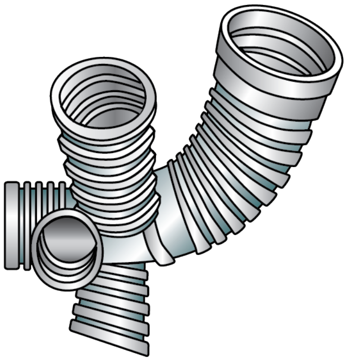
Selection Case Study:

Processes



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About these Case Studies

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1. Introduction

This document is a collection of case studies in Process Selection. They illustrate the use of a selection methodology, and its software-implementation, Ansys Granta EduPack. It is used to select candidate manufacturing processes for a wide range of applications. Each case study addresses the question: out of all the processes available to the engineer, how can a short list of promising candidates be identified?

The analysis, throughout, is kept as simple as possible whilst still retaining the key physical aspects which identify the selection criteria. These criteria are then applied to selection charts created by Granta EduPack, in sequence, to isolate the subset of processes best suited for a certain material in combination with the application. Do not be put off by the simplifications in the analyses; the best choice is determined by function, objectives and constraints and is largely independent of the finer details of the design. The intention is that the case studies should have generic value. The included examples are: Spark plug insulator, Car bumper, Aluminum cowling and Manifold jacket. The criteria they yield are basic to the proper selection of manufacturing processes for these applications.

There is no pretense that the case studies presented here are complete or exhaustive. They should be seen as an initial statement of a problem: how can you select the small subset of most promising candidates, from the vast menu of available materials? They are designed to illustrate the method, which can be adapted and extended as the user desires. Remember: manufacturing is open ended — there are many solutions. Each can be used as the starting point for a more detailed examination: it identifies the objectives and constraints associated with a given process; it gives the simplest level of modeling and analysis; and it illustrates how this can be used to make a selection. Any real manufacturing, of course, involves many more considerations. The 'Postscript' and 'Further Reading' sections of each case study give signposts for further information.

1.1 The Design Process

1. What the steps in developing an original design?

Answer:

- Identify market need, express as *design requirements*
- Develop *concepts:* ideas for ways in which the requirements might be met
- *Embodiment:* a preliminary development of a concept to verify feasibility and show layout
- *Detail design:* the layout is translated into detailed drawings (usually as computer files), stresses are analyzes and the design is optimized
- *Prototyping:* a prototype is manufactured and tested to confirm viability

1.2 From Design Requirements to Constraints

2. Describe and illustrate the “Translation” step of the material selection strategy.

Answer:

Translation is the conversion of design requirements for a component into a statement of function, constraints, objectives, and free variables.

Function	What does the component do?
Objective	What is to be maximized or minimized?
Constraints	What non-negotiable conditions must be met?
Free Variable	What parameters of the problem is the designer free to change?

2. Spark Plug Insulator

The anatomy of a spark plug is shown schematically in Figure 2-1. It is an assembly of components, one of which is the insulator. This is to be made of a ceramic, alumina, with the shape shown in the figure: an axisymmetric-hollow-stepped shape of low complexity. It weighs about 0.05 kg, has an average section thickness of 2.6 mm and a minimum section of 1.2 mm. Precision is important, since the insulator is part of an assembly; the design specifies a precision of 0.2 mm and a surface finish of better than 10 µm and, of course, cost should be as low as possible.

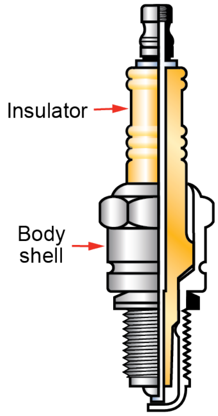

Figure 2-1. Spark Plug Insulator

Table 2-1. Spark Plug Insulator: design requirements

Material Class	Ceramics
Process Class	Primary, discrete
Shape Class	prismatic-axisymmetric-hollow-stepped
Mass	0.05 kg
Minimum Section (thickness)	1.2 mm
Precision (Tolerance)	0.2 mm
Surface Finish (Roughness)	10 µm
Batch Size	100,000

2.1 The Selection

We set up five selection stages, shown in Figures 2–2 through 2–6. The first (Figure 2-2) combines the requirements of material and mass. Here we have selected the sub-set of ceramic-shaping processes which can produce components with a mass range of 0.04 to 0.06 kg bracketing that of the insulator.

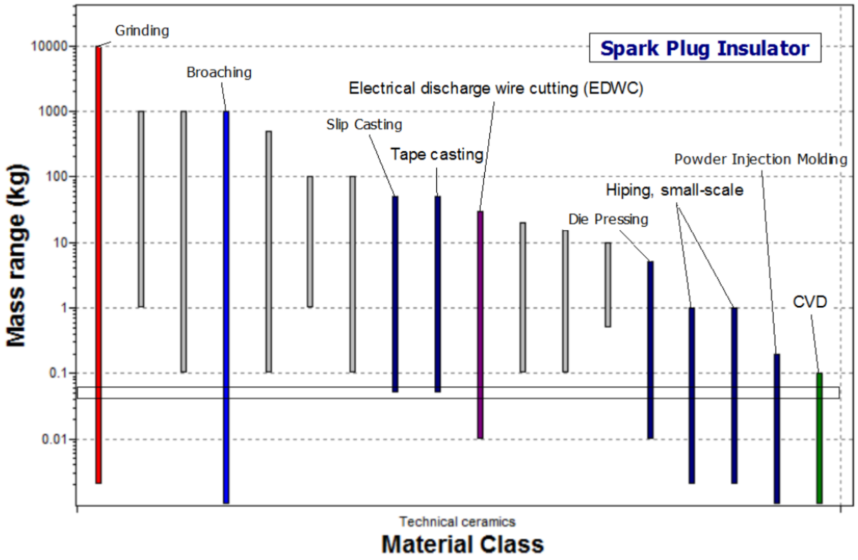

Figure 2-2. A chart of mass range against material class. The box isolates – from the processes which can shape fine ceramics – the ones which can handle the desired mass range.

