Product Assessment Report
October 2002

An Analysis of the Restraint Sufficiency of the Happijac Tie-Down System for Truck-Mounted Slide-In Campers

Spencer P. Magleby, PhD
Associate Professor of Mechanical Engineering
Brigham Young University
Provo, UT 84604

Summary

Truck-mounted slide-in campers experience a variety of loads and forces that can cause them to move relative to the truck. The Happijac tie-down system reports to be designed to resist these relative motions. There are six movements that must be restrained and two directions for each movement. For the tie-down system to be effective it must have at least one significant restraining method for each translation and two for each rotation. This report analyzes the Happijac system's capabilities to provide these required restraining forces.

Introduction

As truck-mounted, slide-in campers are carried on both rough and smooth road surfaces they are subjected to a variety of loads and forces that can cause them to move relative to the truck frame and bed. These loads can come from winds, angles of the roadbed, accelerations due to turning, starting and stopping, uneven road surfaces, and combinations of these situations. In order to avoid damage to the camper and truck, and maintain stability of the truck/camper system, it is desirable to minimize the relative motion of the camper and the truck.

A previous report, titled ***An Analysis of Restraining Requirements for Truck-Mounted Slide-In Campers,*** has outlined the types of movements that can occur and the requirements for resisting those movements. As a result of this previous study it is possible to analyze any tie-down system in terms of restraint sufficiency.

The objective of this report is to analyze the Happijac system in the context of this previous study. The report will first review the possible camper movements and required resisting forces. The restraint approach of the Happijac system is then reviewed, followed by an analysis of the restraints in terms of the required resisting loads. The conclusion summarizes the findings and the opinions of the author.

Camper Movements and Resisting Forces

A previous report has developed the possible movements of the camper relative to the truck. These are shown in Figure 1 below, and briefly reviewed. Throughout the report rotations will be shown in yellow, translations in blue, and resisting forces from the tie-down system in red.

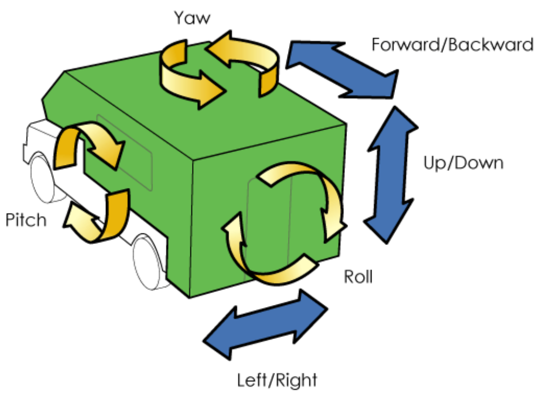

Figure 1: Six possible movements of the camper relative to the truck.

Three of the movements are translations and must be resisted by at least one force component in a direction that opposes the movement. As shown in Figure 2 there are three translations and two directions per translation meaning that there must be at least 6 restraining forces.

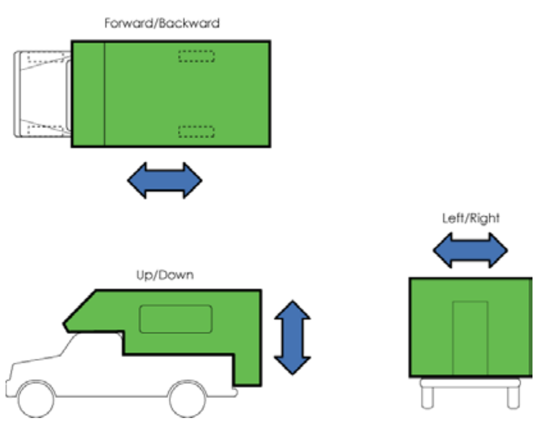

Figure 2: Three possible translations of the camper relative to the truck.

Three of the movements are rotations and must be resisted by at least one force couple consisting of two opposing and parallel forces. As shown in Figure 3 there are three rotations and two directions per rotation meaning that there must be at least 6 restraining force couples.

