DESIGNING THE WORLD’S LARGEST INJECTION MOLDED NYLON PART, A COWLING ASSEMBLY FOR A MERCURY MARINE LARGE FOUR-STROKE OUTBOARD ENGINE

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ABSTRACT

The cowling (engine cover assembly) for a marine outboard engine serves several critical functions. It protects the engine from the environment and provides structural protection to the under-cowl components. The cowling routes air into the engine with minimal power loss, and at the same time prevents water from entering the engine compartment. The cowl assembly dampens engine noise and vibration thus providing improved NVH (Noise Vibration and Harshness) characteristics. The cowl assumes the form of styled surfaces to make the engine aesthetically pleasing. In addition, a well designed latching system ensures that the cowling stays on the engine, and provides structural protection to internal components in the event of the boat striking submerged objects such as floating logs or rocks.

These requirements of an outboard engine cowling demand special considerations in design, material selection, and manufacturing. The top cowl is the world’s largest structural and cosmetic glass reinforced nylon part, the development of which was very challenging. The key aspects of a patented, innovative, low cost cowling assembly for a large four-stroke outboard engine, its advantages and benefits are presented in this paper.

BACKGROUND

Mercury Marine, which is a manufacturer of outboard engines and stern drives, has developed a new class of high horse power outboard engines. Driven by environmental concerns and customer demand, the new outboards are designed with technologically advanced four-stroke engines. To match the technological advances that went into the engines, the cowling system has also been designed to push the envelope of technology.

An outboard engine is the propulsion system that is used on many marine vessels from high speed bass boats to large pleasure cruisers. The cowling system of an outboard is the outer exterior surface that surrounds the engine. Typically, cowling systems consist of a top cowl, and a lower cowl, which is commonly referred to as the “chaps” (see Figure 1).

Figure 1: Cowling Assembly of a Conventional Outboard Engine.
The top cowl typically covers the engine portion of the outboard while the lower cowl covers the driveshaft housing which is the structure below the engine. Traditionally, Mercury cowls have been made by compression molding SMC (sheet molding compound) materials, or by thermoforming of thermoplastic sheet material. Since the new large four-stroke engines are different than any other outboard engine created, the cowling system had to take a different approach than what was done in the past. The style and configuration of Mercury’s new large four-stroke outboard assumed the shape of a multiple component cowling system which is illustrated in Figures 2 and 3. Mercury Marine has received two United States patents (U.S. Patent # 6,669,517 B1 and U.S. Patent # D474,480 S) for this cowling system.

The new cowling system was designed to provide the outboard with superior reliability, durability and exceed performance goals through innovative design. High strength, weight reduction, improved NVH and compact packaging was achieved by using injection molded materials.

**COWLING SYSTEM DESIGN**

**Structural Considerations**

Mercury Marine has some basic structural requirements that all cowls must meet. These requirements include the ability to withstand impact loading from all sides of the outboard both above and below the waterline. This is to ensure that no damage occurs if a foreign object hits the engine or if the engine hits any objects while operating in the water. Another basic requirement is that the cowling must protect the engine from any static loads placed upon its structure. The cowling may be abused by people stepping or sitting on it.

The new four-stroke engine design required many additional considerations. As shown in Figure 2,
the new Mercury four-stroke engine is compact, very tall and narrow. This compact engine package was created to accommodate engine mounting space constraints on boat transoms. To meet these space constraints, a rear cowl was created. The rear cowl allowed the outboard to stay narrow and reduce the size of the top cowl. The rear cowl is mounted on a structural aluminum member of the outboard. Therefore any loads that are placed on the cowling must be transferred through the rear cowl before the load is transmitted to the structural member of the outboard. Having to transmit loads back down to the engine required that the rear cowl be designed to be very strong and rigid. A key element, in creating a cowl that could transfer loads back to the engine, was the design integration of a structural rib in the rear cowl. The structural rib, as seen in Figure 4, is a part of the cowling system that is not exposed to the exterior of the outboard. The structural rib is bonded to the inside of the rear cowl, and structurally ties the rear cowl to the aluminum engine structure. This component gives the rear cowl the strength and stiffness it needs to support the upper cowling and any loads that might be applied to the cowling system.

