TP 13344E

ENGINEERING ANALYSIS OF SIX-WAY TRANSFER SEAT BASES

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16. Abstract

TES Limited was contracted by the Transportation Development Centre (TDC) to follow up on a previous investigation into the crash-worthiness of six-way power transfer seat bases. The main objective was to determine the feasibility of modifying or redesigning them to meet CMVSS 207/210 performance requirements.

The work involved:

- Collecting information on seat belt assembly configurations in current model vans/minivans;
- Performing an engineering analysis on a representative transfer seat base;
- Developing a surrogate vehicle test fixture and procedure for generic vehicle testing;
- Conducting a static pull test in accordance with the developed procedure; and
- Making recommendations regarding the current suitability and crash-worthiness of transfer seat bases if used in current model year vans/minivans.

Based on the survey results, a large proportion of current model vans/minivans are being equipped with seat-mounted seat belt anchors. Thus, a transfer seat base may be installed in conjunction with an original equipment manufacture (OEM) seat whereby at least one seat belt anchor is attached to the seat; in this case, the transfer seat base is likely to fail the CMVSS 207 performance requirements (based on recent physical testing, documented in TDC report TP 13246E).

The engineering analysis determined that a critically weak link in current transfer seat base designs is the worm gear speed reducer, which is not sufficiently robust to be non-reversible. In a previous test case, this was believed to be the sole cause of failure. A re-test using the same unit, but with the speed reducer blocked, confirmed that conclusion. A generic vehicle test fixture with delineated seat belt anchor locations was developed.

Generic vehicle testing is recommended for all transfer seat bases. They should also be tested with the inboard seat belt anchor integrated with the seat as a "worst case" loading configuration.

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16. Résumé

Le Centre de développement des transports a confié à TES Limited un marché qui s'inscrit dans la suite d'une étude antérieure sur la capacité des sièges électriques à six positions de résister aux forces en jeu lors d'une collision. L'objectif principal de la présente recherche était d'évaluer la possibilité de modifier ou de repenser ces sièges pour les rendre conformes aux exigences des normes NSVAC 207 et 210.

Les travaux réalisés dans le cadre de ce marché comportaient plusieurs étapes :

- recueillir des données sur les modes d'ancrage des ceintures de sécurité équipant les modèles courants de fourgonnettes et minifourgonnettes;
- réaliser une étude technique d'un siège électrique à six positions représentatif;
- mettre au point une plate-forme d'essai et une procédure d'essai connexe;
- réaliser un essai statique de traction selon la procédure mise au point;
- formuler des recommandations quant à l'adéquation et la résistance, en cas de collision, des bases de siège électriques à six positions, en supposant qu'elles sont installées dans des fourgonnettes et minifourgonnettes de l'année (1998-1999).

Selon les données recueillies, un fort pourcentage des modèles courants de fourgonnettes et minifourgonnettes sont équipés de ceintures de sécurité dont les ancrages sont fixés au siège. Il est ainsi possible d'installer une base de siège électrique et d'y implanter le siège d'origine du véhicule de façon qu'au moins un ancrage de ceinture de sécurité soit fixé au siège. On peut alors prévoir que le siège faillira à la norme NSVAC 207 (selon de récents essais mécaniques documentés dans le rapport TP 13246E du CDT).

L'étude technique a permis de mettre au jour une lacune grave dans les modèles courants de bases de siège électriques, soit un réducteur de vitesse à vis sans fin peu robuste, susceptible d'inverser sa course. L'échec d'un essai antérieur avait été imputé à cette seule cause. Un nouvel essai réalisé avec la même base de siège, mais dont le réducteur de vitesse avait été immobilisé, a permis de confirmer cette conclusion. Une plate-forme d'essai générique comportant des emplacements précis pour les ancrages de ceinture de sécurité a été mise au point.

Il est recommandé de soumettre toutes les bases de siège électriques à des essais au moyen de la plate-forme générique. Il est en outre recommandé de les essayer surmontées d'un siège incorporant l'ancrage intérieur de ceinture de sécurité, de façon à reproduire la «pire» configuration de mise en charge possible.

17. Mots clés	18. Diffusion
Bases de siège électriques à six positions, aides à la mobilité, véhicules personnels adaptés, NSVAC 207, NSVAC 210	Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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SUMMARY

This project was initiated to further investigate the crash-worthiness of six-way power transfer seat bases. These bases are intended for use by persons with physical disabilities, to facilitate their ingress and egress from the driver's or passenger's seat in suitably modified and equipped vehicles (typically vans and minivans). Over the years, concerns have been raised by users, as well as driver rehabilitation specialists who prescribe them, about the safety of these devices in the event of a vehicle crash impact. A previous study found that six-way transfer seat bases provided longitudinal restraint during simulated (quasi-static) crash impact events when no occupant loads were imposed by seat-mounted seat belts. But, when seat belt loads were superimposed on the seat inertia loads, e.g., on an original equipment manufacturer (OEM) seat with seat-mounted seat belt anchors, the six-way transfer seat bases could not provide longitudinal restraint.

The main purpose of this project was to study in greater detail six-way transfer seat bases used with OEM seats having seat-mounted seat belt anchors. The project included collecting information on seat belt configurations and seat belt anchor locations in current model (1998-99) vans/minivans. Four out of nine vehicles had seat-mounted seat belt anchors.

A representative six-way transfer seat base that had failed previous testing under a combined seat inertia/seat belt loading scenario was examined in detail regarding all possible failure modes. Computer analysis was used to determine the load-carrying capability of selected components. The analysis showed that the principal failure mode during the previous testing was slipping of the fore-aft drive gears. To confirm this hypothesis, the unit was retested with the fore-aft drive gears mechanically blocked (thus preventing the coupled drive gears from rotating or slipping). In subsequent testing with the fore-aft drive gears blocked, the unit maintained position during full-load application, confirming that the drive gears were the sole cause of failure during the initial testing.

As part of additional project objectives, a surrogate vehicle platform was constructed for further testing of the representative six-way transfer seat base. The surrogate vehicle platform, a rigid, non-deforming “B Pillar” and “floor”, enabled the six-way transfer seat base to be tested independently of the vehicle interface. Surrogate seat belt anchors were incorporated in the “B Pillar” (upper, outboard anchor), “floor” (lower, outboard anchor), and six-way transfer seat base (inboard anchor) to which a surrogate seat belt assembly was attached.

Generic vehicle testing is recommended for all transfer seat bases. They should also be tested with the inboard seat belt anchor integrated with the seat as a “worst case” loading configuration.

SOMMAIRE

Ce projet visait à approfondir la recherche sur la résistance de sièges électriques à six positions aux charges résultant d'un choc dû à une collision. Ces sièges sont conçus pour faciliter le transfert de personnes ayant un handicap physique d'un fauteuil roulant au siège du conducteur ou au siège du passager d'un véhicule correctement adapté (habituellement une fourgonnette ou une minifourgonnette). Avec le temps, tant les utilisateurs que les spécialistes en réadaptation qui prescrivent ces sièges ont commencé à exprimer des inquiétudes quant à la sûreté de ces dispositifs en cas d'accident. Une étude antérieure avait démontré la capacité des sièges électriques à six positions de résister à la force d'inertie longitudinale du siège engendrée par une collision simulée (essai quasi statique) lorsqu'aucune charge n'était appliquée sur les ceintures de sécurité. Mais les bases de siège à six positions n'ont pu résister aux forces longitudinales générées par l'application simultanée des charges associées à la ceinture de sécurité (lorsque surmontées de sièges de série avec ancrages de ceinture de sécurité fixés au siège).

Le but premier de ce projet était d'approfondir le comportement des bases de siège électriques à six positions surmontées de sièges de série intégrant les ancrages de ceinture de sécurité. Il a d'abord consisté à recueillir de l'information sur les configurations de ceinture de sécurité et l'emplacement des ancrages de ceinture de sécurité à bord des modèles 1998-1999 de fourgonnettes et de minifourgonnettes. Dans quatre véhicules sur neuf, les ancrages de ceinture de sécurité étaient fixés au siège même.

Une base de siège électrique à six positions représentative qui avait échoué l'essai antérieur comportant l'application simultanée de la force d'inertie du siège et des charges maximales prescrites pour la ceinture de sécurité a été examinée en détail. Le but était d'inventorier tous les modes de défaillance possibles. Un programme informatique a été mis à contribution pour calculer la résistance aux charges de certains composants de la base. Ces calculs ont révélé que le principal mode de défaillance lors des essais antérieurs avait été le glissement des engrenages permettant de régler la position longitudinale du siège. Pour confirmer cette hypothèse, les chercheurs ont immobilisé mécaniquement les engrenages en question, empêchant toute rotation ou glissement de ceux-ci. Soumis à un nouvel essai, le siège est demeuré en place pendant l'application de la pleine charge, ce qui confirme que les engrenages étaient seuls responsables de la défaillance de la base, lors de l'essai initial.