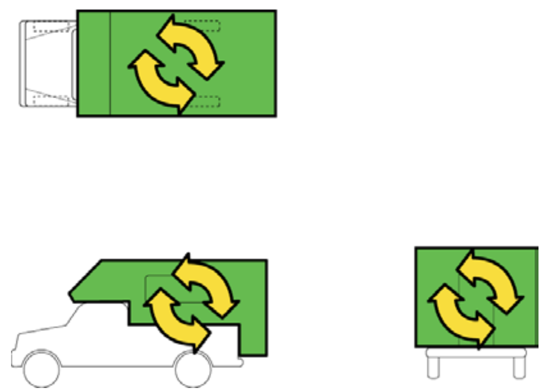

Figure 3: Three possible rotations of the camper relative to the truck: yaw, pitch and roll.

The amount of force in the tie-down system required to resist these movements depends on a number of factors that vary from camper to camper and with the way that the tie-downs are configured. The key issue is the angle of the tie-down tension members relative to the camper. Specific discussion of this issue is contained in the general report.

Happijac System Approach

The Happijac system uses four primary anchor points on the truck that are connected to the camper with special turnbuckles. In addition to the anchor points there are guide locks in the bottom of the bed and in the front panel of the bed. The guide locks serve a valuable function of aligning the camper, but for the purpose of this analysis they will be ignored.

Figure 4 illustrates the anchor components and the turnbuckles that connect the camper anchors to the Happijac anchor system. Additional information on the components and their locations on the truck can be found at www.happijac.com.

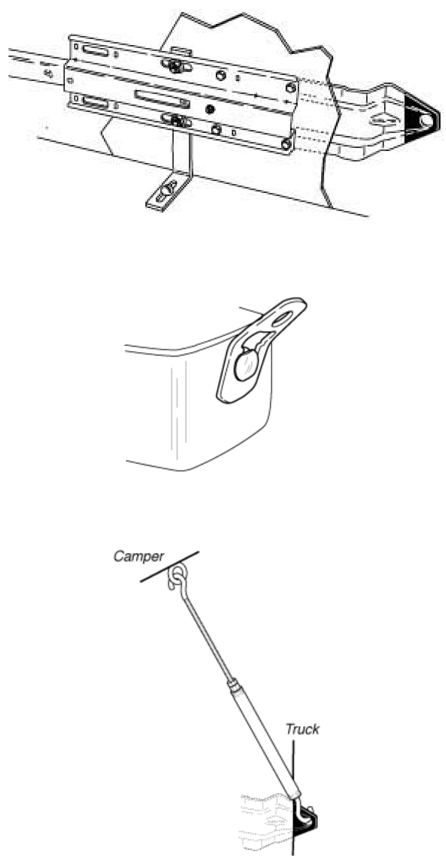

Figure 4: Happijac system components. The top diagram shows the front anchor location that protrudes just forward of the truck bed. The middle diagram is the anchor point on the end of the truck bumper, and the bottom diagram shows a turnbuckle.

Critical to the efficient operation of the tie-down system are the angles of the turnbuckles relative to a vertical and horizontal plane, and the stiffness of the tie-down locations on the truck. The Happijac system cleverly addresses both of these issues by providing front tie-down locations that are as far forward on the truck bed as possible, and rigidly attached to the bed box and frame.

The location of the anchor points at the front of the bed allows the turnbuckles to be at efficient angles for providing restraining force components – especially in the critical direction that holds the camper forward in the truck bed. Locating the anchors as far inboard as possible and relatively high on the truck allows the tie-downs to efficiently provide the force components that act in the left-right directions.

With the front tie-downs attached to the truck frame and front panel of the truck bed, there is very little relative movement of the anchor points. As discussed later, this rigidity allows for controlled compliance of the system through the use of spring-loaded turnbuckles.

