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Neil:

Rumber document attached as requested.

Email verbiage:

When a design is analyzed for structural integrity, a variety of methods can be used to approach the solution. Typically these days, an engineer that specializes in Finite Element Analysis is utilized to input a 3-D model of the structure in question into an FEA program which is then used to simulate various loading possibilities. The model can then show potential hot spots on the structural design that need additional material or design changes to eliminate the weaknesses. Many times, the model is then backed up with real world testing, where a prototype is built, and loaded as the model was loaded, with strain gauges in the various spots that were identified as hot spots, as well as any other areas of interest. To date, I've not been involved in any trailer testing, only tow tractor testing.

When I looked into the structural concerns associated with Rumber, I assumed everything supporting the planking already met the structural requirements, and then proceeded to analyze the board only, using the classical structural equations listed in my report (see attached - pages 9-12). I'm not trained to generate FEA models, nor do I have the equipment to perform such analysis. The equations that I selected to make the calculations included properties of the Rumber (resulting from Rumber's latest strength testing), the dimensions of the boards that were recommended, the dimensions of Rumber-recommended minimum crossmember spacings, and took into consideration my knowledge of how the AF loads and unloads materials of this nature and the design parameters as stated in the AFMAN 91-118. When I performed these sample calculations as seen on pages 9-12 that show a favorable Safety Factor, please keep in mind that the loads used in those calculations are distributed loads over the entire deck of the trailer, a case that is non-existent for the AF. Unfortunately, the methods used to load and unload weapons, and to secure weapons, do indeed introduce concentrated loads onto the platforms of trailers, and as a result, Rumber planking becomes a poor choice when trying to adhere to the rules found in AFMAN 91-118. When substituting the concentrated load values into the equations (using loads as small as the weight of a man), the Safety Factors took a very bad turn and fell below the requirement of 3 to 1, statically loaded. This is largely due to Rumber having a very low Tensile Strength according to the testing submitted to us.

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534
3893
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5/1/2006

Air Force Analysis of Rumber for Nuclear Certified Semi Trailer Applications

Introduction

This document is part of a response to requests made by Bill Reinhardt and other representatives from Rumber Corporation for an evaluation of their product for implementation onto the Air Force's Nuclear-Certified 40', 20 ton Semi-Trailers. Rumber has been presented to the AF as a potential solution to the problem of acquiring replacement hard wood trailer decking, as well as a cost and time savings associated with the frequent replacement of decking due to the subsequent deterioration of the hard wood product.

Summary

Rumber board as a replacement for Oak or Apitong board as decking on Nuclear Certified Semi-Trailers has been found inadequate. The strength of the material does not meet the required Safety Factors as described in AFMAN 91-118, Safety Design and Evaluation Criteria for Nuclear Weapon Systems. While the Rumber-recommended board thicknesses and crossmember spacings (1.75" thickness on 12" centers, and 2.375" thickness on 16" centers) have been shown to achieve a desirable Safety Factor when a 20 ton load is evenly distributed over the entire deck surface of a 40' x 8' trailer deck (yielding 0.868 lbs/in^2), the Safety Factors diminish to below acceptable levels once any significant Point Load or Concentrated Load is introduced. The methods by which nuclear certified loads are placed and secured onto the trailer deck surfaces make Point Loads unavoidable. To reinforce the Point Load problem encountered in the analysis, the following examples are given: A 200 lb human standing on an 8" x 1.75" cross section board of Rumber, suspended between two cross members mounted on 12" centers, will yield a Safety Factor of approximately 1.78 to 1. The same 200 lb human standing on an 8" x 2.375" cross section board of Rumber, suspended between two cross members mounted on 16" centers, will yield a Safety Factor of approximately 2.46 to 1. In these examples, the human load is considered to be a static load and falls short of the required Safety Factor of 3 to 1. Certainly, the Point Loads generated by placing and securing weapons onto the trailer deck surfaces will greatly exceed that of a 200 lb human. Additionally, most AF trailer assets have cross member spacings that exceed 12" and 16", further diminishing the Safety Factor for Rumber. In comparing the yield strength of Rumber to that of Oak or Apitong board, the Oak or Apitong board is found to be anywhere from 12 to 40 times as strong as Rumber.

Background

Bill Reinhardt and other representatives of Rumber have visited the Air Force Semi-Trailer IPT on many occasions and have shown interest in selling their product to the AF for implementation on both Nuclear Certified and non-Nuclear Certified trailer assets. This product might be a good candidate for implementation onto Nuclear Certified trailer assets were it not for the stringent strength requirements for Nuclear Certified assets.

