VEHICLE MODIFICATION AND INSPECTION

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ABSTRACT

Automotive adaptation for disabled drivers or passengers takes two forms, usually admixed: adaptive equipment installation and modification of the basic vehicle to accommodate both the equipment and the client. Vehicle modifications range from quite minor, nonstructural changes to complete rebuilding from the chassis up. Evaluators, engineers, modifiers, and agencies need to keep 3 principles in mind: (1) Pick the right vehicle, (2) Keep changes to a minimum, (3) Preserve structural integrity, while still suiting the modification to the particular client's needs. Guidelines and resources for accomplishing a quality modification within these principles are discussed.

Key Words: Adaptive Equipment, Automotive, Structures, Inspection, Standards

VEHICLE MODIFICATION AND INSPECTION

Introduction

Once automotive adaptation moves beyond the stage of merely installing mechanical hand controls, clamping on control extensions, and providing assist handles to facilitate driver transfer and wheelchair storage, the prospect of modification of the vehicle itself arises. In the late 1950's and early 1960's, severely disabled drivers not adaptable with the add-on equipment then available turned to special body trucks, such as the International Metro delivery vehicle. Since then, nearly every professional in the area of rehabilitation engineering in which automotive adaptation plays a significant part can recount an experience of inspecting an extensively modified or even totally replaced body on a passenger car chassis which has been built for a particular client by a would-be inventor who has no experience in automotive adaptation. These custom jobs run the gamut from absurd Rube Goldbergs to truly remarkable remanufacturing of the basic motor vehicle. As vans became widely available in the early 1970's, more and more the modified vehicle has come to be a modified *van.*

The experienced automotive adaptor generally follows the conservative principles of:

(1) picking the right vehicle to start with,

(2) planning the least amount of change to the basic vehicle to accomplish the purpose of adaptation for *this* client,

(3) preserving as much as possible of the basic structural integrity of the vehicle as designed in by its manufacturer.

Vehicle manufacturers spend literally hundreds of millions of dollars to design their vehicles to satisfy both commonly accepted principles of structural integrity and mandatory standards set by the Department of Transportation. The small shop should approach major modifications with some humility, since they have neither the resources, engineering support, nor market to undertake modifications that fundamentally change the design of the vehicle.

Each of the three principles and its implications will be discussed in this paper in the context of both guidelines and inspection for adaptation to the client and for quality.

Principle 1: Pick the Right Vehicle

Preliminary Considerations

Prior to selecting the right vehicle there are several issues which need to be resolved. Some of these issues are related to whether the individual will be a passenger or driver. If the person is to be a driver, have they been evaluated for equipment needs and received the proper drivers training and when possible a drivers license? It is also crucial to insure that the individual has the mobility aids which they will be using at the initial fit evaluation. Examples are wheelchairs, scooters, and cushions. Changes in any of these can result in an improper fit and/or vehicle selection.

Level of Modification: Car vs. Van

In the selection of the right vehicle it is important to determine the level of modification that will be needed and whether the person with the disability can use a car versus a van. It must be determined that the person has the ability to lock and unlock the door, open and close the door, transfer in and out of the drivers seat, store and retrieve the wheelchair, or ambulate from the rear of the vehicle to either the passenger or the drivers area. If all of these conditions can be met, then it is possible to modify a car rather than a van. There is adaptive equipment that can assist persons with disabilities in the storing and retrieval of their wheelchairs either on top of the vehicle, or into the rear of the vehicle or even to carry the mobility aid on the rear of the vehicle or in the trunk. If the person with the disability is able to use the automobile, most agencies will restrict the modification process to only those items that would be used on the car. Cars are generally less expensive to modify, the modifications tend to be less extensive and typically cars are much more easier to maintain and cheaper to operate. It should also be noted that the modifications, since they tend to be less extensive, are typically easier to move from one car to another providing that the replacement vehicle is of the same size as the original car that was modified.

Funding Considerations

Some states and organizations provide the end user with the vehicle or assist with the purchase. Examples of this can be seen in insurance companies and by some state departments of Vocational Rehabilitation who purchase vans for modifications. Provided that certain criteria are met (economic need), then these agencies have the ability to supply the van to be modified. In other instances, such as with the Department of Veterans Affairs, providing that certain criteria are met, an allowance toward the purchase of the vehicle is provided. There are numerous states and organizations however, who do not participate in the purchase of the vehicle and feel that it is the persons responsibility to supply the vehicle which is to be modified. Often times this can place the person with a disability in somewhat of a precarious situation. Although it is recognized that it is typically better to start off with as new a vehicle as can be afforded, Often persons with disabilities are unlikely to be able to afford a new vehicle. When the state departments of Vocational Rehabilitation are working with people that are on fixed incomes (SSI or SSDI), such clients will not have sufficient funds either to buy or take out a loan on a new vehicle. In these instances the person will have to go out and seek a used vehicle or try to modify one they already have. It is always recommended that in the purchase of any used vehicle that the vehicle be inspected thoroughly by a mechanic prior to purchase to insure that the vehicle is in good operating condition. The Texas Rehabilitation Commission, for example, recommends that vehicles over 4 years old or having an excess of 50,000 miles be evaluated by a mechanic to insure that it is functioning properly. It can be extremely frustrating (and costly in time and money), if after high level modifications such as reduced effort power steering are installed, it is discovered that the vehicle is so old that the seals for the power steering are worn and begin leaking when subjected to higher temperatures and pressures associated with steering modifications.

Every organization will have their own purchasing procedures for the modification of vehicles. Although there might be several variations to the purchasing procedures, the two basic procedures are (1) low bid, which many state and federal entities use and (2) selection from an approved vendor list. Both methods have pluses and minuses, but just a few of these will be mentioned. On the low bid it is crucial to have specifications drawn up that are as specific as possible. It is very difficult for modifiers to bid on a job adequately without having seen the person with the disability and their vehicle prior to modifications. The low bid approach also limits some of the last minute changes which occur at the time of final fitting. Persons who have dealt with the low bid process have found that it can create a very competitive atmosphere among the modifiers. As a result, there often will not be a good flow of information and sharing among the modifiers when they are placed in this competitive situation. The low bid also typically does not take into account any hardship which must be faced when transporting the vehicle and the person with the disability from one city to another to have modifications done when there is a modifier closer by who could do the work.

