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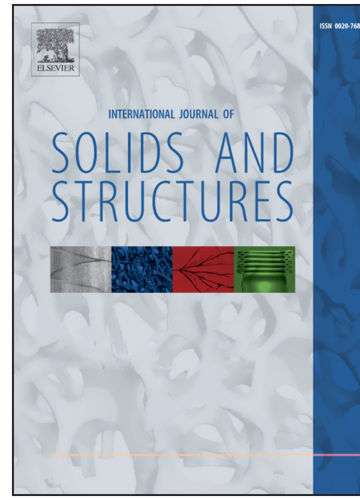


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# De-wrinkling of Pre-tensioned Membranes

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**Abstract**

Thin membranes are used in the spacecraft industry as extremely lightweight structural components. They need to be stiffened, usually by applying discrete forces, and this increases their susceptibility to wrinkling in regions where high tensile stresses develop. We consider a regular polygonal membrane uniformly loaded at its corners by equal forces and we prevent wrinkle formation by trimming the edges of the polygon into very gentle curves. We confirm this performance through simple physical experiments using Kapton, a typical membrane material and, using computational analysis, we show how the distribution of compressive stresses, responsible for causing wrinkles, dissipates following trimming. Finally, we accurately predict the required level of trimming for any number of sides of polygon using a simple, linear model, which invokes a plate-bending analogy.

**Keywords: membranes, de-wrinkling, spacecraft, uniform loading, trimming**

## 1 Introduction

Gossamer structures are thin-walled membranes, or meshes, favoured in the design, construction and operation of lightweight spacecraft, such as solar-propelled sails, optical antennae for space telescopes and, more recently, de-orbiting chutes. Once folded inside restricted payload volumes, they offer the highest packaging ratios of any deployable structure; and post-deployment, the mass-to-area, or "areal", density is much lower than conventional monolithic structures [1]. Correspondingly, they afford greater potential for launching sails and telescopes of ever increasing size, but after deployment the membrane must be stiffened to be effective in operation. Current design architectures centre on polygonal layouts pre-tensioned by means of cables attached to their vertices, and shown schematically in Fig. 1(a). The membrane is largely unobstructed for maximal reflection of incident light or radio waves, and the cables are connected to a supporting edge structure in this case, which enables pre-tensioning either passively by geometrical means or actively by embedded actuators. The edge structure is not our concern here, but we assume that it functions ideally, by enabling deployment and membranal tensioning without its own members buckling or failing; rather, we focus on the shape of membrane after tensioning, and the potential for *wrinkling*.

In this sense, out-of-plane displacements become important, and the membrane is locally no longer flat, which can disrupt the reflection quality. If any of the in-plane stresses are compressive, the possibility of out-of-plane buckling increases and, because the membrane is very thin, the buckles have a short wavelength, manifesting as narrow wrinkles. This effect is more pronounced when the loading is applied as discrete forces