The second stage (Figure 2-3) establishes that the process is a primary one (one which creates a shape, rather than one which finishes or joins) and that it can cope with the section-thickness of the insulator (1 to 4 mm).

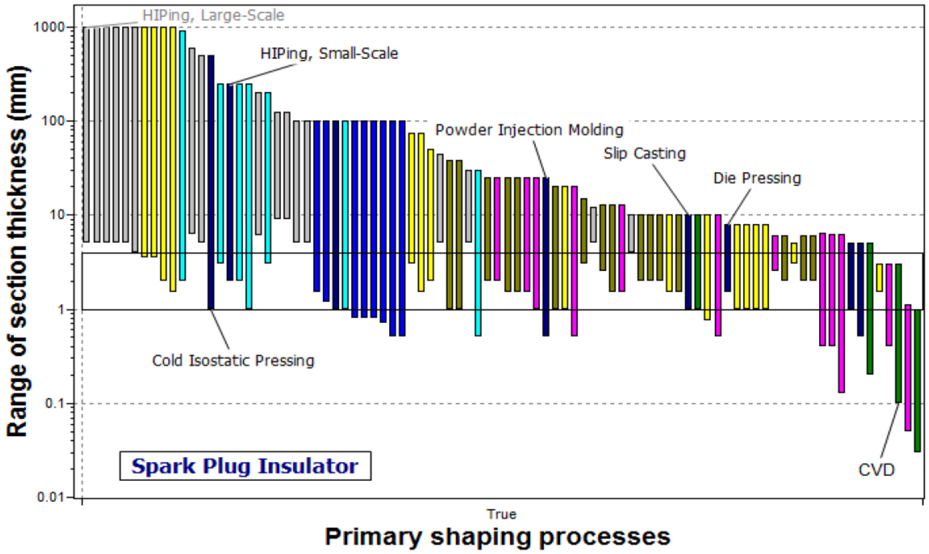

Figure 2-3. A chart of section thickness range against process class. The chart identifies primary processes capable of making sections in the range 1–4 mm.

The third stage (Figure 2-4) deals with shape and precision: processes capable of making 'prismatic-axisymmetric-hollow-stepped' shapes are plotted, and the selection box isolates the ones which can achieve tolerances better than 0.2 mm.

2.2 Conclusions and Postscript

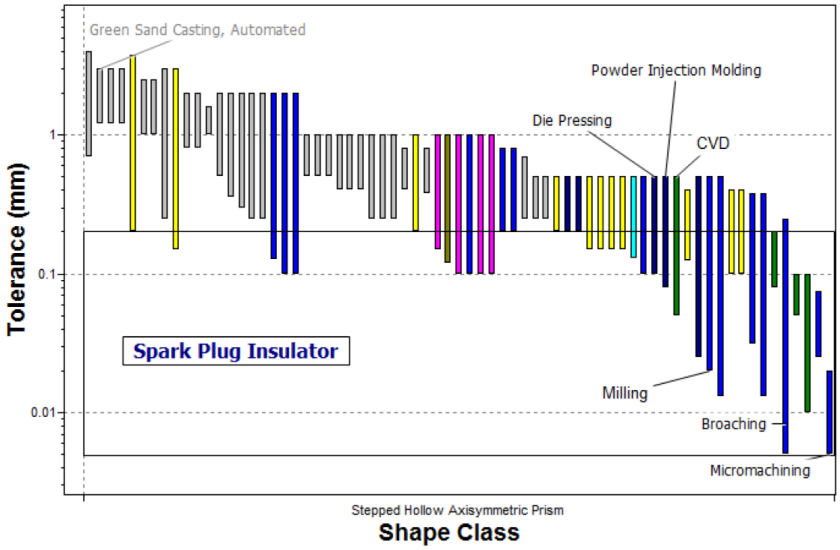

Figure 2-4. A chart of tolerance against shape class. The chart identifies processes capable of making 'prismatic-axisymmetric-hollow-stepped' shapes and are capable of achieving tolerances of 0.2 mm or better.

The fourth stage (Figure 2-5) deals with process class and surface finish: primary shaping processes are plotted, and the selection box isolates the ones which can achieve roughness less than 10 µm.

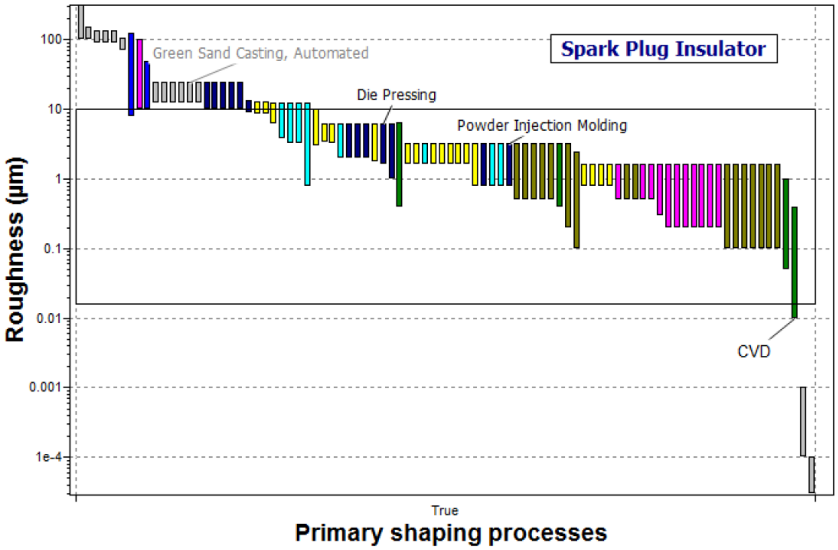

Figure 2-5. A chart of roughness against process class

The previous stages allowed the identification of processes which satisfy the design requirements for the insulator. The final stage (Figure 2-6) allows the most suitable processes to be identified by considering economic batch size. Table 2-2 shows the results.

