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Review article

Accordion shelters: A historical review of origami-like deployable shelters developed by the US military ☆

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ABSTRACT

Origami, the art of paper folding, is becoming increasingly recognized as a fruitful area of inspiration for engineering design and research. The state-of-the-art in origami engineering ranges across disciplines. At the structural scale, origami-inspired structures offer particular advantages for rapidly deployable shelters since (1) in the deployed form, the folded panels offer enhanced structural performance and (2) these folds enable the structure to be packaged small. In this respect, origami-inspired structures feature the deployability of soft wall (tent) structures, while providing the advantages of rigid wall systems such as thermal insulation. Though not identified as gaining inspiration from origami, the US military developed a series of accordion shelters in the mid-twentieth century which embody many of the qualities of origami-inspired shelters of interest today. This paper will review accordion concepts developed by the US military and the military evaluations of these systems with the aim of informing design today.

Contents

1. Introduction and motivation

The art of origami offers inspiration for science and engineering applications across disciplines. As evidence of the growing interest in origami science and engineering, the US National Science Foundation has identified it as a topic for its 2012 and 2013 Emerging Frontiers in Research and Innovation program. Architects and engineers have grown increasingly interested in origami engineering at a structural scale, including applications for deploying space structures (e.g. [1,2]), for deploying temporary shelters (e.g. [3–9]), for static folded-plate architecture (e.g. [3,10,11]), and for adaptive architecture (e.g. [12,13]). For military operations and disaster

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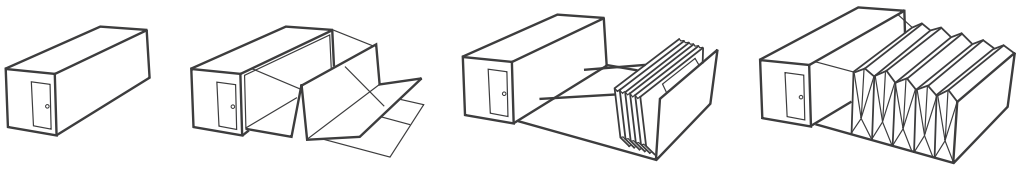


Fig. 1. Accordion concept. Image based on diagram by US Army.

relief applications where space is at a premium, origami-inspired deployable shelters offer key advantages. More specifically, the folds enable a rigid wall system to be compactly stowed in a small packaged volume and these folds provide enhanced structural performance in the deployed form. Here, enhanced structural performance refers to the additional flexural rigidity provided by angling thin plates so that they are not perpendicular to applied loads (i.e. the moment of inertia is increased). Origami-inspired shelters provide the deployability of a soft wall (tent) structure while providing the advantages of a rigid wall structure, including thermal insulation.

While not identified as gaining inspiration from origami, the US military developed a variety of accordion-type shelter concepts in the mid- to late-twentieth century that offer valuable experience that can inform origami-inspired design today. Fig. 1 shows the deployment process for one of the leading concepts developed by the military. In the packaged state, the entire shelter fits within a shipping container. During deployment, the side walls are removed and accordion-like panels expand to form a much larger deployed shelter. The efficiency lies in the use of the shipping container for both transportation and as a part of the deployed structure [14]. This represents just one accordion-like concept developed by the military.

This paper will provide a historical review of accordion-like concepts developed by the US military, including the military's evaluation of the advantages and disadvantages of each structural concept, with the aim of informing design today. These concepts fall roughly into the following categories: (1) soft wall shelters which are comprised of a rigid frame covered by fabric, (2) rigid wall shelters that unfold like clamshells, and (3) rigid wall shelters that expand longitudinally. This review will also highlight lessons to be learned from each form. The reader, however, must be aware that there is very limited information available about each system and how they evolve from one to the next. There is also more information available for some systems as opposed to others. The authors have compiled this review based on the available de-classified reports.

Note that many of these forms carry the same name. Therefore, the reader is encouraged to rely heavily on the images provided. All dates are approximate as they are based on the date when the systems appeared in technical reports and manuals.

2. Soft Wall Accordion Shelters

While the majority of the accordion shelters presented in this paper are rigid wall, a few soft wall versions exist (Fig. 2). Each

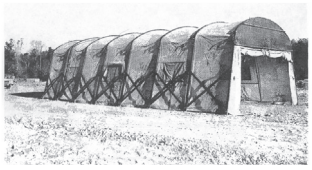
A. Accordion Shelter 	Material: Aluminum Frame, Nylon Packaged Size: 2.80 m^3 Deployed Size: 4.88 m x 10.67 m x 3.05 m Weight: 4.58 kN Erection: 8 people, 12 minutes	Pros	Integrated fabric cover for easy erection [15] Unobstructed interior space [15]
		Cons	High cost, weight, and packaged volume [15] Awkward handling during erection [15] Covered area does not meet requirements [15]
B. Accordion Shelter 	Material: Aluminum Frame, Nylon Packaged Size: NA Deployed Size: 3.05 m x 6.10 m x 2.44 m Weight: 1 kN Erection: 4 people, 15 minutes	Pros	Similar to above
		Cons	Similar to above
C. Tent, Maintenance, Army Aircraft 	Material: Hybrid air and frame supported, Nylon Packaged Size: NA Deployed Size: 21.95 m x 24.38 m x 8.23 m Weight: 26.2 kN Erection: 8 people, 24 hours	Pros	Unobstructed interior space Unique opening and closing mechanism
		Cons	Power source required for constant air flow and winch operation for opening/closing

Fig. 2. Soft wall accordion concepts. Note that pro and con evaluations are cited when made by military, not cited when made by authors. Images courtesy of US Marine Corps and US Army.