March 25, 1969 C. P. RUBIN 3,434,254

DEPLOYABLE BOOM

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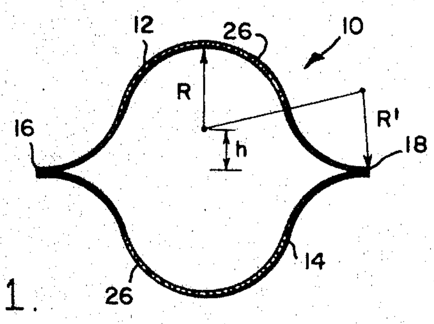

Fig. 1.

Fig. 6.

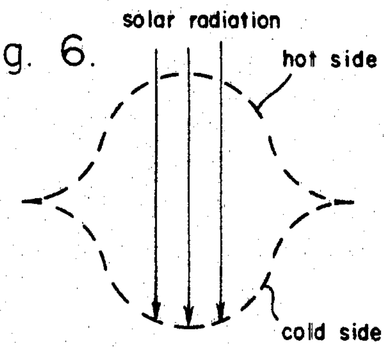

Fig. 2.

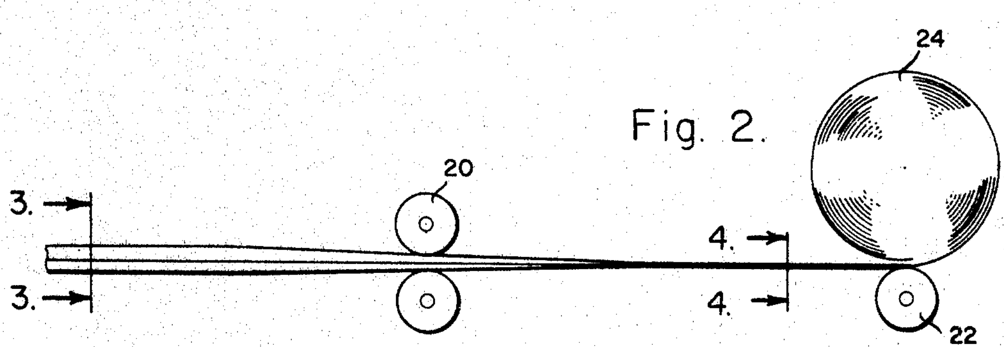

Fig. 3.

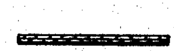

Fig. 4.

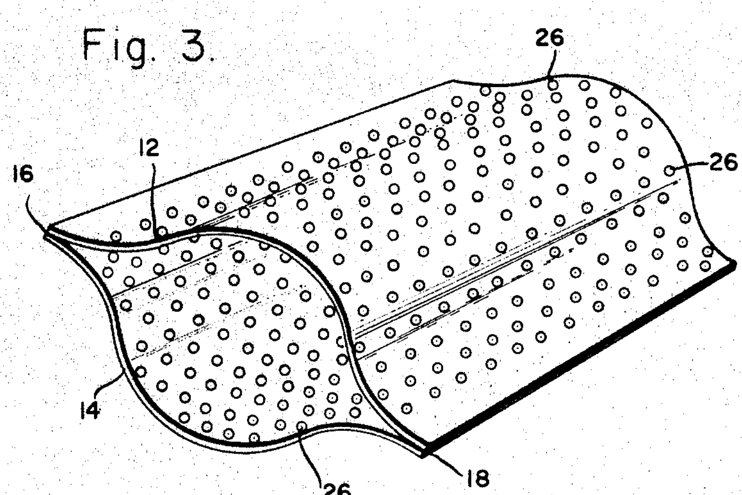

Fig. 5.

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DEPLOYABLE BOOM

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ABSTRACT OF THE DISCLOSURE

An extendable boom formed of a pair of mated strips of thin spring material joined at margins and curved in cross section outwardly and oppositely so that when the boom is flattened and rolled into a coil, the margins and curved portions will lie juxtaposed without exceeding the yield of strength of the material.

Background of the invention

This invention relates generally to deployable booms of the type used in aerospace applications, for example, as antennae on space vehicles or as booms on gravity gradient stabilized satellites. Deployable booms of this type are required to be packagable in the space vehicle during launching into a compact (usually coiled) condition and are required to be extendable or deployable into long straight elements, sometimes in the order of the magnitude of 1,000 feet or more. In addition, many applications can tolerate only slight deviation from initial straightness when the boom is exposed to solar and other radiation, i.e., thermal deflection must be held to a minimum. This behavior is desirable when the boom is used to orient or stabilize the satellite as by gravity.

Another requirement of deployable booms in some aerospace applications is repeated retraction and deployment. This means that the material must be able to withstand continual and repeated flexing and that the shape of the deployed boom may be completely recoverable.