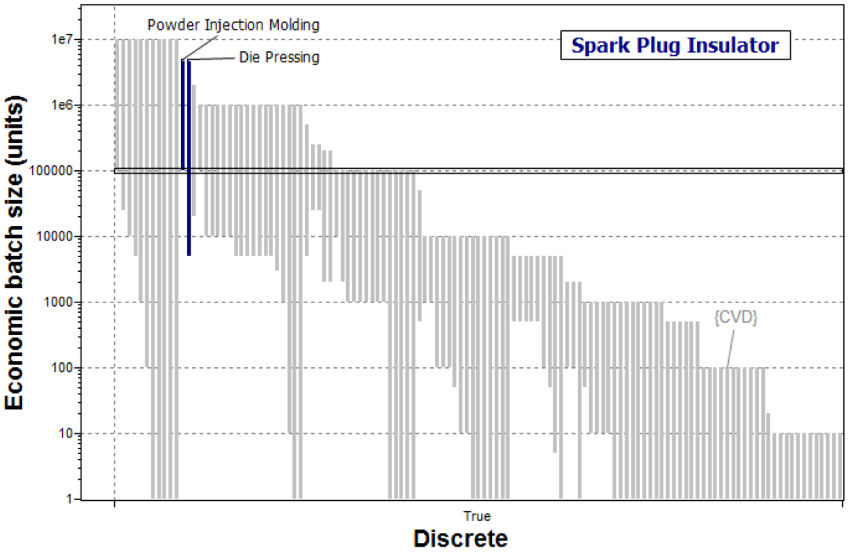

Figure 2-6. A chart of economic batch size against process class. The labeled processes are the ones which passed all the selection stages. The box isolates the ones which are economic choices for the insulator.

Table 2-2. Processes for the spark plug insulator

Die pressing and sintering
Powder injection molding (PIM)

Because of the large batch size desired, the most suitable processes are die pressing and powder injection molding (PIM). CVD — though technically feasible — is a slow process and therefore not suited for such high production volumes.

2.2 Conclusion and Postscript

Because of the constraint of the material of the insulator, only three processes were successful. One of them — CVD — is not economically feasible. The insulator is commercially made using pressing followed by sintering. According to the selection, PIM may be a competitive alternative. More detailed cost analysis would be required before a final decision is made. Spark plugs have a very competitive market and, therefore, the cost of manufacturing should be kept low by choosing the cheapest route.

3. Car Bumper

The materials used for car bumpers (Figure 3-1) have evolved with time. Originally, they were made from electroplated steel then aluminum was used. Starting from the 1980s, plastics were introduced: glass-reinforced polyesters and polyurethanes, modified polypropylene and blends of thermoplastic polyesters and polycarbonates. Plastic bumpers have the advantage of being lighter than their metal counterparts and they are better able to absorb energy in minor collisions without permanent damage.

Figure 3-1. A Car Bumper

A typical car bumper is made from glass-reinforced polyester. It weighs between 4 and 10 kg and has a minimum section thickness of 5 mm. The shape could be described as either a sheet (since the thickness is uniform) or a 3-D solid shape. The surface finish for the bumper should be 0.4 µm or better. The design requirements are listed in Table 3-1.

Table 3-1. Car Bumper: design requirements

Material Class	Composite (thermoset-matrix)
Process Class	Primary, discrete
Shape Class	3D-solid or sheet-dished-non-axisymmetric-shallow
Mass	4-10 kg
Minimum Section (thickness)	5 mm
Surface Finish (Roughness)	0.4 µm
Batch Size	100,000

3.1 The Selection

Figure 3–2 through 3–5 show the selection for a car bumper. Figure 3-2 shows the first of the selection stages: a bar chart of mass range against material class. Thermosets and polymer-matrix composites are selected from the material class menu. The selection box for the bumper is placed at a mass in the range 4–10 kg. Many processes pass this stage.

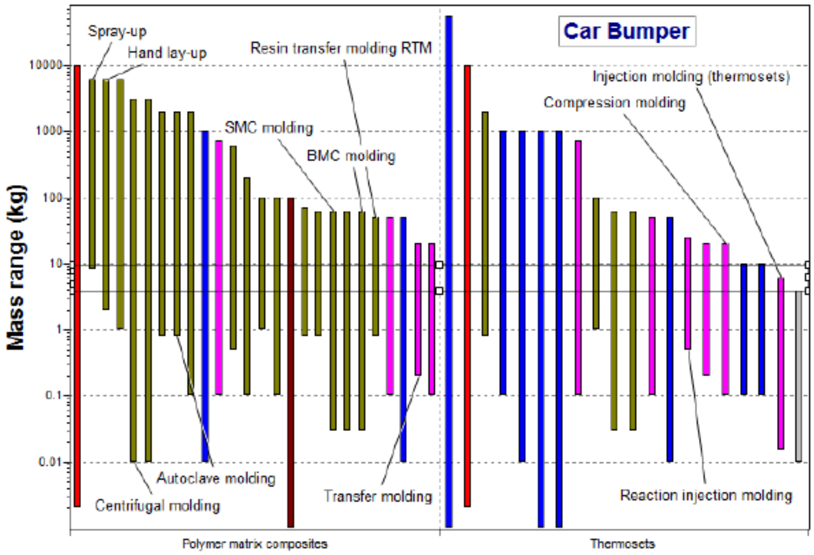

Figure 3-2. A chart of mass range against material class. The box isolates processes which can shape thermoset composites and can handle the desired mass range.

