Report No. UM-HSRI-78-13

AN EVALUATION OF THE SAFETY AND HANDLING PROPERTIES OF THE CAB-UNDER TRUCK-TRACTOR VEHICLE

For:

Safety and Health Department
The International Brotherhood of Teamsters,
Chauffers, Warehousemen, and Helpers
Washington, D.C.

By:

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The University of Michigan
Ann Arbor, Michigan

June 1978

Technical Report Documentation Page

1. Report No. UM-HSRI-78-13	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle An Evaluation of the Safety and Handling Properties of the Cab-Under Truck-Tractor Vehicle		5. Report Date June 1978
		6. Performing Organization Code
7. Author(s) H. M. Bunch, J. W. Melvin, P. L. Olson, R. G. Snyder, C. B. Winkler		8. Performing Organization Report No. UM-HSRI-78-13
9. Performing Organization Name and Address Highway Safety Research Institute The University of Michigan Ann Arbor, Michigan 48109		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
		13. Type of Report and Period Covered Task Report
12. Sponsoring Agency Name and Address International Brotherhood of Teamsters 25 Louisiana Avenue, N.W. Washington, D.C. 20001		
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

A multidisciplinary team of HSRI researchers examined several safety aspects of a cab-under heavy duty truck-tractor manufactured by the Strick Corporation. The study team found that the cab-under vehicle examined has major safety deficiencies in the areas of (1) cab intrusion, (2) down-the-road visibility, and (3) vehicle roll and yaw sensing by the driver. Positive features are (1) rollover reduction potential, (2) safer ingress and egress, and (3) lower center of gravity. Because of time and funding limitations, the evaluation by the study team was judgmental and qualitative, rather than experimental and definitive.

17. Key Words		18. Distribution Statement	
19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages 19	22. Price

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I. INTRODUCTION

A. OBJECTIVE OF THE STUDY

This study was made at the request of the International Brotherhood of Teamsters, Chauffeurs, Warehousemen and Helpers of America (Teamsters).

Strick Corporation, Fort Washington, Pennsylvania has been developing a heavy-duty-cargo truck-tractor that is approximately four feet high. As a result of this low-slung configuration, the vehicle is capable of being placed completely under the cargo body. This truck configuration has been commonly called a "cab-under." The developmental effort has proceeded to the stage that prototype vehicles have been built, and some road evaluations have been performed. Additionally, discussions have been conducted with selected carriers in an effort to place prototype vehicles in actual field service on an experimental basis. Figure 1 is a side-view schematic of one of the possible trailer combinations that might be available in the cab-under configuration.

The purpose of this study was to evaluate the safety qualities of the "cab-under" heavy-duty truck-tractor-trailer system, and to estimate the changes that might occur in injury exposure to the driver and to the general driving public as a result of its introduction into the vehicle population.

B. METHOD OF APPROACH

The investigative team selected to perform the study consisted of:

Mr. Howard M. Bunch, Transportation Research Program Manager. Mr. Bunch served as overall project coordinator.

Dr. Richard G. Snyder, Research Scientist and Head of Biomedical. Dr. Snyder was responsible for evaluating those aspects of the vehicle's configuration relating to human anthropometry and occupant restraint and impact protection.