The selection of modifiers from an approved list can promote a process of the person with the disability meeting with the modifier and the modifier reviewing the specifications from the driver evaluator and inspecting the vehicle which is to be modified. Early in this process, if there are personality conflicts or problems, they can be dealt with as they arise and not linger on and create problems after the modifications have been completed. It is also found that there are many decisions that the person with the disability is not able to make for themselves due to regulations. By having the person with the disability be a part of the decision process by which a modifier is chosen (provided the modifier is on the approved list), the likelihood of satisfaction with the end product can be increased. There are situations in which the modification is very complex and can only be performed at one locale in the country. When dealing with this type of situation, agencies must decide whether to have all the modification done at that locale or whether to have some of the modifications performed at a local shop and then have the vehicle transported to be completed. Some of the problems that can arise with this situation is that one vendor may do part of the modification in such a way as to preclude the second modifier from being able to complete their work. Situations can also result when dealing with a sole source in that when the vehicle has mechanical problems, there is no one locally who can trouble shoot and repair the modification. In Texas, prior to doing any type of modification that is sole source, a local vendor is required to be trained on repairing that modification prior to purchase. This is in an effort to try and assist in minimizing the problems that are encountered with mechanical breakdowns.

Vehicle Selection Guide

The Texas Rehabilitation Commission has developed and disseminates to clients a vehicle selection guide (Figure 1). At the time of this printing, the Commission has not approved mini-van conversions with dropped floors. It is anticipated that when that modification has been approved that the TRC will re-do the guide to include that type of a conversion. Until that time, however, TRC will continue to provide the information on mini-vans that is in the guide.

Principle 2: Plan the Least Amount of Change to Effect Adaptation

Resale Value of the Vehicle

Although some adaptations of necessity require such radical modifications to the passenger compartment and/or body of the vehicle to render it unsuitable for resale, many adaptations do not require this degree of redesign of the OEM vehicle. Radical modifications are usually made on vans, light duty truck chassis, which are designed for much harder usage for more years than a passenger car. The client will literally drive his or her vehicle into the junkyard, thus resale is not a consideration. On the other hand, an adaptation that uses "bolt on" equipment, whether van or car, will probably be traded in five to seven years or 100,000 miles. with some forethought, the vehicle modifier can use fastening and installation techniques to minimize cosmetic damage to the vehicle when the adaptive equipment is removed before resale. The key to this is really no different than a general commitment of the vehicle modifier to a policy of good workmanship, comparable to the best commercial practice in custom body shops. Use of rubber gaskets, avoidance of unnecessary drilling (and subsequent failure to seal or repair), proper attention to sealing and corrosion protection, careful removal of OEM trim to permit installation of adaptive equipment (with equally careful preservation of the trim pieces for re-installation after the adaptive equipment is removed) are all recommended practices to assure retention of as much of the value of the adapted vehicle as possible, without losing sight of the fundamental goal of providing personal transportation for the client who is disabled.

Single Point Failures

A great many standards and specifications contain language something like this:

"Any installation of equipment or modification of the motor vehicle shall not introduce new single-point failures of the associated vehicle subsystem which

VEHICLE SELECTION FOR CLIENTS OF
THE TEXAS REHABILITATION COMMISSION

The Texas Rehabilitation Commission has spent a great deal of time, energy and money to develop standards for vehicle modification services. An important component in vehicle modification services is the selection of an appropriate vehicle to be modified. The Texas Rehabilitation Commission does not indorse one manufacturer over another but offers the following suggestions:

CARS

1. If you are capable of using a car we will limit modification to a car only. Cars are cheaper to modify and more economical for you to maintain.

2. Most car modifications are done on two door sedans. This is because the door is wider and easier for you to transfer. It also makes it possible to stow and retrieve a wheelchair in the vehicle.

3. Intermediate size or larger cars typically are better.

4. You should have the ability to:

   a. lock/unlock door
   b. open/close door
   c. transfer in and out of drivers seat
   d. store and retrieve wheelchair *

* There is adaptive equipment to assist with this i.e., car top carriers and inside loaders. Consultation with a modifier on our approved vendor list should occur to ensure appropriate vehicle selection.

RECOMMENDED OPTIONS	AUTOMATIC TRANSMISSION
POWER STEERING	POWER BRAKES
ADJUSTABLE (TILT) STEERING	AIR CONDITIONING
POWER SEAT	SPLIT BENCH TYPE FRONT SEAT
CRUISE CONTROL	POWER DOOR LOCKS
POWER WINDOWS	REAR WINDOW DEFROSTER
REMOTE ADJUSTABLE OUTSIDE MIRRORS (MANUAL OR ELECTRIC)	

VANS

1. The selection of which make and model of van to purchase is more crucial if you are going to be a driver as opposed to a passenger. Even if you are going to be riding as a passenger now, you may be able to drive unassisted at a later time in your rehabilitation process. If that is an option for you, be sure that you do not purchase a vehicle that makes that option more difficult or even impossible!

2. If the conversion of the van for your use requires a dropped floor, then only one full-size van can be used. This is the Ford E series van, which has a separate frame and body. The dropped floor conversion does not require cutting the frame or changing the fundamental structure of the vehicle. All other vans, both full-size and minivans, use unibody construction (no separate frame). Installing a dropped floor in a unibody

Figure 1. An Example of a Vehicle Selection Guide

van is a major structural modification which at the present time is prohibited by the Texas Rehabilitation Commission Standards unless extensive testing is performed by the vehicle modifier to show that the modification is safe. Such a conversion on a unibody vehicle may also void the warranty.

3. If you will be driving your van from your wheelchair, then the Ford E-series full-size van offers the most space, although other vans can be used, as long as you consider the cautions in paragraph 2 above.

4. If your van will be equipped with a dropped floor, do not order the auxiliary fuel tank unless you really need it. It takes up alot of space underneath, and may interfere with the modification.

5. When ordering a van the following options should be considered:

Ford E150 Cargo Van (138 inch wheelbase) *

Power Steering	Power Brakes
Power Mirrors	302 CID/EFI V8 Engine
Automatic Transmission	6500 LB. GVW Package
Air Conditioning (Front only)**	100 Amp Alternator
Handling Package	Insulation Package
Light and Convenience Group	Power Windows and Door Locks
Tilt Steering	Cruise Control
P235/75R 15 Radial Tires	Heavy Duty Suspension

* It will be less expensive and take less time to modify your vehicle to begin with a bare cargo van. You may purchase the windows to be cut int the van and dress out the vehicle during or after the modifications are complete.

** For the persons who will require auxiliary air conditioning, it should be ordered for installation after the vehicle has been modified. In many cases, factory installed auxiliary air conditioning will interfere with the vehicle modifications and will have to be relocated.

