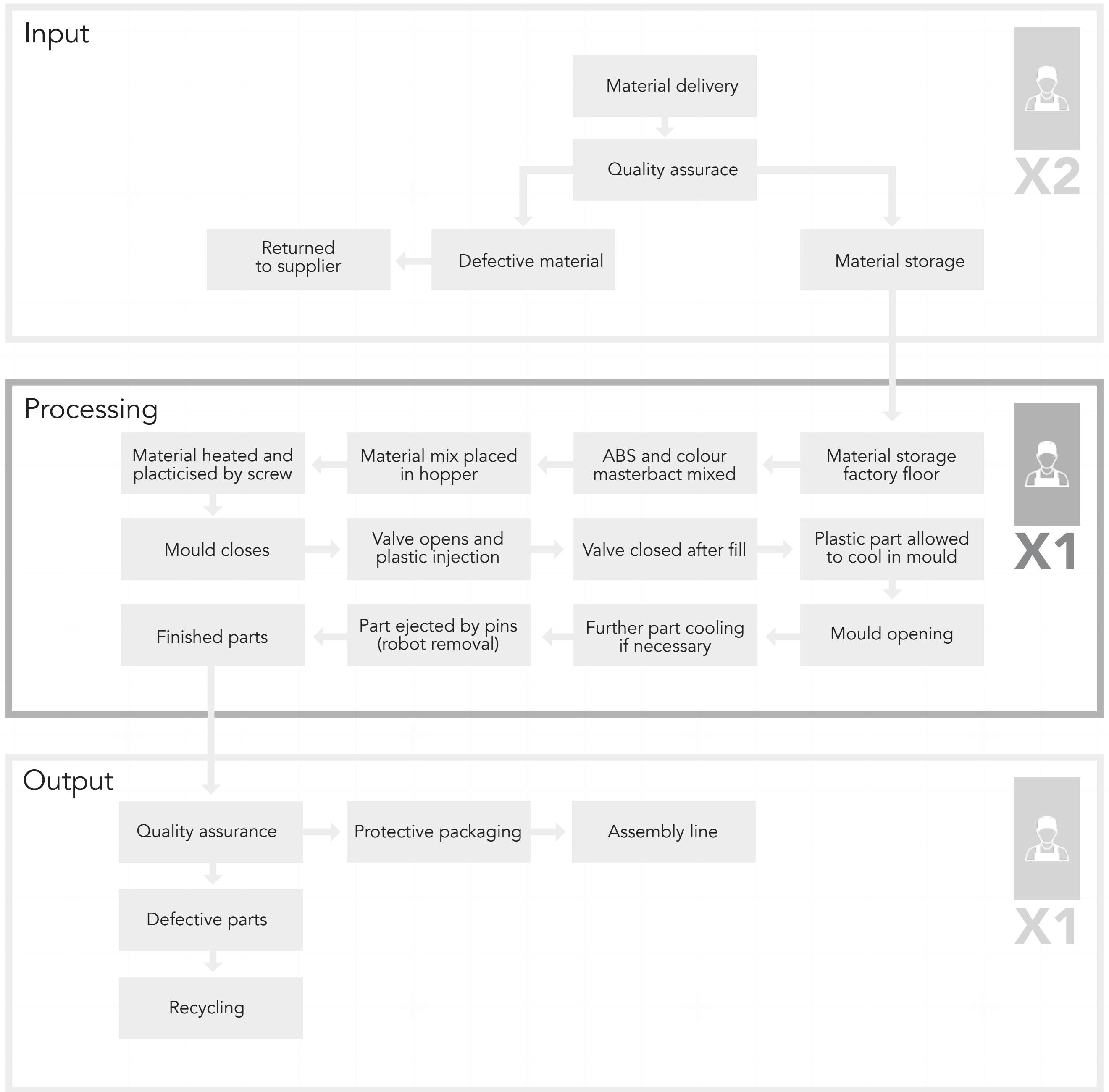
Processing paramaters

Material	
Weight (kg):	0.10.00
Price (£/kg):	2.16.00
Markup (%):	25.00
Production	
Machine:	Injection moulding
Clamp force (kN):	750.00
Setup time (hrs):	8.00 (est)
Up-time (%):	98.00 (est)
Post-processing (hrs):	0.00
Defect rate (%):	2.00 (est)
Production rate (p/hr):	120.00 (est)
Hourly rate (£/hr):	17.95 (est)
Production markup (%):	10.00 (est)
Tooling	
Number of cavities:	1.00
Number of dies:	1.00
Die making rate (£/hr):	N/A

Cost summary:

Die casting	£42,500 (£0.85 per part)
Material cost	£33,500,000 (£0.67 per part) (est)
Production cost	£9,000 (£0.18 per part) (est)
Tooling cost	£3,810 (£0.076 per part) (est)
Total cost	£39,000 (£0.78 per part)

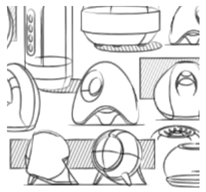
Production
System diagram



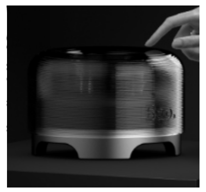
Change log
Design revisions

Stage 1
Conceptualisation

We initially worked to produce a range of ideation sketches defining the desired aesthetic shape / feel of the product. After a final shape was chosen this design was further explored with materials and design features more clearly defined.



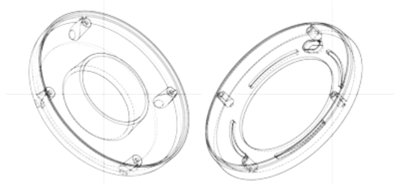
Stage 2
Aesthetic concept



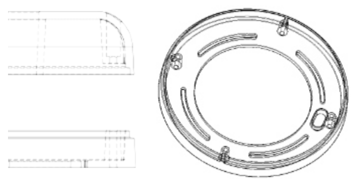
The concept design phase identified the need for an inexpensive housing for the electronics that is inexpensive to produce at quantity. The parts would need to have complex design features (e.g. fixings) and an appealing surface finish. A general purpose, injection moulded plastic was chosen at this phase.

Stage 3
Manufacturing

Research into manufacturing processes showed that it would be practical to make the components using injection moulding with an ABS resin that is popular for consumer electronics for it's impact resistance, formability, aesthetic qualities and cost effectiveness.



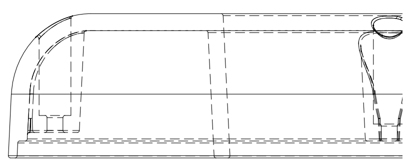
Stage 4
Part development



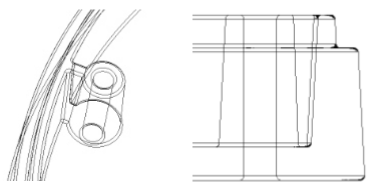
The part was developed with typical injection moulding features such as 1° draft angles and radii. After a consultant review, vents were added making it easier for air to pass through the enclosure dissapating heat from the speaker and PCB as-well as pressurising the passive enclosure subwoofer.

Stage 5
Part development

Potential injection moulders were researched and Protolabs was chosen. After reviewing the drawings Protolabs requested that the draft angles be increased to 3° to make the part easier to form and eject. Drawings and costings, were updated to reflect this change.