We next seek the subset of processes which can produce the shape (described as either a 'sheet-dished-nonaxisymmetric-shallow' or a '3-D-solid shape') and the desired section thickness. The corresponding chart is divided into two sections corresponding to each shape (Figure 3-3). In each section, the processes which can make that particular shape are plotted. The selection box specifies the requirement of a section thickness of about 5 mm which is within the capability of many processes.

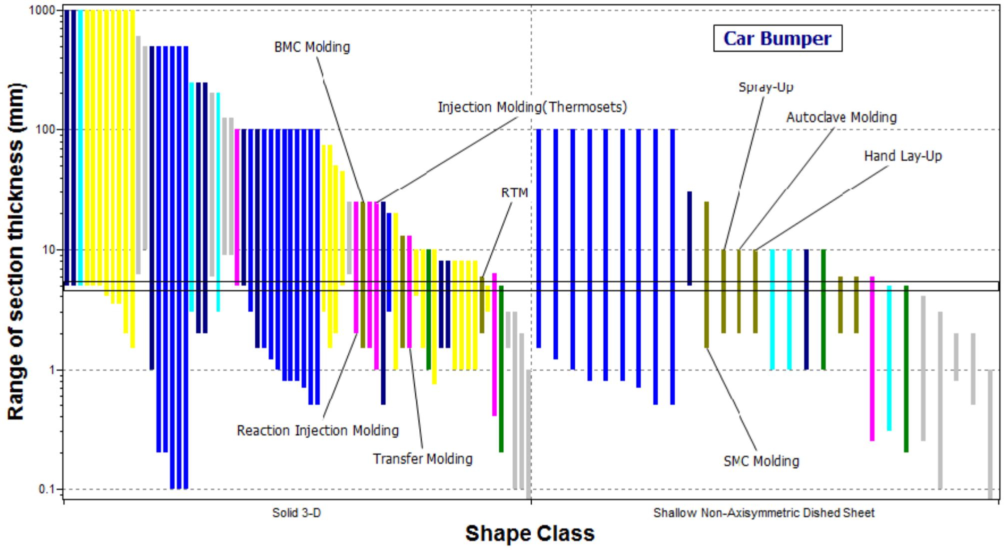

Figure 3-3. A chart of section thickness range against shape class. The chart identifies processes which can make 'sheet-dished-nonaxisymmetric-shallow' or '3-D-solid' shapes with sections of about 5 mm.

The next selection stage is shown in Figure 3-4. It is a bar chart of surface roughness against process class selecting primary from the process class menu. The selection box specifies a smoothness requirement of 0.4 µm or better. This is a demanding requirement of which many processes are not capable, as seen in the figure. Open-mold composite processes such as hand lay-up and spray-up fail for that reason.

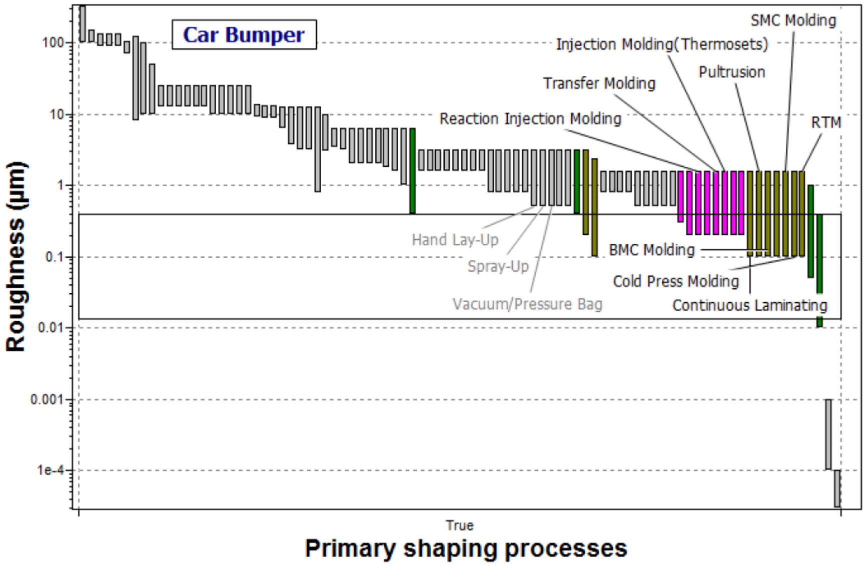

Figure 3-4. A chart of roughness against process class. The box isolates primary processes which are capable of roughness levels of 0.4 µm or better.

One further step is required in order to identify the processes which can produce the bumper cheaply. The appropriate chart (Figure 3-5) is that of economic batch size against process class. Only discrete processes are plotted on the chart. The selection box specifies a batch size of 100,000 for the bumper. Processes which have passed all the previous selection stages are labeled. The ones which can produce the bumper economically are listed in Table 3-2.