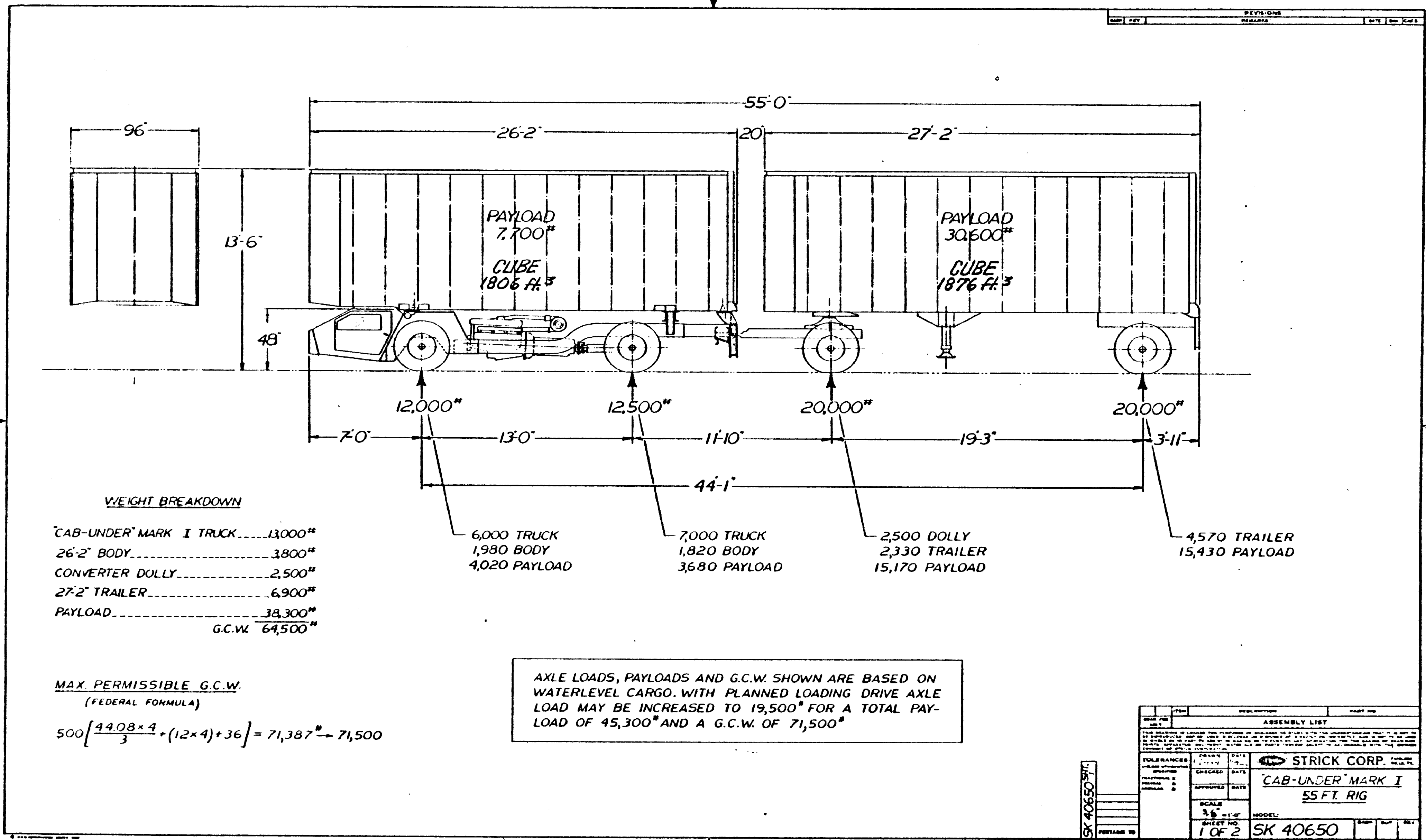

FIGURE 1. Cab-Under 55 Ft. Rig

Dr. John Melvin, Research Scientist and Head of Biomechanics. Dr. Melvin was responsible for evaluating the vehicle for occupant survival attributes in a crash environment.

Dr. Paul Olson, Research Scientist and Head of Human Factors. Dr. Olson evaluated vehicle design as it might affect driver performance, with his main concern being driver visibility.

Mr. Christopher B. Winkler, Assistant Research Scientist in Physical Factors. Mr. Winkler evaluated vehicle stability and other dynamic qualities of the vehicle.

First, a literature search was conducted to locate material and information concerning the cab-under concept. Most documents were obtained directly from the manufacturer or from the Teamsters. The material that was obtained from all sources included:

- detailed line drawings of the vehicle and some of its components;
- articles that have appeared in technical journals concerning the vehicle;
- a motion picture of the vehicle in operation;
- letters and memoranda from several organizations, such as the Teamsters, Department of Transportation, and Strick Manufacturing Company; and
- selected reports and studies from the HSRI Library.

The study team individually reviewed all of the material. Subsequently, the team members met as a group and discussed their initial perceptions of the safety attributes of the cab-under vehicle. Later, the team examined one of the vehicles while it was in the Detroit area. Subsequently, the team visited the manufacturer's facility where the vehicle was again examined. Also on this trip the team members conducted interviews with the manufacturer's representatives, including the vehicle driver, the vehicle's design engineers, and the program manager. Finally, each team member prepared a memorandum detailing his reactions to the cab-under concept, emphasizing problems associated with his area of expertise.

This report was prepared by the project team utilizing all of the information and material described above.