The deployable boom, according to the invention, is an improvement over the varieties of presently used booms. For example, one type of deployable boom presently utilized comprises a single strip of a narrow flat tape which is initially wound around a drum or spool in a stressed condition, and when the boom is to be deployed the tape is unwound from the boom and allowed to assume its unconstrained condition which forms a tube with overlapping edges.

Another type of boom comprises a longitudinally flexible, hollow, thin-walled tubular structure comprising a pair of strips of thin material with planar oppositely extending margins and bowed center sections. The bowed center sections are compressed transversely toward one another to form a flat tape configuration of double material thickness and rolled onto a drum for storage purposes. Upon deployment, the walls are allowed to relax into their original bowed configuration, thus forming a hollow tubular boom with oppositely flat planar margins as aforesaid.

In the first type of boom which deploys into overlapping marginal edges, several problems exist. First, because of the open cross section and the overlapping edges, solar radiation produces severe nonuniform temperature distributions around the circumference of the cross sec-

tion which cause large thermal deflections. Secondly, to attempt to solve the deflection problem, the overlapping marginal edges complicate the alignment of the perforations. If the perforations are originally aligned when the boom is fabricated, as for example by boring through the overlapping marginal edges, the perforations may not realign upon deployment after a retraction and thus the function of the perforations would be nullified. Thirdly, the random contact which exists between the overlapping edges produces uncertainties in the behavior of the boom.

The othre described boom with its flat planar margins and curved or bowed center portion introduces severe stresses during packaging which may exceed the yield strength of the material where the flat margins are connected to the center portion. Consequently, while such a boom could be perforated to provide for thermal deflection control, such a boom would not meet the other requirement of ability to be retracted and deployed several times without damage because the yield strength of the material could easily be exceeded and thus prevent recovery of the initial unconstrained cross sectional shape.

Summary of the invention

The invention is comprised of a deployable boom having a new and improved construction that is lighter in weight, torsionally stiffer, has greater buckling strength and a more predictable behavior than the presently known booms. It is not subject to damage upon repeated deployment, and equally important, is compensated against deviations from straightness due to solar radiation.

Accordingly, it is an object of this invention to meet the above stated requirements of aerospace applications. This is accomplished by the provision of a boom structure comprising a closed hollow tube of a cross section having sufficiently large radii of curvature to permit complete flattening without exceeding the yield strength of the material, and provided with means for passively compensating against deflections due to solar radiation. In a preferred embodiment of this invention, the boom comprises a pair of mated strips of thin spring material of hat-like, cross-sectional configurations, i.e., curved in cross section and joined at mating margins. The curved central section between the margins and the radii of curvature between the margins and the central section are sufficiently large so that when the two strips are compressed toward one another to form a flat tape-like structure, the yield strength of the material is never exceeded. The means for passively controlling the thermal deflections of the boom comprises a plurality of perforations which permit solar radiation to pass through the strip of the boom facing the sun and to strike the opposite strip, thus alleviating temperature gradients in the material.

From the foregoing it can be appreciated that the disadvantages of the prior art booms are overcome by this invention and other and additional advantages of the invention will be apparent to those skilled in the art after having read and understood the following specification, taken together with the drawings which form a part thereof and wherein:

FIG. 1 is a cross sectional view of the boom constructed in accordance with the teachings of this invention and showing to advantage the large radii of curvature of the strips of spring material in addition to the distance *h* depending upon the desired bending stiffness and stress distribution (resulting from packaging) in the boom;

FIG. 2 illustrates schematically the means for retracting the deploying the boom;

FIG. 3 is a cross sectional view of the boom, taken along the line 3—3 of FIG. 2 looking in the direction of the arrows, and showing a boom construction which is typical for small values of h in FIG. 1;

FIG. 4 is a cross sectional view of the boom adjacent the drum, taken along line 4—4 of FIG. 2, and looking in the direction of the arrows;

FIG. 5 is an enlarged perspective view of the boom constructed in accordance with the teachings of this invention and illustrating the means of thermal deflection control; and

FIG. 6 is an enlarged cross sectional view illustrating the function of the perforations in connection with solar radiation.

With reference to FIGS. 1 and 2, it can be seen that the boom constructed in accordance with the teachings of this invention is indicated in its entirety as **10** and comprises a hollow tubular closed-section type elements formed of two thin flexible spring strips **12** and **14** of suitable material, such as beryllium copper, welded or otherwise permanently fixed to each other at their margins. Each spring strip is preformed with a curved or outwardly bowed center portion having a radius of curvature indicated by arrow R which joints the marginal edges **16** and **18** at a curved juncture of a radius of curvature indicated by the arrow R′. Actually the bowed center portion and marginal edges are a continuous curve of hat-shaped configuration formed as shown in FIG. 1 in their relaxed or deployed condition, and, when packaged, the walls are moved toward one another to form a flat tape of a thickness equal to the thickness of the two strips.