MINI-VAN

1. Mini-Vans are generally not recommend due to limited interior space to maneuver a chair.

2. In most conversions they are not recommended for driving from a wheelchair.

3. Rotary lifts are not available.

4. They usually require a raised roof.

PURCHASE OF USED VEHICLES

1. Vehicle should be inspected thoroughly before purchase and modification or installation of adaptive equipment.

2. On vehicle over four years old or having in excess of 50,000 miles w. need to be reviewed by a mechanic.

Figure 1. An Example of a Vehicle Selection Guide

which otherwise do not exist in that subsystem and which compromise user safety, or safety of the motoring public."

A single point failure can sometimes be difficult to identify as such, and definitions of this term are many and varied. ANSI Standard Z94.0-1982 (1) gives a definition for "primary failure" as a failure which is responsible for system malfunction, and then goes on to define a "critical failure" as a failure which could result in major injury or fatality to people or which could result in major damage to any system or loss of a critical function. Then "single point failure" is defined as "a failure of a subunit which by itself will cause a failure of the system or equipment." The Nuclear Regulatory Commission (2) defines a "Single Channel Failure Mode" as a situation in which one failure can result in system failure.

Misunderstanding of this concept of "single point failure" and how it affects automotive adaptive equipment and vehicle modifications leads to needless redundancy and complexity. Any system or structure has numbers of components or subunits, which, if they fail, break, or malfunction will cause the system in which they are installed to fail. If a tie-rod end in a steering system breaks, steering of the vehicle will be affected to the point that control probably will be lost. If a chassis rail on a vehicle cracks, the vehicle will probably be greatly affected, and may come to rest in two pieces. If the solid-state ignition module fails or the timing belt breaks, the vehicle comes to an abrupt stop.

Something must be added to the industrial concept of "single point failure" to render it useful for automotive adaptive equipment. A recent adaptive equipment Standard (3) defines single point failure as "any failure mode that in happening results in hazard or otherwise adversely affects the safe operation of the system." Vehicle manufacturers handle single point failures by providing generous margins of safety wherever possible (heavier structure, lower running speeds, heat sinks, etc.) and either redundancy or preventive maintenance (or both) where safety margins are not practicable. Dual belts are used, an on-board processor has a "limp home" mode which is automatically selected, and owners are advised to change the timing belt every 50,000 miles.

Hence the automotive adaptor must consider whether introduction of a piece of equipment constitutes a new single point failure, a hazard to which the able-bodied counterpart of the driver who is disabled is not exposed. For example, provision of a secondary control console with pushbuttons for ignition and starter makes the original keyswitch inoperative. In order to provide at least a modicum of security for the client, a modifier very kindly provided an unmarked toggle switch to disable the vehicle ignition, and located the switch in the passenger area of the van where the client could operate the switch as he left it via the wheelchair lift. This switch constituted a single point failure for the modification, since the switch was very vulnerable to inadvertent actuation by any passenger in the van. This "kill" switch would necessitate (1) the driver realizing that the switch had been thrown, (2) instructing the passenger to restore power to the ignition, (3) shifting the vehicle to neutral or park to restart the vehicle--all of this perhaps at 55 MPH on an urban freeway! The solution hit upon in this case was to substitute a starter "kill" switch to provide security. The only effect of inadvertent throw of the switch by a passenger would be loss of ability to restart the vehicle if the engine suddenly died in traffic: a double failure. Playing a little "what if" game (known in engineering circles as an FMEA, Failure Mode Effects Analysis) before going ahead with an adaptive approach certainly beats the formalized "Monday morning quarterbacking" that the unwary adaptor will encounter in a lawsuit.

Provisions for the Automotive Environment

In doing quality control inspection of adapted vehicles, one of the problems often encountered with inexperienced (and sometimes experienced) modifiers is the use of household, temporary, or otherwise unsuitable devices, materials, and connectors. The automotive environment is a brutal one, characterized by temperature extremes, vibration, mechanical shock, dust and dirt contamination, electromagnetic and electrostatic interference, salt spray, splashing with water and other chemicals (especially petroleum based hydrocarbons) and moisture, all defined in SAEJ1211, "Recommended environmental practices for electronic equipment design" (4). Components purchased at automotive supply outlets will usually meet these standards (especially if the "bargain" equipment is avoided). Electronic parts and wire purchased at electronic hobbyist stores must be approached with some caution, since some of this gear will be suitable for the automotive environment, and some will not. Selection of suitable electrical and electronic components is especially critical if that device is part of adaptive equipment which, if the device fails, constitutes a single point failure. For example, the ubiquitous "squeeze" type device sometimes used (among other things) to connect temporary trailer wiring to vehicle wiring without cutting wires has no place in an adaptive equipment installation. The connection must be a permanent splice, properly soldered and then insulated. Similarly, garden hose, twist-on wire caps, lamp wire, stove bolts, duct tape, or cardboard should never be found in automotive adaptations, but the authors have encountered all of these at one time or another, singly or in combination. Take a look under the hood of your vehicle or under the dash. You will find that all the vital connectors are of the positive retention type: a tab must be raised or a screw must be removed to take the connector apart. Connectors for adaptive equipment must also be positive retention type, keyed or otherwise designed to preclude incorrect connection. Perhaps to conclude this section, some words from a recent Standard (3) would not be out of place:

> "The Texas Rehabilitation Commission's goal is to provide simple, cost-effective, and reliable adaptive equipment that will remove as much as possible of the handicap to using a personal motor vehicle that is presented by a physical disability. Awkward, needlessly complicated, makeshift equipment has no place in this program, and will not be purchased by the TRC."

Compromise to Crashworthiness

This an area of great concern to vehicle modifiers, but one where little guidance can be offered. Most automotive adaptive equipment installed as after-market equipment tends to compromise the crashworthiness of the design built by the vehicle manufacturer. Steering assists are probably the most obvious example of this extra risk that drivers who need such a device incur. Contact with the steering wheel is minimized if the driver uses his or her restraint system properly, but the injury potential is still there. This is true of most mechanical extensions and add-on devices. Servo controls are less obtrusive in the driver compartment, and new membrane type secondary control consoles have some provision for breakaway in the event of a collision. But anyone experienced in automotive rehabilitation engineering knows that a complex installation tends to have hardware, edges, and structures that could, by their very presence, produce injuries that would not happen with the unmodified vehicle. But then, the client would not be driving or riding either. He or she must clearly understand the greater risk that they face in regaining their automotive independence, and be willing to assume that risk.