Au titre d'un des objectifs subsidiaires du projet, une plate-forme simulant un véhicule a été construite en vue de soumettre la base de siège à des essais complémentaires. Cette plate-forme rigide, indéformable, constituée d'un montant B et d'un plancher, a permis d'essayer la base de siège électrique à six positions isolément de l'influence de son interface avec le véhicule. Des ancrages de ceinture

de sécurité représentatifs ont été fixés au montant B (ancrage supérieur extérieur), au plancher (ancrage inférieur extérieur) et à la base du siège (ancrage intérieur), auxquels une ceinture de sécurité représentative a été attachée.

Il est recommandé de soumettre toutes les bases de siège électriques à des essais sur la plate-forme représentant un véhicule générique. Il est en outre recommandé de les essayer surmontées d’un siège incorporant l’ancrage intérieur de ceinture de sécurité, de façon à reproduire la «pire» configuration de sollicitation possible.

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Glossary

The following is an alphabetical list of the acronyms, abbreviations, and definitions of terms used throughout this report. For brevity, acronyms and abbreviations will not normally be defined in the text.

Anchorage – the final point of attachment for transferring seat belt assembly loads to the vehicle structure (from SAEJ383)

Automotive Adaptive Product – a piece of equipment designed to enable a person to operate an automotive vehicle (from SAE J2094).

CoG (Centre of Gravity) – centre of mass in an assembly of separate mass particles

CMVSS – Canadian Motor Vehicle Safety Standard

FMVSS – Federal Motor Vehicle Safety Standard

H Point – see definition for SRP

OEM (Original Equipment Manufacturer) – a term used to refer to the vehicle manufacturer, or to the vehicle and vehicle components as they are designed and produced by the vehicle manufacturer

SAE – Society of Automotive Engineers

Seat Adjuster – a device anchored to the structure, which supports the seat frame assembly and provides for seat adjustments in the longitudinal and/or vertical direction. This includes any track, link, or power actuating assemblies necessary to adjust the position of the seat (from SAE J879b).

Seat Frame – the structural portion of a seat assembly. The frame may be constructed with springs attached directly to the structural frame or with the springs attached as a separate assembly (from SAE J879b).

Six-Way Transfer Seat Base (Transfer Seat Base) – see Transfer Seat Base

Six-way Under Test (SUT) – a term used in this report to refer to a representative six-way transfer seat base subjected to physical testing

SRP (Seat Reference Point) – the Design H-Point with the seat in the rearmost, lowest normal design position. The “Design H-Point” has co-ordinates relative to the design vehicle structure. It is located at the H-Point of the two-dimensional drafting template placed in any designated seating position (from SAE J383).

Transfer Seat Base – a powered seat base that provides additional seat travel to facilitate movement of the handicapped user to and from the seat. This includes the following (from SAE J2094):

- Two-way transfer seat base;
- Four-way transfer seat base;
- Six-way transfer seat base; and
- Eight-way transfer seat base.

1. INTRODUCTION

1.1 Scope

This project was initiated as a follow–on study to a previous investigation into the crash-worthiness of six-way transfer seat bases (transfer seat bases). Transfer seat bases are adaptive devices intended for persons with physical disabilities who require a means of transferring from their wheelchair (or other mobility aid) to a vehicle seat (either driver's or passenger's). They normally replace the original equipment manufacture (OEM) seat pedestal and are installed between the vehicle floor pan and the OEM seat assembly. The scope of the current study was to investigate and report on the following:

- OEM vehicles that are typically used as candidate platforms into which transfer seat bases are installed, particularly with regard to the OEM seats and their respective seat belt anchors;
- The feasibility of modifying an existing transfer seat base to withstand combined seat inertia/seat belt loads from a 48 km/h frontal crash impact;
- A test procedure that can be used for impact testing of transfer seat bases using surrogate vehicle platforms; and
- Recommendations on whether transfer seat bases can be modified to withstand combined seat inertia/seat belt loading.

1.2 Report Structure

The main body of the report is organized into the following sections:

1. **Introduction.** This section provides a general overview of the purpose and objectives of the evaluation study.
2. **Standards and References.** This section lists the CMVSS and SAE Standards and References that are relevant to seat and seat belt testing.
3. **Installation Configuration Study.** This section describes information obtained on OEM candidate vehicles and OEM seats typically used in the installation of transfer seat bases.
4. **Engineering Analysis.** This section describes the failure analysis of the representative transfer seat bases and the results of stress/load analysis on various computer models representing transfer seat base components.
5. **Surrogate Testing.** This section presents a proposed test procedure for the crash impact testing of transfer seat bases using surrogate vehicle platforms.
6. **Conclusions.** This section describes the main findings of the study.
7. **Recommendations.** This section presents recommendations and design modification suggestions.

2. STANDARDS and REFERENCES

The standards, recommended practices, and technical reports reviewed in the preparation of this report are listed in this section.

2.1 Canadian Motor Vehicle Safety Standards (Consolidated)

1. MVSR 207 Anchorage of Seats;
2. MVSR 208 Seat Belt Installations; and
3. MVSR 210 Seat Belt Assembly Anchorages.

2.2 Society of Automotive Engineers (SAE) Standards (1993 SAE Handbook)

1. SAE J117 Dynamic Test Procedure – Type 1 and Type 2 Seat Belt Assemblies;
2. SAE J383 Motor Vehicle Seat Belt Anchorages – Design Recommendations;
3. SAE J384 Motor Vehicle Seat Belt Anchorages – Test Procedure;
4. SAE J385 Motor Vehicle Seat Belt Anchorages – Performance Requirements;
5. SAE J782b Motor Vehicle Seating Manual;
6. SAE J826 Devices For Use In Defining and Measuring Vehicle Seating Accommodation;
7. SAE J879b Motor Vehicle Seating Systems; and
8. SAE J2094 Vehicle and Control Modifications For Drivers With Physical Disabilities – Terminology.

2.3 Transport Canada Reports and Technical Papers

1. TP 13246E Evaluation of Six-Way Transfer Seat Bases (TDC, September 1998);
2. TC 80-64-9 CMVSS210 Seat Belt Assembly Anchorage Standards Standard Enforcement Testing;
3. TC 92-127 Test Report, Seat Anchorages NSVAC-CMVSS 207, Mazda MPV, 1992;
4. TC 96-131 Test Report, Seat Anchorages NSVAC-CMVSS 207, Dodge Caravan, 1996;
5. TC 97-126 Test Report, Seat Belt Anchorages NSVAC-CMVSS 210, Honda Odyssey, 1997; and
6. TC 91-037 Test Report, Seat Belt Anchorages NSVAC-CMVSS210, Mazda MPV, 1991.

3. INSTALLATION CONFIGURATION STUDY

3.1 Purpose of Study

During a previous study (reference: TDC report TP 13246E), three (3) representative six-way transfer bases were subjected to two different load scenarios: first, to seat inertia loads (20 times seat assembly weight), and second, to combined seat inertia and occupant inertia (seat belt) loads. The rationale for the combined loading situation was as follows: in the situation where the OEM seat incorporated into its design the inboard seat belt anchor, some portion of the total seat belt load (26,688 N as prescribed in current seat belt tests) is borne by the OEM seat. If the OEM seat is re-installed on a six-way transfer seat base (after removal of the original seat pedestal), then a similar load would be transferred to the six-way transfer seat base. During the first study, the distribution of OEM seats with/without seat-belt anchors was unknown. However, it was expected that the situation regarding OEM seats with seat-mounted seat belt anchors (at least the inboard anchor) was not uncommon.

The test results from the first study indicated the representative six-way transfer seat bases were not capable of withstanding the combined loading configuration, even when only a portion (the inboard anchor) of the seat belt assembly load was transferred to the six-way transfer seat base. Therefore, the configuration of the OEM seat belt assembly, and how it is integrated into the final installation of the six-way transfer seat base, was crucial in determining the crash worthiness of existing six-way transfer seat bases. In short, existing transfer seat bases cannot be expected to withstand both seat inertial and occupant inertial loads commensurate with a crash impact.

