Vehicle Description Form

(Form 6)

Updated 12/3/13

Human Powered Vehicle Challenge

Competition Location: San Jose, California

Competition Date: April 24-26, 2015

http://go.asme.org/HPVC

This required document for all teams is to be incorporated in to your Design Report. Please Observe Your Due Dates; see the ASME HPVC for due dates.

Vehicle Description

School name: Olin College of Engineering

Vehicle name: Llama Del Rey

Vehicle number 9

Vehicle configuration

Upright ______ Semi-recumbent X

Prone ______ Other (specify) ______

Frame material Carbon Fiber-Aluminum Monocoque

Fairing material(s) Carbon Fiber

Number of wheels 3

Vehicle Dimensions *(please use in, in^3, lbf)*

Length 94.7 in Width 31.0 in

Height 43.5 in Wheelbase 39.4 in

Weight Distribution Front 60%* Rear 40%* Total Weight TBD**

Wheel Size Front 16 in Rear 20 in

Frontal area 920 in^2

Steering Front X Rear ______

Braking Front X Rear ______ Both ______

Estimated Cd 0.089

Vehicle history (e.g., has it competed before? where? when?) *Llama del Rey* was designed exclusively for the 2015 ASME HPV Challenge and has not yet competed.

* Vehicle has not been completed, weight distribution estimated.

** Expected weight is 64lbf.

Olin College OF ENGINEERING Human Powered Vehicles

2014 - 2015 Innovation Report

Llama Del Rey

Vehicle #9

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Multi-Cavity Composite Molding for Stronger and More Accurate Bulkheads

In 2015, the Olin College Human Powered Vehicle Team developed a novel multi-cavity male molding process for producing composite structures with stronger and more accurate bulkheads; allowing us to create an integrated seat and rollbar in our carbon monocoque. This process increased the strength of the monocoque fairing and reduced the skill, resources, and time necessary to build the structure. The process was prototyped on a small scale before being used in the production of the team's final vehicle, *Llama Del Rey*.

1 Design

Background: Closed hollow fiber-reinforced plastic (FRP) structures are typically manufactured using either male or female molding techniques. To create a closed surface with female molds, multiple open surfaces are typically created and later joined. A closed surface can be made in a single operation on a male mold, but the mold must be destroyed to create the hollow center.

Figure 1: Two male mold halves before joining.

Need: Traditional male and female molding techniques do not permit the direct creation of multi-cavity compartmentalized structures. With existing processes, spanning bulkheads must be added after separating the mold, decreasing positional accuracy and requiring difficult internal layups. In addition, shortening the manufacturing time of the monocoque fairing leaves more time for integration, testing, and rider practice.

Description: *Llama Del Rey's* carbon fiber-reinforced plastic (CFRP) monocoque was constructed as two closed forms, which were later joined with carbon, and a Nomex honeycomb core along a flat mating surface (Figure 1). This process increased the strength and improved the geometrical accuracy of the bulkhead on the resultant multi-cavity structure.

Impact on Human Powered Vehicle Design: This process allows for strong structural bulkheads to be created in the monocoque bodies of human powered vehicles. Stronger bulkheads result in a stiffer vehicle frame, allowing for weight to be reduced while maintaining rider safety. The single mold greatly simplifies the manufacturing process by eliminating the need for a fiberglass female mold. This improves manufacturing efficiency and enables faster production of one-off vehicles customized to fit the needs of the team.

Feasibility: The multi-cavity molding process was successfully implemented in the production of a one-fifth scale prototype of *Cheryl* (Figure 2) and of the final vehicle, *Llama*

Del Rey. Because there is no longer the need to perform internal layups, the process reduces the amount of skilled labor necessary to produce spanning bulkheads, thus improving mass manufacturability.

1.1 Literature & Patent Review

Research into the field of composite molding and structure creation was done through a thorough patent search and examination of technical literature across several relevant industries. Past human powered vehicles were also inspected. Multi-part male molds are not a new technique. Past human powered vehicle fairings have been constructed with two symmetric mold halves[7].

Combining composite structural elements is done regularly in autosport and aircraft production [3] [4]. However, these structural elements are designed to be removable and are installed with bolts rather than permanently mated with composite joining material. Permanent composite joining is done during the molding process in the production of some surfboards [1]. However, the joint is not a bulkhead, as it is less structural than the surrounding laminate body.