The rear anchor mount points are at the ends of the bumpers. This location allows for efficient angles of the tie-downs for producing force components that hold the camper down in the back and resist left-right movement. Providing mounts as far back in the truck as possible (as this system does) also minimizes the required forces in the rear turnbuckles for resisting rotations as the forces in the force couple systems are further apart (see the previous report for details).

Translational Restraint Analysis

Figures 5 through 11 below illustrate the restraints that are used to resist the six translations outlined above. Note that in many cases the restraints are redundant, that is, there are more restraints than are required.

A backward translation of the camper is shown in Figure 5 below. This translation occurs during acceleration or climbing a hill. It is resisted by the horizontal force vector of the front tie-downs.

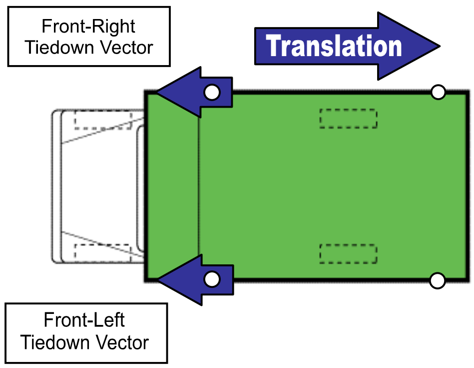

Figure 5: Top-view showing restraint vectors to "backward" translations.

For the forward translation illustrated in Figure 6, bearing against the front of the truck bed itself provides most of the restraint with additional forces being provided by horizontal vectors of the rear tie downs. This translation occurs during braking and going down a steep hill. The system of front and rear tie-downs with a spring in the front tie-down assures that the camper is forward and bearing against the truck bed before this translation occurs.

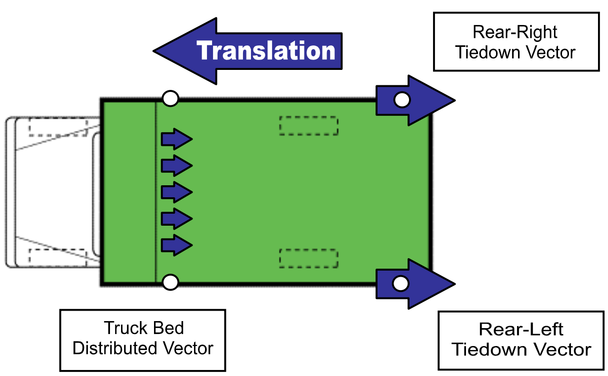

Figure 6: Top-view showing restraint vectors to "forward" translations.

As seen in Figure 7, the truck bed itself resists the movement of the camper down (caused largely from its own weight). In fact, the tie-downs pull the camper into the bed in order to balance the forces they create to hold the camper in the forward/backward and left/right directions.

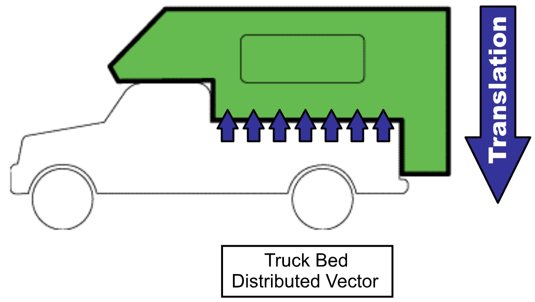

Figure 7: Side-view showing restraint vectors to "down" translations.

Surprisingly, there are many cases when the camper will experience forces wanting to translate it up away from the truck bed. As shown in Figure 8, this movement is resisted by the vertical force vectors of the four tie-downs. Given the configuration of the system, most of the resisting force will be provided by the front tie-downs.

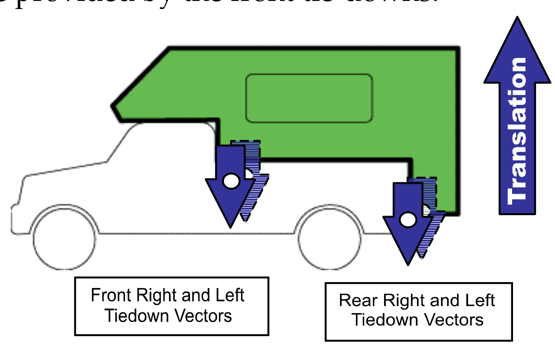

Figure 8: Side-view showing restraint vectors to "up" translations.