5/1/2006

Evaluation Criteria

From the Design Criteria for Noncombat Delivery Vehicles and Support Equipment found in AFMAN 91-118, Trailer and Semi-Trailer designs must follow the guidance found in the General Design Criteria -- Section 3A. The underlined passages were used in determining the applicable Safety Factors for the Rumber boards, however, all of the below passages apply.

3.1. Design Philosophy. The design of noncombat delivery vehicles and equipment used to transport, store, support, load, and unload nuclear weapons must incorporate positive safety features. The vehicles and equipment must meet appropriate structural, environmental, stability, and mobility requirements. The STS document defines modes of transportation. The safety design factors must allow for uncertainties in predicting operational conditions; uncertainties or variations in material strength and manufacturing techniques; and uncertainties introduced by simplified design and test procedures. The criteria in this section supplement good industrial design practices, standards, and features and are not intended to prohibit the use of any commercial design of non-specialized equipment (such as trucks, truck tractors, semi trailers, trailers, and cranes) that meet the stated criteria.

3.2. Structural Load Definitions:
3.2.1. Rated Load. Base the rated load on the combination of load forces the basic equipment must support or resist in a static state. This static load consists of one or more weapons and the associated handling and restraint equipment and is the nuclear-certified load.
3.2.2. Dynamic Load. Determine the dynamic load by using the rated load and factor in the loads and acceleration in all directions encountered during ground and air transport and the shock load associated with mate, demate, load, and unload operations.
3.2.3. Design Load. Base the design load on the rated load multiplied by a factor of 3 or the dynamic load multiplied by a factor of 2, whichever is greater. This design load is considered the minimum load for attaining the design stress levels.

Evaluation Results

Rumber Board with a Uniformly Distributed Load

The following calculations are made based on Rumber's claims from their test data. Table 1 and Table 2 consider two thicknesses of Rumber Board using a Uniformly Distributed Load (UDL) derived in the Supporting Analysis. Based on the material property testing conducted by Stork Materials Laboratory, a range from 498 psi to 787 psi was achieved from the Ultimate Tensile Strength test. Taking a standard deviation of the ranges of values, the lowest value is 524 psi and the highest value is 856 psi. For Safety Factor consideration, the lowest tensile strength value is used for our calculations.

5/1/2006

Table 1 – 1.75" thick Rumber Board, with Uniformly Distributed Load

Cross-Member spacing (in)	Area (in^2)	Load (lbs)	$M_{(actual)}$ (in*lbs)	$M_{(Max\ Rumber)}$ (in*lbs)	$SF_{(UTS)}$	Acceptable
8	64	55.56	222.22	2139.67	9.63	Yes
10	80	69.44	347.22	2139.67	6.16	Yes
*** 12**	**96**	**83.33**	**500.00**	**2139.67**	**4.28**	**Yes**
14	112	97.22	680.56	2139.67	3.14	Yes
16	128	111.11	888.89	2139.67	2.41	No
18	144	125.00	1125.00	2139.67	1.90	No
20	160	138.89	1388.89	2139.67	1.54	No
22	176	152.78	1680.56	2139.67	1.27	No
24	192	166.67	2000.00	2139.67	1.07	No
*** See Supporting Analysis**						

Table 1 lists various cross member spacings with resulting data using a Rumber Board thickness of 1.75" and a UDL. Based on test data provided, the longest cross member spacing that can be used is 14". The Air Force's trailer assets utilize cross member spacings that range from 12" to 40".

Table 2 – 2.375" thick Rumber Board, with Uniformly Distributed Load

Cross-Member spacing (in)	Area (in^2)	Load (lbs)	$M_{(actual)}$ (in*lbs)	$M_{(Max\ Rumber)}$ (in*lbs)	$SF_{(UTS)}$	Acceptable
8	64	55.56	222.22	3940.92	17.73	Yes
10	80	69.44	347.22	3940.92	11.35	Yes
12	96	83.33	500.00	3940.92	7.88	Yes
14	112	97.22	680.56	3940.92	5.79	Yes
*** 16**	**128**	**111.11**	**888.89**	**3940.92**	**4.43**	**Yes**
18	144	125.00	1125.00	3940.92	3.50	Yes
20	160	138.89	1388.89	3940.92	2.84	No
22	176	152.78	1680.56	3940.92	2.35	No
24	192	166.67	2000.00	3940.92	1.97	No
*** See Supporting Analysis**						

Table 2 lists various cross member spacings with resulting data using a Rumber Board thickness of 2.375" and a UDL. Based on test data provided, the longest cross member spacing that can be used is 18". The Air Force's trailer assets utilize cross member spacings that range from 12" to 40".