C. STUDY LIMITATIONS

The evaluation of a vehicle system is a complex and expensive undertaking. Because of the time and funding limitations of this study, it has not been possible to perform a definitive evaluation on the cab-under vehicle. Therefore, <u>it must be understood by the reader that this report represents only judgmental and qualitative estimates of the safety attributes of the vehicle, based on available material</u>. As more data are presented, the study team may revise, perhaps even reverse, conclusions and opinions expressed in this document.

II. VEHICLE DESCRIPTION

The cab-under vehicle assessed is manufactured by Strick Corporation, Fort Washington, Pennsylvania. To date, two prototypes have been built: the "Mark I," which is a 26-foot two-axle vehicle, and the three-axle "Mark II," which has 12,000-pound tandem steering axles. A third prototype is presently being designed, and will have several important changes over the Mark II. Among these are (1) reinforcing the doors to provide additional driver protection, and (2) increasing the cab height so that the driver may have better visibility and interior head room. This third prototype was not sufficiently advanced in its construction to permit any evaluations; therefore this evaluation will be confined almost exclusively to the Mark II configuration. (In instances where one of the other configurations is being discussed, it will be so stated.)

Figure 2 shows the general arrangement of the Mark II. Figure 3 shows the vehicle depositing its removable cargo body. Figure 4 gives the dimensions for the Mark II vehicle.