Based on this examination of prior art, the multi-cavity molding scheme described here is novel within the realm of human powered vehicles and beyond. A patent application could be submitted. Note that this technique may be in commercial use, but guarded as a trade secret.

2 Concept Evaluation

The team tested the multi-cavity molding process on a one-fifth scale model of *Cheryl* before committing to its use on *Llama*. The prototype was constructed from XPS foam by using a CNC router to create two closed shapes with inlaid ribs for the front and rear of the vehicle. Both molds were covered in carbon fiber. Nomex honeycomb was applied to the ribs and mating surfaces with epoxy. The halves were joined with a final layer of carbon fiber around the entire model.

Figure 2: One-fifth scale process prototype.

Intended Benefits: The process tests confirmed both that the process was technically feasible and that it led to increased strength, better accuracy, and reduced labor.

- The structural bulkhead substantially improved the strength of the vehicle. The small-scale monocoque was loaded with 175 lbf at the top and side of the rollbar and no measurable deformation was observed. Extensive load testing on the full vehicle revealed that this year's vehicle is the team's stiffest yet.
- With this process, the labor required to produce a structure with internal bulkheads is substantially reduced. Once the male mold is produced, the shell can be completed in six days, assuming a 24-hour cure time. Previous processes required eleven days.
- The interior surface finish of the monocoque was dramatically improved by the elimination of internal layups, which are difficult to vacuum bag (Figure 3).

- Compared to past processes, this process results in higher accuracy during manufacturing. The inlaid ribs and surface cuts into the mold clearly indicated where to position structural elements. The manufactured structure precisely matched the CAD model, which made analysis significantly more accurate. The ease of performing external layups limited the number of overlapping carbon fiber layers, making the fairing thickness more even and accountable.

Unanticipated Benefits: In addition to the projected benefits, several unanticipated benefits were realized during concept evaluation.

- Creating a structural bulkhead with a two-part molding process requires substantially less skill than fitting and laying up a bulkhead into an existing hollow shell.
- Parallelizing work on the two halves of the fairing allowed for efficient labor distribution.

3 Learnings

In the creation of the small-scale prototype and of *Llama's* monocoque shell, several issues were encountered that will influence the team's future use of this process:

- Alignment between the mating surfaces was an issue that was identified on the small-scale prototype. The halves of the model were coarsely lined-up, resulting in cattywampus alignment. In the production of *Llama*, the halves were joined with the front half sitting vertically on the nose. The back half was placed on top and aligned carefully, yielding a torsionally accurate fairing.
- When the process was scaled up for use on *Llama*, not enough care was taken to ensure that the mating surfaces were flat and lined up. The resultant gaps were filled with an additional layer of carbon fiber which added weight.

Figure 3: Smooth interior surface of bulkhead and front cavity.

In future iterations of this process, the team will design the two molds so that the mating surfaces remain flat and add superior interlocking features at the mating points to ensure proper alignment. The mold design must take into account the inaccuracies inherent to laying up carbon on mating surfaces.

Negative Aspects of Process: The negative aspects of the design are as follows:

- Using a male mold for the creation of a closed structure requires that a new mold be made for each shell, adding waste and expense in mass manufacturing.
- Extracting the foam mold proved challenging and time consuming. New processes would need to be developed to scale this approach to mass manufacture.
- A shell molded over a male form has a worse initial exterior surface finish to one produced with a female mold. More fairing was required to produce an acceptable finish.

References

[1] Mead, K., 2003, "Flexible Male Female Mold for Custom Surfboard Production," U.S. Patent 6623323.

[2] Guitton, M., Aulenback, T., Davison, M., Baril, C., Guitton, S., Steck, K., Bruhm, P., and Myra, M., 2012, "Composite Mold with Expandable Boot," U.S. Patent 20120040042.

[3] Savage, G., 2009, "Formula 1 Composites Engineering," Engineering Failure Analysis, 17(1), pp. 92-115.

[4] Laja A., Dominguez F., 2012, "Pressure Bulkhead Made of Composite Material for an Aircraft," U.S. Patent 8226870 B2.

[5] University of Toronto Human Powered Vehicle Design Team, 2014, "Valkyrie," Toronto, ON.

[6] Aird, F., 2006, *Fiberglass and Other Composite Materials*, Penguin Publishing Group, New York, NY.

[7] Beauchamp, W., 2000, "Barracuda Fairing Phase 3," Web.