Provisions for Operation by Drivers Who Are Not Disabled

"No man (or woman) is an island" certainly applies equally to persons who are disabled. A client will have relatives, a spouse or companion, and friends who may drive the adapted vehicle from time to time or even on a routine basis. Any motor vehicle requires servicing and maintenance, and that becomes a lot easier if mechanics can drive the vehicle. Those states that have safety inspection programs usually permit the inspector to ride along with the client at the controls to assess drivability aspects (steering and brakes) but again it helps to retain the OEM controls and access to them. As a general design principle, all adaptive equipment and vehicle modifications should permit operation by an able-bodied driver and transport of an able-bodied passenger, with as little change as possible from conventional subsystems operation and function.

That said, it is recognized that the adaptation comes first: the client's needs take precedence over the needs of any other user of the vehicle. An adaptation for a little person may not be suitable in any way for a larger person; a setup for a driver with a bilateral upper amputation which places all controls accessible to the feet may also be entirely too bizarre to expect another driver to cope. If the client will be driving from a wheelchair, provisions should be made for substitution of the original seat in the vehicle for another driver. The simplest way to do this is to provide four t-handled mounting bolts which pick up matching threaded holes in the floor of the vehicle. A discussion of what these bolts should be is provided in the section of this article on Fasteners. If a dropped floor is installed (as is often the case) then the OEM seat or aftermarket seat will need to be equipped with a raised base to bring the driver's eye level to the nominal height required for visibility out the windshield. A less desirable approach is to equip the substitute seat with the same interface hardware as the wheelchair tiedown. This approach may be more costly, and probably will be difficult to operate (engage, disengage, maneuver the seat) unless it is very well engineered. To provide adequate occupant protection, the OEM restraint system should be retained for the use of an alternate driver, even though the wheelchair user may have an entirely different restraint system suited to his or her needs.

Wherever possible, the OEM pedals for throttle and brake should be retained, and should be operable in parallel with the adaptive mechanical or servo controls. If reduced effort power brakes are installed, the able-bodied driver may have to operate the vehicle with great care to avoid overbraking. It makes sense to install a warning decal on the visor or other suitable location advising unwary drivers that the brakes are "sensitive." Reduced effort power steering should pose no particular problem to a driver who is not disabled, although the backup pump operation (at startup and at lock) and possible heat buildup if the valve is not completely closed should probably be called to the uninitiated driver's attention by a decal. If routine use of the vehicle by an undisabled driver is anticipated, any steering assist should be of detachable or demountable design.

As more advanced systems for primary control by severely disabled drivers become available (5) it will become more difficult to retain controls sufficiently close to OEM for uninitiated drivers to use, but the majority of adaptive installations should continue to be accessible to persons other than the client for whom they are intended.

If adaptations of secondary controls (transmission, lighting, wipers, parking brake, etc.) are suitably labeled, little difficulty should be encountered with other drivers' use of the vehicle. Again a sound principle is KISS: keep it simple, stupid! In many cases the client was a driver before disability; why adapt controls to make them operate any different than *necessary* and thus throw away all that previous psychomotor experience? Those expectations are still present. When control will be transferred to another limb, or the client has never driven and thus has no motor learning accumulated, then the adaptor is more free to improvise. But the needs of other drivers should still be a factor. Much good guidance for adaptive engineers regarding directions of motion, labeling, and much else besides can be found in a military standard which is widely available, MIL-STD-1472D (6). Labeling of automotive controls can also be found in Federal Motor Vehicle Safety Standard (FMVSS) 101 and 102 (7, 8).

Provisions for Maintainability

"Maintainability" is formally defined (1) as a characteristic of design and installation which is expressed as the probability that an item will be retained in or restored to a specific condition within a given period of time, when the maintenance is performed in accordance with prescribed procedures and resources. Nearly all equipment requires maintenance and/or repair, certainly automotive equipment. The goal in maintainability is to provide adaptive equipment that has provisions for making periodic maintenance as simple, inexpensive, and time-conservative as possible consistent with cost effectiveness. Adaptive equipment should not render original subunits of the vehicle more difficult to access and maintain than on the unmodified vehicle. Parts requiring owner or service garage maintenance should be readily accessible without major disassembly or the use of special tools. In Figure 2 the battery hold down clamp passes over one of the caps for the non-maintenance-free battery. What is the probability that this battery's electrolyte level in 3 of the 6 cells will ever be checked in a full-service filling station?

In addition to providing maintainability through design and installation with a "plan ahead" orientation, modifiers should supply written instructions for periodic maintenance of the adaptive equipment, and guidance for trouble-shooting as appropriate. Granted that the client will generally not be able to perform such operations himself or herself; but he will be able to see to it that the maintenance is done. These instructions for each piece of adaptive equipment should (1) specify whether maintenance is required, the cycle of maintenance, and by whom the work should be done; (2) if owner or operator maintenance, adequate instructions to assure that the work will be correctly done; (3) a parts list with instructions on how to obtain space parts or replacements; (4) names, addresses, and telephone numbers of the manufacturer or his representative, and authorized service agencies or distributors.

None of this is much different than the owner's manual supplied with the vehicle, but the modifier should make some effort to assure that the client is at least aware of the instructions and of the need for maintenance.

Principle 3. Preserve the Structural Integrity of the Vehicle

Over the last two decades innovative adaptive equipment manufacturers and vehicle modifiers have continuously expanded and improved the vehicle equipment and modifications which are available for disabled drivers. Vans with wheelchair lifts, automatic door openers, raised roofs, lowered floors, power seat bases, low effort steering and brakes, and various wheelchair and occupant restraints now allow many severely physically disabled individuals to drive. However, trends in the automobile industry toward building unibody vehicles have greatly complicated the task those vehicle modifiers who make extensive structural modifications to vans to allow access to wheelchair bound individuals.

The term "unibody" refers to a type of construction or vehicle in which the body and the frame are one and the same. In the past most vehicles had a separate frame and body; the frame was the main load bearing structure and both the body and the suspension were mounted to it. Body design was dictated mainly by aesthetics, not by strength, since the frame supported the large loads imposed on the vehicle by the suspension and the engine and drive train. With this type of construction major structural modifications such as lowered floors and raised roofs can be made to the body without too much concern for structural failure as long as the frame is not modified. In contrast, in a unibody vehicle the frame and body are integrated into one structure (unibody) so that what was formerly the body is now a major load bearing structure. Vehicle manufacturers invest a great deal of time and money