Rumber Board with a Point Load

Since it is not reasonable to assume that the trailer deck will only see a Uniformly Distributed Load of 20 tons over a 40' x 8' deck surface (0.868 lbs / in^2), the calculations were then shifted to consider

Point Loads. Table 3 and Table 4 consider a 10,000 lb vehicle loaded onto the trailer deck. Assuming four points of contact, the Point Load is considered to be 2,500 lbs on one board. It is reasonable to assume that a vehicle of this size that will generate a point load of this magnitude or greater could be used in transporting munitions and in loading the deck of a trailer from a loading dock.

Table 3 – 1.75" thick Rumber Board, with a 2500 lb Point Load

Cross-Member spacing (in)	Area (in^2)	Load (lbs)	$M_{(actual)}$ (in*lbs)	$M_{(Max\ Rumber)}$ (in*lbs)	$SF_{(UTS)}$	Acceptable
8	64	2,500.00	10,000.00	2,139.67	0.21	no
10	80	2,500.00	12,500.00	2,139.67	0.17	no
12	96	2,500.00	15,000.00	2,139.67	0.14	no
14	112	2,500.00	17,500.00	2,139.67	0.12	no
16	128	2,500.00	20,000.00	2,139.67	0.11	no
18	144	2,500.00	22,500.00	2,139.67	0.10	no
20	160	2,500.00	25,000.00	2,139.67	0.09	no
22	176	2,500.00	27,500.00	2,139.67	0.08	no
24	192	2,500.00	30,000.00	2,139.67	0.07	no

Table 3 shows the highest Safety Factor achieved is 0.21, which is far below the standard Safety Factor threshold of 3.00 for static loads.

Table 4 – 2.375" thick Rumber Board, with a Point Load

Cross-Member spacing (in)	Area (in^2)	Load (lbs)	$M_{(actual)}$ (in*lbs)	$M_{(Max\ Rumber)}$ (in*lbs)	$SF_{(UTS)}$	Acceptable
8	64	2,500.00	10,000.00	3,940.92	0.39	no
10	80	2,500.00	12,500.00	3,940.92	0.32	no
12	96	2,500.00	15,000.00	3,940.92	0.26	no
14	112	2,500.00	17,500.00	3,940.92	0.23	no
16	128	2,500.00	20,000.00	3,940.92	0.20	no
18	144	2,500.00	22,500.00	3,940.92	0.18	no
20	160	2,500.00	25,000.00	3,940.92	0.16	no
22	176	2,500.00	27,500.00	3,940.92	0.14	no
24	192	2,500.00	30,000.00	3,940.92	0.13	no

Table 4 shows that increasing the thickness of the Rumber board to 2.375" did raise the Safety Factor for the Rumber board, but not to the Safety Factor threshold of 3.00.

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Rumber Board and the T-Rail Support System

During the course of discussions concerning strength of materials issues with the Rumber material, Rumber representatives have proposed various design alternatives to enhance the overall strength of the product. One of the alternatives proposed, the T-Rail system, utilizes two pieces of angle iron to encase a single Rumber board, thus creating a composite beam for consideration.

A sample that was brought in as an example for consideration was an 8" x 1.5" board of Rumber encased by 1.5" x 1.5" x 0.25" steel angle iron. An analysis of a similar sample, where the 1.5" thick board of Rumber is replaced with a 1.75" thick board of Rumber and suspended between two 12" cross member centers, yields the following results:

Using AISI 1012 steel for the 1.5" angle iron (45 ksi), calculations (not shown) yield a maximum allowable bending moment for the two angles of:

$M_{(max\ 1.5\ angles)} = \underline{12{,}057.30\ in*lbs}$

Using the maximum allowable bending moment for Rumber derived in the Supporting Analysis:

$M_{(max\ 1.75\ Rumber)} = \underline{2{,}139.67\ in*lbs}$

Using the actual bending moment for the Point Load of <u>2500 lbs</u> on an 8" x 1.75" board on 12" cross member centers:

$M_{(actual\ w/2500\ lb\ point\ load)} = \underline{15{,}000\ in*lbs}$

The resulting Safety Factor is as follows:

$$\begin{aligned}\text{Safety Factor} &= (M_{(max\ 1.5\ angles)} + M_{(max\ 1.75\ Rumber)}) / M_{(actual\ w/2500\ lb\ point\ load)} \\ &= (12{,}057.30\ in*lbs + 2{,}139.67\ in*lbs) / 15{,}000\ in*lbs \\ &= \underline{\mathbf{0.95}} < 3.00\end{aligned}$$

Only when the point load is reduced to <u>788 lbs</u> do we begin to see a favorable Safety Factor:

$$\begin{aligned}\text{Safety Factor} &= (M_{(max\ 1.5\ angles)} + M_{(max\ 1.75\ Rumber)}) / M_{(actual\ w/788\ lb\ point\ load)} \\ &= (12{,}057.30\ in*lbs + 2{,}139.67\ in*lbs) / 4{,}728\ in*lbs \\ &= \underline{\mathbf{3.00}}\end{aligned}$$

It is not reasonable to restrict the 20 ton trailer deck to a 788 lb point load, and most AF trailer assets have cross member centers greater than 12". Cross member spacings greater than 12" will further diminish the Safety Factor.

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Similarly, a sample of 8" x 2.375" board of Rumber encased by 2.25" x 2.25" x 0.25" steel angle iron and suspended between two 16" cross members is considered. The analysis yields the following results:

Using AISI 1012 steel for the 2.25" angle iron (45 ksi), calculations (not shown) yield a maximum allowable bending moment for the two angles of:

$M_{(max\ 2.25\ angles)}$ = <u>28,462.02 in*lbs</u>

Using the maximum allowable bending moment for Rumber derived in the Supporting Analysis:

$M_{(max\ 2.375\ Rumber)}$ = <u>3,940.92 in*lbs</u>

Using the actual bending moment for the Point Load of 2500 lbs on an 8" x 2.375" board on 16" cross member centers:

$M_{(actual\ w/2500\ lb\ point\ load)}$ = <u>20,000 in*lbs</u>

The resulting Safety Factor is as follows:

Safety Factor = ($M_{(max\ 2.25\ angles)}$ + $M_{(max\ 2.375\ Rumber)}$) / $M_{(actual\ w/2500\ lb\ point\ load)}$
= (28,462.02 in*lbs + 3,940.92 in*lbs) / 20,000 in*lbs
= **1.62** < 3.00

Only when the point load is reduced to <u>1350 lbs</u> do we begin to see a favorable Safety Factor:

Safety Factor = ($M_{(max\ 2.25\ angles)}$ + $M_{(max\ 2.375\ Rumber)}$) / $M_{(actual\ w/1350\ lb\ point\ load)}$
= (28,462.02 in*lbs + 3,940.92 in*lbs) / 10,800 in*lbs
= **3.00**

It is not reasonable to restrict the 20 ton trailer deck to a 1350 lb point load, and most AF trailer assets have cross member centers greater than 16". Cross member spacings greater than 16" will further diminish the Safety Factor.

Table 5 shows various mechanical properties of selected woods found on the internet at the following website: http://www.floorings.com/decking/ipe/ipeproperties.shtml. This website is one of many that contains mechanical properties for Oak and Apitong.

Table 5 – Mechanical Properties of Selected Woods

	White Oak	Red Oak	Apitong
Density	40-50	40-50	40-50
Bending strength (psi)	14,500 – 17,000	12,000 – 14,500	14,500 – 19,500
Stiffness (psi)	1,400 – 1,800	1,800 – 2,200	1,800 – 2,600
Crushing strength (psi)	7,000 – 8,000	6,000 – 7,000	8,000 – 10-000

5/1/2006

Results and Recommended Actions

Rumber board as a replacement for Oak or Apitong board as decking on Nuclear Certified Semi-Trailers has been found inadequate. The strength of the material does not meet the required Safety Factors as described in AFMAN 91-118, Safety Design and Evaluation Criteria for Nuclear Weapon Systems. While the Rumber-recommended board thicknesses and cross member spacings (1.75" thickness on 12" centers, and 2.375" thickness on 16" centers) have been shown to achieve a desirable Safety Factor when a 20 ton load is evenly distributed over the entire deck surface of a 40' x 8' trailer deck (yielding 0.868 lbs/in^2), the Safety Factors diminish to below acceptable once any significant point load or concentrated load is introduced. The methods by which nuclear certified loads are placed and secured onto the trailer deck surfaces make point loads unavoidable.

