



Composite intake and exhaust louvers for marine applications

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Abstract

Commercial, naval ships, as well as other marine transport vessels use heavy, multi-blade steel weather louvers to cover their intake and exhaust openings to the outside. Costly time, labor and materials are constantly expended to protect and maintain these steel louvers from the corrosive effects of the sea environment. Louvers made from fiber-reinforced plastic composite materials such as fiberglass are low in weight and can eliminate corrosion and deterioration caused by salt-laden moisture and ship-stack exhaust gases. The use of weather tight non-metallic composite louvers will also eliminate galvanic corrosion problems due to inadequate louver-to-bulkhead attachment practices. Such low maintenance louvers will provide reliable operation and will eliminate the current shipboard maintenance burden. This paper will discuss in detail a composite louver design that is simple and reliable and can be fabricated by an inexpensive composite pultrusion process which is integrated with an inexpensive numerically controlled (NC) finishing operation. The paper presents the details of this composite pultrusion process, including the composite design architecture. A finite element model (FEM) and stress analysis is also presented. The composite louver concept discussed in this paper has robust, yet lightweight composite structural characteristics. It is attractive from the ship designer's point of view since it will provide a greater level of design flexibility at a minimum cost. The proposed composite louver design can be easily adapted to satisfy economically any gamut of ship-set sizes for any ship compared to metallic louvers or other composite louvers that may be in current ship use. The authors of this paper have successfully demonstrated the environmental and structural feasibility as well as the economical practicality of the proposed composite louver for use on U.S. Navy ships.

1 Introduction

There are three primary markets for the fiber-reinforced plastic composite louver, namely commercial marine vessels, naval ships and industrial land-based facilities. The U.S. Navy's interest in a composite louver is to reduce maintenance costs through the use of corrosion resistant composite material, reduce top-side weight and to lower production cost through simplified, modular design characteristics of the louver. Life cycle costs for Navy ship steel louvers in the intake, uptake and exhaust systems for gas turbine generators and gas turbine main engines are unacceptably high. Steel louvers on these ships may range in size from 450 mm x 650 mm through 2300 mm x 1500 mm as shown in Figure 1.

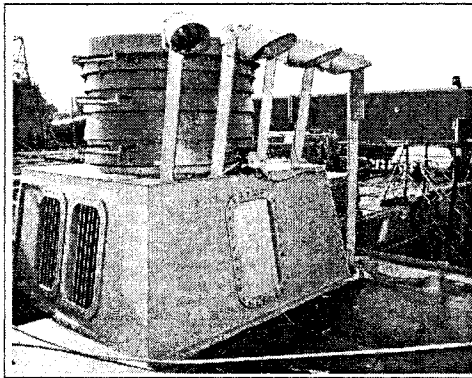
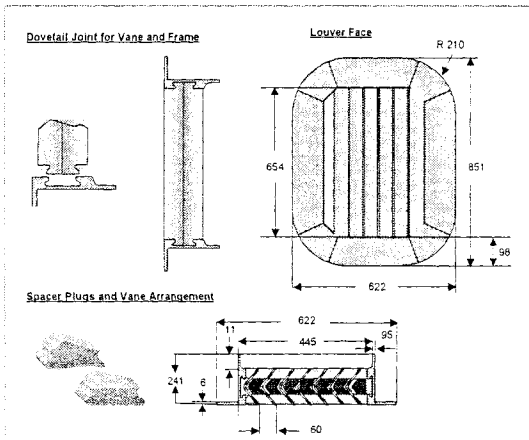


Figure 1: Example of a steel louver installation on a naval ship.

Steel louvers have historically experienced severe corrosion problems, requiring the fleet to frequently remove, re-preserve and re-install the louvers upon availability of the ship. For example, it is estimated that for 50 louvers this problem may cost up to \$100,000 (U.S.) per ship every three years. The Navy has tried different methods for coating steel louvers, but in effect these methods have had limited success, and were costly. In an attempt to remedy the maintenance situation, an alternate affordable composites approach to ship louvers is being proposed by the authors. The authors were able to design, fabricate and demonstrate a unique prototype design and manufacturing process for composite louvers. The inexpensive composite louver that was developed is based on a system of pultruded composite inter-locking, dove-tailed parts. It is a robust structure that integrates Navy specific requirements as well as fire, structural and reduced maintenance requirements. Initial acquisition cost estimates put this composite louver design on par with a steel louver at approximately one third the weight with significant maintenance savings over the life of the vessel.