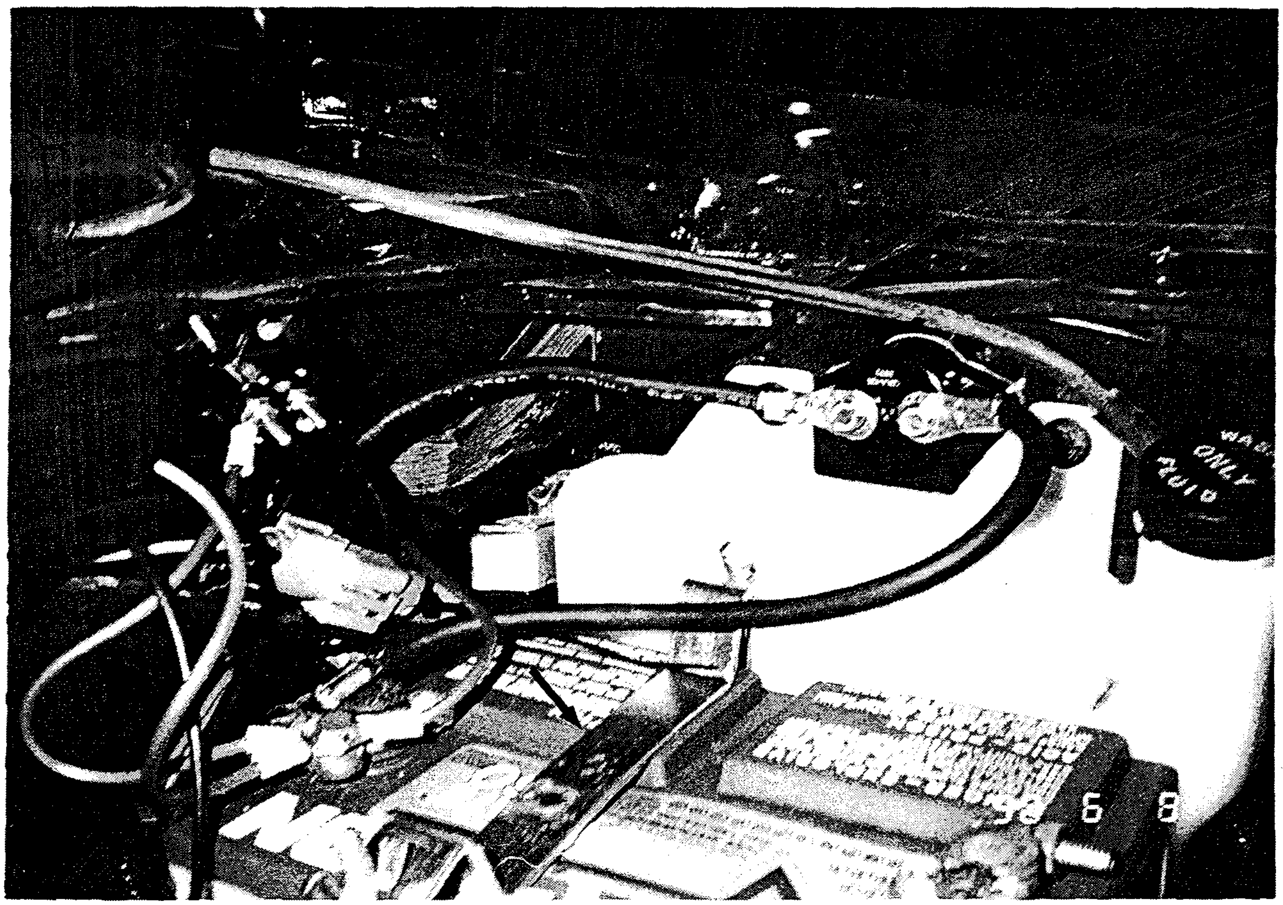


Figure 2. How Often will This Auxiliary Battery be Checked?

into designing unibody vehicles which achieve both eye appeal and structural integrity. The main tools for structural analysis of unibody vehicles are very large finite elements computer programs which have been developed by the manufacturers over many years at considerable expense. This analysis is followed by both destructive and long term testing. For a unibody vehicle a modifier must carefully evaluate a structural modification to the body, such as a lowered floor, in terms of its effect on the integrity of the overall vehicle structure. Most modifiers have neither the resources nor the expertise to perform the required analysis and testing.

At present all U.S. manufactured vans are unibody construction except the full size Ford vans which still retain a separate frame and body. For this reason full size Ford vans are the only vans which are recommended if a dropped floor is required to serve the client.

Full Sized Vans Versus Minivans

This section will address structural modifications to full size vans and passenger cars. Structural modifications to minivans will not be specifically addressed. Our experience with minivans has been that they are "nearly big enough" to accommodate most clients. Many of those clients who have insisted upon purchasing minivans or who already had minivans have eventually found them unsatisfactory. There are certainly exceptions, such as very small individuals in small wheelchairs, but in general, use of a minivan by a person who cannot transfer out of a wheelchair is like wearing shoes every day which are "nearly big enough"; your feet hurt all of the time. Extensively modified Chrysler (Dodge Caravan or Plymouth Voyager) minivans with variable height suspension, lowered floors, and ramps instead of lifts have been available for several years. They are very complex and very expensive. Up to a dozen modifiers nationwide do such major conversions, some of which have conducted crash tests to demonstrate structural integrity and conformance with Federal Motor Vehicle Safety Standard 301, which covers fuel system integrity (10). Although such conversions, carefully and conservatively done, have been reasonably trouble-free in service, standards have yet to be developed to assist agencies and purchasers.

Raised Roof and Doors

A raised roof on a van provides head room inside the van for a tall client. Raised roofs were originally developed for recreational vehicles and this is still their largest market. The manufacturer of a raised roof should provide an installation kit and instructions and these should be used by the modifier. The best raised roofs are made of fiberglass with wood slats and sometimes foam sandwiched in the fiberglass. The sandwich construction (thickness) provides strength and stiffness to prevent flexing of the roof and the vehicle. The method of fastening the raised roof to the van is also critical and is discussed in the section on fasteners. Stiffness and strength in the OEM roof are provided by sheet metal beams which span the roof from side to side and are spot welded to the roof and by ridges which are stamped in the roof and run longitudinally. If a raised roof is not stiff enough the whole van body will flex excessively. The first signs of excessive flexure are body squeaks and groans as the van travels uneven surfaces or rough roads, rattles, doors which are hard to close and don't seal well (particularly when the van is parked on an uneven surface), and inability of the van to maintain wheel alignment. Excessive flexing will eventually cause cracks in welds and body panels and will accelerate corrosion.

Raised roofs can be installed on either full size Ford or unibody vans, but Ford vans are preferred.

Raised doors provide head room during entry and exit. If a client requires raised doors, swing out double doors are preferred to sliding doors. The door extensions in a raised door modification should be of welded steel construction comparable to the OEM doors and must be stiff (thick) enough that the doors seal well and will continue to do so for the life of the van. The main problems you should look for in a raised door modification are a good, weather tight seal and OEM quality fit and finish. The sealing problem is compounded by the fact that automatic door openers usually require removal of the OEM door latches and the automatic openers do not hold the doors closed as tightly as the OEM latches.