Figures 9 and 10 below show the possible translation of the camper to the right and left. These translations are most common during turning of the truck or when the truck goes over an uneven road surface and rocks from side to side. Both of these translations are resisted by the horizontal force components of the front and rear tie-downs in the same side as the direction of translation.

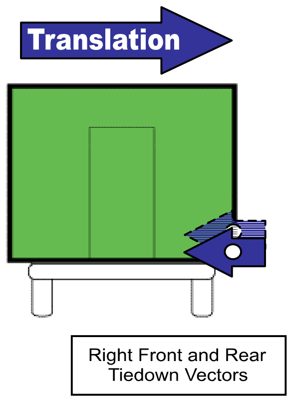

Figure 9: Rear-view showing restraint vectors to "right" translations.

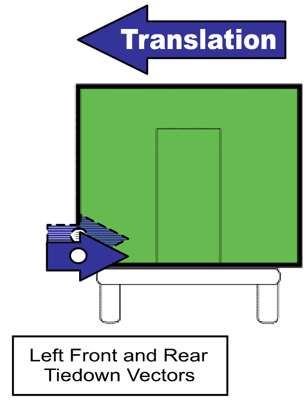

Figure 10: Rear-view showing restraint vectors to "left" translations.

Figure 11 below summarizes the Happijac products that prevent relative translation of the camper. Note that the translations are grouped into the three directions presented at the beginning of the paper. Since the turnbuckle systems are installed at efficient angles, it is possible for them to provide forces in three different directions allowing them to resist all three directions of translation.

Happijac Products that Prevent Translations

	Translation		
Product	Forward/Backward	Up/Down	Left/Right
Front Tiedown	✔	✔	✔
Anchor Bolt and Rear Tiedown Coupler	✔	✔	✔
Turnbuckles	✔	✔	✔

Figure 11: Summary of Happijac products that restrain translations.

Rotational Restraint Analysis

Figures 12 through 17 below illustrate the restraints that are employed to resist the six possible rotations outlined above. Unlike the translations illustrated above, resisting rotations requires *two* forces arranged as a couple (see the previous report).

Figure 12 shows the primary force vectors that can act as a couple to resist a clockwise yaw rotation. In this case the rotation is resisted by a force couple consisting of the fore-aft force components from the front-right and rear-left tie-down forces. As required, these forces act in opposite, but parallel directions. The Happijac system has redundant restraints for this rotation as the front-right force and the bearing of the camper on the left side of the front of the truck bed also form a resisting force couple.

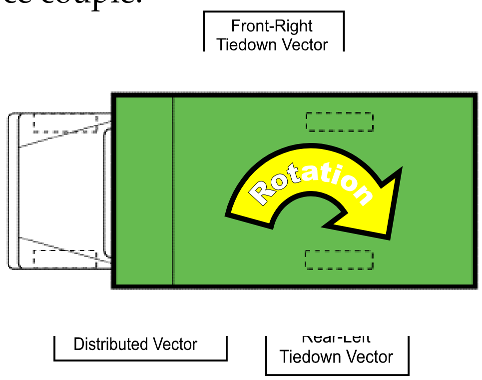

Figure 12: Top-view showing restraint vectors to clockwise yaw rotations.

Figure 13 also illustrates a yaw movement, but in the counter-clockwise direction. This rotation is resisted in the same way as the clockwise rotation discussed above, but with force components on the opposite corners of the camper.