During the first study, a number of articles were reviewed in various trade journals that indicated a manufacturing trend whereby OEM seats would be manufactured with some or all of the seat belt anchors integrated with the seat (e.g. SAE 930348 Safety Performance of Motor Vehicle Seats). It was proposed to Transport Canada, and accepted, that a study be conducted to determine the current distribution (in current model vehicles) of the various seat belt assembly configurations. The following sub-sections of Section 3 describe the results of the survey of a number of current model vehicles.

3.2 Seat Belt Assembly Distribution in Current Model Vans/Minivans

A survey of current model vans and mini-vans, and their attendant seat belt assembly configurations was conducted for the purpose described in Section 3.1. The distribution of seat belt assemblies is summarized in Table 3.1. The nomenclature used to describe the seat belt assembly types follows the conventions established by the SAE (and in most cases by the FMVSS and CMVSS).

The following types of seat belts (IAW SAE J141) are typical:

Type 1	A seat belt assembly that provides pelvic restraint only.
Type 2	A seat belt assembly that provides both a pelvic and upper torso restraint.
Type 2A	A seat belt assembly consisting of either a separate upper torso restraint intended for use only with a Type 1 seat belt assembly or an upper torso restraint that may be connected to a Type 1 seat belt assembly for use as a Type 2 seat belt assembly.

The following types of seat belt anchors (IAW SAE J383) are typical:

Type A	Seat belt outside seat or through seat springs.
Type B	Seat belt over seat cross bar.
Type C	Seat belt attached to seat frame.

To further differentiate, seat belt anchors that were found attached to the OEM seat pedestal (the structure used to interface the OEM seat to the vehicle floor) are designated simply as Type "C", while those attached directly to the OEM seat are designated as Type "C*" in Table 3.1. During the survey, measurements of the seat belt anchor locations were also taken and reported in Table 3.1. A diagrammatic sketch of the seat belt anchor measuring points is shown in Figure 3.1. This sketch is based on the recommended seat belt loading device and seat configuration prescribed by SAE J117 Dynamic Test Procedure – Type 1 and Type 2 Seat Belt Assemblies.

As shown in Table 3.1, the anchor point measurements taken from the nine (9) vehicles were very close in value, as can be seen from the small values for the standard deviations. Also, mean values corresponded closely to the seat belt loading device recommended in SAE J117, with the following exceptions:

- The vertical distance ("b" in Table 3.1 and Figure 3.1) from the vehicle floor to the bottom of the seat pan; and
- The horizontal distance ("c" in Table 3.1 and Figure 3.1) from the upper torso anchor to the rear edge of the seat pan.

The anchor points referenced in SAE J117 were used in a computer model to estimate anchor reaction forces that were subsequently used in finite element analysis of selected six-way transfer seat bases. With the aforementioned exceptions of dimensions "b" and "c" the measured values of the nine (9) sample vehicles were deemed sufficiently close to the seat belt configuration referenced in SAE J117 that the original anchor loads (used in the computer analysis) were considered valid.

Interestingly, the seat pan heights measured in the nine (9) sample vehicles were very close to the maximum heights of the three (3) representative six-way transfer seat bases. From the survey, the mean vertical height was found to be 33 cm versus 35.5, 38, and 38 cm for the three (3) representative six-way transfer seat bases. Therefore, it would appear likely that six-way transfer seat bases would be used in the maximum vertical position while operating the vehicle since this height would be similar to the OEM installed seat height.

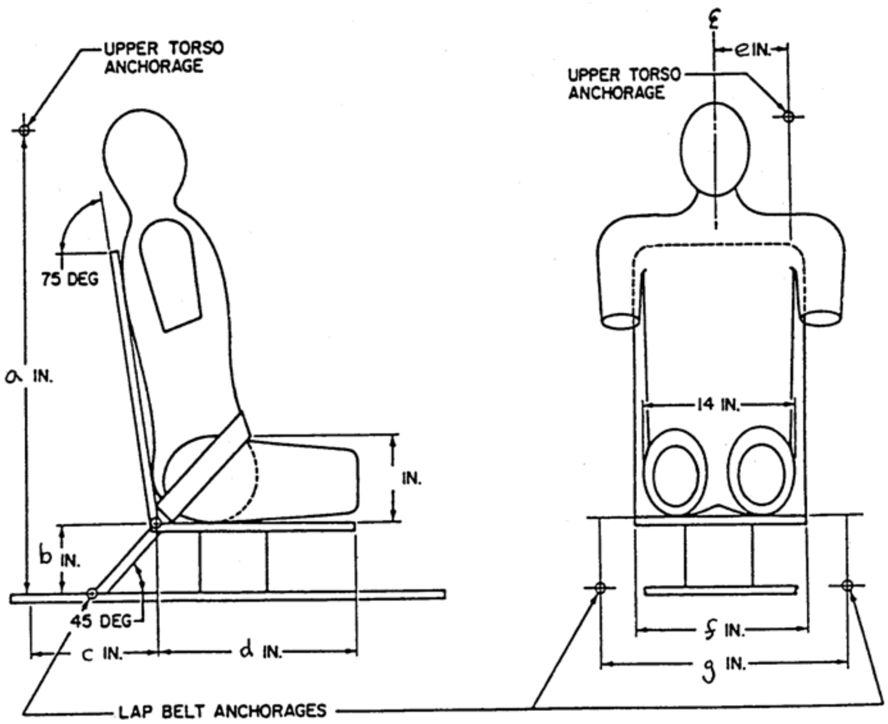

Figure 3.1 Seat Belt Anchor Location – Diagrammatic Sketch (based on SAE J117)

Table 3.1 Driver's Seat Belt Anchor and Seat Installation Data Sheet

Vehicle Mfg.	Model/Year	Seat Belt Type	Anchor Type	a cm	b cm	c cm	d cm	e cm	f cm	g cm	Comments
Ford	Windstar/99	2	C	92-110	37	18	43	25	42	52	Belt attached to seat pedestal
Honda	Odyssey/99	2	C*	91-105	37	17	32	23	49	54	Belt attached to seat assembly
GM	Astro/98	2	A	86-100	28	17	40	25	38	50	Belt attached to floor
GM	Venture/99	2	C	96-107	33	14	38	25	41	53	Belt attached to seat pedestal
GM	Transport/98	2	C*	97	34	20	34	26	45	57	Belt attached to seat assembly
GMC	Safari/98	2	A	100	27	15	44	25	36	51	Belt attached to floor
Mazda	MPV/98	2	C*	106	35	16	41	27	43	54	Belt attached to seat assembly
Dodge	Grand Caravan/99	2	C*	97-102	32	10	38	25	44	54	Belt attached to seat assembly
Toyota	Sienna/99	2	C	84-100	33	17	42	25	43	53	Belt attached to seat pedestal
Mean				99	33	16	39	25	42	53	Statistical mean (average) value
Std dev				4.3	3.5	2.8	4.0	1.1	2.8	2.0	Standard deviation of the mean value
SAE				99	15	56	46	23	46	64	SAE J117 Dynamic Test Procedure

Legend:

Seat Belt Type 1	A seat belt assembly that provides a pelvic restraint only
Seat Belt Type 2	A seat belt assembly that provides both a pelvic and a upper torso restraint
Seat Belt Type 2A	A seat belt assembly consisting of either a separate upper torso restraint intended for use only with a Type 1 seat belt assembly or an upper torso restraint that may be connected to a Type 1 seat belt assembly for use as a Type 2 seat belt assembly
Anchor Type A	Seat belt outside seat or through seat springs
Anchor Type B	Seat belt over seat cross bar
Anchor Type C	Seat belt attached to seat pedestal
Anchor Type C*	Seat belt attached to seat assembly
a,b,c,d,e,f,g	Anchor location measurements (in cm), refer to Figure 3.1 for physical meaning

3.3 OEM Seat Assembly Information

The purpose of collecting OEM seat information was to determine a mean or estimated value for OEM seat weight that could be used in load and stress analysis of the six-way transfer seat base. In the event of a 48 km/h (30 mph) frontal crash impact, the following loads will contribute to the overall stresses in the six-way transfer seat base:

- A load equal to the inertial mass of the six-way transfer seat base times 20 g with a line of action directed forward through its own centre of gravity (CoG);
- A load equal to the inertial mass of the OEM seat times 20 g with a line of action directed forward through its own CoG;
- In the case of a six-way transfer seat base with seat-mounted seat belt anchors, a load equal to 13,344 N (3000 lb) applied equally to both the pelvic belt anchors and the torso belt anchors (the exact load taken by the six-way transfer seat base depending upon the seat belt assembly configuration).