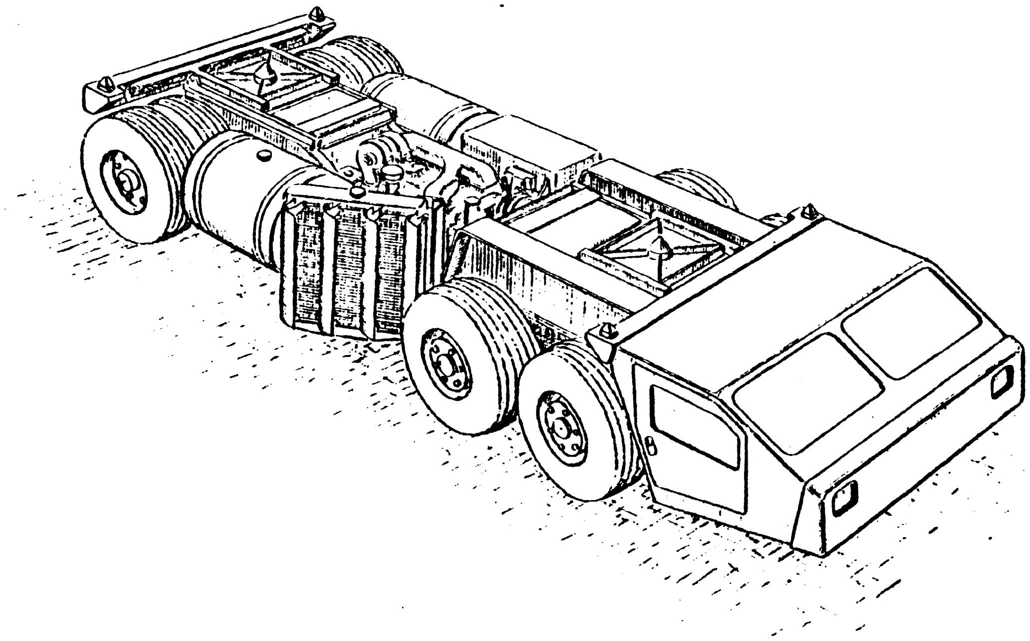

FIGURE 2. Cab-Under Truck, General Arrangement

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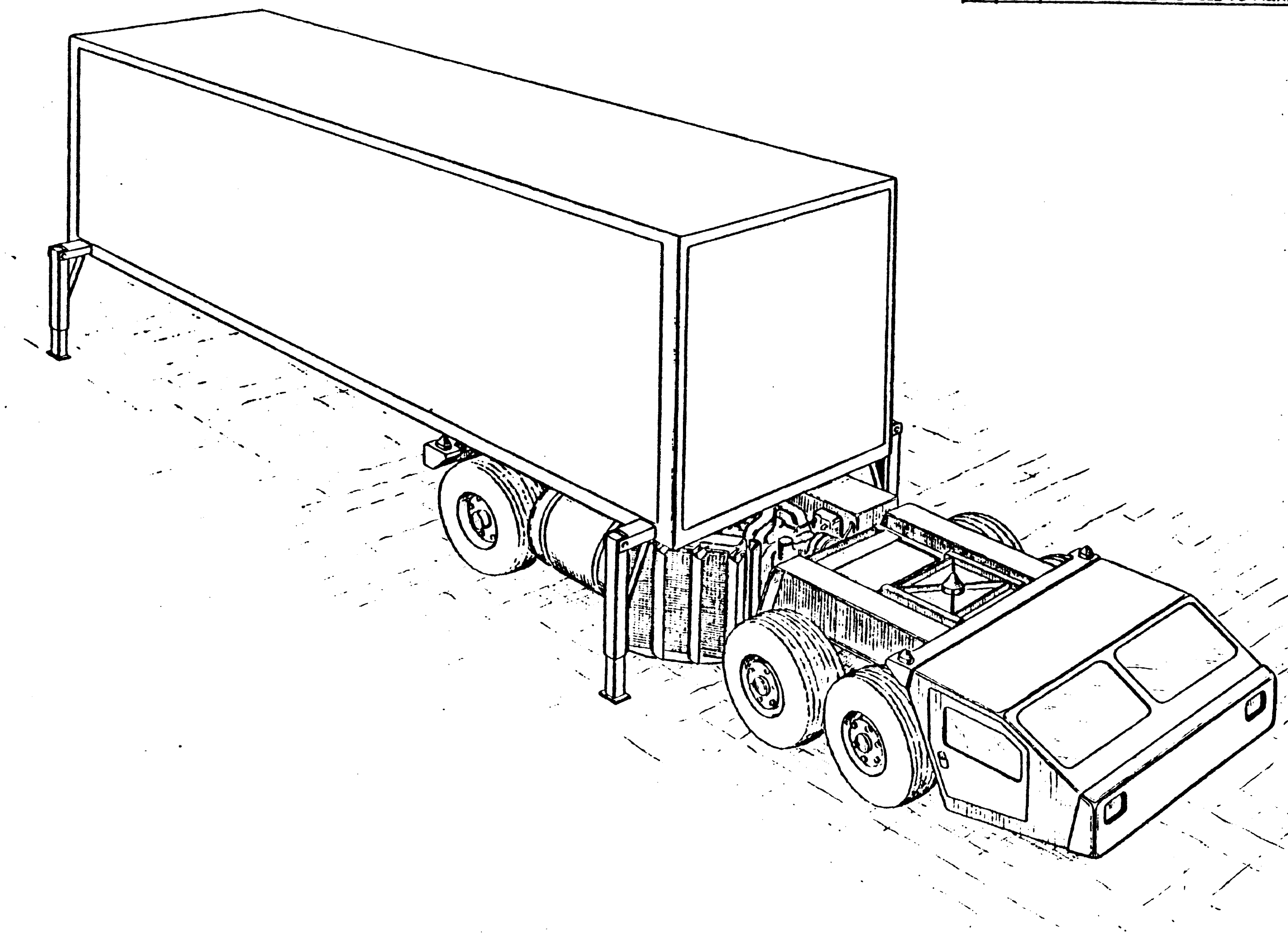

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		ASSEMBLY LIST	

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DRAWN A.A. DATE 5/10/76
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SCALE NONE =1'-0"
SHEET NO. 1 OF 1

STRICK CORP. FAIRLESS HILLS, PA.

"CAB-UNDER" MARK II TRUCK

SHOWN DEPOSITING ITS REMOVEABLE CARGO BODY

MODEL:

SK-33001 | DASH | SUF. | REV.