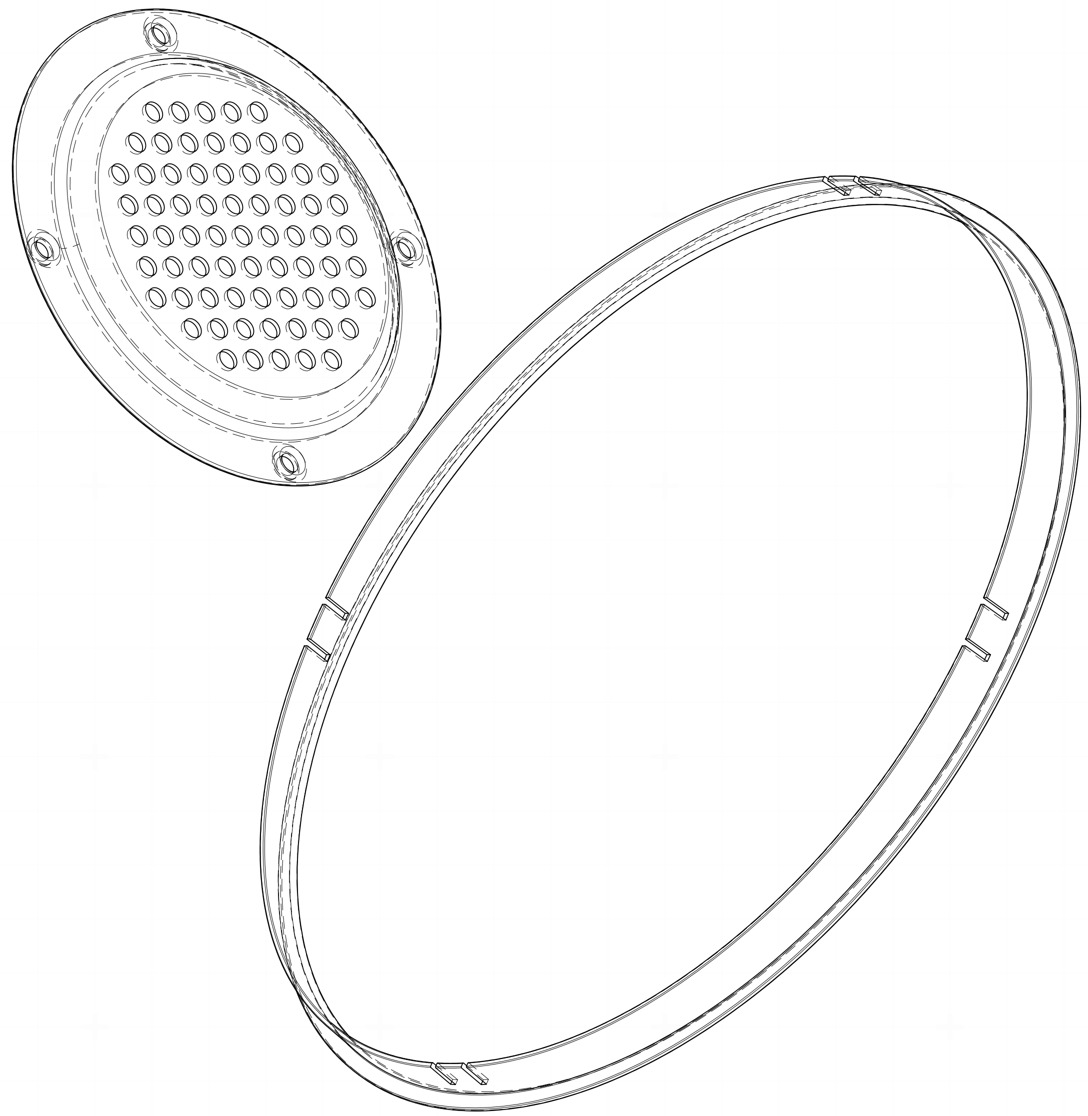


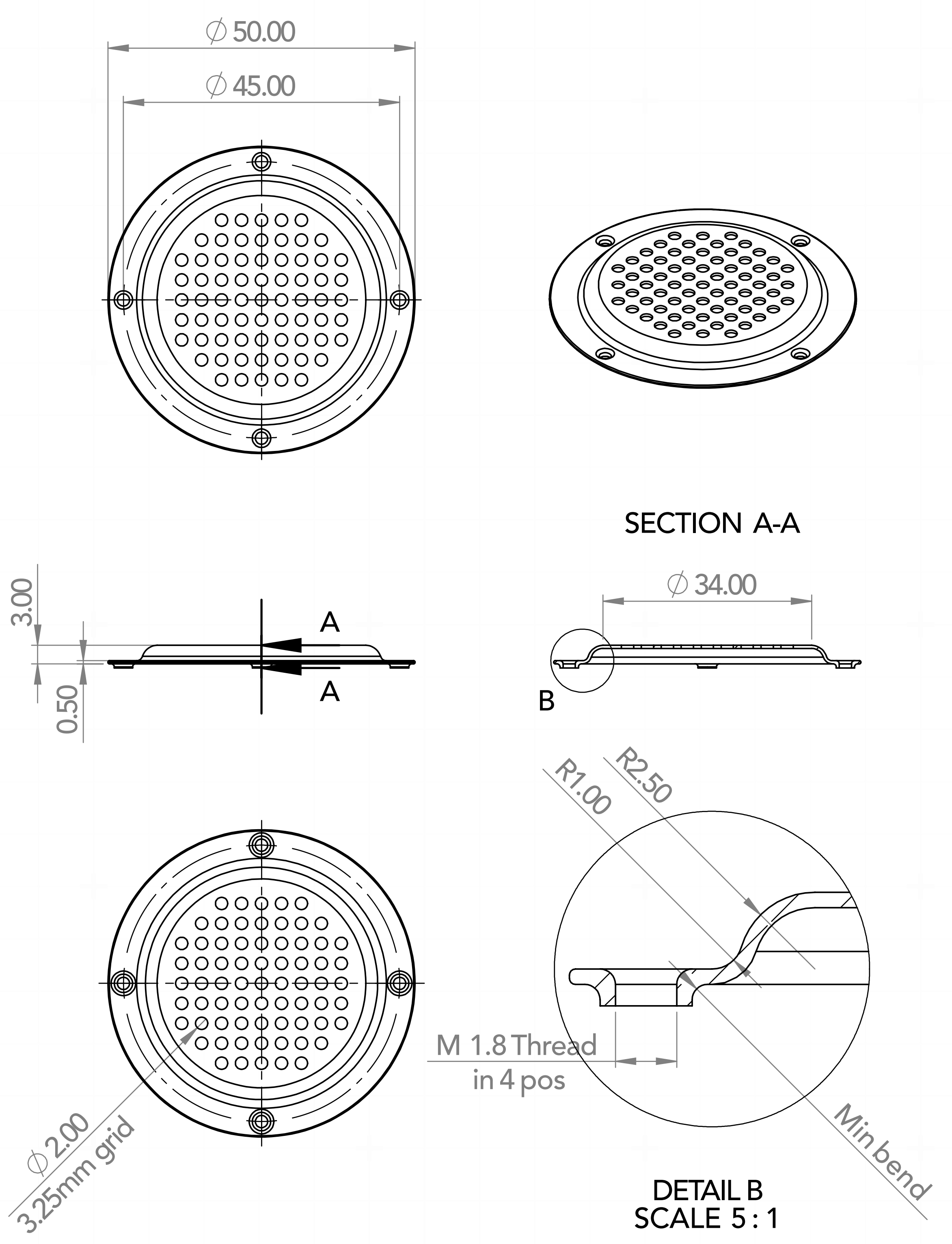
Stage 6
Manufacturer selection



Protolabs also suggested that the bosses for the screw fixings be moved away from the outer wall, and connected with a rib, to keep the wall thickness consistent and reduce the likelihood of shrink marks on the outside face. Protolabs confirmed they could manufacture the part with these revisions.

Manufacturing guide
Sheet metal parts
Speaker grill and glass fixing ring





THIRDANGLE PROJECTION UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: Gloss 0.06-0.10Ra	TOLERANCES WHOLE NUMBERS +-0.5 1Dec 0.0 +-0.25 2Dec 0.00 +-0.1 3Dec 0.000 +-0.01 Angles +-0.5deg	DEBURR AND BREAK SHARP EDGES	DO NOTSCALE DRAWING	REVISION: Version 1

	NAME	SIGNATURE	DATE
DRAWN	PBM		06/03/21
CHK'D			
APPV'D			
MFG			
Q.A			

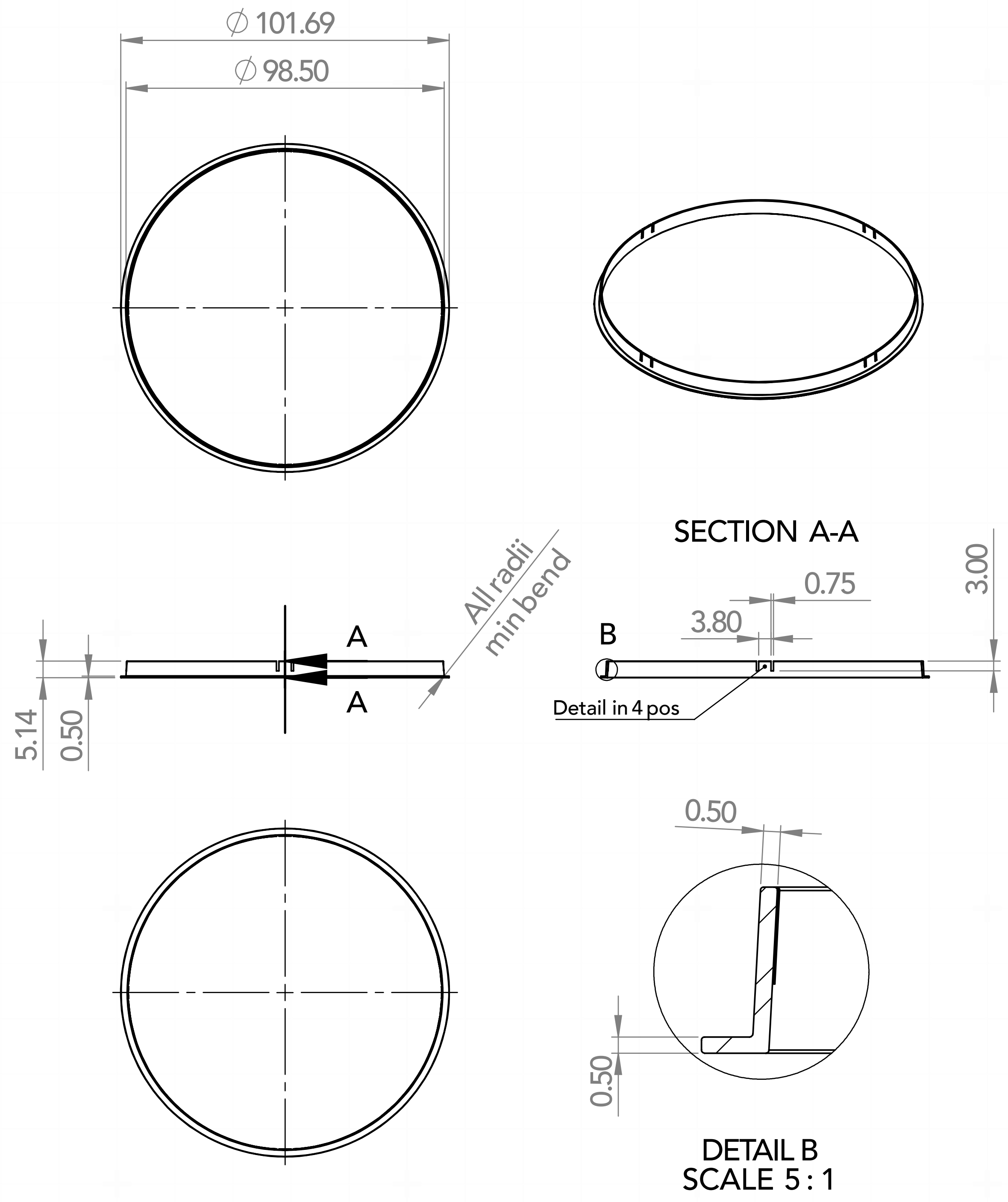
TITLE: Speaker grill

MATERIAL: 0.5mm Stainless steel sheet 304
MANUFACTURE: Punch / Press

DWG NO. BAOSG01 A4

WEIGHT:

SCALE:1:1 SHEET1 OF 1



THIRDANGLE PROJECTION UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN MILLIMETERS SURFACE FINISH: Gloss 0.06-0.10Ra	TOLERANCES WHOLE NUMBERS +-0.5 1Dec 0.0 +-0.25 2Dec 0.00 +-0.1 3Dec 0.000 +-0.01 Angles +-0.5deg	DEBURR AND BREAK SHARP EDGES	DO NOTSCALE DRAWING	REVISION: Version 1

	NAME	SIGNATURE	DATE
DRAWN	PBM		06/03/21
CHK'D			
APPV'D			
MFG			
Q.A			

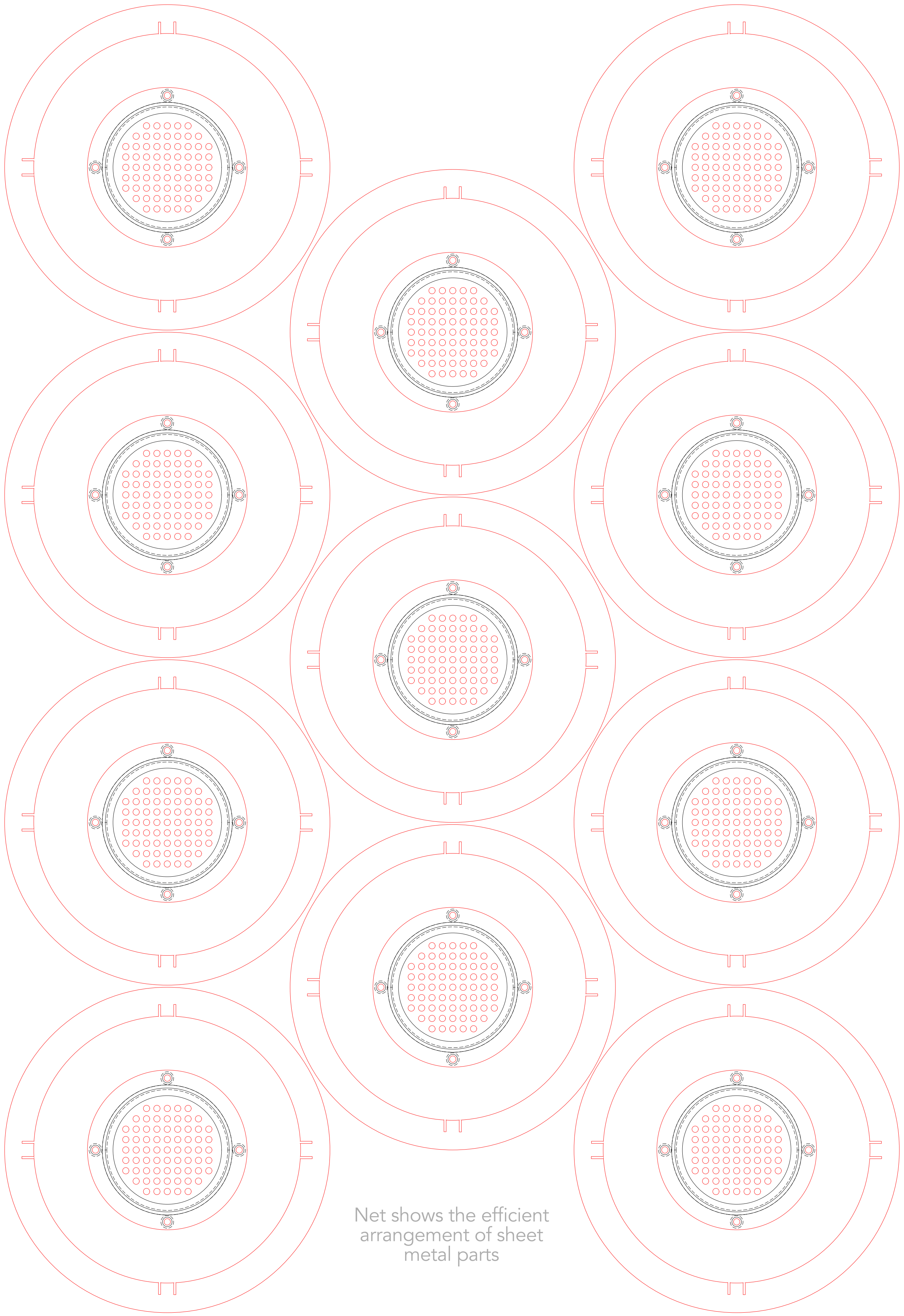
TITLE: Steel fixing ring

MATERIAL: 0.5mm Stainless steel sheet 304
MANUFACTURE: Punch / Press/ CNC cut

DWG NO. BAOSR01 A4

WEIGHT:

SCALE:1:2 SHEET1 OF 1



Net shows the efficient arrangement of sheet metal parts

Material
304 Stainless steel

"304 Stainless Steel is the most versatile and widely used stainless steel in the industry."