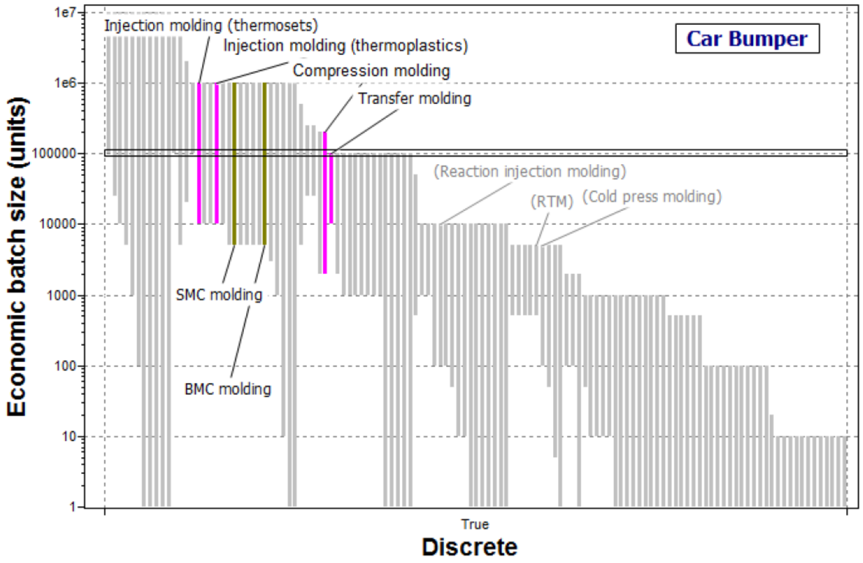

Figure 3-5. A chart of economic batch size against process class. The box identifies the processes which are economic for a batch size of 100,000.

Table 3-2. Processes for the car bumper

BMC molding
Compression molding
Injection molding--thermosets and thermoplastics
SMC molding
Transfer molding

3.2 Conclusion and Postscript

Several processes are technically capable of making the bumper (though the manufacturing cost varies greatly). The competitive ones for a large batch size of 100,000 bumpers are transfer molding, injection molding, compression molding, BMC and SMC molding.

Commercially, several processes are used depending on the volume of production: injection molding is used for high volume cars, whereas reaction injection molding and compression molding are used for medium volume production. The decisive factor is obviously the batch size.

4. Materials for Springs

A thin-walled aluminum cowling is shown in Figure 4-1. It weighs about 0.1 kg and has a nearly uniform section thickness of 1 mm. The shape is a dished sheet. A tolerance of 0.4 mm is desired. The number of cowlings required is 10. The design requirements for the cowling are listed in Table 4-1. What process could be used to make it?

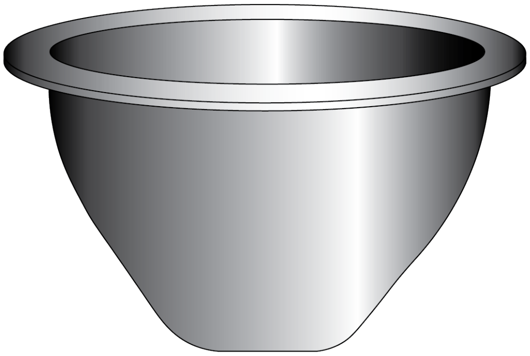

Figure 4-1. An aluminum cowling

Table 3-1. Car Bumper: design requirements

Material Class	Light alloy (aluminum)
Process Class	Discrete
Shape Class	sheet (dished-axisymmetric-deep-nonreentrant)
Mass	0.08 kg
Minimum Section (thickness)	1 mm
Tolerance	0.4 mm
Batch Size	10

4.1 The Selection

The selection has four stages, shown in Figures 4–2 through 4–5. Figure 4-2 shows the first. It is a chart of section thickness against material class. Only processes which can handle aluminum (selected on the x-axis) are plotted. The selection box specifies processes which can produce a section thickness of about 1 mm. Most casting processes are eliminated by this stage.

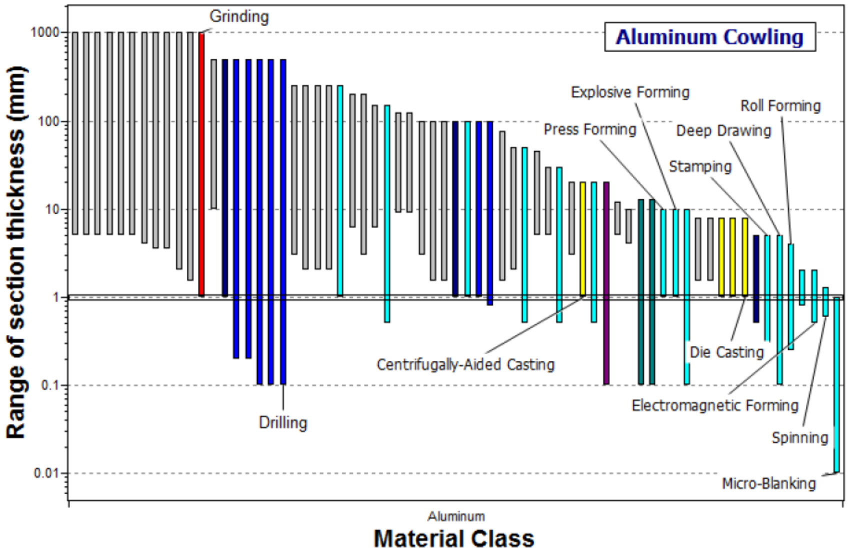

Figure 4-2. A chart of section thickness range against material class. The box isolates processes which can shape light alloys and create 1 mm sections

Figure 4-3 shows the second selection stage: it is a bar-chart of mass range against shape class, selecting 'Sheet-dished-axisymmetric-deep-non-reentrant' from the shape class menu. A selection box for the cowling is shown on it; the box brackets the mass of 0.08 kg. This stage identifies the processes which satisfy the second set of design requirements. Those which pass include some sheet forming processes.