SK-33001 | PERTAINS TO

FIGURE 3. Cab-Under Truck Depositing Its Body

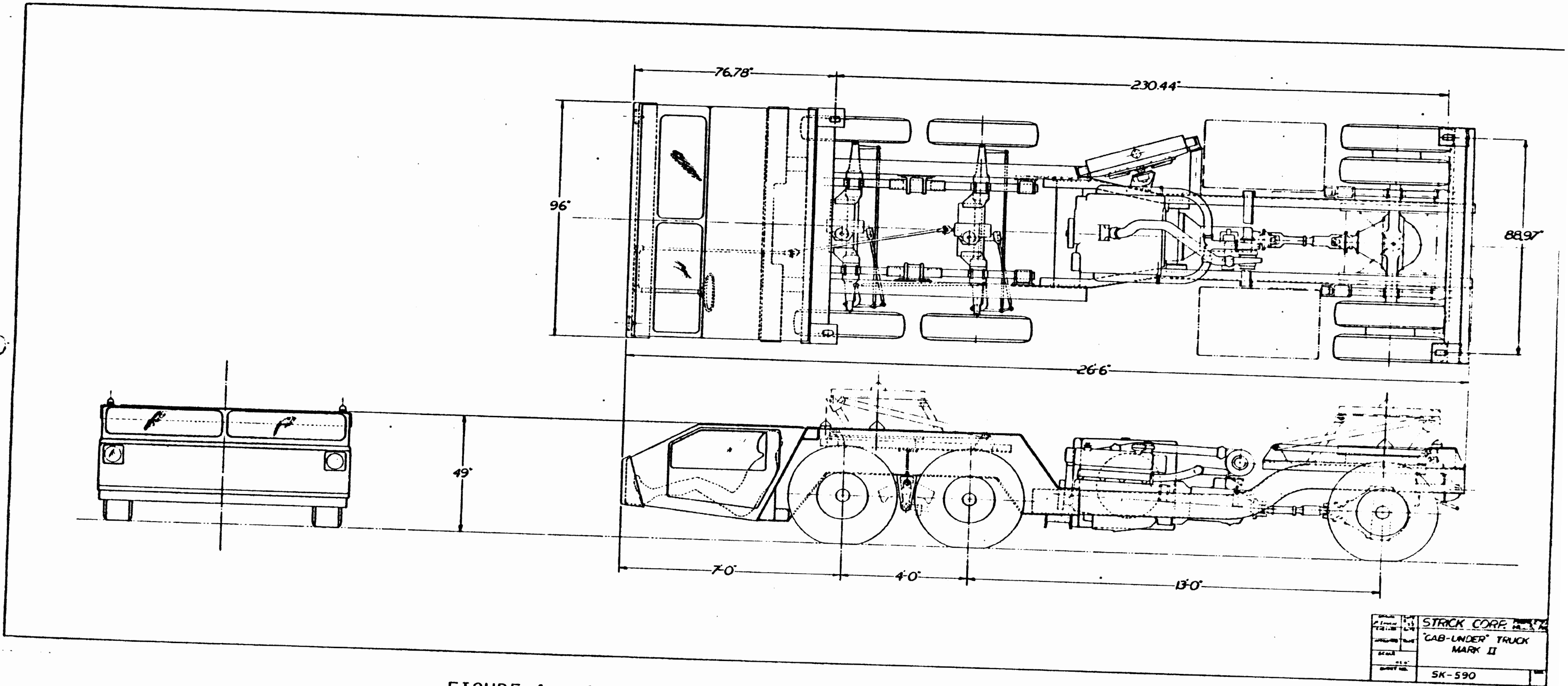

FIGURE 4. Cab-Under Truck, Dimension Details

III. STUDY FINDINGS

The findings discussed below represent qualitative judgments made by members of the HSRI team on the basis of examining the vehicle, riding in it, and discussing its performance with test drivers. No experimental tests of safety-related aspects of the vehicle were conducted in this brief study. Therefore, the conclusions reached by study team members are tentative.

A. FACTORS AFFECTING DRIVER PERFORMANCE

1. Low Driver Height

The cab-under vehicle is unique with respect to the height of the driver from the road surface: his eye-level height is significantly less than 49 inches from ground level, as shown in Figure 4. This attribute affects the safety aspects of the vehicle in many ways. Perhaps the most significant negative aspect is the driver's reduced capability to see over other vehicles and beyond grade obstacles. The typical truck driving position allows the operator to look well down the road and to see problems developing that would otherwise be screened by intervening vehicles. With the cab-under vehicle, the driver loses this down-the-road vision. For reasons of safety, the driver will need to compensate for this loss by maintaining greater headway (distance between vehicles in the same lane). Whether the drivers will do so to an extent that balances out the loss of visibility can only be guessed at, given the present lack of information.

The low driver height will also have an effect on the driver's ability to sense vehicle roll. In the cab-under, the driver's head is very near the roll axis of the vehicle. Consequently, vehicle roll does not produce the large lateral driver motions that it does in conventional trucks. Since this motion may play a significant part in sensing the severity of a handling maneuver, the driver's ability to sense an impending handling performance limit condition may be reudced. This rationale was confirmed in conversations with the cab-under test driver.