(Masteel, 2021)

304 is known for its excellent corrosion and heat resistance and its excellent machinability, weldability and can be readily work hardened. (Masteel, 2021)

304 Stainless Steel cannot be hardened with heat treatment; annealing will take place by rapid cooling after the 304 sheets have been heated at a temperature of 1010-1120C
There are several variants of 304-grade stainless steel, but we opt for 304H Stainless Steel due to its exceptional yield strength, robustness and shock-resistance. (Masteel, 2021)

metalsdatabase.com, 2019

Carbon	0.07
Chromium	19.50
Manganese	2.00
Silicon	1.00
Sulphur	0.045
Nickel	0.015
Nitrogen	10.50
Iron	0.10
Phosphur	0.10

We chose 304H stainless steel grade as it is superior to other 304 derivatives in its chemical characteristics.
304 Stainless Steel is high carbon steel composed of 18% chromium and 8% nickel and has good resistance to atmospheric corrosion and oxidation due to its high nickel-chromium alloy content. (Masteel, 2021)

Physical properties

There are several variants of 304-grade stainless steel, but we are opting for 304H Stainless Steel due to its exceptional yield strength, robustness and shock-resistance (Masteel, 2021)

Property	Value
Density	8.00 g/cm³
Melting Point	1450 °C
Modulus of Elasticity	193 GPa
Electrical Resistivity	0.72×10^{-6} Ω.m
Thermal Conductivity	16.2 W/m.K
Thermal Expansion	17.2×10^{-6}/K

+++

Mechanical properties

304H has good physical durability that is guaranteed to last. It benefits from excellent workability and lends to applications requiring high-strength plates or complex and tight radii and challenging features requiring high strength impact resistance. (Masteel, 2021)

metalsdatabase.com, 2019

Property	304	304H	304L
Tensile Strength (MPa)	540 - 750	520 - 700	-
Proof Stress (MPa)	230 Min	220 Min	-
Elongation A50 mm	45 Min %	45 Min %	-

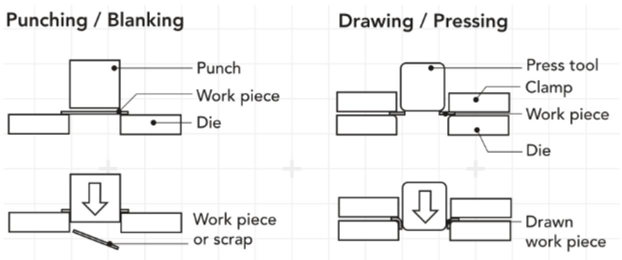
Processing
Sheet metal working

Our processes

The grill and fixing ring are punched and pressed from polished sheet stainless steel. The grill component is created from the steel in the centre of the fixing ring to increase material utilisation and reduce costs and scrap.

After punching, both components are pressed to achieve their final three-dimensional forms. Because holes in the speaker grill lie on a relatively flat surface, it should be possible to make these when the grill blank is punched.

Vertical slots in the fixing ring are made after pressing by CNC machining. This is because significant deformation of the flat blank is necessary to achieve the vertical walls, and slots would affect the uniformity of the thinning of the wall. Also, it would be difficult to predict what the initial cut from of the slots would need to be to achieve the desired tab form for the final, pressed part.



304 polished stainless steel was chosen for the material as it provides both an attractive look without the need for additional processing. And, has a modulus that is ideal for the spring metal tabs that clip into recesses in the plastic base moulding to fix the glass top in position. (Masteel, 2021)

Machines

To produce both components from sheet steel, two machines are required. Punching, pressing, and threading is completed using a CNC punch/press with a combination of standard tools for hole flanges and tapping and custom tools for pressing and blanking the overall shape.

Slots are created in the fixing ring with a vertical CNC milling machine.

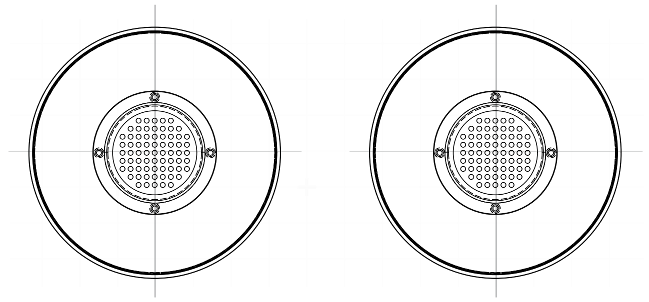
+++

Tool design

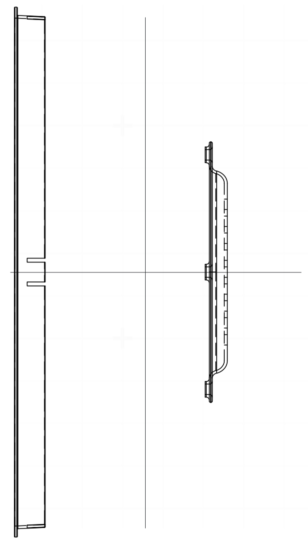
Custom tools are required for blanking the shapes of both the speaker grill and fixing ring. Custom tools are also required for pressing/drawing the grill and fixing the ring to their final shapes.
Tool steels are used for cutting and pressing the sheet metal parts. These are carbon and alloy steels, well-suited to be made into tools (carbon 0.5% -1.5%). Their suitability comes from their hardness, resistance to abrasion and deformation, and ability to hold a cutting edge at high temperatures. (Masteel, 2021)
Custom tools are made with a variety of standard grinding and CNC machining processes before the tool steel is hardened. Tool life can be extended through the use of PVD wear-resistant coatings teated to the inside of the mould cavities. (Masteel, 2021)

Design
Our design

Rules



The sheet metal parts' walls are uniform in thickness (2mm) due to the nature of the material being used. The sheet metal parts exhibit holes and fixings >= 2mm (t) to prevent high punch loading in these areas. Holes integral to the structure of the material exhibit spacing of at least 2t to retain the material's structure. Parts are designed to reduce the requirement of extra mechanical parts where possible, noted in the interference pegs on the fixing ring. Metalfacuture, 2021

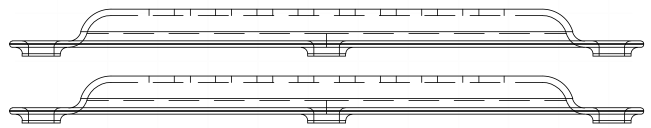


A draft angle of 3° applied to surfaces perpendicular to the edge of the glass part reduces the stress during the drawing process and allows the part to tightly the interior rim of the glass part. Metalfacuture, 2021

A bend radius of at least 1.5t is used to design each part to prevent defects like stress fractures and warping, causing the part to become unstable. Metalfacuture, 2021

Finishing processes

The sheet material for the speaker grill is polished to a surface finish of 0.06-0.10Ra, once the part has been punched and pressed from the initial blank sheet. No finishing process is required for the fixing ring as this component adheres to the inside of the speaker's glass top. Metalfacuture, 2021



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Structural design

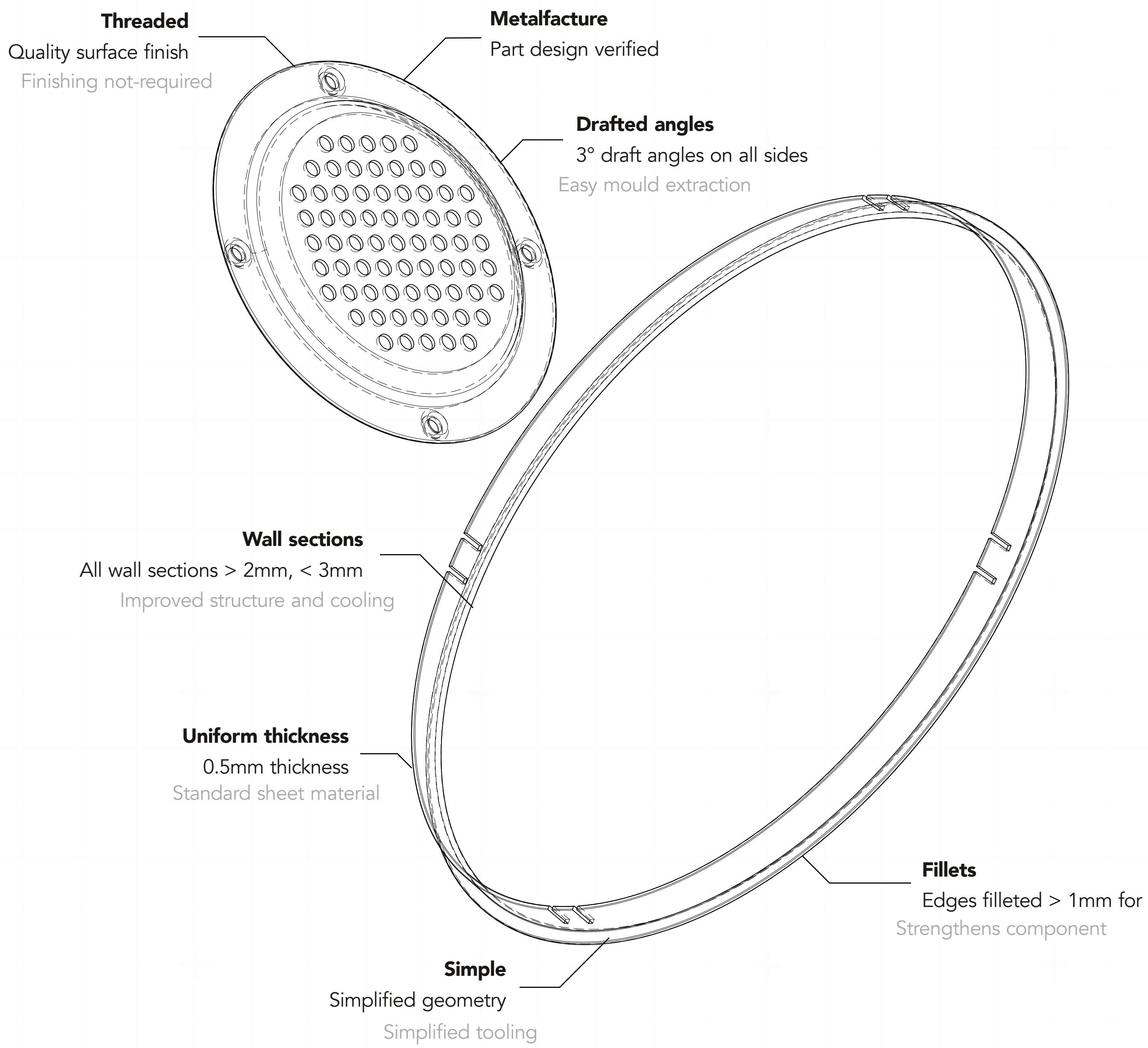
Drawing the sheet steel to shape the fixing ring for the glass component improves the 3d geometry of the component to add definition and structure. This drawn feature exhibits a minimum bend radius at the point of bending to avoid weakening the steel part. Metalfacuture, 2021

The pressed (embossed) speaker grill shows similar structural improvements, although less defined. The curve adds structure and rigidity to the steel part, an essential addition to the weakening of the material from the speaker holes.

Threaded hole flanges increase the relative thread depth of the sheet steel in areas where bolt fixings are needed improving the strength of these areas of material.