2 Concept and design

From the Navy's point of view, it was desirable to develop a composite louver that could easily be produced and adapted to fit any ship with radiused bulkhead openings without sacrificing significant airflow. The current industry approach to building composite louvers involves costly hand lay-up operations that require a multitude of molds to satisfy the various louver frame sizes possible for a complete ship set. Our concept for a composite louver, as it is shown in its most basic form in Figure 2, uses "dovetail" joints that securely hold together all the components of the louver. We demonstrated that this parts-based simple, yet flexible design, would be compatible with a composite fabrication process known as pultrusion. This is an inexpensive composite manufacturing process that addresses the desired cost savings. We coupled this process with an inexpensive numerically controlled (NC) secondary grinding operation as shown in Figure 3. Pultrusion technology is based on the continuous processing of fiber reinforcement in woven or non-woven tape form which has been impregnated with liquid resin and then pulled through a heated die to produce continuous output structural lineals with profiles of constant cross-section and length. Pultrusion gets its name from the method that creates the profiles, i.e. the composite material is drawn through the forming die by a "puller". In Figure 4, we can see the resin impregnated fibers entering and being pulled through the die where curing occurs. In Figure 5, we see the cured, rigid structural composite profile exiting from the die. A prototype composite louver, as illustrated in Figure 2, was built and successfully shock and vibration tested to Navy requirements according to Mil Std 901D and Mil Std 167-1 respectively.



Note: Dimensions are in millimeters.

Figure 2: Composite louver assembly: Spacer plugs and dovetail joints are key elements in the Navy design. This efficient parts-based concept greatly reduces the labor involved in making composite louvers of different sizes.

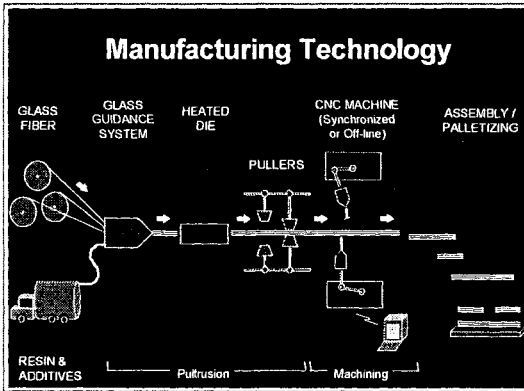


Figure 3: Pultrusion manufacturing technology.

The design employs a unique approach that requires only three different forming dies for the pultrusion-based parts production process: one for the frame elements, one for the chevron vanes, and one for the spacers that keep the vanes separated at a constant distance. With pultrusion, as shown pictorially in Figure 3, the fabrication process for making many louver units becomes very economical due to its inherent continuous feature. The louver's interlocking component parts can be permanently assembled with or without adhesive. In an unbonded approach, easy disassembly would allow repair or replacement of a louver's components rather than replacement of the entire unit. This "knock-down" design could also save money in shipping, handling, and on-site assembly.

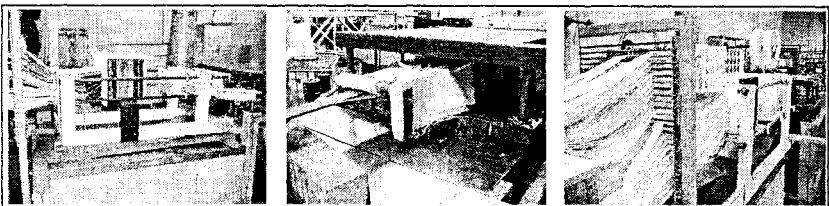


Figure 4: Woven glass cloth tapes entering and exiting pultrusion machine.