In addition to the down-the-road visibility problems, there might be other difficulties of visibility resulting from body overhang. Depending on the seated height of the driver, the maximum visual-up angle is about 10 degrees. This means that a sign or signal suspended 23 feet above the road could not be seen if it is less than 115 feet in front of the truck. This restriction may be an inconvenience at times but the impressions of the team members when they rode in the vehicle was that visibility in all directions was generally adequate. But loss of direct sight of an overhead signal would be a problem if the truck were moving very slowly (e.g., 10-20 mph) with no traffic in front (to provide a signal cue) as it approached an intersection. In this case its speed would be such that it could enter the intersection after the signal had changed. It is also true that an individual operating the truck would not be able to directly determine when a signal changes, if he stops closer than 75-100 feet from it. The project team concluded that this would not result in a significant safety problem. The most serious potential hazard would be caused by the vehicle being stopped at an unexpected point (100 feet from the normal stopping point, for example), but even this hazard is believed to be relatively unimportant because of the vehicle speeds that would be occurring at the time.

The low cab, which can be easily stepped into without a step, is a significantly safer configuration from the point of view of driver injuries from falls. Presently falls from cab steps and rails account for about three percent of all injuries sustained by drivers. It would appear that the low configuration could reduce such injuries.

2. Driver Comfort, Fatigue, and Morale

Although there has been a great deal of research on driver comfort and fatigue, predictions concerning the effect of a specific vehicular configuration on either of these areas are difficult to make.

Based on their inspection, the investigative team agreed that there was no reason to believe that the cab-under provided any special problems or benefits in comfort and fatigue. In all likelihood, matters such as the seats selected, the placement of controls and displays, etc., will have more effect than the vehicle configuration.

There were some problems with the Mark II vehicle which could cause problems if not corrected. First, there does not appear to be sufficient head room for the taller (sitting height) driver. One person in the investigative team who is in the 95th percentile for the sitting height measurement indicated that his head touched the ceiling in an erect driving position. The Strick people plan to increase this dimension by 2.5 inches in the next version.

The Mark II cab is equipped with two Recaro seats featuring back adjustment, headrest, vertical and forward adjustments, and fore-aft adjustments of the forward edge of the seat cushion. Under all adjustments, however, the forward edge of the seat (popliteal) thigh tuck-up is ineffective and leaves the occupant with no (vertical) under leg support. The leg angle appears satisfactory, but this could also present problems under long-trip conditions.

Several members of the team were driven at about 45 mph over some large bumps, equivalent to a small section of Belgian Block road, which produced high vertical motions on the body. They indicated there was little real energy absorption from the seat pan (cushion), and definite jolts occurred.

The altered driver position of the cab-under has had a direct effect on the nature of the ride problem. In other trucks, the high driver position results in large fore-aft motions of the seat due to vertical pitch. This effect has been called "backslap." In the cab-under, the low position has all but eliminated this problem. However, the extreme forward position, ahead of the front axle, now results in very large vertical motions of the seat which are also quite uncomfortable. The condition is worse with the vehicle empty. (Air suspension is to be used on the third prototype; this should significantly reduce the vertical motion problem.)

It is believed that the low driver position, and unusual appearance of the vehicle will result in problems with driver acceptance. Poor acceptance in turn will cause other driver-morale-related problems, including complaints about matters pertaining to the vehicle which might be ignored under other circumstances. The driver of the prototype vehicle indicated that in his conversations with other drivers at truck stops, etc., there were always strong opinions expressed concerning the vehicle, and many were negative.

The ability of the driver to sense vehicle roll response has already been discussed in the previous section. A companion topic is the ability to sense yaw reaction of the vehicle. The very forward position of the driver alters the combination of yaw and lateral accleration which he experiences during turning. This will, in turn, alter his overall perception of vehicle yaw. Further, the limited vehicle structure within the driver's field of view may reduce the visual cues available to him for sensing yaw. (The contrast with yaw perception is primarily with the conventional truck, not the cab-over, since the cab-over driver also sits well forward of the vehicle's wheelbase.)

It is difficult to judge whether the changes in driver cue mechanism can or will be compensated for through experience and resulting re-education of the driver. It would appear that there is potential for degradation of performance.

3. Conspicuity

The cab-under configuration represents a drastic change from truck configurations normally observed on the highway. People are used to seeing a tractor in front of the trailer and when they don't (and can't readily see the cab) the impression is that the trailer is going backwards. This visual impression is enhanced by the large frontal area observed.

The driver related two instances where mis-identification of direction occurred. In one instance a driver ahead of him at a toll gate bolted ahead in panic when he saw what appeared to be a runaway trailer coming up behind him. Providing unique lighting or paint design would possible reduce the operational problems of mis-identification.

4. Lighting

The lower driving position places the trucker much closer to his or her own headlamps than when driving other vehicles. As a result, drivers will experience higher levels of glare from oncoming headlamps than they have been accustomed to. This will certainly be annoying (although no more than to many automobile drivers) and will probably add to the fatigue problem in night driving.