Design
Closer look

Metalfacture
- Verified part for manufacture



Production
Manufacturing cost
Speaker grill

Metalfacture
- Provided this quote

General Information

Name:	BAOGS01
Description:	Sheet steel speaker grill

Part information

Quantity:	50,000.00
Material:	Stainless steel 304H
X-Y-Z (mm):	50.00 x 50.00 x 3.00
Weight (kg)	0.10.00 kg
Tolerance:	High precision (+/- 0.076mm)
Surfacing:	Gloss surface

Processing paramaters

Material	
Weight (kg):	0.10.00
Price (£/kg):	2.16.00
Markup (%):	N/A
Production	
Machine:	N/A
Clamp force (kN):	N/A
Setup time (hrs):	N/A
Up-time (%):	N/A
Post-processing (hrs):	N/A
Defect rate (%):	N/A
Production rate (p/hr):	N/A
Hourly rate (£/hr):	N/A
Production markup (%):	N/A
Tooling	
Number of cavities:	N/A
Number of dies:	N/A
Die making rate (£/hr):	N/A

Cost summary:

Manufacturing	£85,000 (£1.70 per part)
Material cost	N/A
Production cost	N/A
Tooling cost	N/A
Total cost	£85,000 (1.70 per part)

Production
Manufacturing cost
Steel fixing ring

Metalfacture
- Provided this quote

General Information

Name:	BAOFR01
Description:	Sheet steel fixing ring

Part information

Quantity:	50,000.00
Material:	Stainless steel 304H
X-Y-Z (mm):	102 x 102 x 5.14
Weight (kg)	0.90.00 kg
Tolerance:	High precision (+/- 0.076mm)
Surfacing:	Medium quality (matte)

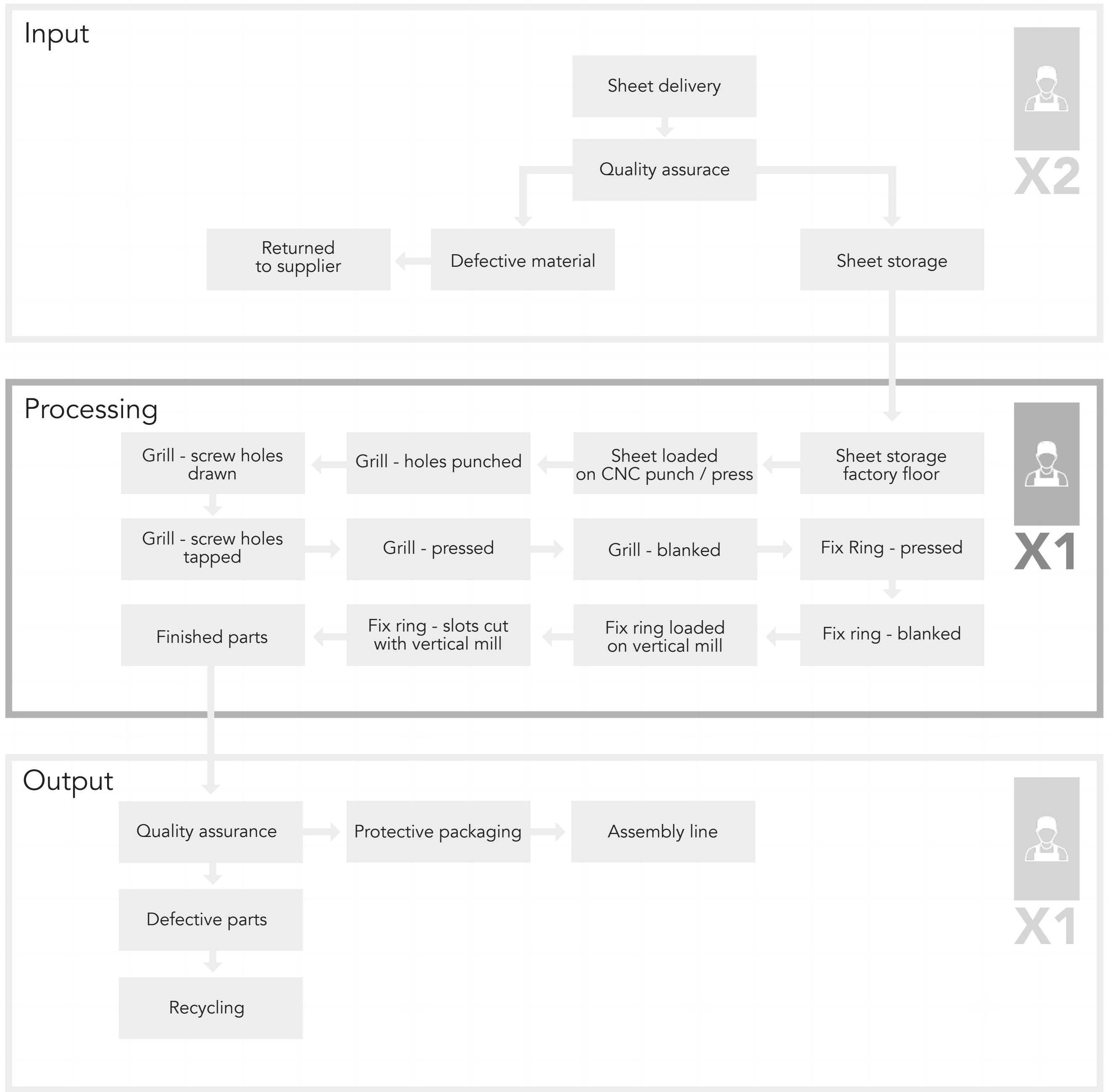
Processing paramaters

Material	
Weight (kg):	0.10.00
Price (£/kg):	2.16.00
Markup (%):	N/A
Production	
Machine:	N/A
Clamp force (kN):	N/A
Setup time (hrs):	N/A
Up-time (%):	N/A
Post-processing (hrs):	N/A
Defect rate (%):	N/A
Production rate (p/hr):	N/A
Hourly rate (£/hr):	N/A
Production markup (%):	N/A
Tooling	
Number of cavities:	N/A
Number of dies:	N/A
Die making rate (£/hr):	N/A

Cost summary:

Die casting	£57,500 (£1.15 per part)
Material cost	N/A
Production cost	N/A
Tooling cost	N/A
Total cost	£57,500 (£1.15 per part)

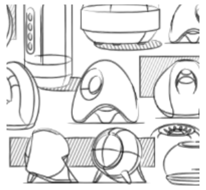
Production
System diagram

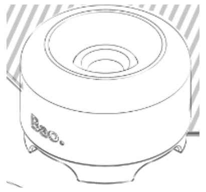


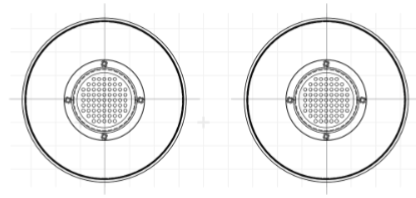
Change log
Design revisions

Stage 1
Conceptualisation

The Speaker Grill and Fixing Ring were not considered within the initial concept design phase. These were added after a consulting session to meet the requirements for manufacturing processes with additional design rules and functionality to protect the speaker as well as fasten the glass top.





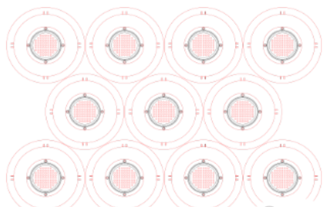


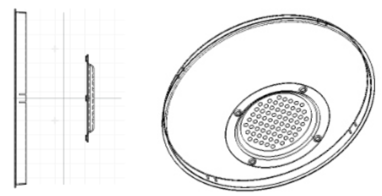
Stage 2
Initial consideration

Sheet stainless steel was initially considered for the production of these steel parts, given its ability to be drawn, punched and trimmed to the necessary component geometry. The parts would ideally be cut from the same sheet in a compact net, seperately drawn / stamped to create their unique geometry.

Stage 3
Manufacturing

Research into punching and pressing steel revealed an opportunity to create both a fixing method for the Glass Top and Speaker Grill from a shared process. The grill component is created from the steel in the centre of the fixing ring to increase material utilisation and reduce costs as well as scrap.



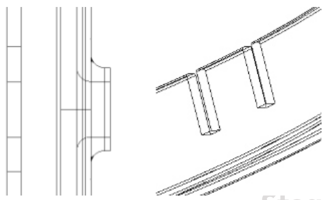


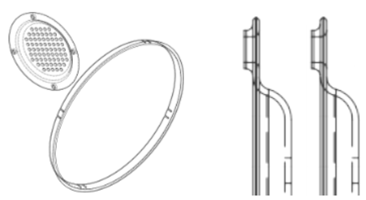
Stage 4
Part development

The components were both developed following design rules for sheet metal manufacture and CNC machining. Bonding was chosen as the method to attach both the Fixing Ring and Speaker Grill to the Glass Top meeting the need for a fixing method that spreads load etc.

Stage 5
Part development

Fixings fasten the glass top to the assembly using spring tabs that compress as the component slides over the plastic moulding and eventually return when they locate over specially designed recesses. After assembly, these tabs can also be depressed through slots in the base to enable disassembly.

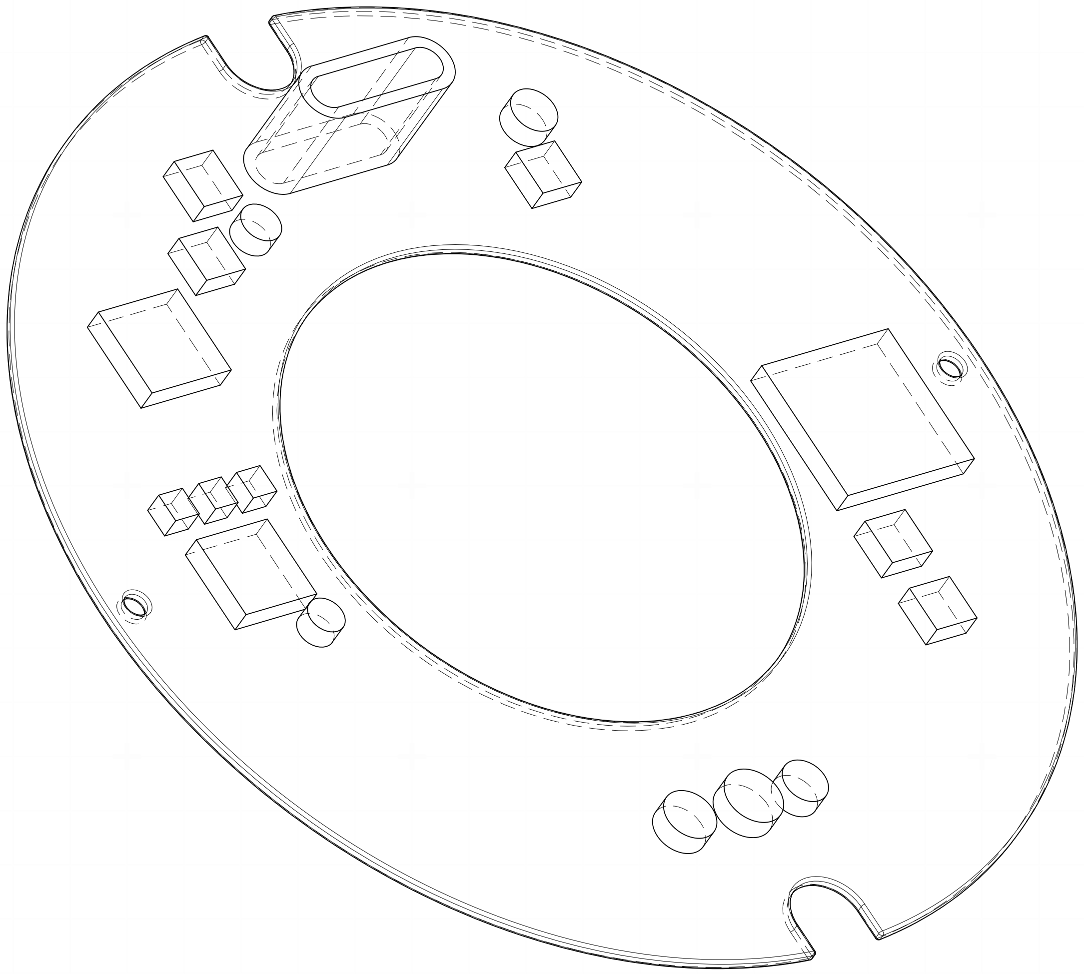




Stage 6
Manufacturer selection

Sheet metal processing specialists were identified and Metalfacture was chosen because of their production facilities. Metalfacture confirmed that they could manufacture the part without revisions to the design and the production cost of parts.