All three (3) of the aforementioned loads are prescribed, in more detail, in CMVSS 207 and the Reference Test Laboratory Procedure for CMVSS 207. The first load is dependent on the actual six-way transfer seat base in question. The three (3) representative six-way transfer seat bases evaluated in the first study ranged in weight from 34.5 kg (76 lb) to 43.2 kg (95 lb). The OEM seat weight used in the current analysis was 15.5 kg (34 lb), based upon a single representative OEM seat.

An extensive search was conducted at the Transport Canada library (330 Sparks Street, Ottawa) to obtain test reports pertaining to CMVSS207 and CMVSS210 testing. Only two (2) CMVSS207 test reports were found, namely:

- Report TC# 92-127, Test Report, Seat Anchorages, NSVAC-CMVSS 207, Mazda MPV, 1992; and
- Report TC# 96-131, Test Report, Seat Anchorages, NSVAC-CMVSS 207, Dodge Caravan, 1996.

In Report TC# 92-127, the 1st row seats were listed as being individual, folding, adjustable seats, with seat belt anchorages attached to the seat (the 2nd and 3rd row seats are bench type seats). The seat mass was listed as 28.7 kg (63.1 lb), comprising a 6.2 kg (13.6 lb) seat back and a 22.5 kg (49.5 lb) seat cushion. It is assumed the seat cushion mass included the seat pedestal mass (which would be replaced by the six-way transfer seat base if so installed).

In Report TC # 96-131, the 1st row seats were also listed as being individual, folding, adjustable seats, with seat belt anchorages attached to the seat (the 2nd and 3rd row seats were bench type seats). The seat mass was listed as 19.4 kg (42.7 lb) for the left seat and 21.3 kg (46.9 lb) for the right seat. Once again, it is assumed the seat mass included the seat pedestal mass.

Although the aforementioned seat masses (21.3 to 28.7 kg) are larger than the 15.5 kg used in the analysis, some fraction of the seat mass must be subtracted to account for the pedestal which is replaced by the six-way transfer seat base. Since the pedestal mass was not listed separately (in the reports) there is at present no accurate method of determining an average OEM weight. However, if a seat pedestal mass of approximately 5 kg is assumed, then the three (3) OEM seats listed in the report would have masses (excluding seat pedestal) ranging from 16.3 to 23.7 kg.

If the seat belt loads are considered in the total load situation, then a small variation in OEM seat mass is not significant. For example, if we consider the case whereby the following loads apply:

- 196 (20 x 9.81m/s^2) x 40 kg (six-way transfer seat base mass) = 7840 N;
- 196 (20 x 9.81m/s^2) x 20 kg (OEM seat weight) = 3920 N;
- resultant seat belt load on six-way transfer seat base = 14,200 N; then
- total load on six-way transfer seat base = 25,960 N.

From the above example, it can be shown that a difference of ± 5 kg would change the total resultant load by less than 4%. Therefore, for the purposes of this report, an OEM seat weight of 20 ± 5 kg would appear reasonable.

3.4 Significance of Survey Findings

Table 3.1 presents the findings from nine (9) representative candidate vehicles, all vans or mini-vans, with respect to seat belt assembly configurations. In the nine (9) vehicles surveyed only two (2) vehicles had the seat belt anchors wholly mounted on the vehicle with no direct/indirect attachment to the OEM seat. In the seven (7) remaining vehicles four (4) had the inboard seat belt anchor attached directly to the OEM seat and three (3) had the inboard seat belt anchor attached to the seat pedestal. Examples of current model vans/minivans with Type C* seat belts are shown in Figures E1 through E4, of Appendix E; examples of current model vans/minivans with Type C seat belts are shown in Figures E5 through E7.

Based upon the previous study (TP 13246E), six-way transfer seat bases, as currently designed, can not withstand the combined loading of both seat inertia and occupant inertia, whereby the occupant inertia load is transferred through the seat belts to the seat anchors. With respect to those vehicles with some or all of the seat belt anchors integrated with the OEM seat, there is an outstanding issue as to how those seat belt anchors are re-installed when the OEM seat pedestal is replaced with a six-way transfer seat base.

It is a fair and reasonable assumption based upon the survey results that an OEM seat with seat-mounted seat belt anchors could be installed on an existing six-way transfer seat base. The engineering analysis, which is described in Section 4 of this report, therefore focuses on the performance of six-way transfer seat bases under this known "worst-case" scenario.

4. ENGINEERING ANALYSIS

4.1 Failure Analysis

The purpose of Section 4.1 is to examine how the three (3) representative six-way transfer seat bases that were physically tested during the previous study (TP 13246E) failed the combined loading situation described in Section 3.2.

Figures E8, E9, and E10, in Appendix E, show the B&D, Braun, and Ricon seats, respectively, just prior to the application of loads as prescribed by the TES210 test procedure. Visible in each figure is a bracket welded on to the rear of the six-way transfer seat base used to apply the seat inertia load. Also visible in the upper right-hand side of Figures E9 and E10 are the (yellow) pelvic and upper torso blocks. The rear bracket, pelvic, and upper torso blocks represent the points of load application.

Figure E11 shows the B&D 908D after it failed the TES210 test and was returned to TES. Clearly visible in the lower right-hand side of the figure are the rear guide roller axles, which have been torn out of the guide rails. The rear deck plate has been bowed considerably. The rack mechanism has also been considerably bent. Bending of the rack probably occurred after the rear guide rollers became dislodged from the guide rails. Due to the substantial structural deformation this transfer seat base was unable to sustain the loads required by the test procedure. The actual loads were measured as follows:

- CoG location 5,930 N (1333 lb) vs required load of 11,300 N (2540 lb);
- Torso block 4,893 N (1100 lb) vs required load of 13,344 N (3000 lb); and
- Pelvic block 4,893 N (1100 lb) vs required load of 13,344 N (3000 lb).

It was noticed that after the TES207 rearward load application (11,300 N) had been applied, there was moderate deformation of the rear deck plate even though the test was considered a pass. Again during the forward load application (11,300 N) there was reverse bending of the rear deck plate (thus undoing the deformation in the preceding test). It is apparent that the rear deck plate and guide rails are inadequate to retain the mechanism during the TES210 combined loading test.

Figure E12 shows the RICON 1208 after it failed the TES210 test and was returned to TES. Clearly visible in the lower left-hand side of the figure are the rear guide roller axles, which have been torn out of the guide rails similar to the previous example. Also deformed were the scissors legs, the rack mechanism, and the guide rails. Due to the substantial structural deformation this transfer seat base also was unable to sustain the loads required by the test procedure. The actual loads were measured as follows:

- CoG location 7,940 N (1785) vs required load of 11,209 N (2520 lb);
- Torso block 8,896 N (2000 lb) vs required load of 13,344 N (3000 lb); and
- Pelvic block 8,896 N (2000 lb) vs required load of 13,344 N (3000 lb).

Figure E13 shows the Braun 13085A after it failed the TES210 test and was returned to TES. Figure E14 shows a close-up detail of the lower, rear, right–hand side frame member which was bowed out slightly (approximately 3 mm) after the test. The seat platform, to which the OEM seat was attached, was also deformed upwards (approximately 5 mm) at the rear right–hand side. Aside from the deformation of the aforementioned components there was no other visible defect or deformation. In fact, the unit was able to operate after the loads were removed. Nevertheless, the unit was unable to hold position during the application of the prescribed loads and was therefore considered to have failed. The loads sustained by this unit during the TES210 procedure were as follows:

- CoG location 2,224 N (500) vs required load of 10,853 N (2440 lb);
- Torso block 9,118 N (2050 lb) vs required load of 13,344 N (3000 lb); and
- Pelvic block 6,227 N (2000 lb) vs required load of 13,344 N (3000 lb).

To determine the exact cause of failure, which in this case (Braun 13085A) was the unit's inability to hold position during the load application, the rack and pinion drive mechanism used to move the seat platform was removed and examined. The rack and pinion drive mechanism used in this unit is similar to the mechanisms used on all three representative transfer seat bases: a DC electric motor drives a worm gear speed reducer, which has on the end of its output shaft a spur gear (pinion). The DC motor/speed reducer assembly (including pinion) is fixed to the carriage assembly while the rack is fixed at one end to the bottom frame assembly (that which is bolted to the vehicle floor). Hence, when the pinion is driven, either clockwise or anti-clockwise, by the motor/speed reducer, the carriage assembly (that part of the transfer seat base which is above the bottom guide rails) is moved fore or aft.