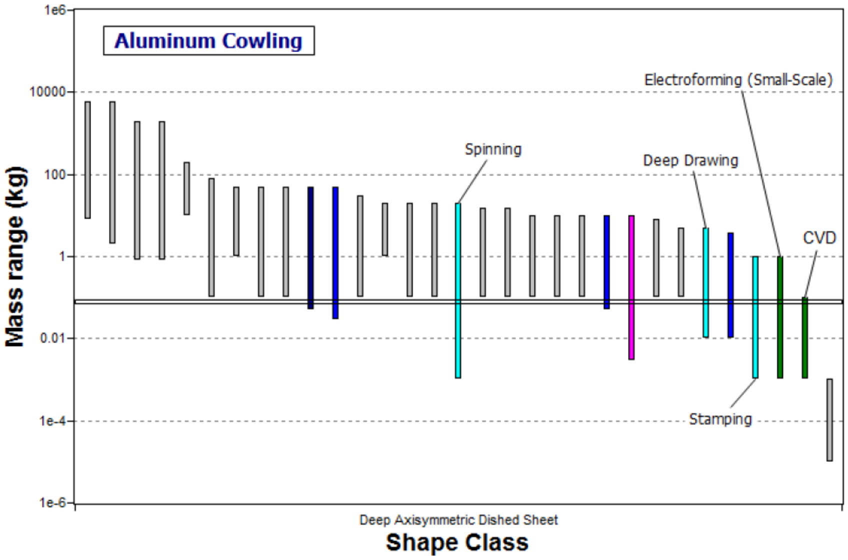

Figure 4-3. A chart of mass range against shape class. Processes capable of making dished-axisymmetric-deep sheet shapes are plotted and the box specifies processes capable of making a mass of 0.08 kg.

A third stage is required as shown in Figure 4-4. This is a chart of tolerance against process class. Primary processes are selected; the selection box specifies a tolerance of 0.4 mm or better. This isolates the processes which satisfy the tolerance requirement.

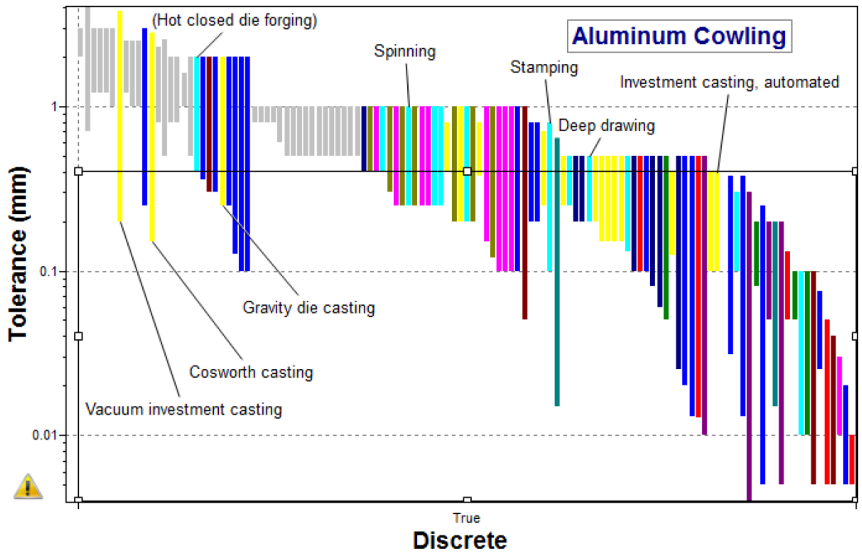

Figure 4-4. A chart of tolerance range against process class. The box isolates discrete processes which can produce tolerance levels of 0.4 mm or better.

The previous stages isolated the processes which satisfy the design requirements for the cowling. It remains to identify — from those — the ones which can produce the cowling cheaply. The appropriate chart (Figure 4-5) is that of economic batch size against process class. Only processes which can produce discrete components are plotted on the chart. The selection box specifies a batch size of 10. The processes which have passed all the previous selection stages are very limited. The only one which would be economical for the desired batch size is listed in Table 4-2.

Table 4-2. Processes for the aluminum cowling

Spinning

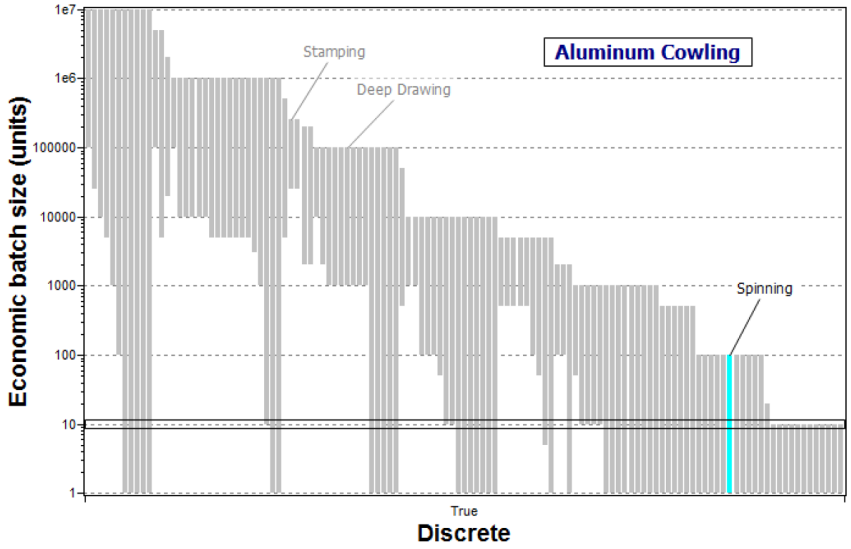

Figure 4-5. A chart of economic batch size against process class. The box isolates the process which can economically produce the desired batch size

4.2 Conclusion and Postscript

Three processes are capable of making the aluminum cowling. Those are the labeled ones in Figure 4-5. However, only spinning (which is the way the cowling is commercially made) can produce the desired batch size economically. The small batch size means that processes requiring expensive tooling are not economic.

