

Design of an Origami-Inspired Deployable Aerodynamic Fairing for Locomotives

K. A. Tolman, E. B. Crampton, C. L. Stucki, R.D. Maynes, L. L. Howell

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Abstract

Aerodynamic drag is one of the largest contributing factors to the fuel consumption of large vehicles at cruising speed. Large freight vehicles would benefit from aerodynamic improvements in their design but are often constrained by functional requirements such as accessibility and overall size. Origami has been used as a source of inspiration in solving some of the most difficult space constrained problems ranging from space to medical applications. This project utilizes the principles of origami to create a transformable aerodynamic add-on device for locomotives. The device, which we will refer to as the fairing, can transform its shape from an aerodynamic form to a collapsed form so that the functional requirements of the locomotive are maintained. The concept of this reconfiguration is shown in Figure 1. The deployed configuration is meant to decrease pressure drag on the lead locomotive of a train. The stowed configuration is meant to have an open walkway between locomotives when not in the lead position.

The fairing was designed using principles of thick origami. When thickness is introduced in an origami-based mechanism, the thickness must be accommodated to prevent self intersection of panels. Several techniques have been introduced to accommodate thickness in origami-based mechanisms. The folding mechanism presented here adopts the offset-panel technique to accommodate the thickness of the fairing panels when folded. The foldable fairing is also

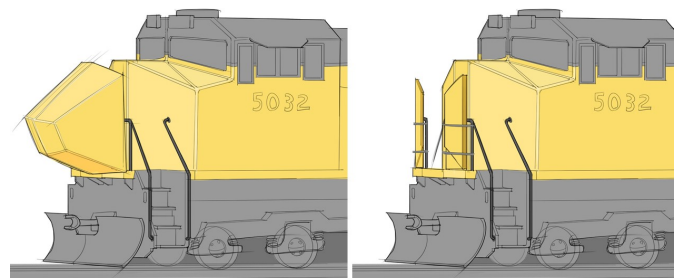


Figure 1: Initial concept for an origami-inspired deployable fairing based on rigid folding panels. Left: The fairing in its deployed state. Right: the fairing in its stowed (folded) state.



Figure 2: Full-scale prototype of the origami-inspired deployable fairing on a freight locomotive shown in both the deployed configuration (left) and stowed configuration (right). Photo has been modified to remove locomotive identity.

based on non-developable origami. A developable surface has zero Gaussian curvature, i.e. it can be flattened into a plane without stretching or ripping the material. Because traditional origami starts with a flat sheet of paper and is folded into a 3D shape, it can likewise be unfolded back into a flat sheet, and is therefore developable. Thickness-accommodation techniques have been applied primarily to developable patterns. This work explores the potential of thickness-accommodation techniques being applied to patterns that are non-developable and discusses additional considerations that must be made when dealing with non-developable thick origami.

This paper outlines the approach taken and the results achieved to design a foldable locomotive fairing based on non-developable thick origami that can meet the general requirements of both the deployed and stowed states. The requirements of foldability and aerodynamic performance make the problem of finding an optimal design challenging. To determine an optimal geometry for a nose fairing an optimization study was conducted where fairing geometries were evaluated using both computational fluid dynamic (CFD) software and wind tunnel experiments. Over 140 different nose fairings were evaluated and a multidimensional polynomial regression was used to determine optimal geometries.

The final fairing design was prototyped and attached to a locomotive, as shown in Figure 2, to demonstrate its functionality. The resulting fairing design is estimated to reduce drag by over 16% for a locomotive cruising at 80 kph. The fairing can be easily deployed and stowed by one person in under 30 seconds and does not interfere with the features or functionality of the locomotive. Using statistics of freight hauling trains, it is estimated that railroads can save over 24,000 liters of diesel annually per train retrofitted with the fairing. For class 1 railroads that have hundreds of trains operating at any given moment, this translates into a fuel savings of 2,400,000 liters annually per 100 trains.