On close inspection of the Braun transfer seat base after the test, no missing, broken, or otherwise damaged teeth on either the rack or pinion were found. To determine what caused the unit to "let go" during the load application, a test was conducted on a similar motor/speed reducer (the unit tested was the drive unit from the B&D 908D, which had the same manufacturer's part number as the Braun unit). Figure E15 shows the test set–up in which a drive socket was welded to the driving pinion of the motor/speed reducer unit. A calibrated torque wrench was fitted to the drive socket and a torque applied to the driving pinion while the main body was secured in a machinist's vise. The maximum torque developed by the unit was 54 Nm (480 inch lb). At this value the metal screw threads of the worm would start to "skip" or slip over the plastic teeth of the worm gear (shown as a light–coloured ring in Figure E15). The maximum possible transmitted load based upon the pitch diameter of the pinion and the torque can be calculated as follows:

$$Wt = \frac{2T}{d}$$

where Wt = transmitted load
T = torque on the pinion
d = pitch diameter

Based on the nominal diameter of the pinion examined, the maximum possible transmitted load that can be sustained by the motor/speed reducer is 6.7 kN (1500 lb). The maximum transmitted load can be interpreted as the force exerted by the rack on the pinion when the transfer seat base is acted upon by external forces. External forces could be inertial force in the case of a crash impact or quasi-static forces in the case of a compliance test (e.g. CMVSS 207/210).

Based upon a computer model developed for this project (and discussed in Sections 3.2 and 3.3) the maximum longitudinal force that would be exerted on the rack during the TES210 procedure would be approximately 19 kN, which is significantly higher than the 6.7 kN sustainable by the motor/speed reducer. During the first test of the Braun transfer seat base (test procedure TES207) the longitudinal force was 10,853 N (2440 lb) which was satisfactorily attained. It is possible that the worm gear teeth were worn slightly during the test; this may account for the relatively low torque values (and corresponding low values for transmitted load). In any case, the mode of failure for the Braun transfer seat base can definitely be attributed to the slipping of the worm gear teeth.

During the TES210 test procedure the Braun transfer seat base sustained only 17kN or approximately 46% of the total required force of 37.5 kN. Applying this fraction to the theoretical longitudinal component of force of 19 kN (from the computer model) resulted in an estimated longitudinal force component of 8740 N. This value is slightly higher than the maximum transmitted load of 6.7 kN calculated from the torque test of the worm gear speed reducer performed afterward the TES210 test. The difference can be attributed to small inaccuracies in the computer model and/or degradation of the worm/worm gear as a result of the TES207, 210 tests.

Interestingly, the RICON transfer seat base had an additional gearset between the worm/worm gear and the rack which effectively doubled the torque output of the speed reducer and hence doubled the transmitted load capability. This may explain why the RICON transfer seat base did not fail by slippage of the drive mechanism and in fact sustained higher total loads than the Braun model (25.7 kN versus 17.6 kN). The spur gear set located between the worm gear speed reducer and rack/pinion was found after the test to have two (2) broken teeth. In addition, the rack was bent and the pinion shaft had been sprung from its retainer.

In summary, the mode of failure for the Braun transfer seat base was attributed to slippage of the worm/worm gear in the rack and pinion drive mechanism. The design modification recommended for this unit is the replacement of the existing fore-aft drive mechanism with a drive system that can not be overdriven even in the event of failure of the drive gears. An example would be a power screw mechanism which uses a lead screw/travelling nut combination to convert rotary input to linear motion. In fact, all three (3) transfer seat bases use a similar type of unit for providing the up-down drive motion. The key performance requirement of such a unit is that **the unit must be capable of withstanding the entire load without being back-driven** (i.e. overdriven). Either a low–efficiency lead screw (e.g. acme screw) or some type of clutch/brake mechanism must be employed on the lead screw to prevent the unit from being overdriven.

The failure mode for the B&D 908D and RICON 1208 transfer seat bases was attributed to structural failure of the rear guide rollers, which then precipitated structural failure in adjoining components (rack, scissors legs, etc). A redesign of the guide rails, guide rollers, and scissors legs (the links connecting the upper carriage to the lower carriage) is required to enable these units to withstand combined seat inertia/seat belt loads. A similar recommendation as for the Braun is made whereby the existing fore-aft drive mechanism be replaced with a lead screw/travelling nut mechanism which is incapable of being overdriven.

4.2 Load Analysis

Section 4.2 describes the loads which typically act upon the six–way transfer seat base when installed in an actual vehicle, and also how these loads can be effectively incorporated into a computer model for analysis of hypothetical six–way transfer seat bases. Loading configurations considered in this evaluation were based on CMVSS207 and 210. The loads imposed upon seat assemblies (and by implication, transfer seat bases) as prescribed by CMVSS 207 and 210 essentially fall into three categories:

- Seat inertia loading;
- Rear impact loading; and
- Combined seat inertia/seat belt loading.

These three loading configurations were presented in the previous study and are reproduced in Table 4.1 of this report for reference.

Table 4.1 Summary of Loading Configurations

CMVSS 207	APPLICATION	CONFIGURATION	LOADS
(1) (a)(i)	Seats w/ or w/o Integrated seat belts.	Any position in which seat can be adjusted.	20 x seat weight applied through seat CoG.
(1)(a)(ii)	Seats w/ integrated seat belts.	Seat in rearmost position	Loads applied simultaneously with (1)(a)(i). 13344N applied to pelvic block. 13344N applied to torso block.
(1)(b)	Seats w/ or w/o integrated seat belts.	Seat in rearmost position.	Force equal to that producing a moment of 365 Nm about Srp.

In the Reference Laboratory Test Procedure for CMVSS No.207 “Anchorage of Seats”, there is a note which states,

> “If any seat belt anchorage is attached to the seat or has the same anchorage as the seat, the loads specified in CMVSS 210 shall be applied simultaneously with the forward longitudinal loads specified in (1) and (2) above. *In this case, the combination 207/210 test will be the only test performed on this particular seat.”*

The indication is that for those seats having one or more seat belt attachments only the combination 207/210 test is required, presumably because the combination 207/210 loads are significantly higher than the other loading configurations.

To estimate the effective loads transferred from a combination 207/210 test configuration to a hypothetical six–way transfer seat base, TES constructed a simple computer model with model constraints representing seat belt anchors located in the relative positions prescribed by SAE J117. Loads equal to those prescribed by CMVSS 207/210 were then applied to the model and the reaction forces at the hypothetical seat belt anchors noted. These reaction forces are presented in Table 4.2 and have not changed since the previous study.

Table 4.2. Seat Belt Anchorage Loads

LOAD DIRECTION	UPPER POINT	OUTBOARD POINT	INBOARD POINT
Fx (transverse)	4463 N (1004 lb)	1307 N (294 lb)	5770 N (-1298 lb)
Fy (longitudinal)	12.82 kN (2884 lb)	4970 N (1118 lb)	8486 N (1909 lb)
Fz (vertical)	11.16 kN (2510 lb)	4414 N (993 lb)	11.38 kN (2559 lb)

In terms of the stresses and strains imparted to the six–way transfer seat base, only those seat belt anchor loads associated with seat belt anchors attached to the transfer seat base are important. From the study of the distribution of seat belt configurations presented in Section 3, only the inboard point was integrated with the OEM seat. In future, however, it may be that none, some, or all seat belt anchors will be integrated with the seat. For the purposes of this project, only the inboard point reaction force was applied to the computer model of the six–way transfer seat base.

The inboard seat belt anchor load was superimposed on the 20 times seat assembly (transfer seat base plus OEM seat) to produce a resultant load and moment through the CoG of the combined transfer seat base/OEM seat model. The horizontal and vertical resultant forces and moment about the CoG are presented in Table 4.3.

Table 4.3 Resultant Forces/Moment Acting On/About CoG

Force/Moment	Value	Description
F_x	19.3 kN (4350 lb)	Longitudinal force through CoG
F_Y	11.4 kN (2560 lb)	Vertical force through CoG
F_z	5.8 kN (1300 lb)	Transverse (right to left) force through CoG
M_{cog}	2035 Nm (1500 lb.ft)	Moment (cw) about CoG

The forces and moment tabulated in Table 4.3 were applied to various computer models representing components of a hypothetical transfer seat base. The reaction forces and stresses resulting from these imposed loads is the subject of Sections 4.3 and 4.4.

4.3 Model Description

Sections 4.3 and 4.4 describe the computer analysis of a modelled six-way transfer seat base, closely represented by the Braun 13085A. The purpose of the modelling study was to determine whether there would be modes of failure other than that previously described in Section 4.1, and if it is feasible for an existing six–way transfer seat base to withstand the loads imparted by the combination 207/210 test.