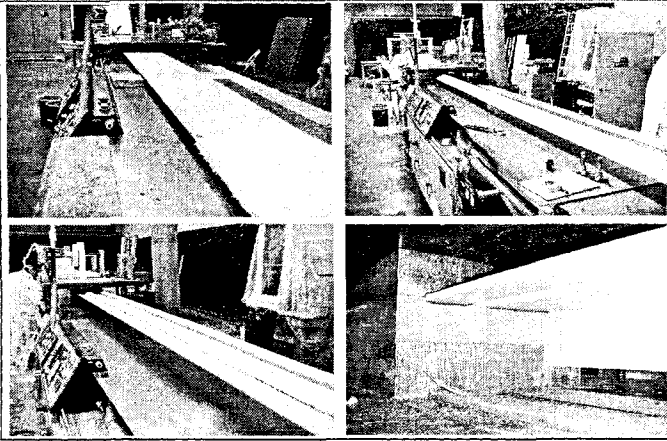


Figure 5: Structural lineals exiting from pultrusion dies.

3 Air flow considerations

Compared to steel louver assemblies, pultruded composites offer increased flexibility for manufacturing more complex cross-sectional shapes required to yield laminar flow efficiency and improve airflow past the vanes of the louver. Airfoil-shaped louver vanes are not unreasonable and would not add to cost. Although our louver concept shows a chevron type geometry vane, oriented in a vertical direction, there is no “show stopper” that could stand in the way of other profile vane or frame geometries and orientations that may be more desirable. Pultrusion can inexpensively produce flow-optimized vanes, while steel-manufacturing techniques cannot readily achieve such shapes. With improved airflow per unit area, the size of the louvers might be reduced, lowering manufacturing costs and reducing topside weight.

4 Material and structural considerations

All of the louver components are made from E-glass fabric reinforcement, which is bound in a vinyl ester resin matrix. The composite material used is identified in Table 1 and the reinforcement ply sequencing architecture is shown in Figure 6. The material properties of this system are given in Table 2 and satisfy the static and dynamic loading requirements specified by the Navy. In order to meet the Navy’s fire requirements for flame spread and smoke generation, we chose to use a vinyl ester resin system loaded with 75 pph of an Alumina Trihydrate fire retardant. Alumina Trihydrate was



selected based on its pultrusion compatibility with the resin system and its low smoke and toxicity properties. Fire tests were conducted on representative pultruded flat panels, according to ASTM-E-162 for flame spread, ASTM-E-662 for smoke generation, and ASTM-E-1354, cone calorimeter time to ignition and heat release. The test results showed that the Navy's requirements were satisfied.

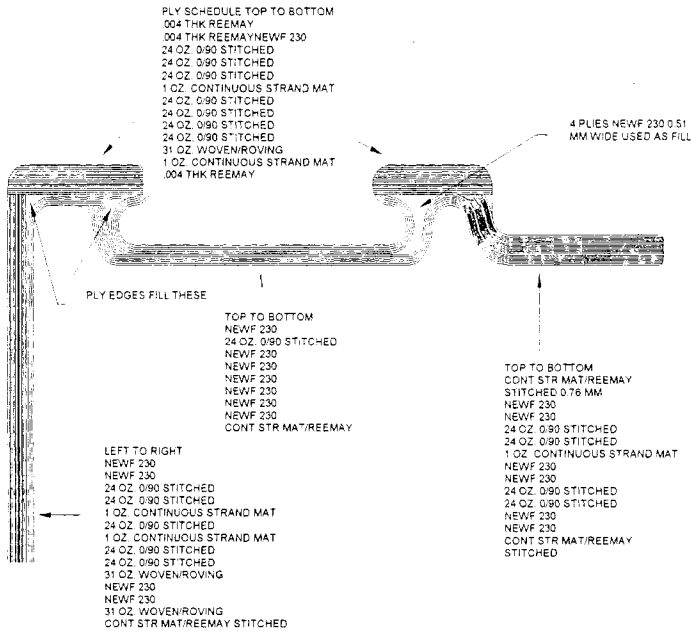
Table 1: Composite material constituents used in louver construction.

Material Constituents	Description
Resin	Vinyl Ester, Dow Derakane 411-350
Fiber Reinforcement	E-Glass (See Ply Schedules in Figure 6)
Fire Retardant	Alumina Trihydrate (ATH), 75 pph
Adhesive	Pliogrip 7770/Ashland Chemical Co.

Table 2: Composite material properties used in the louver construction.