Being closer to one's own headlamps will increase the backscatter effect associated with fog and snow. Auxiliary lamps projecting little illumination above the horizon would be helpful under such conditions.

On the other hand, being closer to one's own headlamps will cause reflectorized signs to appear much brighter and more easily read. The distance between the driver's eyes and headlamps on a cab-over truck may be six feet or more. When viewing a sign at 800 feet, for example, this represents an angle of about 0.5 degree. In the cab-under design, at the same viewing distance, the angle between the driver's eyes and headlamps is less than 0.2 degree. Because the brightness of retro-reflective materials drops off very fast as this angle increases, signs will appear two to four times brighter to the driver of a cab-under truck.

5. Rear View Mirrors

The lower driver position of a cab-under results in better mirror coverage, in that the substantial blind stops to the sides and just behind the driver associated with the typical cab configuration are virtually eliminated. On the other hand, the mirrors may be more vulnerable to damage because they are close to the ground. Indeed, one of the most serious problems with the Mark II (from the standpoint of visibility) is that the mirrors are virtually useless in wet weather because of spray thrown forward by the front wheels.

B. FACTORS AFFECTING VEHICLE PERFORMANCE

The general cab-under design would appear to influence other vehicle properties, most importantly, center of gravity height. The low drive train, frame, and cab of this vehicle make it appear to have a center of gravity location significantly lower than that of other heavy highway unit vehicles. Other things being equal (height of the center of gravity of the cargo, track width) this property would tend to reduce the rollover potential of this vehicle relative to conventional or cab-over trucks.

Other properties, whose effects are more difficult to assess, are (1) the use of two steering and one non-steering axle, and (2) the generally more forward location of cargo area, which may result in a more forward location of the vehicle center of gravity. Since the ultimate effect of this property is intrinsically tied to the properties of tires and suspensions used on the vehicle, there can be no sure conclusion. Number (1) above might be expected to have mixed results. The lack of non-steering tandem axles will remove the rigid-body aligning moment which such arrangements produce. This could improve the low speed maneuverability of the vehicle. However, more tires forward and less rearward could increase the relative front cornering stiffness which is generally a destabilizing effect. With respect to (2) above, a more forward center of gravity position can be expected to increase yaw stability.

There appears to be no strong reason to expect the cab-under design to alter the particular handling properties of articulated vehicles. The cab-under that was examined has been operated as a truck pulling a full trailer. When compared to other trucks pulling full trailers (assuming similar wheelbases, etc.), it is difficult to see any additional effects other than those discussed above. Plans are being made by Strick to construct cab-under vehicles which will be used as tractors in tractor-semitrailer vehicles. Since the planned wheelbase of this vehicle is comparable to more conventional tractor-semitrailer combinations, no major change in open-loop handling response is expected. Possibly, the yaw moment of inertia of the cab-under could be larger than that of other tractors. This might tend to reduce the severity of jackknife instability, although it will also tend to make cornering responses more sluggish.

Taken as a whole, the open-loop response qualities of the cab-under could be somewhat, but not greatly, improved relative to more conventional heavy trucks and tractors.

C. CRASHWORTHINESS

1. General Occupant Protection

The study team found significant problems relating to protection of occupants in the current versions of the cab-under vehicle. Specific areas of concern are:

- major contact areas, e.g., the panel, the door, the A-pillar, the roof, have unacceptable contact profiles because of inadequate energy absorbing padding.

- the heavy metal protrusions of the door latch and window control offer potential hazards.

- the header material is inadequate to offer head protection in roof contact, such as a vertical jolt where head contact is made.

- the present lap belt will not prevent torso jack-knifing and upper body structural contact.

- the overhang of the cargo container body, coupled with the wide expanse of windshield, could result in a driver-cab intrusion problem. The overhead container would serve as a deflector, directing objects toward the windshield.

The investigative team concluded that the deficiencies found in the cab interior could be solved with more efficient design, and are not inherent with the cab-under concept. In fact, most of the cited deficiencies are also found in trucks presently on the highways. The only possible exception is the problem of cargo body overhang serving as a deflector into the driver cab. In this case the low height of the driver windshield results in greater deflection exposure.