TRC Standards (3) require a separate welded steel structure be added to vans with raised roofs to insure adequate stiffness. This structure consists of steel tubes which connect the door pillars on either side of the vehicle and are interconnected by additional steel tubes to provide longitudinal stiffness. This additional structure is especially important when raised side doors are added to the raised roof since the raised side doors require removal of the OEM structure above the original door opening.

Lowered Floor

Lowered floors should be installed only on full size Ford vans for the reasons discussed at the first of this section. Lowered floors provide more head room and a lower eye height for individuals riding in or driving from wheelchairs. They are required for tall drivers who cannot transfer to a vehicle seat to allow them to see out under the top edge of the windshield. A large area of the floor can be permanently lowered or a powered pan can be installed in the driver's position only; the same guidelines apply to either modification. The floor can be lowered four inches in a full size Ford van without interference with the frame. If more than a four inch drop is required a body lift kit may be installed to provide an additional two to three inches of clearance between the body and the frame. Body lift kits were developed for off road vehicles to provide additional ground clearance and are available from dealers who supply off road equipment. The frame should not be cut under any circumstances.

The OEM floor is made of very thin metal but has ridges stamped in it to provide strength and stiffness. If the replacement floor is flat (no ridges) it should be at least 0.1046 inch thick (12 gage). Structurally the weakest point in a dropped floor modification is the weld where the new floor is welded to the original body. This is a difficult weld to execute because of the difference in thickness between the two pieces being joined and the fact that the weld must often be made in an overhead and/or awkward position. In addition, the abrupt change in thickness causes a stress concentration at this point, increasing the likelihood of failure. All welds on lowered floor modifications should be continuous around the entire perimeter of the floor and should be inspected for quality. The new floor must be primed and painted inside and outside and undercoated to prevent corrosion.

If the van has an auxiliary gas tank and installation of the lowered floor requires that it be lowered so that it extends below the vehicle frame in its new position, then the tank must be protected at the front and bottom by a skid plate. This can usually be avoided if a large OEM tank is used instead of an auxiliary tank.

As a final note on lowered floors, it is recommended that the client transfer to a vehicle seat and use a powered seat base to lower herself to the driver position if possible, and avoid the lowered floor entirely. The main reason for this recommendation is not expense, but the fact that the client is much safer in an OEM seat than in a wheelchair.

Modifications To Passenger Cars

In every case that we have encountered, if a client requires major structural modifications to a passenger car to meet his needs he will be better served by a van. Thus, the only feasible modification which will alter passenger car structures and dynamics is the addition of a wheelchair carrier which extends past the rear of the vehicle. Any load which is carried beyond the rear of the vehicle will increase the load on the rear of the vehicle and decrease the load at the front. For example, a 200 pound wheelchair and carrier at the rear will typically increase the rear axle load by 300 pounds and decrease the front axle load by 100 pounds. The increased load at the rear can overload the rear suspension and tires. More importantly, the redistribution of weight will dramatically change the steering and handling response of the vehicle from understeer to oversteer. Since most drivers have no experience driving an oversteering vehicle and some people consider them unsafe, heavy wheelchairs on rear carriers which extend beyond the rear of the vehicle should be avoided, especially on light vehicles where their effect will be maximized. Roof top carriers or assistive devices to load the wheelchair inside the vehicle should be used instead.

<u>Fasteners and Associated Hardware</u>

One purpose for inspecting adapted vehicles, is to attempt to gain better quality in the final vehicle. Fasteners are as important to quality as any other portion of the adapting process. They are labor intensive; the cost of the labor to install them is far more than the cost of the parts and materials and they are critical to durability. A nut working its way off a bolt soon leads to a rattle, a leak, and ultimately a failure of whatever it secures. So a detailed inspection of fasteners is important.

All holes should be carefully drilled to avoid damaging the exhaust system, brake lines, fuel lines or electrical leads. Avoid drilling holes near other holes which might weaken the capacity of the bolts. Care should be taken not to drill holes through sheet metal severely weakened by corrosion. If it is necessary to anchor a bolt in a corroded sheet, install a doubler plate to restore the original strength of the weakened sheet. A drilled hole should be not more than 1/8-in larger than the nominal diameter of the bolt for which it is being drilled.

Bolts

Figure 3 illustrates some bolt geometries more commonly used for fasteners in vehicles adapted for use by persons who are handicapped. In addition to being referred to by their geometric character as shown in the Figure, they are designated by their size and thread and by the grade of the material of which they are made. The coarse thread series (NC and UNC) is the most common and finds general application where quick and easy assembly and disassembly is desirable. The fine thread series (NF and UNF) is used where closer tolerances are required or to prevent loosening under vibration. Both types of threads are found on bolts and the smaller shanked numbered screw sizes (below 1/4 in diameters). Fine threads have greater holding power than comparable coarse threads; however, coarse threads are generally preferred because they are so much cheaper, both to buy and to install.

Any of the bolts in Figure 3 might have the designation on an engineering drawing as

7/16 in. -- 20 UNF 2A

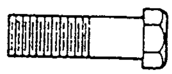
or

1/2 in. -- 13 UNC 2A

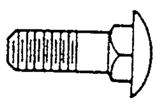
which means a 7/16 in. diameter bolt with 20 universal fine threads per inch or a 1/2 in. diameter bolt with 13 universal coarse threads per inch, respectively. A thread class designation follows defining the allowances and tolerances of the threads. The symbol 2A designates the most common commercial class. If the letters LH follow it means the threads are left handed otherwise right handed threads are assumed. Finally they may be designated in accordance with the material of which they are made. These grades of materials are defined in SAE Standard J429 (9). It is recommended that only Grade 5, or better, be used for adaptive modifications involving the anchoring of lap or torso belts, or any part of the occupant restraint system (including seat mountings). Figure 4 shows the SAE bolt marking scheme.

Screws

Screws are similar to bolts with the single exception that they do not require nuts. Some are self tapping and make their own threads. Others may not even require predrilling



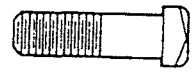
HEXAGON HEAD: A common standard fastener produced in sizes ranging from 1/4 in. up. The hex head is often easier to install than the other types of bolts.



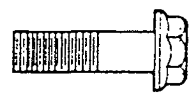
CARRIAGE: Squared, or ribbed, shank prevent turning when bolt is tightened.

ROUND: Presents a smooth external appearance. Bolt is tightened simply by tightening the mated nut.