5. Manifold Jacket

The component, shown in Figure 5-1 is a manifold jacket used in a space vehicle. It is to be made of nickel. It is large — weighing about 7 kg — and has a 3D-hollow shape. The section thickness is 2–5 mm. The requirement on precision is strict (precision = 0.1 mm). Because of its limited application, only 10 units are to be made. Table 5-1 lists the requirements.

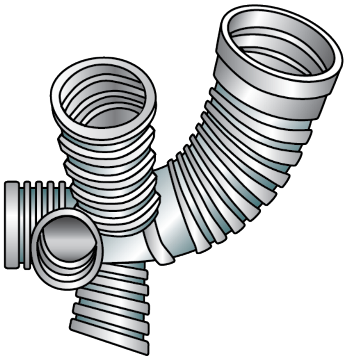

Figure 5-1. Manifold Jacket (source: Bralla[1])

Table 5-1. Manifold Jacket: design requirements

Material Class	Nonferrous metal
Process Class	Primary, discrete
Shape Class	3D-hollow-transverse features
Mass	7 kg
Minimum Section (thickness)	2-5 mm
Precision (Tolerance)	0.1 mm
Batch Size	10

5.1 The Selection

The application of the process selector to this problem is shown in Figures 5-2 to 5-5. The results are listed in Table 5-2 on page 19. Figure 5-2 shows the first of the selection stages: a bar chart of mass range against material class, choosing non-ferrous metal from the material class menu. The selection box is placed at a mass in the range 5–10 kg. Many processes pass this stage, though, of course, all those which cannot deal with non-ferrous metals have been eliminated.

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[1] Bralla, J. G. (1986), 'Handbook of Product Design for Manufacture', McGraw-Hill, New York, USA.

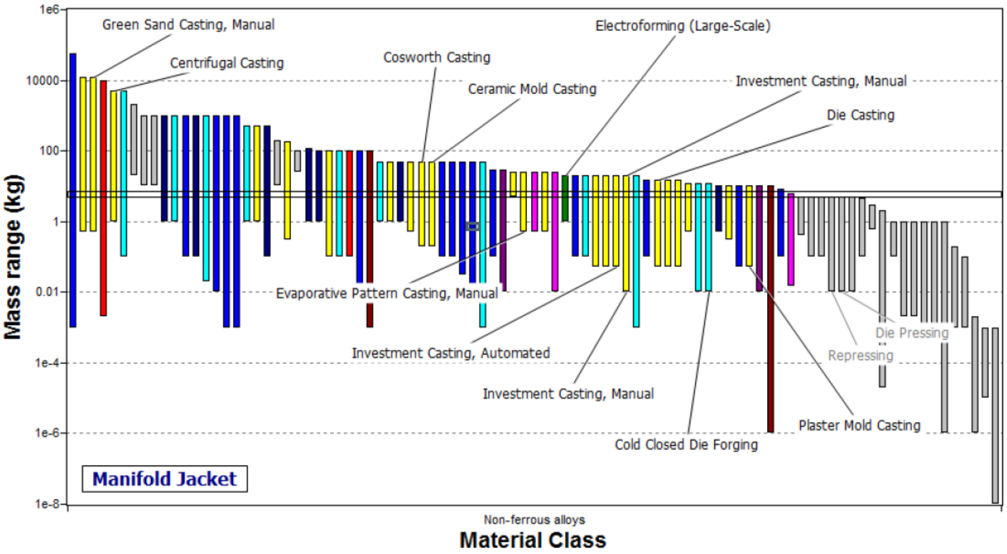

Figure 5-2. A chart of mass range against material class. The box isolates processes which can shape non-ferrous alloys and can handle the desired mass range.

We next seek the subset of processes which can produce 3D-hollow shapes with transverse features and the desired section thickness. ‘3D-hollow-transverse features’ is selected as the shape class on the x-axis and section range was chosen as the y-axis in Figure 5-3. The selection box specifies the requirement of a section thickness in the range 2–5 mm. Again, many processes pass, though any which cannot produce the desired shape has failed.

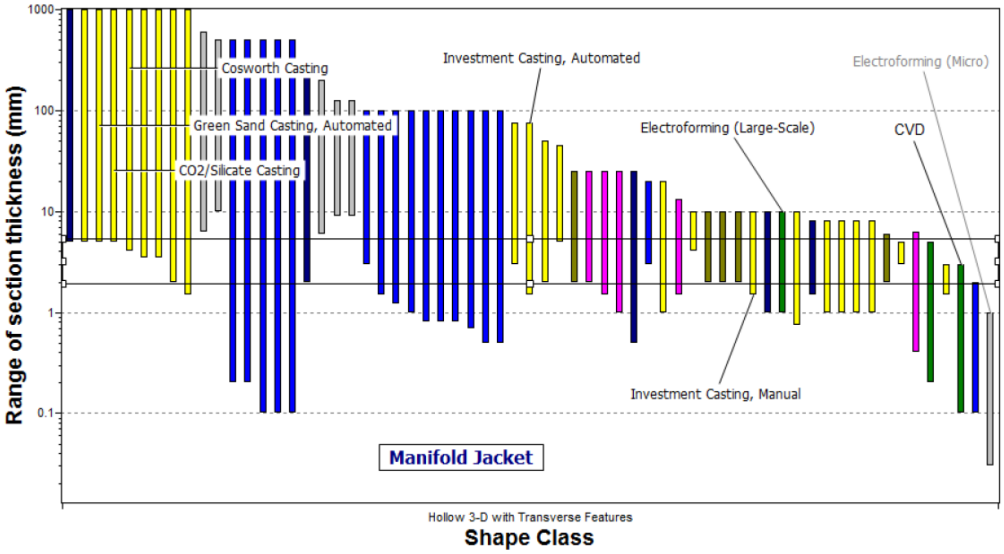

Figure 5-3. A chart of section thickness range against shape class. The chart identifies processes capable of making 3D-hollow shapes having transverse features with sections in the range 2–5 mm.