Properties	Elastic Constant
Modulus in the Warp Direction, E_x (MPa)	24,479
Modulus in the Fill Direction, E_y (MPa)	22,876
Modulus in the Thickness Direction, E_z (MPa)	11,060
Shear Modulus, G_{xy} (MPa)	3,698
Shear Modulus, G_{yz} (MPa)	2,927
Shear Modulus, G_{xz} (MPa)	3,012
Poisson Ratio, ν_{xy}	0.1313
Poisson Ratio, ν_{zy}	0.2007
Poisson Ratio, ν_{xz}	0.4079
Poisson Ratio, ν_{yx}	0.1227
Poisson Ratio, ν_{yz}	0.4151
Poisson Ratio, ν_{zx}	0.1843
Allowable Tensile Strength Wet (MPa)	231 (Warp)
	231 (Fill)
Allowable Compressive Strength Wet (MPa)	231 (Warp)
	231 (Fill)
Allowable Flexural Strength Wet (MPa)	242 (Warp)
	301 (Fill)
Allowable In-Plane Shear Strength Wet (MPa)	48 (Warp)
	48 (Fill)
Allowable Bearing Strength Wet (MPa)	308 (Warp)
	305 (Fill)
Allowable Interlaminar Shear Strength (MPa)	27 (Warp)
	27 (Fill)

(a) Frame



(b) Vane

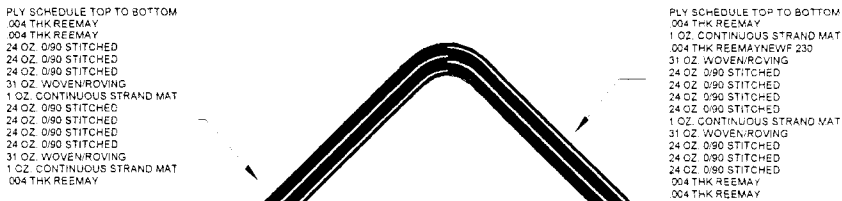


Figure 6: Pultruded composite ply sequencing architecture in cross-section of (a) frame and (b) vane.

5 Structural finite element model

A simplified louver model consisting of three chevron vanes within the frame, as shown in Figure 7, was analyzed for static structural performance. A finite element model of this configuration was created using the IDEAS Code with quadratic brick elements. A linear analysis in IDEAS was performed using orthotropic material properties given in Table 2. The objective of the analysis was to predict the maximum expected deflections and stresses at a vane center span, as well as the stresses at the dovetail joint interface between the vane and the frame. The latter stresses were found to be minimal.

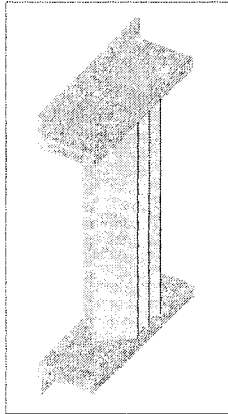


Figure 7: Simplified louver configuration used for FEM analysis.

Two sets of analyses were performed: one model had a vane span of 654 mm and the other had a span of 1854 mm. The 654 mm model used 6,648 quadratic 20-node brick elements with 35,611 nodes and 19,944 degrees of freedom. The FEM model for the 1854 mm model was created with 8,780 quadratic 20-node brick elements with 38,880 nodes and 26,340 degrees of freedom. The boundary conditions for both models were intentionally simplified such that all degrees of freedom were fixed at the frame-to-vane interface. The applied load was a uniformly distributed static load of 31.6 kPa acting on the projected faces of all vanes in the model. This was a Navy specified load for this analysis. The performance specification also called out a desirable but non-obligatory deflection of $L/100$, where L is the length of the chevron vane with the maximum deflection being at the center of the vane span.

Our FEM analysis of the 665 mm model showed that the maximum deflection for the louver was 3.50 mm and the maximum tensile stress at that location was 5.95 MPa, transverse to the vane span. This is well within the desired limit of $L/100$, as well as within the composite material factor of safety based on allowable strength of 231 MPa wet. These results are shown in Figure 8. In-plane and out-of-plane shear stresses were 2.58 MPa and 1.4 MPa, respectively, and these are also well within the allowable wet in-plane shear

strength of 48 MPa and the inter-laminar shear strength of 27 MPa for the composite material.