Part guide
Electronics & PCB
Our PCB



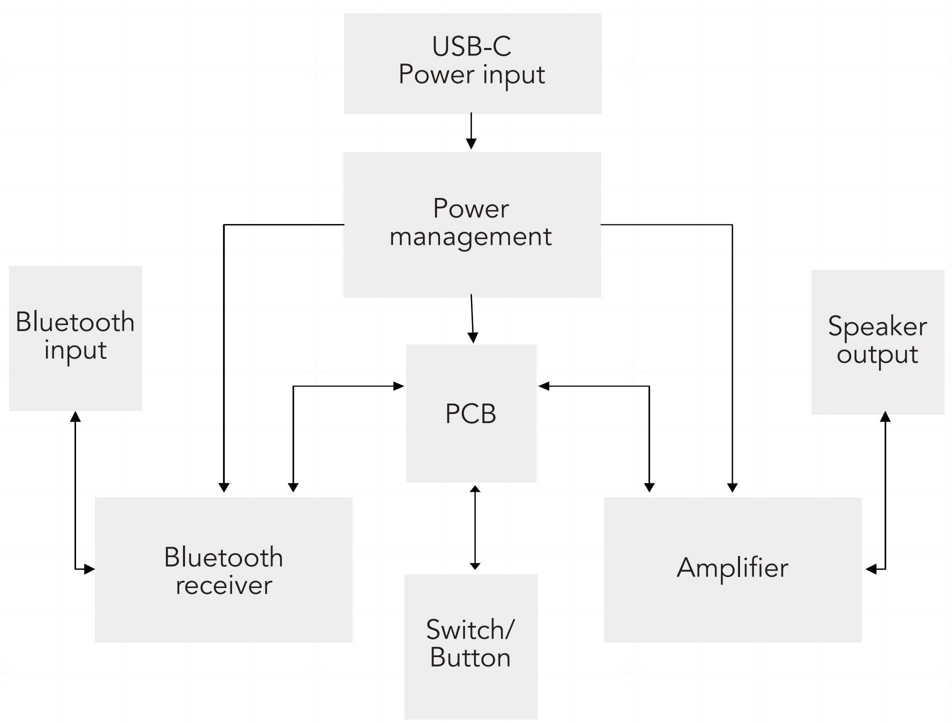
Electronics
Block diagram
Key features

Key:

+ This is how the speaker will work and get its power—made possible due to the USB-Power cable connected to the power management system powering the PCB, which ultimately controls the circuit board's features.

+ Bluetooth allows the user to connect to the speaker wirelessly, eliminating the need for buttons and switches, creating a more minimalist design. The PCB features a Bluetooth receiver.

+ The speaker on the unit is powered by an amplifier which allows it to be sufficiently audible. The speaker output on the block diagram describes this feature.



Illustrator diagram

Electronics
Schematic diagram
Our product schematic

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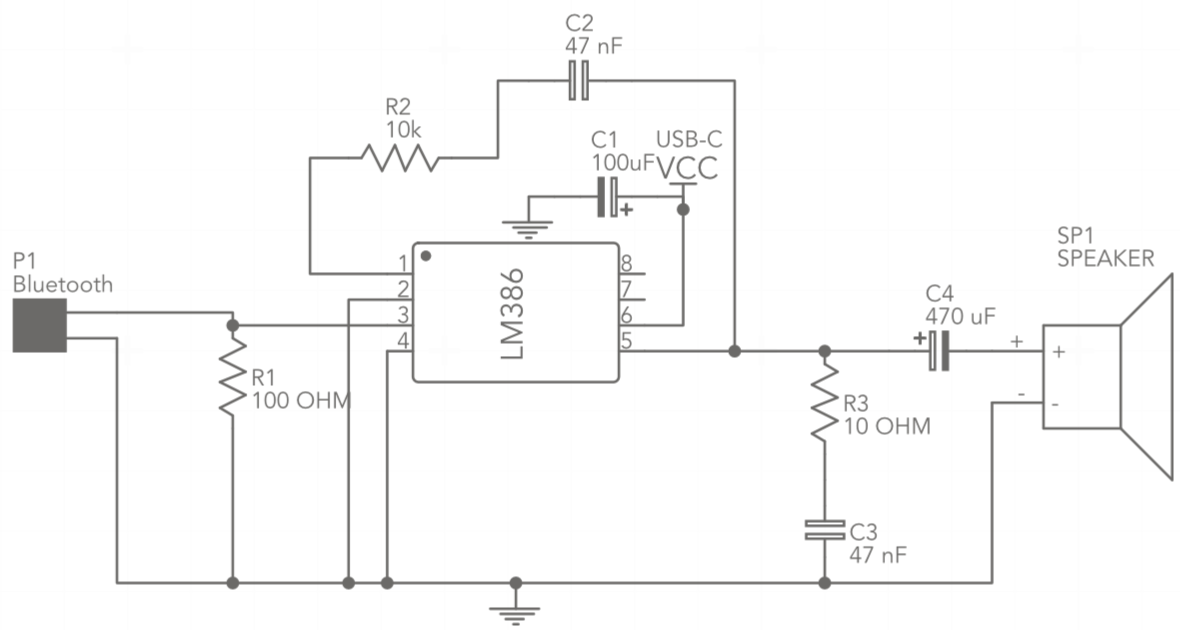
This is the schematic diagram for our speaker design. This shows all electronic connections and includes

inputs and outputs along with the PCB board. This was taken from another source, and annotations and features were added to make it fit our design more.

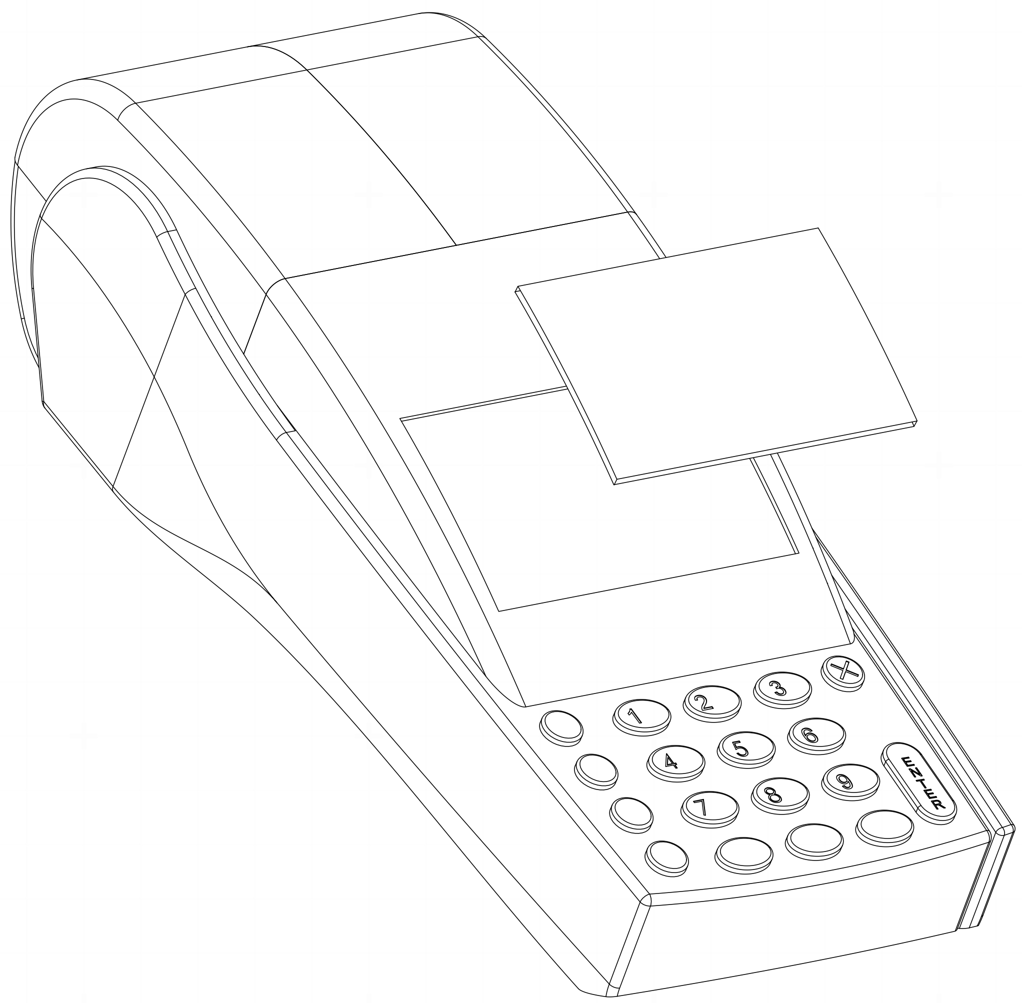
This diagram is a generic speaker design for the schematic layout, and our design is not anything different

Apart from a few features, the main two are Bluetooth and USB-C input for power.



Kirton D, 2018

Finance
Costing analysis
What does it all cost?



Finance
Costing analysis
Complete costs

COSTINGS		
Parts	Per Unit	Total Cost for 50K Units
PCB	£ 1.50	£ 75,000.00
Speaker Driver	£ 0.32	£ 16,000.00
Cable	£ 0.39	£ 19,615.00
Passive Radiator	£ 0.17	£ 8,720.00
Packaging -Boxes	£ 0.06	£ 2,980.00
Packaging -Filler	£ 9.44	£ 1,255.52
Packaging -Tape	-	£ 2,262.28
M2 16mm Screw	£ 0.02	£ 4,000.00
Manufacturing	Per Unit	Total Cost for 50K Units
Plastic Upper Cost	£ 0.85	£ 42,500.00
Plastic Lower Cost	£ 0.78	£ 39,000.00
Die Casting	£ 0.90	£ 45,000.00
Glass Manufacturing	£ 1.24	£ 62,102.74
Speaker Grill	£ 1.70	£ 85,000.00
Fixing Ring	£ 1.15	£ 57,500.00
Total Costs For Manufacturing & Parts	£ 15.68	£ 460,935.54
Overheads	Per Month	Per Annum
Warehouse Rent	£ 791.67	£ 9,500.00
Council Rates	£ 375.00	£ 4,500.00
Bills	£ 100.00	£ 1,200.00
Cleaner	£ 270.00	£ 3,240.00
Insurance	£ 500.00	£ 6,000.00
Shipping Costs		£ 35.71
Staffing Costs		
Assembly Staff	£ 13,866.67	£ 166,400.00
Sales&Marketing	£ 8,125.00	£ 97,500.00
Electrical Engineer	£ 6,500.00	£ 52,000.00
One off Costs		(Spread over 3 years)
Consultant	£ 24.00	£ 8.00
R&D	£ 7,734.13	£ 2,578.04
Technical Author	£ 2,250.00	£ 750.00
Translation Service	£ 800.00	£ 266.67
Plastic Upper Mould	£ 3,810.00	£ 1,270.00
Plastic Lower Mould	£ 3,355.00	£ 1,118.33
Glass Mould	£ 3,900.00	£ 1,300.00
Total Overheads	£ 30,528.34	£ 347,666.76

Finance
Components list

Full component list

Standard parts quoted from Alibaba; and Accu.co.uk for the fixings. Electrical parts include:

50mm speaker driver,

PCB (Syhogy (Xiamen) Tech Co., Ltd, 2021),

USB-C power cable (Shenzhen Focuses Electronics Co, 2021)

Passive subwoofer (Shijiazhuang QJZL Network Technology, 2021).

Injection moulded parts; the metal die casted base, pressed glass dome and sheet metal parts are manufactured in the UK.