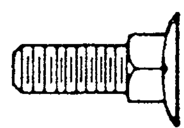
COUNTERSUNK: Provides for a flush surface.



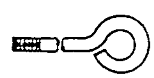
SQUARE HEAD: Produced in sizes from 1/4 in. up.



FLANGED: Head with large bearing area often eliminates the need for a separate washer.



ELEVATOR: Large-diameter flat-head bolt yields a near flush surface and large bearing area. As with the carriage bolt the square neck prevents rotation when installing the nut.



BENT: Threaded rod with the end bent to form an eye.

Figure 3. Bolts Often Used When Adapting Vehicles for a Handicapped Person

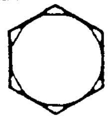
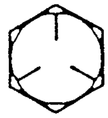
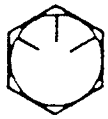
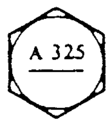
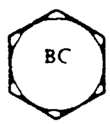
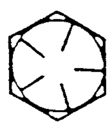
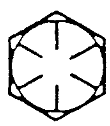
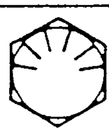
Grade Marking	Specification	Material
 NO MARK	SAE — Grade 1	Low or Medium Carbon Steel
	ASTM — A307	Low Carbon Steel
	SAE — Grade 2	Low or Medium Carbon Steel
	SAE — Grade 5	Medium Carbon Steel, Quenched and Tempered
	ASTM — A 449	
	SAE — Grade 5.2	Low Carbon Martensite Steel, Quenched and Tempered
	ASTM — A 325 Type 1	Medium Carbon Steel, Quenched and Tempered Radial dashes optional
	ASTM — A 325 Type 2	Low Carbon Martensite Steel, Quenched and Tempered
	ASTM — A 325 Type 3	Atmospheric Corrosion (Weathering) Steel, Quenched and Tempered
	ASTM — A 354 Grade BC	Alloy Steel, Quenched and Tempered
	SAE — Grade 7	Medium Carbon Alloy Steel, Quenched and Tempered, Roll Threaded After Heat Treatment
	SAE — Grade 8	Medium Carbon Alloy Steel, Quenched and Tempered
	ASTM — A 354 Grade BD	Alloy Steel, Quenched and Tempered
	SAE — Grade 8.2	Low Carbon Martensite Steel, Quenched and Tempered
	ASTM — A 490 Type 1	Alloy Steel, Quenched and Tempered
	ASTM — A 490 Type 3	Atmospheric Corrosion (Weathering) Steel, Quenched and Tempered

Figure 4. ASTM and SAE Grade Markings for Steel Bolts and Screws (ASNI B18.2.1-1981, Appendix III)

a hole for the screw to be forced into. Virtually all raised roofs are installed using tapping screws, usually in predrilled holes through the fiberglass roof into the sheet metal van body (See Fig. 5).

Nuts

Square and hexagonal nuts are the most common method of securing bolts. Nuts come in a variety of shapes and uses. Jam nuts, slotted nuts, and castle nuts are used primarily to provide added security against vibrating loose. In addition to these, nuts which bind upon being seated against the base can then be further tightened to provide a locking action. Such special nuts are often referred to as free-spinning locknuts in contrast to prevailing-torque locknuts which start to bind as soon as the threads are engaged and then must be wrenched all the way tight. Cap nuts cover the sharp parts of a protruding bolt. Wing nuts are used in applications where the nut must be frequently removed and replaced.

Three other types of nuts sometimes found during adapted vehicle inspections are caged nuts, anchor nuts, and single thread nuts. Cage nuts are often used when the holes are blind, i.e., the nut cannot be reached again after assembly. Anchor nuts are similar to caged nuts except that provision for quick removal is provided. The third, and most common of the other types, is the single-thread nut. These nuts depend largely on spring action to hold them tight in the presence of vibration. They are particularly suitable for use with thin metal and where clearances are limited. They are frequently found securing electrical components to underhood firewalls. Fig. 6 shows some nuts of this variety.

Washers

Washers are used for a variety of purposes including sealing out water and wind, providing electrical connections, providing a locking action for the nut, but most importantly to add to the strength of the sheet metal as a structural anchor. Flat washers can, of course, be used to distribute the bearing of the nut or bolt head when the drilled hole is too large.

Figure 7 shows an integral conical washer and some frequently used lock washers intended to prevent nut loosening.

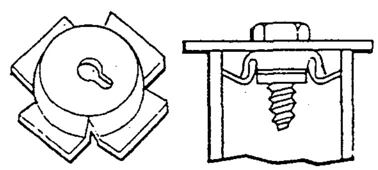
Seat Belt Installations

Both pelvic and torso restraint anchorages require special attention. The bolts should be installed in substantial metal unweakened by the presence of corrosion or other nearby holes. Should the metal be artificially weakened through excessive grinding or for other reasons, a doubler plate restoring the sheet to its original strength should be used. In any event the bolts should be either:

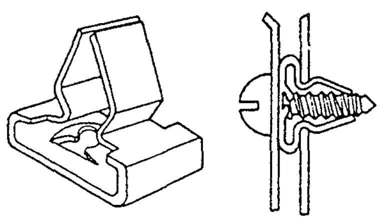
7/16 - 20 UNF 2A or 1/2 - 13 UNC 2A

Figure 5. Minivan with a Raised Roof Secured into Position with a Number of Screws

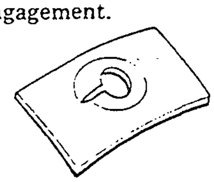
Tube nut: Components can be joined to tubes with this nut, which wedges within the tube. Various sizes are available to match tube ID.



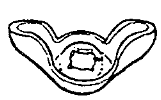
Spring arm nut: Arms expand when screw is threaded, locking the fastener in place.



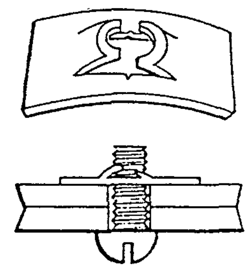
Dome nut: Nut has an opening which matches the pitch of the engaging screw. Advantages of this type of nut are high torque and 360° thread engagement.



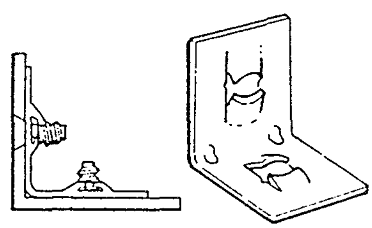
Wing nut: These are used in applications where frequent disassembly is anticipated.



Flat type: This has prongs which engage the screw threads. Advantages include positive locking and vibration resistance.



Angle nut: This nut joins perpendicular panels quickly and easily combines the functions of three to six separate pieces.