### Aesthetic Considerations
Enhancing the customers boating experience is also an important attribute of the cowling system. Mercury’s Styling Studio crafted the cowl assembly to make the engine beautiful and aesthetically pleasing. The styled surfaces called for a Class ‘A’ surface finish which has superior gloss, smooth surface, and is free from defects. The structural components (top cowl and rear cowl) of the new cowling system are made from a glass reinforced Nylon material made by DuPont. These surfaces need to be painted to achieve a Class “A” surface finish. Other non-structural components such as the lower chaps are made from a molded in color ionomer resin alloy made by DuPont. The ionomer resin alloy produces a part with a Class “A” finish in the mold and does not require painting.

### Noise Vibration Harshness (NVH) Considerations
Reduction in NVH also contributes to a pleasurable boating experience. The cowl system can play a big role in reducing NVH. Sound and vibration produced by the engine at certain frequencies can be irritating to the operator. These irritating frequencies can be dampened and tuned by the cowling system. This is done by selecting the right material to limit noise and vibration transmission. Material selection was done after reviewing DMA (Dynamic Mechanical Analysis) data and performing sound transmission tests on panels. The noise and vibration can also be reduced by designing appropriate isolation and tuning features within the cowling components. With reduced NVH, this new engine is one of the quietest and smoothest running engines in its class.

### Environmental Considerations
The primary function of the cowling system is to protect the engine. In addition to structural considerations, the cowling must protect the engine itself from the environment. Being an “outboard engine” literally means that the engine is mounted outside the marine craft. Being outside, the engine
is exposed to the harsh elements of weathering. Weathering elements such as rain, wind, snow, ice, extreme heat, extreme cold, and ultra-violet (UV) light from the sun can be detrimental to the cowl assembly. These elements add to its already harsh operating environment of the open seas where salt water and pounding waves challenge the engine.
The cowl assembly, in many ways is similar to the exterior body of an automobile. In recent years, many automobile manufacturers have been successful in designing plastic body panels that survive these types of environments. But the cowl assembly differs from the exterior of an automobile in the sense that it creates the engine compartment of the outboard. Hence the cowl assembly experiences temperature fluctuations, heat soak and is exposed to chemicals such as fuel vapors, oil residue, degreasers and cleaners commonly found in an engine environment.

Weight Considerations
A traditional cowl assembly for a large outboard engine, made from SMC materials comprises approximately 10 to 20% of the weight of the total engine. Hence weight of the cowl assembly is extremely important. Excess weight leads to less buoyancy and reduces the payload capacity of the boat. The new cowl assembly uses injection molded thermoplastic materials, and provided a weight savings of 30% (-15.2 Kgs) compared to SMC materials that are traditionally used. This is particularly advantageous for ergonomic considerations when routine maintenance of the engine is performed by a mechanic and the cowling needs to be removed.

DESIGN INTEGRATION

Integration of Design Features
Injection molding allowed the integration of parts within the cowl design. The new cowls have been designed to incorporate latch features into the cowl as shown in Figure 5. Injection molding provided the ability to mold intricate features in the top cowl that retained the latching system. This reduces the number of parts in the assembly and hence reduces part cost, assembly cost and weight. Figure 6 shows a close up view of the latch components. Mercury Marine has received a United States patent (U.S. Patent # 6,663,450 B1) on the integral cowl latching system.