The model developed for the analysis was based on the Braun 13085A because this transfer seat base sustained the least amount of deformation during the testing conducted during the previous study (TP 13246E) and was still operable after the testing. All three (3) transfer seat bases tested in the previous study failed the combination 207/210 test and the test results differed at the extremes between 41% of the required load (lowest total sustained load) versus 68% (highest), a difference of only 27%. However, the Braun model appeared to have the most robust carriage system and therefore was chosen as a candidate for the analysis.

The initial model used for the analysis was a 2–D planar kinematic/dynamic model developed using ALGOR® software. A graphical representation of this model is presented in Appendix A. The loads tabulated in Table 4.3 (with the exception of the transverse load) were applied to the kinematic/dynamic model to determine the reaction forces at the joints connecting the various linkages. These reaction forces were then used as load (force) inputs to subsequent finite element analysis (FEA) models to determine whether the loads would cause failure of the analysed components.

4.4 Stress Analysis Results

A number of component models were constructed for the analysis including the following:

- The upper platform (used for attachment of the OEM seat);
- The lower carriage guide rails;
- The links that connect the upper carriage to the lower carriage; and
- The upper, front, link pin (pin 50).

A detailed description of the loads and resulting stresses are presented in Appendix B of this report.

The upper platform was predicted to yield and hence to deform, but not to necessarily fail catastrophically (the analysis cannot determine the amount of plastic deformation). Since there is a generous amount of material in this region and the material is ductile and the loads quasi-static, local yielding can be expected to reduce areas of localized high stress. Based upon the analysis, it was decided to proceed with physical testing of the Braun six-way transfer seat base (discussed in Section 5).

The analysis indicated that the lower carriage guide rails were stressed below their material strength and were not considered to be a candidate for failure.

The front arm link exhibited localized stresses exceeding the material strength. A decision was made to proceed with testing since it would have been difficult to implement a design modification.

The upper front link pin was found to have an average shear stress close to the tensile strength for mild steel. A decision was made to proceed with testing and to evaluate the results.

5. SURROGATE TESTING

5.1 Test Approach

Based on an extensive analysis of the Braun 13085A (presented in Section 4), it was determined that during the previous phase of testing, this particular model had failed the combined TES207/TES210 test due to slippage of the fore-aft drive mechanism. Specifically, it was determined that the worm gear teeth had slipped (temporarily come out of mesh), allowing the carriage unit to move forward.

Computer analysis (presented in Appendices A and B) of the Braun six-way transfer seat base indicated that while several components would be stressed very close to their maximum working strength there was a fair-to-good possibility that the unit would pass if the fore-aft drive mechanism could be prevented from slipping. Therefore, a decision was made to test the unit for a second time to the TES207/TES210 loading configuration, but with the fore-aft drive mechanism "blocked". Figure E16 of Appendix E shows the blocking plate used to restrain the lower carriage to the rack, thereby preventing the movement of the lower carriage relative to the rack.

The rationale for testing the Braun unit with the fore-aft drive mechanism blocked was to determine whether the fore-aft drive mechanism was the critically weak link in the unit and the solitary cause of failure. The following sections describe the test procedure and test results.

5.2 Test Procedure

The test procedure used for testing the Braun unit six-way transfer seat base was the same procedure using during the previous study, namely procedure TES210. Testing of the unit was similar to the previous testing with the following exceptions:

- There was no TES207 test performed prior to the TES210 test; and
- Centre of gravity measurements were omitted since there was negligible change from the previous measurements.

A copy of the TES210 test procedure is presented in Appendix C of this report.

5.3 Test Apparatus

The test apparatus consisted of several systems and sub-systems as follows:

1. The NMEDA/Transport Canada Test Rig;
2. Pelvic and torso body blocks;

3. A surrogate seat belt assembly;
4. A surrogate automotive “B Pillar”;
5. A surrogate OEM seat; and
6. A surrogate inboard seat belt anchor.

The first three (3) items were essentially unchanged since the testing conducted during the previous study. The NMEDA/Transport Canada Test Rig is currently operated by SRD Bolduc; SRD Bolduc was contracted to perform the current testing. The pelvic and torso body blocks, which are used to represent the upper human body, conform to CMVSS 210. The surrogate seat belt assembly consisted of wire rope cable sheathed in the specified locations (where it contacted the body blocks) with rubber and secured with metal clamps.

The surrogate automotive “B Pillar” was constructed by SRD Bolduc under direction of TES Limited. It was constructed of sturdy metal frame members welded into a tripod arrangement with surrogate seat belt anchors at the top and bottom of the vertical member. The vertical distance between the top and bottom seat belt anchors was 99 cm; this was the mean distance calculated from the seat belt assembly survey (see Section 3). The top and bottom seat belt anchors on the “B Pillar” were arranged vertically in-line. The vertical distance between the bottom seat belt anchor and the “floor”, or horizontal mounting plane, was 5.5 cm.

The surrogate OEM seat was an industrial–type seat with padded back and seat cushion. It was securely fastened to the six-way transfer seat base and was used to support the pelvic body block during test set-up; it was not designed, and not intended, to support any load during testing.

The surrogate inboard seat belt anchor was a short length of structural angle with a feed-through hole of 19 mm diameter for the surrogate seat belt. It was attached to the upper platform of the six-way transfer seat base with weldments. The vertical distance between the inboard seat belt anchor and the “floor” was 37 cm versus the mean distance of 33 cm calculated from the survey; some measurements from the survey were as high as 37 cm (e.g. Ford Windstar, Honda Odyssey). The horizontal spacing between the inboard and lower outboard seat belt anchors was 51 cm versus the mean distance of 53 cm calculated from the survey; the range in the survey was 50 to 57 cm. The fore-aft horizontal distance between the upper seat belt anchor and the inboard seat belt anchor was 23 cm versus 16 cm; the range in the survey was 10 to 20 cm.

The six-way transfer seat base, just prior to load application, is shown in Figure E17 of Appendix E of this report. The surrogate “B Pillar” is the tripod arrangement as shown in the left side of the figure. The rear push ram used to provide the 20 x seat weight force can be seen going through the angle formed by the front two members of the tripod and attaching to the rear of the six-way transfer seat base. The lower frame unit of the seat base was attached directly to the transverse “I-beams” of the test rig. Note that there was no additional “floor” substrate added to the test rig. The surrogate seat belt was attached to the upper, outboard, seat belt anchor, passed over the torso block, looped through the inboard seat belt anchor, and then passed over the pelvic block before being attached to the lower outboard seat belt anchor.

5.4 Test Loads

The six-way transfer seat base was subjected to the following loads, as prescribed by the TES210 test procedure:

- A rear push of nominal 10.85 kN (2440 lb) through the centre of gravity of the entire seat assembly;
- A nominal 13.3 kN (3000 lb) pull on the torso body block in the forward direction; and
- A nominal 13.3 kN (3000 lb) pull on the pelvic body block in the forward direction.

5.5 Test Results

The Braun 13085A six-way transfer seat base sustained the prescribed forces for 14 seconds, which was the entire time during which the load was applied. The seat base after test is shown in Figure E18 of Appendix E of this report. Although the seat base suffered some severe deformation, it did not reach the end of its maximum travel (in any direction) and was therefore considered to have passed by the definition of the test procedure.

The test results data sheets, completed immediately after the test, along with the test agencies official test report, are presented in Appendix D. Please note that the calibration charts used to correlate the pressure in the load actuator cylinders with the force applied to the unit are presented separately, in Appendix F.

6. CONCLUSIONS

- *A significant number of OEM seats with seat-mounted seat belt anchors at the inboard location currently exist*. The implication is that in a vehicle that has seat-mounted seat belt anchors, the installer of the transfer seat base may simply elect to re-install the OEM seat, with attached seat belt anchor, onto the installed transfer seat base. In this configuration, the transfer seat base must withstand some portion of the occupant inertial loads superimposed onto the seat assembly inertial loads.

- *The current fore-aft drive mechanism, which was found to be similar on all transfer seat bases, is inadequate to provide longitudinal restraint in situations where the aforementioned combined loading exists*. The implication is that transfer seat bases must be redesigned, either by adding supplemental restraint, or by replacing the existing fore-aft drive mechanism with a mechanism that cannot be overdriven, nor is prone to slipping under the considerable forces commensurate with crash impacts.

- *At least one representative transfer seat base is currently being manufactured, the Braun model 13085A, which if redesigned with a suitable fore-aft drive mechanism, would likely pass a combined CMVSS 207/210 test*. The amount of redesign required is not expected to considerably increase weight or cost.