The FEM analysis for the 1854 mm model used the same boundary conditions and was also loaded with a uniformly applied static load of 31.9 kPa. The results showed a maximum mid-span vane deflection of 27 mm. The maximum tensile stress developed in the transverse direction (across vane) was only 12 MPa. Although the $L/100$ limit was exceeded, in this instance by 8.5 mm, the developed maximum stress was still well within the allowable wet strength bounds of the material. Due to the elastic behavior and subsequent recovery of the vanes this deflection was deemed to be inconsequential in terms of operational louver performance. This is considered to be a non-issue since longer vane spans can be internally stiffened in their composite architecture or braced with relative ease to minimize vane deformation. If stiffeners are used, they could be installed at the trailing edge so they would not adversely impede airflow performance.

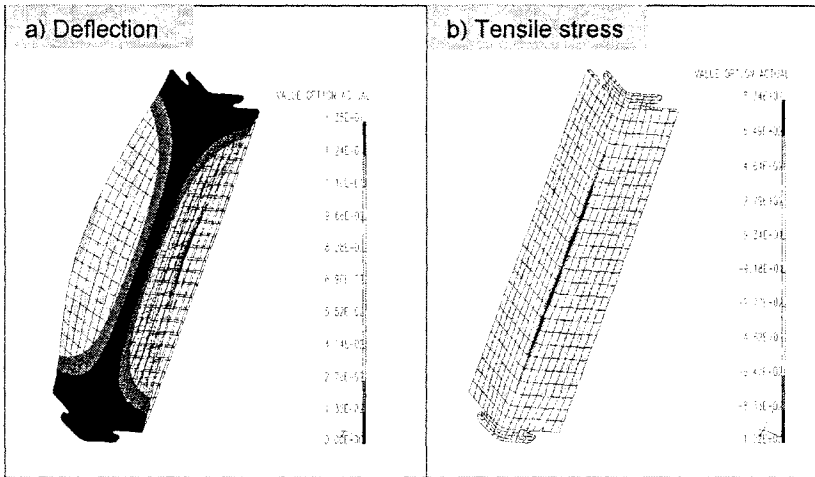


Figure 8: FEM analysis of the 665 mm vane model showing maximum (a) deflection and (b) tensile stress with uniformly distributed load of 31.6 kPa. Deflection and stress scales above are in English units.

6 Parts production and assembly

The louver frame, which holds the chevron vanes, or for that matter any other shaped vanes in place, consists of eight contiguous elements (previously shown in Figure 2) that can be cut from the same continuously pultruded lineal. The four corner pieces are identical for any size louver and act as adjoining pieces between the vertical and horizontal frame sections, approximating the corner radius traditionally associated with shipboard louvers. (It is noted that a simpler frame design could be obtained if square corners were permitted.) The four

remaining frame pieces (two vertical and two horizontal) vary in length according to the size of the louver to be produced. Similarly, the vanes can be cut from their lineal to the length required for a particular size louver. The spacers are also cut from their respective lineal, with the number required being based on the number of vanes in a given louver. Thus, in summary, the dovetailed frame, vane and spacer elements are all pultruded lineals, which are NC machined to produce:

- The male ends on the vanes as well as the male and female ends in the frames;
- The rounded corners and the canted lap joints in the frames;
- The in-plane spacers that separate the vanes in the top and bottom frames that also act as fillers in the side frames.

All of these NC machining operations may appear to be complex and expensive but in fact have been demonstrated to be simple, fast, inexpensive and therefore very attractive from the production point of view. Our composite louver design concept is versatile in that it features inter-locking component parts that can be permanently assembled with or without adhesive. In an unbonded approach, easy disassembly would allow repair or replacement of a louver's components rather than replacement of the entire unit. This "knock-down" design could save money in shipping, handling and on-site assembly. Several trial assemblies were made with louver sub-assemblies to insure that components fit properly. Final assembly of the louver was completed in approximately 60 minutes. Figure 9 shows the various stages in the louver assembly. Figure 10 shows the assembled louver.