Part	Description	Unit Cost (£)	Total Tooling Cost (£)	Source	Cycle Time	Mater	Process	Quantity Required
Glass Top	Outer material of speaker.	1.24	34,261. 82	-	-	Tempere glass	Glass Pressing	50 000
Plastic Upper	House the speaker internals.	0.85	17,459.63	Protolabs	26s	ABS	Injection Moulding	50 000
Plastic Lower	House speaker internals.	0.78	17,459.63	Protolabs	20	ABS	Injection Moulding	50 000
Metal Base	Metal base stand for the speaker	0.9	30,273.31	Harrison Casting	69s	Al A380.0	Die Casting	50 000
Speaker Unit	Speaker driver to produce sound	0.3	-	Alibaba	-	-	Outsourced	50 000
PCB	PCB Bluetooth board for speaker	1.5	-	Global Sources	-	-	Outsourced	50 000
Fixings 16mm	M2 16mm star drive screw	0.02	-	Accu.co.uk	-	-	Outsourced	200 000
Passive Radiator	Subwoofer	0.18	-	Alibaba	-	-	Outsourced	50 000
Speaker Grill	Hold the speaker driver	1.70	Included in price per part.	Metalfacture	-	304 Stainles Steel 0.5mm	Die Cut and Embossed	50 000
Glass Fixing Ring	Ring to attach glass dome without adhesive	1.15	Included in price per part.	Metalfacture	-	304 Stainless Steel 0.5mm	Die Cut and Deep Drawn, Notched	50 000

Finance
Financial review

Bulk sourcing Parts from Alibaba (global sources) drastically reduced these parts' costs as quotes from UK manufactures were over £2 per unit (RS Components Ltd, 2021).

Indirect staff costs such as cleaning staff or electrical engineers were more cost-effective to hire as in-house staff. This would remove additional hidden costs such as company profit margins if an external service were to be used.

One-time costs were distributed over the first three years of production; these costs include the research and design staff and moulds required for manufacturing and technical document writers. This reduces the cost per annum, and in the fourth year of production, one-time costs will no longer apply, so the overall profit will be higher, on condition that annual inflation is accounted for. Government grants could be claimed to claw back the research and design costs after the first year (Innovate UK; UK Research and Innovation, 2021).

It was more financially viable to outsource the part manufacture to specific manufacturing companies as the machine and qualified engineer's cost to run the machines would be too high as an initial investment for the company, especially when at least four machines would be needed. Nevertheless, this investment could be considered in the future, depending on the success of the business.

Speakers take 15 minutes to assemble and pack into boxes. We approximate that 200 speakers will be assembled a day (1000 a week / 50 000 per year). The technical author and translator will be hired to write a user manual for the speaker and translate them into any relevant languages.

R&D costs are for seven designers, working each for 10 hours a week at an hourly rate of £18.41. (Totaljobs Group Ltd, 2021). This cost is for six of production. However, this cost can be claimed back over the first three years of production through a Government grant for business innovation.

A 40% profit margin has been set, producing a total revenue of £1 347 670.50, leaving a gross profit of £539 068.20. After corporate tax at 19%, the first year's net profit is £436 645.24 (HM Revenue & Customs, 2021). This would increase year on year. Each speaker costs a total of £16.17 to manufacture (40% profit margin) sold to wholesalers for £26.95. At a profit margin of 35%, wholesalers can market the speaker at £41.47 to retail companies. The final recommended retail price would then be £79.99 (40% retailer profit margin, including 20% VAT). Selling to wholesalers is a more cost-effective approach compared with selling directly to the consumer as wholesalers buy in bulk.

Finance
Financial review

Standard parts were sourced from China due to cost. Custom part quotes were generated from companies in the UK; these parts were expensive by comparison.

Speaker drivers (lowers cost part) are £0.32 per unit, bringing total costs for the part to £16,000 (Shenzhen Yulin Industrial Co., Ltd, 2021).

Injection moulded parts quoted from Protomould, who provide a total production cost. The glass dome manufacturing cost was estimated at a total of £62 102.74 by John Moncrieff. Ltd.

Metalfacture provided quotes for the speaker grill and glass fixing ring. Quote provided a cost per part for 50 000 units, not providing a breakdown cost for material, tooling and production cost (Metalfacture, 2021). Harrison Casting provided a quote for the die-cast base. The quote featured an estimated break down of the production cost (Harrison Castings, 2021).

Production costs cover direct and indirect labour, manufacture and assembly. Costs are split into five sections: outsources parts, manufactured parts, overhead costs, staff costs and one-time costs.

Four M1.8 16mm star drive bolts are required to assemble each speaker, along with some adhesives. Packaging equipment was also accounted for in the costings.

The product is packed into a small 12.7cm square cardboard box, filled with EcoFlo loose-fill packing filler (100% biodegradable). Boxes are taped using a custom label tape. (Kite Packaging Ltd, 2021).

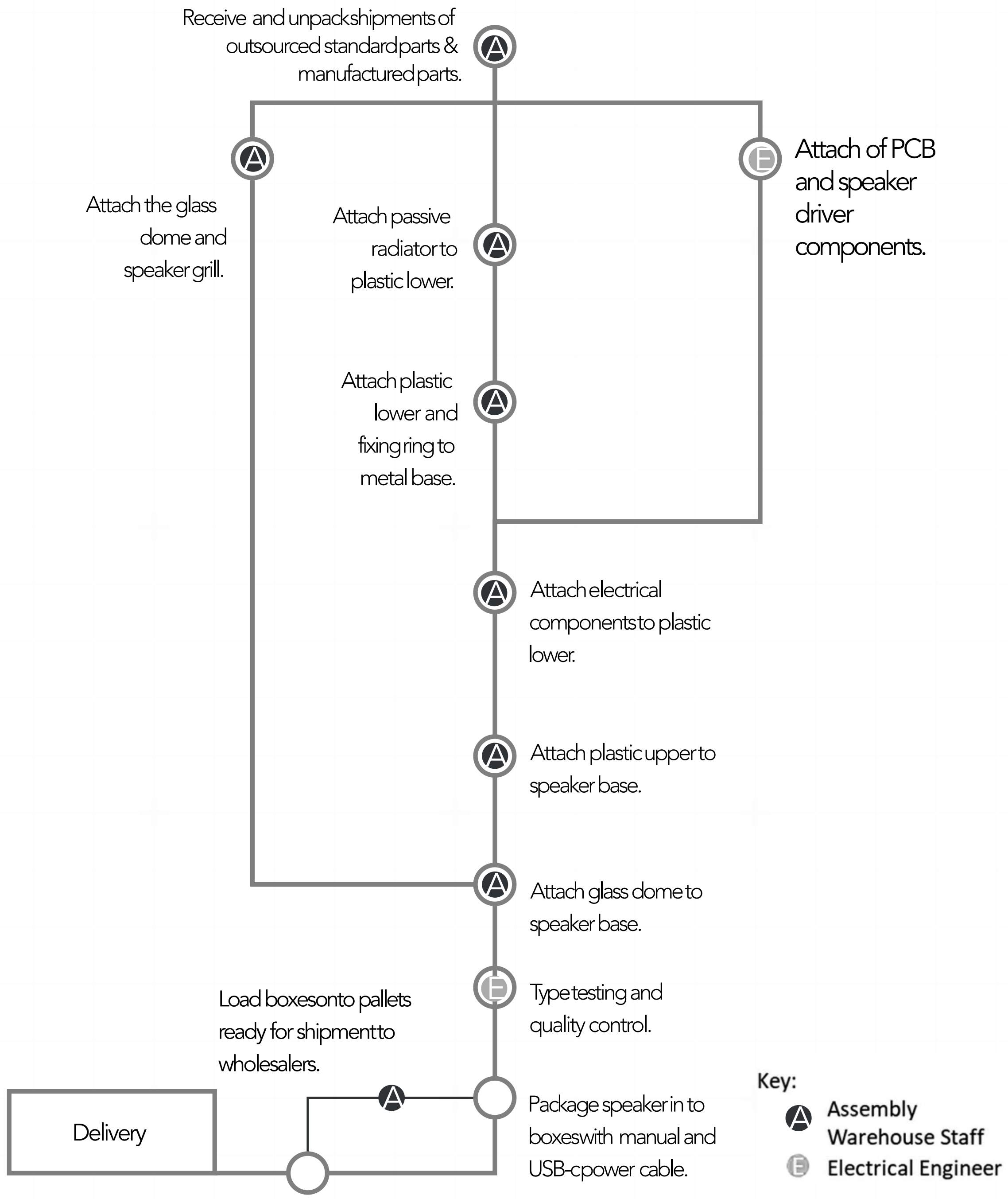
Direct overheads total £347 666.76. Cost includes a 1040 square foot warehouse in the East Midlands, adequate for production, storage and assembly.

Warehouse costs include the eight-assembly staff with a yearly salary of £20 800 (£10ph). Two electrical engineers test components (salary of £26 000) (Payscale, 2021).

Sales and marketing staff work on-site on a salary of £32 500 a year (Totaljobs Group Ltd, 2021), reducing office costs. Bills covering heat, power and water would cost approximately £100 a month. (approx for building size). We also employ a technical author working at a day rate of £450 contracted for a week and a technical translation service of £800 (IT Jobs Watch Ltd, 2021).

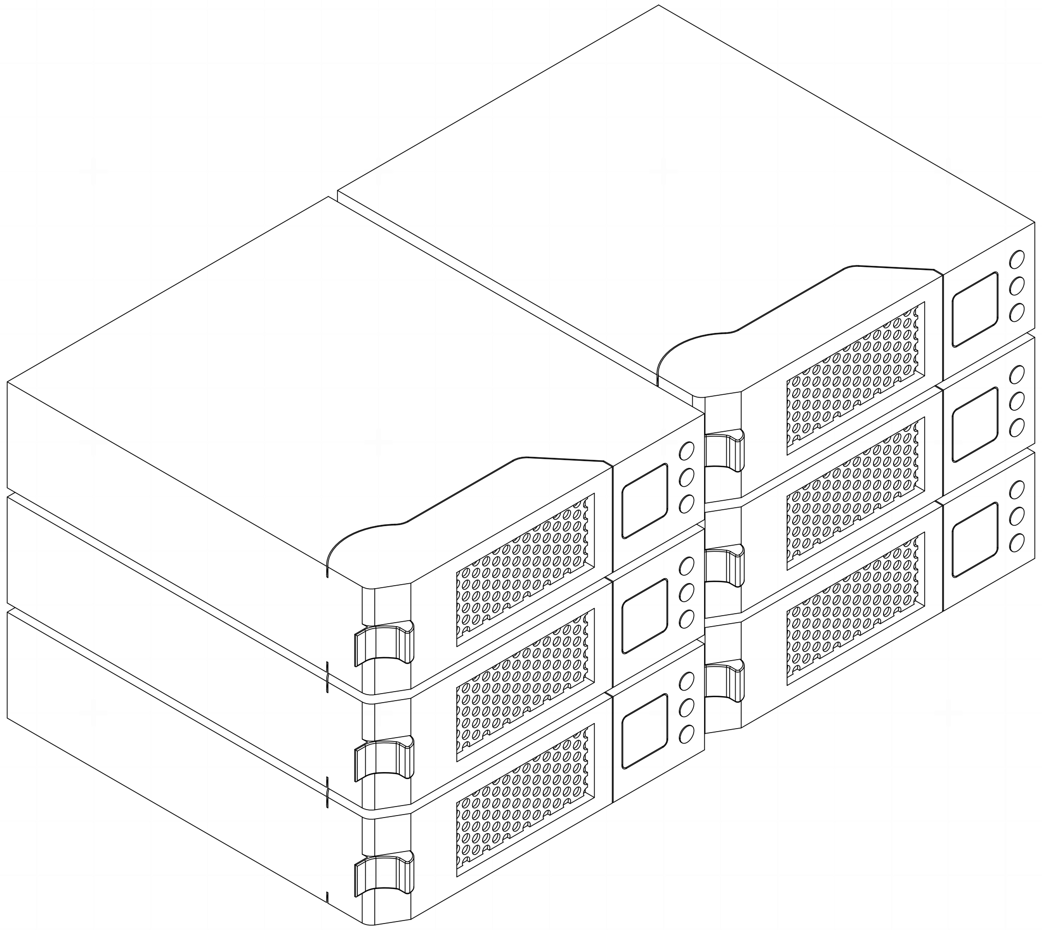
The company breaks even at 75 000 units, projected to happen after the first 18 months of sales.