The next selection stage is shown in Figure 5-4. It is a bar chart of tolerance against process class selecting ‘primary shaping processes’ from the process class menu. The selection box specifies the tolerance requirement of 0.1 mm or better. Very few processes can achieve this precision.

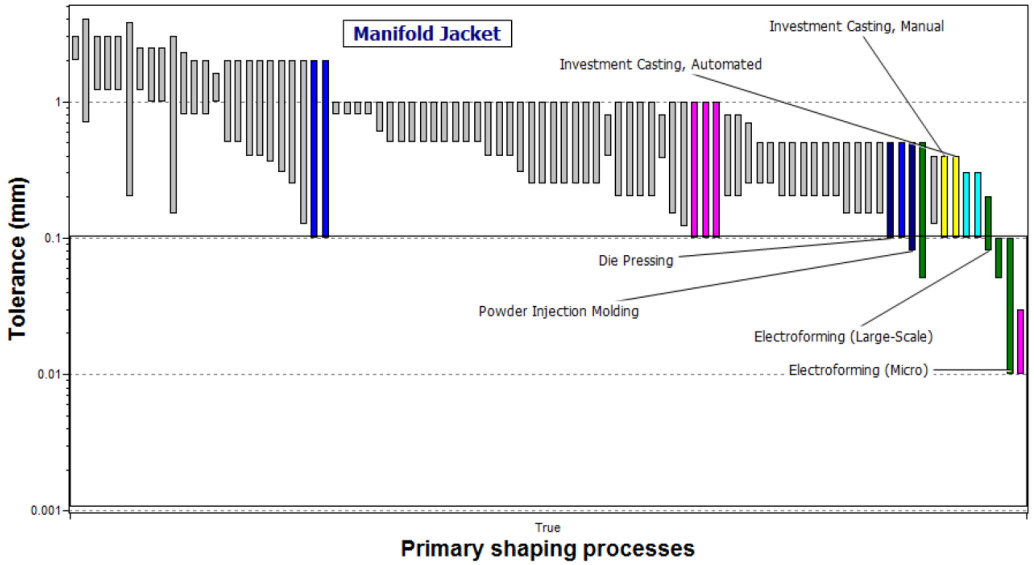

Figure 5-4. A chart of tolerance against process class. The box isolates primary processes which are capable of tolerance levels of 0.1 mm or better.

The last selection stage (Figure 5-5) involves a consideration of the cost of manufacture. The selection box specifies a batch size of 10 units. The processes which passed all the previous selection stages are labeled. The ones which can produce the desired number of components most economically are listed in Table 5-2.

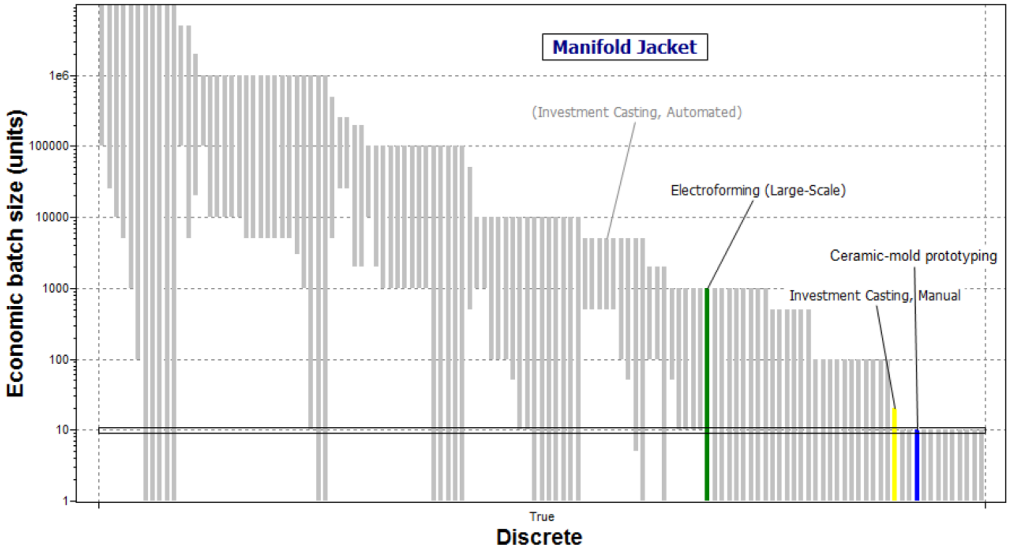

Figure 5-5. A chart of economic batch size against process class. The box isolates a batch size of 10 units.

Table 5-2. Processes for the manifold jacket

Ceramic-mold prototyping
Electroforming (Large-scale)
Investment casting (manual)

5.2 Conclusions and Postscript

Electroforming and investment casting emerged as suitable candidates for making the manifold jacket. The small number of units required for such a limited application as a space shuttle, does not justify the investment in more expensive automated processes. A more detailed cost analysis is needed before a final decision is made.

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