7. RECOMMENDATIONS

- *Consideration should be given to a requirement that all transfer seat successfully pass a test involving both seat inertia and seat belt loads, similar to the testing described within this report*. The rationale is that it should be possible to ensure that all manufactured transfer seat bases, regardless of whether they are intended for first point of sale vehicles, or retrofitted vehicles will provide adequate restraint in the event of a vehicle crash. By the same respect, it should be possible to ensure that transfer seat bases will provide adequate restraint regardless of whether the re-installed OEM seat has an attendant seat-mounted seat belt anchor in the inboard location, or whether the OEM seat is unencumbered by seat belt anchors.

- *Consideration should be given to adopting a test requirement that allows for the use of surrogate vehicle platforms*. A surrogate vehicle platform, with suitably prescribed geometrical boundaries, will allow for substantially reduced cost of testing of transfer seat bases. In addition, transfer seat base manufacturers will be able to design their product to a known performance requirement, regardless of vehicle interface. In turn, the installer of the transfer seat base, who may or may not be the manufacturing company, will know that the product has met minimal performance requirements beforehand.

- *The existing rack and pinion drive mechanism, currently favoured by all transfer seat base manufacturers, should be replaced by a system whereby "slip" is all but eliminated*. A fore-aft drive mechanism with a similar level of system simplicity to the current one, could possibly be developed using a power screw type mechanism (similar to the manual lifting screw employed in automotive type jacks). By judicious use of thread forms and thread sizes the screw could be made non-reversible. The advantage over the current system is that the rack and pinion is reversible whereby the power screw could be easily made non-reversible. Thus, even if the speed reducer sub-assembly (driving the power screw) were to fail catastrophically, the unit would still not necessarily be eliminated of longitudinal restraint; this is not so in the case of the current systems. A supplemental, manually applied, restraint (i.e. a "parking brake") would provide a further assurance of safety.

APPENDIX A

STATIC ANALYSIS OF A SIX-WAY TRANSFER SEAT BASE

A1. MODEL DESCRIPTION

The structure examined was a six way transfer seat base (hereafter referred to as a transfer seat base). A 2-D (planar) model was constructed using Algor's Dynapak Analysis software. The model was based upon a representative transfer seat base, a Braun, model 13085A. The model, shown in Figure A1, was constructed using the following elements:

1. Five (5) rigid bodies or links (including ground);
2. One (1) translational joints: J10 (label "10" on figure);
3. Four (4) revolute joints: J20, J30, J40, J50 (label "20", "30", "40", and "50"); and
4. Two linear springs: S1, S2 (not shown).

The links and interconnected joints represent the mechanical structure while the springs were used to represent two force actuators. The first spring represented the rack and pinion drive assembly used for fore/aft movement of the transfer seat base; the second spring represented the linear drive assembly used for up/down movement of the parallelogram lift assembly.

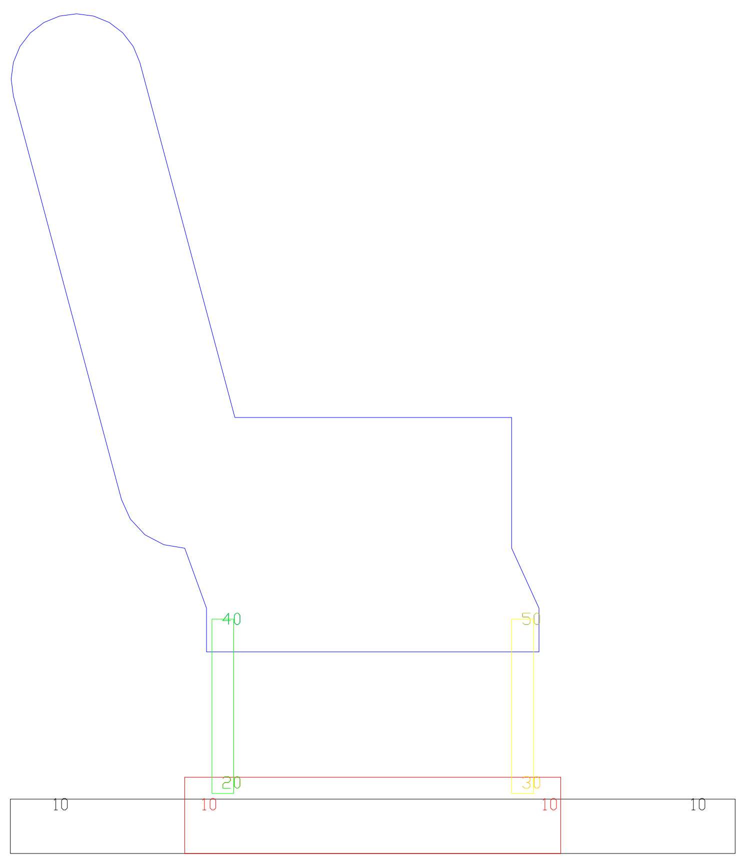

Figure A1. Transfer Seat Base Model

A2. LOADING CONFIGURATION

The analysis software allows for a variety of inputs, for both motion and force. In the present study only static forces and equilibrium reactions were examined. The loads imposed on the model incorporated both seat inertia and seat belt loads (the seat belt load was applied to a fictitious seat belt anchor located at the lower right side of the OEM seat).

The actual values for the seat belt loads were derived from a separate modelling study used to determine the loads imposed upon the transfer seat base by the seat belt assembly when subjected to the performance requirements of CMVSS 210. The separate modelling study analyzed seat belt loads based upon a configuration of seat belt anchors described in SAE J117 - Dynamic Test Procedure - Type 1 and Type 2 Seat Belt Assemblies. The loads that resulted from the modelling simulation are shown in Table A1. The loads at the inboard anchorage point were then transferred to the transfer seat base model to determine the reaction loads in the model.

Table A1. Seat Belt Anchorage Loads In Newtons, N

LOAD DIRECTION	UPPER POINT	OUTBOARD PT.	INBOARD PT.
P_Z (transverse)	4,463 N (1004 lb)	1,307 N (294 lb)	5,770 N (-1298 lb)
P_X (longitudinal)	12,819 N (2884 lb)	4,970 N (1118 lb)	8,486 N (1909 lb)
P_Y (vertical)	-11,157 N (-2510 lb)	4,414 N (993 lb)	11,375 N (2559 lb)

A3. Reaction Loads

The model, diagrammatically shown in Figure A1, was subjected to the following forces and moment about the CoG:

Table A2. Resultant Forces/Moment Acting On/About CoG

Force/Moment	Value	Description
F_x	19.3 kN (4350 lb)	Longitudinal force through CoG
F_Y	11.4 kN (2560 lb)	Vertical force through CoG
M_{cog}	2035 Nm (1500 lb.ft)	Moment (cw) about CoG

The forces and moment were applied to the CoG location as shown on Figure A1. The CoG location was derived from CoG measurements taken on an actual OEM seat weighing 151 N (34 lb) and the Braun 13085A transfer seat base which, as tested, weighed 391 N (88 lb). The forces and moment were derived from the 20 times seat weight performance requirement (10,840 N) superimposed on the seat belt loads on the inboard anchor as tabulated in Table A1.

The reaction forces on the joints and springs resulting from the Seat Inertia loading case only are tabulated in Table A3.

Table A3. Seat Inertia Loading Reaction Forces In Newtons, N

PT.	J10	J20	J30	J40	J50	S1	S2
Fx	0	29 N (7 lb)	480 N (108 lb)	29 N (7 lb)	10.9 kN (2450 lb)	10.9 kN (2440 lb)	11.3 kN (2550 lb)
Fy	542 N (122 lb)	613 N (138 lb)	6980 N (1570 lb)	597 N (134 lb)	194 N (44 lb)	0	7156N (1610 lb)

The reaction forces on the joints and springs resulting from the seat belt loading case only are tabulated in Table A4.

Table A4. Seat Belt Loading Reaction Forces In Newtons, N

PT.	J10	J20	J30	J40	J50	S1	S2
Fx	0	382 N (86 lb)	287 N (65 lb)	382 N (86 lb)	8090N (1820 lb)	8446N (1900 lb)	8360N (1880 lb)
Fy	10.8 kN (2440 lb)	11.0 kN (1210 lb)	5378N (1210 lb)	11.0 kN (2480 lb)	30 N (7 lb)	0	5334N (1200 lb)

The reaction forces on the joints and springs resulting from the combined seat inertia and seat belt loading case are tabulated in Table A5.