The Rumber-recommended T-Rail Support System seems to be the most promising design alternative for supporting a Nuclear Certified load, as it begins to approximate the strength characteristics of Oak, but the current proposed design still lacks the structural properties needed to achieve the statically-loaded Safety Factor of 3 to 1. While it is conceivable that some combination of angle iron shapes, dimensions, and higher-strength steel could surpass the required Safety Factor threshold, it is unclear what that combination would produce in terms of additional weight on the trailer, and whether or not the Rumber-recommended T-Rail attaching methods (spot welding) would be something that the Nuclear Safety Center at Kirtland AFB would embrace. Another concern that would likely be encountered and warrant exploration if submitted for certification/approval would be the question of whether the plastic/rubber product generated significant levels of static electricity, and if so, how those levels would affect Nuclear Weapons.

At this point in the discussion, the question of whether the Rumber product can be used as a replacement for wooden decking on Nuclear Certified trailer assets is answered by the Air Force Technical Representatives as no; the Rumber board does not meet the minimum strength requirements to warrant sending a request for Nuclear Certification to the AF Safety Center.

<u>If Rumber would like to pursue this application further, it is recommended that they contract with an independent engineering firm for the following:</u>

1. Study the AF's use of Nuclear Certified Semi-Trailers at various Munitions and Nuclear Weapons bases to determine what munitions and weapons are loaded onto the trailers, as well as the methods used to load and secure the weapons

2. Determine and test the appropriate cross-sectional shapes of the Rumber material to attain consistent Strength of Materials values of Rumber for use in an analysis of the design structures, and submit to the Air Force, an original, signed document reporting the findings by the testing and certifying agency

3. Create an alternative design structure for the board that takes into consideration the Point Loads generated by the heaviest applications, and is designed with the Strength of Materials Safety Factors in mind

4. Create an alternative design structure for the board that uses fastening techniques that are equivalent to OEM procedures; fastening techniques that do not require welding on the trailer chassis

5. Define minimum trailer structural requirements for applications of the board on Nuclear Certified trailer assets

6. Provide data to the AF that demonstrates both analytically and through testing that the appropriate Design Safety Factors are met for a proposed board design by submitting an original, signed document reporting the findings by the design, testing and certifying agency

Reviewers

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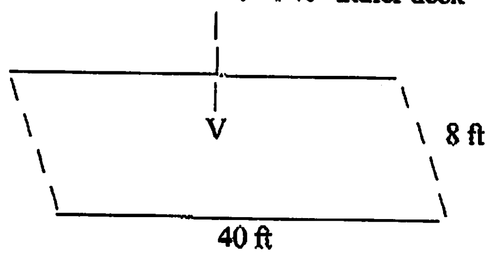
Supporting Analysis
Rumber-Recommended, Minimum Crossmember Spacing and Board Thickness

Assumption 1: *Trailer deck surface is totally covered in Rumber decking. Rumber decking is mounted on 12" cross-members, the minimum recommended spacing for 1.75" board thickness, and supported by the trailer frame rails below the trailer deck surface. This trailer load is 20 tons distributed over the trailer deck.*

20 tons (40 K lbs)
distributed over the 8' x 40' trailer deck



Area = **320 ft²**   Distributed Load = 20 tons = **40,000 lbs**

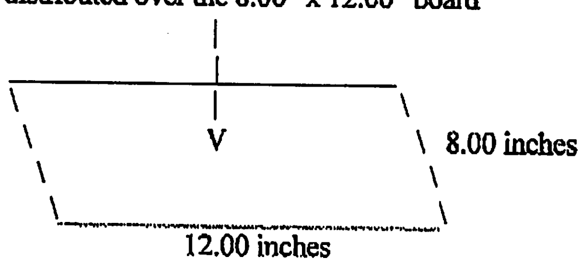
Load / Area = 40,000 lbs / 320 ft² = 125 lbs / ft² = **0.868 lbs / in²**

Redistribute the Load / Area over a single board of Rumber on 12" cross-member spacing.

Area = 12.00" x 8.00" = **96 in²**

Load = Area • Load / Area = 96.00 in² x 0.868 lbs / in² = **83.33 lbs**

83.33 lbs
distributed over the 8.00" x 12.00" board



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Treat the distributed load of 83.33 lbs as a concentrated load on the center of the board to compute the bending moment.

```
        83.33 lbs
            |
            |
____________V____________
^                       ^
|<--------12.00"------->|
```

$M_{(actual)} = r \bullet L$
$= 6.00" \times 83.33$ lbs
$=$ **<u>499.98 in*lbs</u>**

Compute the Safety Factor for Rumber based on the Ultimate Tensile Strength of Rumber. For the purposes of this analysis, we'll look at a sample of Rumber with cross-section measuring 8.00" x 1.75".