Turning now to FIGS. 2, 3, and 4, it can be seen that the boom **10** may be easily packaged on any suitable device as by initially compressing the strips, such as shown in FIG. 3, by rollers **20**, and then ultimately to a flat double thickness tape, as shown in FIG. 4, by roller **22**. Once flattened, the boom element may be wound around a reel **24**. The deployment of the boom consists in unwinding the flattened boom from the drum and allowing the strips to return to their unconstrained condition, as shown in FIG. 3.

As hereinabove mentioned, it is to be noted that the marginal edges are joined to the center section of each of the strips by a large radius of curvature as distinguished from sharp curves so that during repeated retraction and deployment the stress distribution in the boom is maintained at a level safely below the yield strength of the material.

It should be noted that, while FIG. 1 shows the junction radius R′ substantially equal to the radius R′ these radii as well as the distance h may be varied depending upon the desired bending stiffness and stress distribution (resulting from packaging) in the boom.

FIG. 3 shows one example of the variation, i.e., the distance h is small providing a shallow cross-section. In all cases the cross sectional shape will be of a continuous curve construction in contrast to sharp changes in the radius of curvature where the center portion joins the margins.

As hereinabove mentioned, inasmuch as these booms in space environment are subject to solar radiation which cause them to deflect from their desired straightness, means should be provided for compensating against such deviation. This is accomplished in this invention by minute perforations in the strips as illustrated at **26** in FIG. 5. If these perforations **26** are judiciously located, possibly in a random fashion, so that there is no preferred orientation of the boom with respect to the radiation source, the solar radiation will pass through the side of the boom facing the sun and strike the opposite side, such as shown schematically in FIG. 6. The effect of this is to reduce the temperature on the hot side, that is the side facing the sun, and raise the temperature on the cold side, that is the side opposite the sun, and thus alleviate the temperature gradient between the two sides. The size and number of perforations required depend upon the solar absorptivities of the inside and outside surfaces of the boom and the number of perforations that can be accommodated while still maintaining a required level of structural stiffness. Thus, with the outside surface having low solar absorptivity and the inside surface having high solar absorptivity, the number of perforations can be small to maintain the temperature relationship between the sides the same.

From the foregoing it can be appreciated that this invention provides a boom having the following advantages:

(a) A reduction of thermal gradients achieved more reliably;

(b) The torsional stiffness and buckling strength are significantly greater than the type where the marginal edges overlap and are slidable relative to one another;

(c) The bending stiffness may be altered by simply varying the depth of the cross-section; and

(d) Repeated retraction and deployment does not damage the boom.

This completes the description of the embodiment of the invention illustrated herein. However, many modifications and advantages thereof will be apparent to persons skilled in the art without departing from the spirit and scope of this invention. Accordingly, it is desired that this invention not be limited to the particular details of the embodiment disclosed herein, except as defined by the appended claims.

The embodiments of the invention in which an exclusive property or privilege I claim are defined as follows:

1. An extendable boom comprising:

mated strips of thin spring material disposed in face-to-face relation;

said strips each having margins curved in cross section and permanently joined to mating margins and each having a central section curved outwardly and oppositely to the curvature of its margins with radius of curvature such that when the boom is flattened and rolled into a coil the margins and curved sections will lie juxtaposed the center plane formed by the marginal edges without exceeding the yield strength of the material, and when relaxed the boom is a substantiallly straight rigid torsionally stiff, tubular member; and

a plurality of perforations in said strips to permit solar radiation to pass through the side of the boom facing the sun and strike the opposite side to alleviate temperature gradients causing thermal deflection of the boom.

2. An extensible boom of the type which is repeatedly collapsible from a substantially straight tubular member to a substantiallly flat double wall tape and capable of being coiled, the boom being formed from a pair of elongated walls joined at their longitudinal margins, the improvement comprising:

each wall having an outwardly curving central portion defined in cross section by a first radius of curvature, and reversely curved marginal portions, each defined in cross section by a second radius of curvature, said central portion and said marginal portions integrally forming a continuously curved wall; and

a plurality of perforations in said walls to permit solar radiation to pass through the side of the boom facing the sun and strike the opposite side to alleviate temperature gradients causing thermal deflections of the booom.

3. The extendable boom claimed in claim **2** wherein the distribution of said perforations over said boom such that solar absorptivity of the inner surface of the walls of said tubular member is increased along the longitudinal extent thereof.

4. The extendable boom claimed in claim 2 wherein the distribution of said perforations over said boom is such that solar absorptivity of the outer surface of the walls of said tubular member is decreased along the longitudinal extent thereof.

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