2. Specific Crash Scenarios

Specific crash situations for the cab-under vehicle were evaluated, and comparisons were made relative to other conventional designs. The scenarios were:

a) a frontal collision with an equally massive and agressive vehicle or obstacle, such as another truck or large roadside object;

b) a frontal or lateral collision with a passenger vehicle;

c) a single-vehicle accident, such as a rollover or jackknife; and

d) shifting loads.

a) Frontal Collision With an Equally Massive Object. In a frontal collision with a massive or immovable object there would seem to be very little basic difference between this design and conventional designs, since there is no attempt in any truck design to manage the enormous energy of such a collision through crushable structure. Any differences in expected performance would depend upon the specific nature of the object being struck. If a cab-under tractor struck the rear of a flat-bed trailer or low roadside obstacle, this could be more dangerous for the cab-under driver; however, he would be below any cargo shifts which could more seriously jeopardize the driver of a conventional truck. But, ignoring the effects of shifting load, the risk to the cab-under driver is greater in crash involvements with low-profile fixed objects (e.g., bridge abutments). In any case, a severe frontal collision of a truck into another truck or a solid roadside obstacle is a serious threat to the survival of the truck occupant, regardless of where he is located vertically.

b) A Frontal or Lateral Collision With a Passenger Vehicle, or Smaller Objects. Collisions with passenger vehicles and other relatively small objects on the highway would present some special problems with the cab-under design that are not generally a problem with conventional designs. The problems are intrusions through the windshield and/or the door of the cab by the object being struck. The low placement of the cab puts it down where a car colliding with the side of the cab could intrude if sufficient side structure is not there to prevent it. Similarly, a frontal impact with a car, road debris, or an animal on the road could result in intrusion of the debris through the windshield. But the effect of this type of penetration could be minimized by innovative design efforts to improve windshield retention. Regardless of windshield design, however, there is greater risk exposure with the cab-under if for no other reason than increased frequency of potential intrusion encounters.

The problem of driver safety when the cab-under vehicle is subjected to a lateral collision is compounded by the fact that the driver location is at a height where the penetration force generally occurs. And, because of the greater mass of the cab-under vehicle relative to a car or small truck, the cab-under will not move to any significant extent. The lack of movement can be directly translated into greater injury exposure for the occupant, because the intruding object will penetrate further into the vehicle. The only possible deterrent is to increase the vehicle's side structure to the point that the structure totally prevents the penetration. A critical design requirement for a cab-under configuration would be providing this protection.

c) A Single-Vehicle Accident. Single-vehicle accidents such as running off the road and rolling over appear to be an area where the low placement of the driver in a cab-under may be an advantage over conventional configurations. In such accidents the driver is surrounded by strong structures and would be relatively immune to entrapment and injury due to structural collapse. Likewise, in a jackknifing situation the low placement of the driver would also be to his benefit.

d) Shifting Loads. In accidents resulting from shifting loads, a person in a cab-under vehicle would have better protection than a person in a conventional or cab-over vehicle. This feature is a positive safety feature for the cab-under, and would have a positive effect on injury statistics.

D. SUMMARY OF VEHICLE ATTRIBUTES

A summary of the positive and negative features of the cab-under vehicle when compared with a conventional vehicle is presented in Table 1. Those deficiencies inherent in the vehicle design do have significant safety implications. Of particular concern are problems associated with down-the-road visibility and with intrusion from the side and front. Several of the deficiencies found in the vehicle's safety attributes are correctable, or at least can be improved over their present condition. In the event the manufacturer proceeds with other prototypes he would be well-advised to seek professional advice on ways to improve the vehicle's correctable safety deficiencies.

On the positive side are (1) the ingress and egress features of the vehicle, (2) the reduced roll-over potential, and (3) the protection from the shifting load.

TABLE 1

Summary of Safety Feature Differences for the Cab-Under Truck

Feature	Magnitude
Positive	
1. Rollover advantage--shifting load potential	Major
2. Compartment ingress and egress	Major
3. Lower Center of Gravity	Major
4. Sign visibility	Moderate
5. Mirror coverage	Moderate
6. Removal of rigid body aligning moment	Moderate
Negative - Inherent	
1. Cab intrusion	Major
2. Down-the-road visibility	Major
3. Vehicle roll and yaw sensing by driver	Major
4. Cornering stiffness	Moderate
5. Conspicuity	Moderate
6. Upper vision limitations	Moderate
7. Glare and backscatter	Moderate
8. Mirror exposure to damage and spray	Moderate
Negative - Correctable	
1. Interior contact areas 2. Metal protrusions 3. Header material 4. Restraint system 5. Head room	All are moderate in magnitude and can be significantly reduced or eliminated