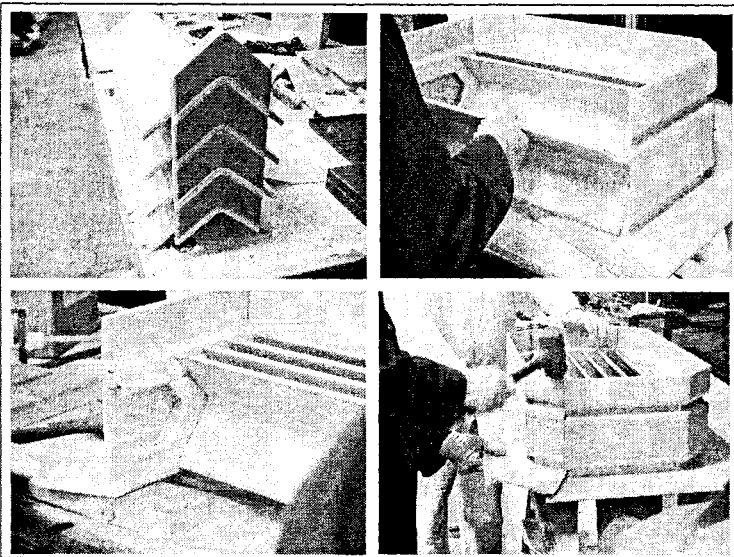


Figure 9: Various stages of louver assembly.

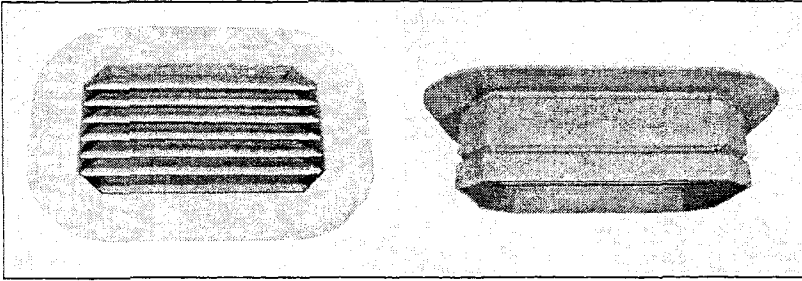


Figure 10: Fully assembled and painted louver.

7 Cost consideration

Steel louvers currently in use on ships may appear to be low-cost items, but in reality their acquisition is costly when considering the add-ons used in re-preserving these louvers against the effects of corrosion. Total ownership costs for steel louvers are high because these protection practices are, in effect, only maintenance stop-gaps, rather than long term solutions. Composite louvers are amenable to low-cost fabrication processes like pultrusion, which translates into reduced acquisition cost and lower total ownership costs. The proposed louver design concept lends itself to easy assembly. The design is also dimensionally adaptable to the multitude of louver geometries and sizes found on any vessel or land installation, be it new or backfit, with no extra tooling or manufacturing costs required. The machining of the pultruded lineals has several identical operations, regardless of louver size. For example, the four frame corners are identical for each and every louver on any ship. For certain louver groups, vertical or horizontal frame sections would also be identical. All of these aspects support the “knock-down” feature of this design as mentioned previously.

We have made a preliminary, normalized cost per unit weight estimate for a finished pultruded composite louver relative to a louver fabricated from steel. This estimate is extrapolated from the fabrication and assembly procedure that was experienced with the prototype that was fabricated during the study presented in this paper. The cost presented refers to an “average-size” louver with costs being higher or lower for smaller or larger louvers respectively. Additional, but marginal, up-front tooling and non-recurring start-up costs may be necessary to achieve “production status” for manufacture of large numbers of louvers. Table 3 presents normalized cost factors for a finished composite louver relative to one made of steel.

Table 3: Estimated cost comparison between composite and steel louvers.

	Cost per Weight	Weight Multiplier	Adjusted Cost Per Weight	Maintenance Costs
Composite Louver	3	1x	3	Low
Steel Louver	1	3x	3	High

On a per weight basis, steel louvers are significantly cheaper to manufacture. However, because a steel louver can weigh approximately three times as much as the equivalent composite louver, the average louver costs would appear to be almost identical as observed from Table 3. Total ownership cost for a composite louver should therefore be significantly less than for an equivalent steel louver due to the greatly reduced maintenance requirements.

8 Conclusions

The unique composite louver design and manufacturing technique presented in this paper was demonstrated to be a structurally viable and economically attractive option for use on marine vessels in place of currently used steel louvers. The composite louver will have a distinct total ownership cost advantage because no additional maintenance costs will be incurred.

References

[1] MTTC: Technology and Training for Your Future, *DDG-51 Class Louvers Qualified Coating – Going to Sea in Large Numbers*, <http://www.mttc.org/news>, Louisville/Lexington, Kentucky.