$M_{(max\ Rumber)} = \sigma_{Rumber} \bullet I / c$

Where σ_{Rumber} = Ultimate Tensile Strength of Rumber = **<u>524 psi</u>**

and $I = (1/12) \bullet b \bullet h^3$
$= (1/12) \times 8.00" \times (1.75")^3$
$=$ **<u>3.57 in^4</u>**

and c = h / 2 = 1.75" / 2 = 0.875"

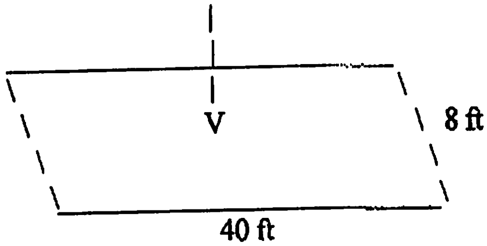
$M_{(max\ 1.75\ Rumber)}$ = (524 psi x 3.57 in^4) / 0.875 in = **<u>2,139.67 in*lbs</u>**

Safety $Factor_{(UTS)} = M_{(max\ 1.75\ Rumber)} / M_{(actual)}$ = 2,139.67 in*lbs / 499.98 in*lbs = **<u>4.28</u> > 3.00**

5/1/2006

<u>Assumption 2:</u> *Trailer deck surface is totally covered in Rumber decking. Rumber decking is mounted on 16" cross-members, the minimum recommended spacing for 2.375" board thickness, and supported by the trailer frame rails below the trailer deck surface. This trailer load is 20 tons distributed over the trailer deck.*

20 tons (40 K lbs)
distributed over the 8' x 40' trailer deck



Area = **<u>320 ft²</u>** Distributed Load = 20 tons = **<u>40,000 lbs</u>**

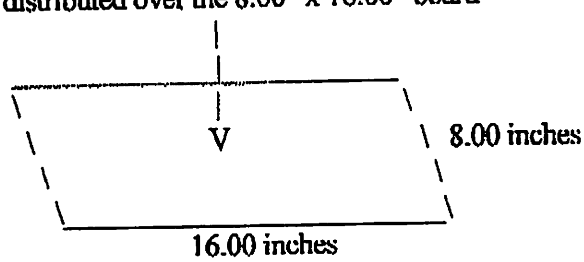
Load / Area = 40,000 lbs / 320 ft² = 125 lbs / ft² = **<u>0.868 lbs / in²</u>**

<u>Redistribute the Load / Area over a single board of Rumber on 16" cross-member spacing.</u>

Area = 16.00" x 8.00" = **<u>128 in²</u>**

Load = Area • Load / Area = 128.00 in² x 0.868 lbs / in² = **<u>111.10 lbs</u>**

111.10 lbs
distributed over the 8.00" x 16.00" board



5/1/2006

Treat the distributed load of 111.10 lbs as a concentrated load on the center of the board to compute the bending moment.

```
          111.10 lbs
              |
              |
_____________V______  ______
^                          ^
|<---------16.00"--------->|
```

$M_{(actual)} = r \cdot L$
$= 8.00" \times 111.10 \text{ lbs}$
$= \underline{\mathbf{888.80\ in*lbs}}$

Compute the Safety Factor for Rumber based on the Ultimate Tensile Strength of Rumber. For the purposes of this analysis, we'll look at a sample of Rumber with cross-section measuring 8.00" x 2.375".

$M_{(max\ Rumber)} = \sigma_{Rumber} \cdot I / c$

Where σ_{Rumber} = Ultimate Tensile Strength of Rumber = **524 psi**

and $I = (1/12) \cdot b \cdot h^3$
$= (1/12) \times 8.00" \times (2.375")^3$
$= \underline{\mathbf{8.93\ in^{\wedge}4}}$

and $c = h / 2 = 2.375" / 2 = 1.1875"$

$M_{(max\ 2.375\ Rumber)} = (524 \text{ psi} \times 8.93 \text{ in}^{\wedge}4) / 1.1875 \text{ in} = \underline{\mathbf{3{,}940.92\ in*lbs}}$

$\text{Safety Factor}_{(UTS)} = M_{(max\ 2.375\ Rumber)} / M_{(actual)} = 3{,}940.92 \text{ in*lbs} / 888.80 \text{ in*lbs} = \underline{\mathbf{4.43}} > \mathbf{3.00}$