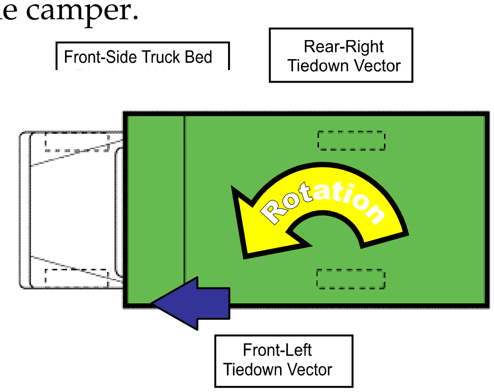

Figure 13: Top-view showing restraint vectors to counter-clockwise yaw rotations.

Figures 14 and 15 illustrate the restraints that are used to resist pitch rotations. In both pitch up and pitch down situations the rotation is resisted by a combination of the bed and the front or rear tie-downs (depending on the direction). The restraints are redundant as either the right or left side could provide the needed restraints.

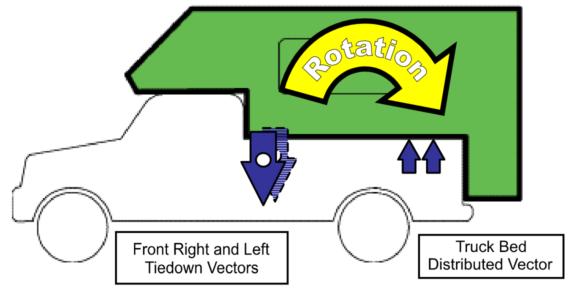

Figure 14: Top-view showing restraint vectors to pitch up rotations.

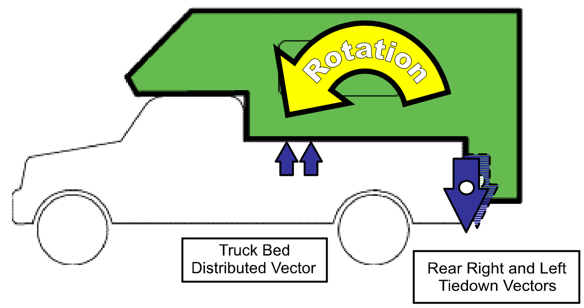

Figure 15: Top-view showing restraint vectors to pitch down rotations.

In Figures 16 and 17 restraints for roll are illustrated. For both directions a force couple is formed from the vertical component of the tie-down and bearing on the truck bed.

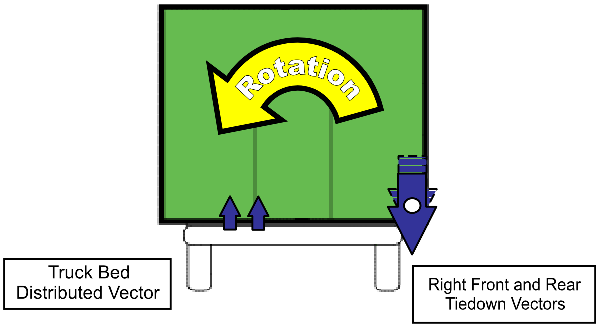

Figure 16: Top-view showing restraint vectors to left roll rotations.

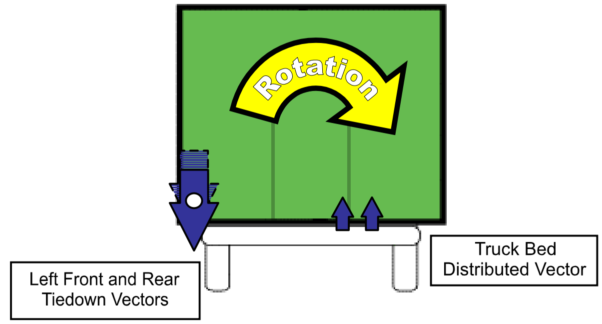

Figure 17: Top-view showing restraint vectors to right roll rotations.

Figure 18 below summarizes the Happijac products that prevent relative rotation of the camper. Note that the rotations are grouped into the three directions presented at the beginning of the paper. As with the translations since the turnbuckle systems are installed at angles, it is possible for them to provide forces in three different directions allowing each of them to be a part of the force couple system required to resist rotations.