Finance
Assembly process



Legal
Standards and patents

Bringing our product to market



Standards
Our product standards

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BS EN ISO 9000—Quality management system

The standard is expected to that we have a system set up to guarantee we meet or surpass our clients' needs and to enable you to improve our activities consistently. It means that we plan how we control our steps and that we give the necessary assets to supply item true to form and needed by our clients. (ISO9000, 2015)CE MarkingThis is the standard that identifies how a product follows the rules and regulations for EU safety, health and environmental standards. It is a mark that is usually placed on the bottom of the product. This symbol is recognised and means that the product complies with these rules and standards. (CE Marking, 2012)

BS EN 201—Injection moulding

This standard covers our safety requirements when using injection moulding machines. There are a few machines that are not covered. Most of these are injection moulding machines that have slight changes to them, e.g. vertical platen movements are driven by an electric axis etc. (Injection moulding,2010)

BS EN 62680-1-3:2016 —USB Type C

This is a standard that refers to the USB-C connector. It covers the aspects of our deisgn that are needed to use the USB cable solution or new devices. For example, it covers USB power delivery for the USB-C. It also covers any adapters that the cable could be connected to. (USB-C, 2017)BS EN 15347:2007—Recycling plastics this standard refers to recycling plastic material. Due to our product having an ABS moulded part within the inside of the glass. This will mean it applies to our product, and our product must meet these standards in relation to any waste produced in manufacturing, and when the product isidentified as waste by the user and it has come to the end of product life, the plastic must conform to these standards in order to be recycled efficiently and correctly. (Recycled Plascs,2008)

The WEEE Directive

This is a directive that refers to the preventing of production of waste electrical and electronic equipment. This is relevant to our product as we have a lot of electric parts such as the PCB board and the amplifier/speaker itself. This would mean that we need to conform to this directive and states that we must provide a way for customers to dispose of the electrical equipment; this can be by collection or a take-back service. (WEEE Direcve, 2007).

Patents
Attention to patents

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Careful consideration

"Patents are documents which is a government authority/license which gives an individual/company the sole rights to an invention".

This would exclude others from making, using or selling them. However, in most cases, they can be allowed for companies to make their productscompatible with their invention. An example of this is that android phones have a power cable that can be compatible with other products due to their USB port, whereas Apple chargers/connectors only are compatible with their Apple products.

Some individuals have tried to copy this and sell them online, but Apple has taken out a patent for the USB connector. It was difficult to find patents for individual speakers designs, to begin with as they are quite complex and unique. Therefore the research began for patents on the components we will be using for our speaker concept.

Relevant patents

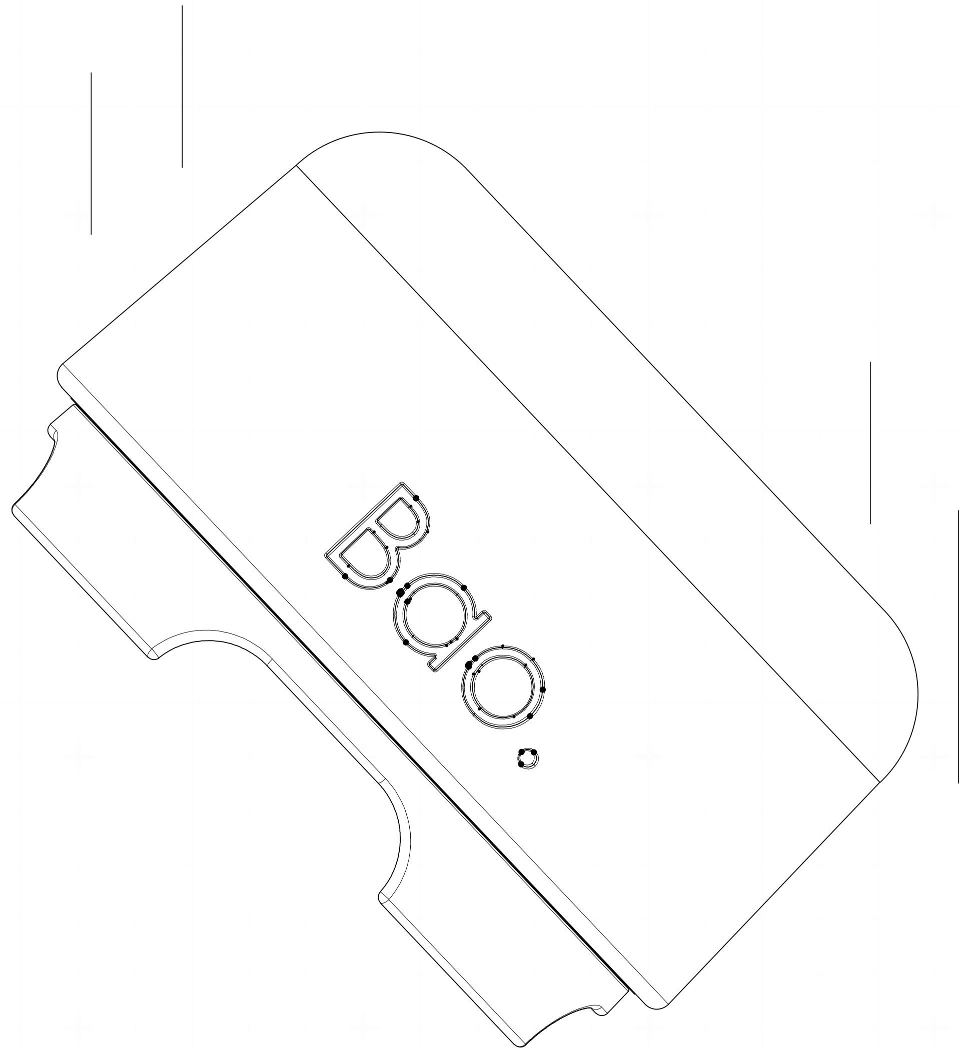
This is an overview for a USB-C United States patent that outlines the different components inside and what the connections; for example, it has CC pins, and these are connected electronically to the CC chip. (USB Type-C, 2015). It essentially just describing what is inside the USB-C port, which would help manufacture our product to get the input slot correct and accurate.

It outlines the inventor, the claims and a description. This would be useful as it is a lengthy account of everything related to the product, including origin, information, and the inside component and drawings.

This also means that we can make the product compatible with this USB-C connector, but we can not make the USB connector and make our version. However, this can be easilyrectified as we will make the product compatible with this product, but will not make one to accompany it. (USB Type-C, 2015).

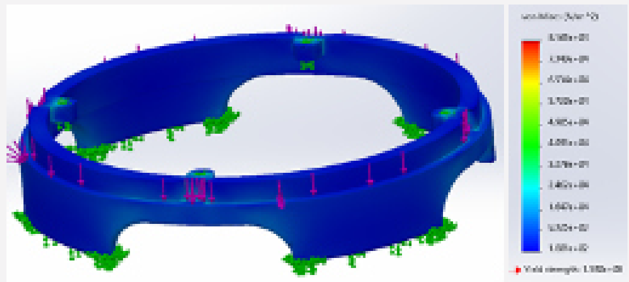
FEA
Simulations & analysis

Understanding our design

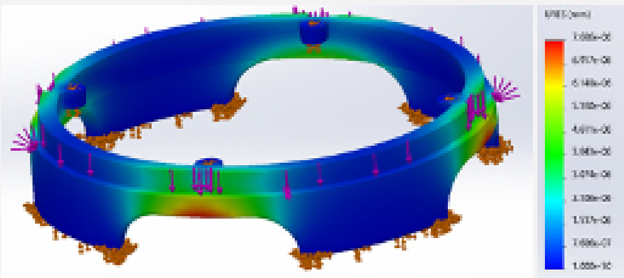


FEA
Base force and stress

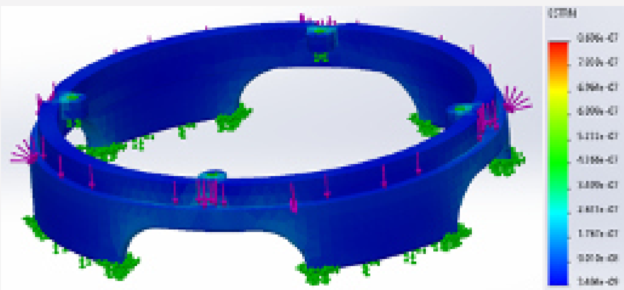
A static force test was conducted on the aluminium base of the speaker. A load of 300 grams was applied to the base's flat outer face to simulate the force that the base would be subject to when the speaker is fully assembled. 300 grams is equal to the weight of the glass dome. Support loads were added in places where fixing bolts would hold the internal components together and at the base where the speaker would stand on a desk. The material used for the part is Aluminium A380.0; this material has a Young's Modulus of 71000 MPa and tensile strength of 317MPa. These values are high; therefore, they can withstand a large force.



The von Mises stress analysis showed that the metal base's material and design are strong enough to withstand the glass dome's force and will not fracture or break. This is proved by the maximum pressure loaded to the base, 0.08163 MPa, which is less than the yield strength, 1.590e+08 Mpa of tempered glass. Since the values are not close, the base's design has sufficient strength to withstand the load of the glass dome in the assembly.



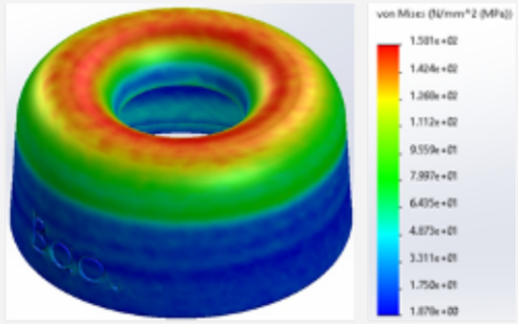
This force does not produce any noticeable deformation or displacement of the metal base. According to the scale, the maximum displacement at the top of the metal arches is 7.686e-06 mm, which is not noticeable to the eye nor would affect the whole speaker's assembly. Therefore, the part's overall deformation is not large enough to cause any defects to the part or speaker.

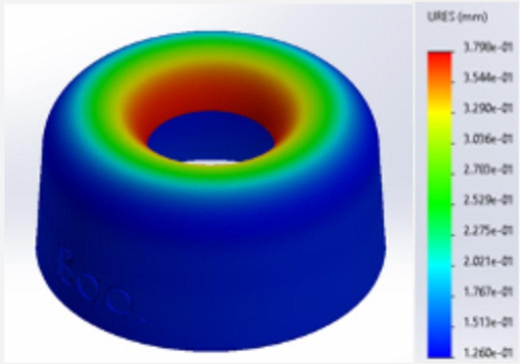


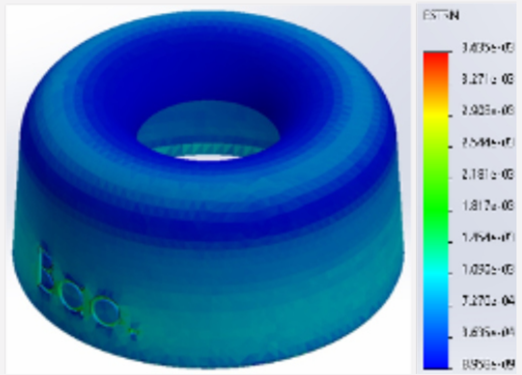
The strain is the change in length after a load is applied. There is no elongation of the material when the glass dome force is applied. According to the scale, the max amount of elongation that would occur to the part is 8.969e-07 which is not noticeable or would affect the speaker's design or assembly; the simulation shows that the highest elongation strain is 2.633e-07 which is not enough to cause ant design or assembly flaws.