Figure 5: Latch Features Incorporated in Top Cowl

Figure 6: Latch Components
PROCESS SELECTION
Traditionally, large cowling assemblies are made by compression molding SMC materials or by thermoforming cowls from thermoplastic sheet materials. Selection of the manufacturing method for making cowls was identified through a benchmarking study. Results of the study were evaluated by paired comparison methods. Manufacturing methods of large cosmetic parts in marine, automotive and agriculture industries were considered. Manufacturing processes considered included compression molding, injection molding, thermoforming and Reaction Injection Molding (RIM). The manufacturing processes were listed and rated along with their attributes against Mercury criteria for cowling. Some of the evaluation criteria included: cost, weight, material compatibility (chemical and structural), tooling cost, aesthetic quality, and design flexibility, recyclability, and environmental impact. From the paired comparison evaluation, injection molding emerged as the best manufacturing method to produce the cowling assembly. Injection molding provided the highest benefit in terms of design flexibility, total assembly costs, overall system weight and finished part quality.

MATERIAL SELECTION
A thorough material investigation was carried out over a period of several years. The results of the investigation culminated into selection of the ideal material candidates, manufacturing process selection (injection molding), assembly methods, paint chemistry and painting process. A detailed FMEA (Failure Mode Effects Analysis) was conducted on the cowling assembly. FMEA results were incorporated in the material selection. Selection criteria fall into six basic categories: structural considerations (mechanical), thermal performance, chemical requirements, aesthetic appearance, paintability and adhesive selection.

Mechanical
Material selection criteria in the mechanical properties include tensile strength, flexural strength, elongation at break and impact strength. The target material properties of this application were determined after performing a Finite Elemental Analysis (FEA) on the design. Various kinds of loading considerations were taken into account in the FE analysis. Safety factors were applied to the mechanical properties that were used as an input for the FE analysis. Safety factors used accounted for the reduction in mechanical properties of the material due to environmental considerations such as engine operating temperature, exposure to chemicals and moisture absorption. The material stiffness and dampening properties (loss and storage modulus) were also taken into account to maximize NVH improvement.

Thermal
The large four-stroke cowling assembly is subject to various temperatures experienced during conditions such as normal engine operation, heat soak after engine shut down, thermal cycling, under cowl temperatures generated by sunlight radiation on a black cowl, exposure to dry-off ovens during wash cycle prior to paint, exposure to paint curing oven temperatures. A typical under cowl engine operating temperature is 100 °C. Under extreme engine operating conditions, under-cowl temperatures can reach a peak of 110 °C. Extreme cold storage temperatures can reach -30°C. Cowl components that need to be painted can experience temperatures as high as 135 °C during the paint curing cycle. Cowl components were successfully tested for thermal performance with tests such as heat aging, thermal cycling, heat soak, combined thermal cycle and vibration tests.

Chemical
The polymer material must resist exposure to chemicals such as fresh water, salt water, various fuels commonly used in engines, four-stroke engine oil, engine cleaners such as fuel injector cleaner and other chemicals commonly found in an
Aesthetic Appearance
The polymer material must provide a substrate free of surface imperfections. This will help in achieving a Class ‘A’ surface finish during the painting process. The glass fiber read through was minimized during injection molding to achieve a good resin-rich skin surface. This helped improve paint coverage and reduced surface defects in paint attributed to glass read-through.

Paintability
A key criterion in the cowl material selection was paintability. The top cowl and the rear cowl components were painted using a three layer paint system. The paint system consisted of a base coat followed by two clear coats of paint. Adhesion of paint to the cowl material and paint layer durability was evaluated by tests such as cross hatch adhesion and pencil hardness test.

Material Selected for the Cowl Assembly
The primary polymer material selected for the structural components (top cowl, rear cowl and structural rib) of the cowl assembly was a heat stabilized, 33% glass reinforced nylon 66 made by DuPont Engineering Polymers. The front cowl material was a mineral and glass reinforced nylon 66, specially formulated to resist warpage during the injection molding process and was made by DuPont Engineering Polymers. The polymer material selected for the air dam cap was an alloy of polycarbonate and polybutylene terephthalate (PC-PBT) made by General Electric, specially formulated for improved UV weathering and chemical resistance. The front cowl and air dam cap use molded in color materials and did not need to be painted. The material selected for the lower cowls was a polymer alloy of ionomer resin, made by DuPont Packaging and Industrial Polymers. The ionomer alloy resin provided a Class ‘A’ surface finish, high gloss, molded in color part which did not need to be painted. The paint system was jointly formulated by PPG Industries Inc. and Mercury Marine.