U-type nut: This nut is used on panel edges to keep the screw perpendicular, preventing cross threading during assembly.

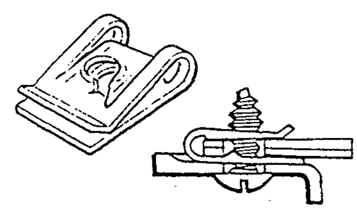


Figure 6. Single Thread Nuts Such as These are Often Especially Advantageous for Use in Adapting Vehicles

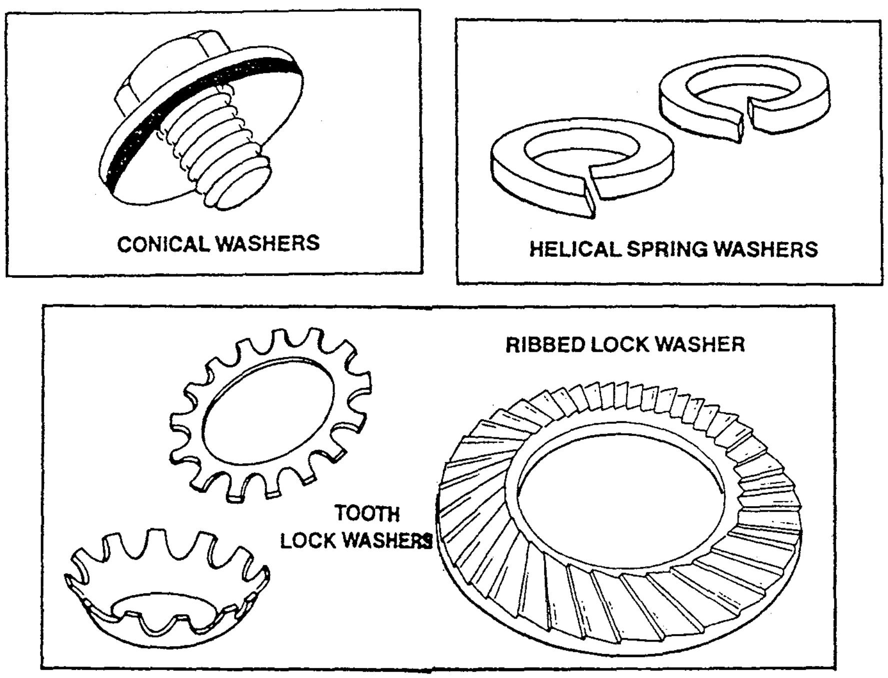


Figure 7. A Sketch of a Bolt with an Integral Conical Washer and Some Examples of Lock-Washers Frequently Used for Adapting Vehicles

and be of SAE Grade 5 material as a minimum. with a grade marking apparent on the head of the bolt. The conventional flat washers should have a total bearing area of at least 4 square inches, which means an outside radius of at least 1 1/8 in, and should be at least 0.06 in thick. Dished reinforcing plates should be installed with the turned up edges away from the body structure. These attachment fittings should be installed so that movement for self-alignment is possible.

Raised Roof Installations

The screws used to install raised roofs should be carefully inspected to assure reliability and weatherproofing of the roof to body joint. Do not skimp on screws; they should be spaced about 4 in apart (Refer back to Figure 5). Be sure the screws penetrate the metal of the vehicle body. Predrill the holes to assure they do. Use longer screws across the front; say 1 1/4 to 1 1/2 in long. Assure the joint is sealed and evaluate the quality of the covering trim.

Seats and Lift Fasteners

The bolts to secure seats (excluding seat belt anchorages), unoccupied wheelchairs, and wheelchair lifts should be adequate to restrain the weight of the item in an 8 g forward deceleration. This leaves quite a bit to the judgement of the inspector, but a good rule of thumb is that bolts should be not less than 3/8 in diameter with at least four bolts securing each item.

Inspection of Adaptive Equipment Installations and Vehicle Modifications

Quality control considerations have been discussed throughout this paper, but some thought needs to be given to the actual process of inspecting the job either in progress or prior to acceptance and release to the client. In Texas, a comprehensive Standard (3) has been in force since 1987 for all modifications purchased by the Rehabilitation Commission (Vocational Rehabilitation agency). Through an interagency agreement, field office personnel arrange for an inspection of the vehicle at completion by Texas A&M University engineers and technicians. Inspection is mandatory above a certain dollar amount for the modification, and can be invoked on any job. On an appointed day, the inspection team from Texas A&M, the TRC Management Support Specialist, and the client meet at the modifier facility for the check-in process. Inspectors use a standard set of forms based on the Standard to perform the inspection, which takes anywhere from 2 to 8 hours. The installation is also documented by photographs. The inspection team interacts freely with the vehicle modifier personnel on the job to obtain clarification of technical approaches, discuss ways to remedy problems that are encountered, and discuss compliance with the TRC Standard. In some sense this is a training opportunity for modifiers, and also provides valuable experience for the inspection team. The client is an active participant in the inspection, to assure adequate physical fit, access, and (to a limited extent) ability to operate the adaptive controls and equipment. Findings are then summarized by the inspectors to TRC representatives, who have also participated in the inspection process. Discrepancies are dispositioned into two categories: those that can be remedied on a call-back basis after acceptance (but before payment by TRC), and those major discrepancies which must be repaired/replaced/reworked before acceptance by TRC. The TRC specialist then conducts a debriefing with the modifier to convey these action items. The inspection process concludes with a written report prepared by Texas A&M which documents all findings and the job itself. On minor installations and even some major ones, TRC specialists do the inspection without technical assistance to the best of their ability.

If it can be afforded, the best quality control approach is 100 per cent inspection: each case is subjected to the above process, or one similar to it. Where budgetary or manpower considerations make this impracticable, the next best approach can be characterized by a phrase taken from law enforcement: "Smokey is there but you never know where!" A modifier has no advance knowledge which jobs he does for the agency will be subjected to the in-depth inspection, hence he will tend not to gamble, and do a quality job on every vehicle.

The Standard adopted by Texas is comprehensive and eclectic by incorporating existing VA, SAE, Dept. of Transportation, military, and other standards as well. In the years to come, the Society of Automotive Engineers (SAE) Adaptive Devices Standards Committee will be developing consensus Standards which will have national impact on the state-of-the-art of vehicle modification and adaptation, as vocational rehabilitation agencies adopt them for their own (5). The quality of conversions over the last 20 years has steadily improved, as well-meant but essentially amateur modifications to basically unsuitable vehicles have given way to adaptations by seasoned and well-financed small businesses and manufacturers. Prospects look bright for this trend to continue into the future.

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