FEA
Glass dome stress analysis

A drop test analysis was carried out on the glass dome. This showed that the glass would be strong enough to withstand a drop from 1.5 meters high. This value was chosen as it is the average chest height, so it was chosen as the would-be the height dropped if a user were carrying the dome or speaker. The Young's modulus of the glass material is 68935 MPa.







The stress acting on the part at the bottom of the drop is most at the top; however, this value, 158.1MPa, is less than the glass material's yield strength, 68935 MPa. Therefore, this value of stress at the bottom of the drop could cause the part to break; however, since the top is in the scale's red area, it is more subject to damage; however, the maximum stress is not close to the yield stress of the material.

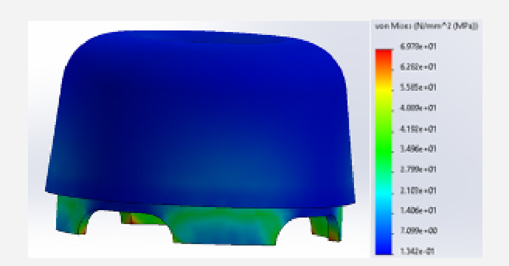
There is no significant deformation that occurs to the glass dome when dropped. The maximum deformation is 0.3798mm, which is not noticeable to the eye nor would not affect the assembly or the speaker's overall design. It only occurs at the top inverted area. It would be necessary to ensure some reinforcement in the area with the most displacement. When the speaker is fully assembled, a steel speaker grill component is attached to that area.

Strain acting on the part during the drop does not affect the shape of the part. The most elongation that could occur during the drop would be 0.003635; however, the simulation does not show the value increase above 0.002181. These values are small and would not affect the speaker's assembly or cause any deformations or disaster to the part.

The speaker's glass dome part is a solid design that does not show deformation in any drastic way when dropped. The stresses caused when the speaker is dropped could potentially cause the inverted part to break; however, this is unlikely due to the material's thickness. When assembled, the inverted part is supported by a metal grill which will provide some reinforcement.

FEA
Full body analysis

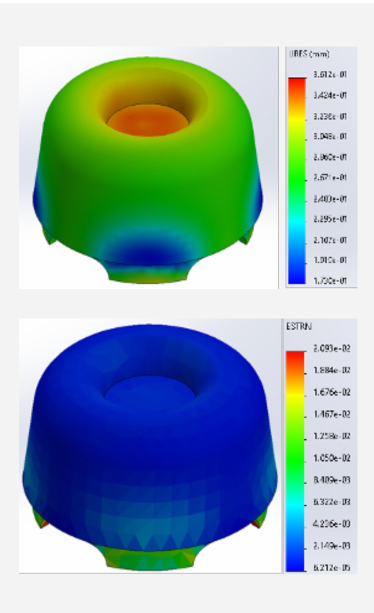
The complete body drop test analysis was run with a replica model of the same mass as the speaker. This allows us to visualise the forces exerted across the whole from the impact of a drop.The speaker was dropped from a height of 770mm, which is slightly higher than the standard height of a desk (Monkey, 2010).It was logical to set the drop height at this distance since the speaker is designed to sit on a desktop.



Stress mainly occurs at the bottom of the drop that happened at the base of the speaker. This part is a metal aluminium base, with a yield strength of 1.590e+08 MPa, much greater than the maximum stress value of 67.78 MPa. Most of the stresses acting on the base are between 0.1342 and 41.92 MPa Therefore, the maximum stress the speaker undergoes is not enough to cause any deformation or buckling to the speaker.

The glass dome is in the simulation scale's blue area; this means that the stress acting on this part is 0.1342 MPa. The yield stress for the glass is approximately 200 MPa; this value is much higher than the stress acting on this part when dropped. Therefore no deformations or damage should occur.

The plastic upper and lower parts that sit inside the glass dome are also in the blue area where little stress is acting. This value of stress is much less than the yield strength, 30 MPa, of the ABS material that they are made from. This shows that these parts will not break when dropped.



This simulation shows that displacement of the parts is a maximum of 0.3612mm; this will not cause a noticeable change on the parts, especially as that part will be made of a different material than what was tested. The strength of the material for that part, when assembled, will be of more robust material so that minor deformation will occur. Overall, there is not much deformation or damage that affects the speaker when dropped off a desk.

The strain analysis shows no visible damage occurs to the unit when dropped. The max strain is 0.02093, not enough to cause any damage that would affect the speaker's design. The base where this occurs would be made of a strong material that would withstand the forces when being dropped and would not elongate the base in either direction.

We can predict that no significant damage will occur to the speaker when dropped from a height. Most forces acting on the speaker occur at the speaker's base due to its centre of gravity.

Our conclusion

"Bao complete sound is a speaker designed for the contemporary style home"

Designing Bao involved working with each other in the teams and consultants/ manufacturers to design a speaker appropriate for manufacture.

From this, we encountered a range of unique challenges that ultimately drove the parts' design to adhere to the design rules for the manufacturing process. As a team, we were able to delegate tasks and responsibilities to overcome these issues.

Working alongside consultants Tim and Marco, we were able to gain valuable design feedback to direct our efforts to create a more robust end product.

The manufacturing companies we worked with provided design revisions that helped guide the components' overall design to fulfil the manufacturing design rules, ensuring successful manufacture and assembly of the parts, reducing production costs.

Overall, we enjoyed working together to produce a unique speaker design suitable for mass manufacture. Our team collaboration worked well as we delegated tasks and focused on one area of the project research to achieve the deliverables successfully, working together to achieve a quality design.

Bao.
Complete sound

Appendix
Self reflections

Michael Riberio
Plastics manufacturing

In my opinion the project went well overall, I found my task easy enough to do as I had to research on how to manufacture specific plastic parts and what design rules was included when doing so. The team worked well together as everyone understood what their tasks were. Everyone helped each other when needed making it very easy to move along the project. I am happy with what I could deliver to the group and happy with our deliverables. One thing to maybe improve on is trying to organise calls where all group members could join to make tasks easy to work through and to check on progression, I also wish to next time get my tasks done quicker so I can help other people in the team if needed.

Ava Kenning
Marketing and finance

My main role of this report was contacting companies for quotes on parts to be manufactured and outsourced standard parts. Therefore, I focussed on the financial analysis of the production of the speaker.

This process worked well as we were able to receive a respectable number of quotes for both standard parts and manufactured parts. I felt that this role worked for me as I had a good number of contacts with manufacturing companies in my local area.

From this, I was able to calculate the indirect and direct costs of for the ‘company’. This experience allowed me to gain an understanding of the breakdown of costs of manufacturing and considering all the possible overheads for a company. Alongside this I was able to create an assembly process map, where I understood designing for assembly and the logistics of manufacturing more.

If I were to do this process again, I would ensure that we, as a group, worked together more from the start of the project and encouraged everyone to input their ideas. I think overall we worked well as a team, for those who took on a strong role in the group, however there was room for more collaboration with research and towards the final report.

Jack Nash
Manufacturing Assembly

This was the first group project for me this year, and I think it went very well. The online calls were challenging (sorted out different sections for team members to complete the report).

For a group of students who hardly knew each other before this project, I feel we communicated well and got an excellent final concept and report.

I had the task of technical documentation for the project. This included a variety of diagrams and looking deeper into patents and standards. This was very challenging as it was difficult to find specific standards and patents, in some cases there weren’t any that were specific to hat we was looking for. If I had to do it all over again, I would maybe confer with the other group members about changing some components to make it easier to find out what we can and can’t do regarding standards and patents. This would have made it easier to find information about them.

Overall I would say the quality of the work was excellent along with the communication of the group. it was nice to work in a group with other individuals with other ideas.

Appendix
Self reflections

Theodora Powell
Metal manufacturing

This was a successful group project. Initially we opted for a curved speaker design. We believed our initial design, ‘the curve’, would boast exceptional sound through the use of piezoelectric speakers, a subwoofer and a curved plastic shield. We had found evidence to support this design theory from a previous market product that is now discontinued. However, feedback from the first milestone presentation confirmed that we needed to rethink our concept because the wooden frame, although attractive, may have posed issues when fitting components and ensuring adequate ventilation. Our Bao speaker, required a major remake to take account of this.

We considered a range of materials and manufacturing processes, prioritising these by cost and efficiency for mass manufacture. We also gave the Bao a compact body to make it space efficient on a desk and a neutral colour palette to suit most tastes and settings Members of the group were assigned different tasks, I was responsible for researching metals; the choice of material and processing to put forward for consultation in the group.

It was decided to use 0.5mm 304H Stainless Steel for the speaker grill and ring and 380.0 Aluminium for the speaker base. I had reservations that the 340H sheet was too thin and may become over stressed and fracture when cast leading to internal weaknesses in the design and compromising the integrity of the circuitry if it were to be handled roughly or dropped.

However, without the opportunity to observe the manufacturing process or see the finished model first hand, I found it hard to evaluate how successful or unsuccessful this would be and whether it would withstand various finishing techniques like CNC punching and cutting.

As in any other working group, it takes a while to establish shared ideas and contributions. In the future, collaborative discussions about allocation of tasks to get the best fit for the task would be the next step forward.

Hugo Burns
Glass manufacturing

I have learnt a lot over the course of completing this design for manufacture analysis project.

This was the first group project I was able to participate in this year which was a welcome change. Even though we had the challenge of not being able to meet physically, I felt for a group of students who had not worked together previously; we completed our project to a standard we are happy with. Having taken personality tests, we divided the workload to play into everyone’s strengths.

My role was to focus on the manufacturing of the glass part. This proved to be very interesting but challenging at the same time. If I were to do it all over, I would have done a few things differently. Firstly, I would have contacted manufacturers earlier in the process as they took much longer than anticipated to provide information and quotes.

I also found it challenging to find good quality information on the manufacturing processes used with glass. The most relevant books I found in the campus library were published in the 1980s with obsolete information. Online sources were also poor, as most manufactures don’t disclose their manufacturing processes as they are competing in a competitive industry.

I enjoyed doing this project with my group. It was fun to put all the theory we learnt in term one into a real-life manufacturing report, including costs etc.

Appendix
Self reflections

Paz Blacher-Moore
Project leader

This project has taught me a huge amount, not only about design for manufacture but also team working and liaison with suppliers.

Normally I'm fairly quiet, preferring to work on my own in the background to accomplish tasks. For this project I took on a greater management and communication role, taking myself very much out of my comfort zone. I've found this very challenging but have learnt a lot about working with others and how best to do this.

Dividing up tasks so that everyone could challenge themselves whilst contributing as much as they could was a difficult balancing act. From a management point of view, it's difficult to know what the strengths and weaknesses of everyone are.

Overall, I think we as a team were able to divide up the tasks in a way that worked. Most of the group also worked together cohesively contributing to the overall design development as well as discussion and then specialising in specific areas to add the depth that was necessary to complete the project.

I am concerned that some team members did not, or were reluctant to engage, not attending consulting sessions and contributing work for example. I tried hard to get keep in contact, and help them along, but there was only so much I could do. I think I acted appropriately in trying to engage these team members and ultimately flagging the situation to tutors for further attention as necessary. Although this was a University group project, working to engage people in all environments is always a key challenge when working in a team.

As well as managing and coordinating the project, my roles were

- Product concept design
- Report design, layout and editing
- 3D modelling (part design)
- Visualisations
- 2D drawings
- Animations and simulations
- Die casting manufacturing process research and selection

I think we applied the design rules for every manufacturing process appropriately, this is borne out by the fact that all suppliers were happy to provide quotes for production. Interestingly, although I followed general design rules for the draft angles on the plastic mouldings, the supplier had their own preference for the size of angles. My takeaway here is that it is good to engage with a supplier early in the design process to understand their specific requirements.

From a management perspective I think my main learning was that coordination and communication takes a very large amount of time as does pulling together and editing the report. It has put me under a great deal of time pressure with this and my other course projects.

I think we worked well as a team and have produced a product that can be produced cost effectively, will work well and looks great. Much credit and thanks goes to everyone in the team.

Appendix
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