Adhesive Material Selection
The function of the adhesive was to create a structural bond between the structural rib and rear cowl which are both made from 33% glass reinforced nylon 66. During service, all loads are transmitted by the rear cowl to the structural rib through the adhesive joint. It is well known in the industry that it is extremely challenging to achieve high bond strengths when bonding to nylon 66 substrates. An adhesive material was selected after testing eleven different adhesive formulations. Adhesive testing consisted of lap shear testing after exposing the test specimens to various chemicals and heat aging.

The material selected for bonding the structural rib was a two component polyurethane based adhesive system made by Lord Engineered Adhesives.

PAINTING
Traditional SMC cowl paint system comprises of a primer coat, base coat, and a clear coat. SMC requires multiple coats of paint to achieve the Class ‘A’ surface finish. SMC parts require significant finessing during the painting process. Surfaces are often buffed to remove defects during painting. Porosity in the SMC material results in outgassing during the paint process, which leads to defects in the paint film. ‘Orange peel’ is an additional commonly found defect in these paint systems.
In the new cowling system, the top and rear cowl components are painted using a different three layer paint system. The paint system consists of a base coat and two clear coats. The thickness of the paint coats applied is lower compared to the SMC paint system. The base paint coat provides the color and the clear coats provide UV resistance, depth of image and high gloss. The 33% glass reinforced nylon 66 produces a sound surface finish after injection molding. Hence surface preparation prior to painting is minimal and only reduced to surface washing. First pass paint line yields are much higher than SMC, thereby improving paint efficiency and reducing cost. Due to the reduced thickness of layers of paint the ‘Orange Peel’ defect is significantly reduced. The reduced amount of paint used also leads to reduced cost.

**LOW COST DESIGN**

The painted, injection molded cowling assembly provided a significant cost reduction of 46% compared to a compression molded cowling assembly made from SMC (Sheet Molding Compound) materials. The cost reduction was primarily a result of savings due to improved efficiency in painting (higher first pass yields in painting and reduced paint layer thickness), elimination of paint in the lower cowl, and reduction in assembly costs due to integration of latching components. SMC parts incur high warranty costs in shipping due to parts cracking. Warranty cost savings in the injection molded design are also anticipated.

**INNOVATIVE MOLD DESIGN**

Die-locked features of styled surfaces of the rear cowl required innovative mold design. The horse shoe shape of the part required an innovative way to eject the part. The problem was solved by CDM Tool and Mfg Company (Mold Maker) and Bemis Manufacturing Company (Injection Molder) by using proprietary mold design and ejection techniques.

**PROCESS OPTIMIZATION**

Process optimization was carried out by Bemis Manufacturing Company and DuPont Engineering Polymers. Scientific injection molding principles and Decoupled SM1 molding techniques were used to achieve an optimum molding process. On-machine rheology studies were conducted to optimize fill speeds and reduce glass read through. Packing and gate freeze studies were conducted to achieve a properly packed part. Sequential gating was employed in some parts to influence glass fiber orientation, reduce glass fiber read through, reduce warpage and improve surface appearance. The top cowl is the world's largest cosmetic glass reinforced injection molded nylon part and therefore these process optimization studies were essential especially during the filling of the mold.

**SUMMARY**

1. A patented, innovative multi component cowl assembly that provides easy access to components that require routine service, and full access to the engine for heavy maintenance was developed.
2. The top cowl is the world's largest cosmetic glass reinforced nylon injection molded part to date.
3. An injection molded cowl assembly resulted in a weight savings of 15.2 kgs and cost savings of 46% over a SMC assembly.
4. Cowling design with integrated latching system, good structural performance and improved NVH characteristics were also achieved.
5. Significant increase in painting efficiency was obtained by improving first pass yields. Paint orange peel, amount of paint used was reduced leading to cost reductions.

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1 Decoupled Molding Technique is a service mark of RJG Inc. [http://www.rjginc.com](http://www.rjginc.com)