Happijac Products that Prevent Rotations

	Rotation		
Product	Yaw	Pitch	Roll
Front Tiedown	✔	✔	✔
Anchor Bolt and Rear Tiedown Coupler	✔	✔	✔
Turnbuckles	✔	✔	✔

Figure 18: Summary of Happijac products that restrain rotations.

Adequacy of Restraining Forces

From the discussion, diagrams and tables above it is clear that the Happijac system provides sufficient restraint systems to address all possible movements of the camper. The analysis of the system should now turn to the adequacy of the individual system components to provide the necessary magnitude of restraint forces.

As discussed in the previous reports, it is difficult to determine the magnitude of loads that the camper is going to exert on the truck due to the large variety of possible use conditions. The best approach to determining sufficiency is likely by looking at the *efficiency* of the system in creating the force components, and the performance record of the system in the field.

In terms of efficiency the Happijac system would be rated very high due to the locations of the tie-down anchors and the resulting angles of the tie-downs themselves. These angles allow the tie-downs to generate sufficient forces in the horizontal plane without requiring extremely high loads in the tie-downs. The system design also results in very stiff mount points on the truck (stiff meaning that they are not easily deflected), especially in the front where they are most critical. The stiffness of the mount points, combined with high stiffness of the turnbuckles results in very little relative movement of the truck and camper.

For performance data the reader should refer to information from the manufacturer.

Accommodating Truck Bed Deformation

In addition to the analysis of restraints it is interesting to examine the ability of the tie-down system to accommodate twisting deformation of the truck bed. The Happijac system ties into the front panel of the truck bed and through the frame in this area. This is an optimal location for locking the camper and truck bed together due to the front panel acting as a large shear panel to resist twisting deformation.

Comparisons to Other Systems

The most commonly discussed competitors to the Happijac system use tie-down locations that are created by extending cantilevered bars attached to the vehicle frame under the truck bed. While these systems have a number of strengths, the design concept generally does not allow for the types of efficiency and stiffness that the Happijac system enjoys.

Efficiency issues arise from the near vertical orientation of the tie-downs. With this orientation it is not possible to generate large force components in the horizontal plane (required to prevent yaw and fore-aft/left-right translations) unless there are extremely high forces in the tie-down chain/cable. The stiffness of such systems generally suffers due to the large length of the cantilevered bars. These essentially act like large springs. To mitigate this low stiffness the tie-downs must be pre-loaded to very high forces.

Conclusions

It is possible to systematically analyze the restraint needs for a truck-mounted, slide-in camper. From the above analyses it can be seen that the Happijac system, properly installed, provides all of the necessary restraining forces to minimize the relative motion of the camper and the truck bed. For some movements there are redundant forces available.

In addition to having sufficient and appropriate forces, the locations of the Happijac tie-down anchors on the truck, properly installed, can create efficient angles for producing the desired force components. This is especially true for the front anchor points as the design places the anchor points as far forward in the bed as possible. This efficiency allows for the lowest possible tension forces in the tie-downs themselves, while still maintaining sufficient force components to resist movements.

Of course the tie-down system is also dependent on having appropriate anchor locations on the camper. Proper matching of the tie-down system and the camper anchor points is essential to proper performance.

Although extreme situations can result in forces that would cause any tie-down system to perform poorly, the Happijac system design is efficient and addresses restraint of the camper in every possible direction.

Acknowledgements

Preparation of this report was funded by Recreation Systems Inc. The opinions expressed herein represent those of the author and do not constitute endorsement by Brigham Young University of any idea or product.

About the Author

Dr. Spencer Magleby is an Associate Professor of Mechanical Engineering at Brigham Young University and a consultant in product design. He received his PhD from the University of Wisconsin with a specialization in Mechanical and Structural Design. He has experience in the aerospace industry with a focus on design of aircraft structure, and worked on the F-16, F-22 and A-12. At the University he teaches undergraduate and graduate courses on design of mechanical products and development of consumer products. Dr. Magleby's research includes development of new design methods, and creating specialized mechanisms and associated products. He has published in a wide range of venues.