Table A5. Combined Seat Inertia/Seat Belt Loading Reaction Forces In Newtons, N

PT.	J10	J20	J30	J40	J50	S1	S2
Fx	0	890N (201 lb)	1,290 N (291 lb)	890 N (201 lb)	18.5 kN (4150 lb)	19.3 kN (4350 lb)	19.7 kN (4440 lb)
Fy	10.8 kN (2440 lb)	10.6 kN (2380 lb)	11.8 kN (2660 lb)	10.6 kN (2390 lb)	365 N (82.2 lb)	0	12.1 kN (2730 lb)

APPENDIX B

FINITE ELEMENT ANALYSIS of a SIX-WAY TRANSFER SEAT BASE

B1. Mounting Plate (First Variant)

The upper mounting plate shown in Figure B1 is similar to the upper mounting plate found on the Braun model 13085A six-way transfer seat base, and is representative, in material and thickness, to the mounting plates found on the three (3) transfer seat bases. The finite element model was constructed using four (4) node "plate" elements in ALGOR® software. The material represented in the model is 6.4 mm (0.25 inch) thick steel, corresponding to the plate found on the Braun transfer seat base. The model is constrained at the center of the plate by the round boss which on the actual transfer seat base is used to retain the swivel mechanism axle. The loads for the model were the same as those estimated for the inboard seat anchor, tabulated in Table A1 under "Inboard Pt.". The loads were applied to the lug which is shown to be joined perpendicularly to the rear right side of the plate.

The stresses calculated for this model are "Von-Mises" stresses are shown in units of pounds per square inch (psi). The stresses are clearly well above the yield strength of mild or even high strength steel and therefore an actual part would fail under this type of loading. To determine whether the effect of mounting a seat frame on the platform would have a mitigating effect on the plate stresses, a number of plate variants, which incorporated various stiffeners, were analyzed. The final plate variant is discussed in section B2.

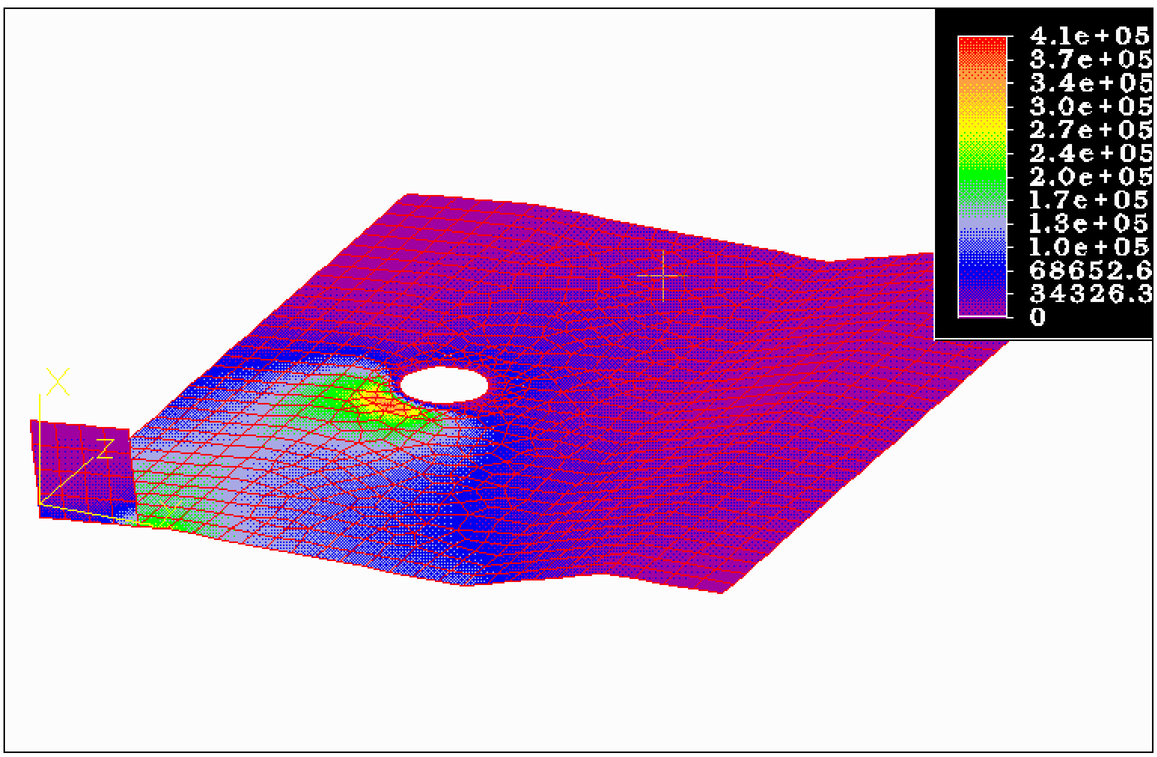

Figure B1. Mounting Plate, First Variant, FEA Model

B2. Mounting Plate (Final Variant)

To assess the effect of stiffening the mounting plate, a number of variant models were produced. One of these variants is shown in Figure B2. It is similar to the original plate variant shown in Figure B1 except that one transverse and two (2) longitudinal channel sections have been incorporated as stiffeners. The result of these stiffeners is quite pronounced in that the maximum stresses have been reduced by 60%. Those areas of the plate which are above the nominal yield strength of the material (assumed 60,000 psi), are in this model quite few in number and quite localized. Figure B3 shows those plate elements with stresses above 60,000 psi (plate elements with stresses below this value have been “turned off”).

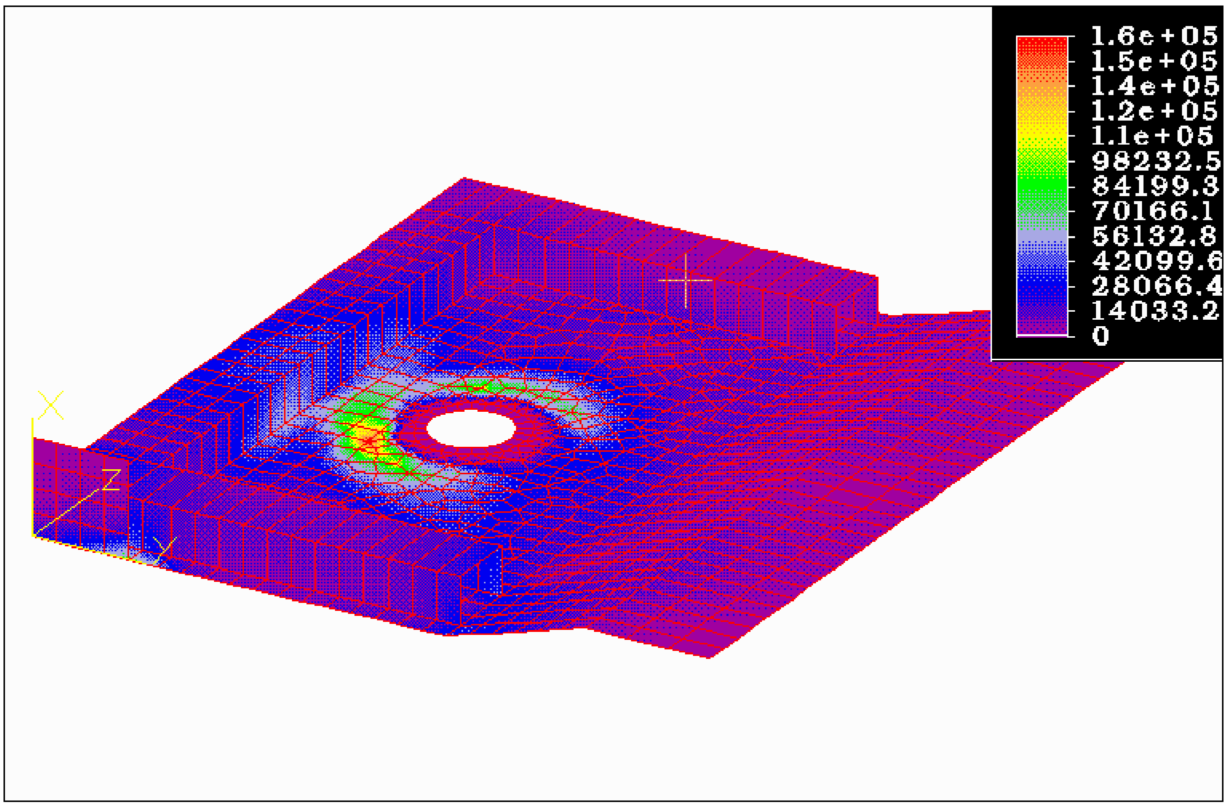

Figure B2. Mounting Plate, Final Variant, All Elements Visible

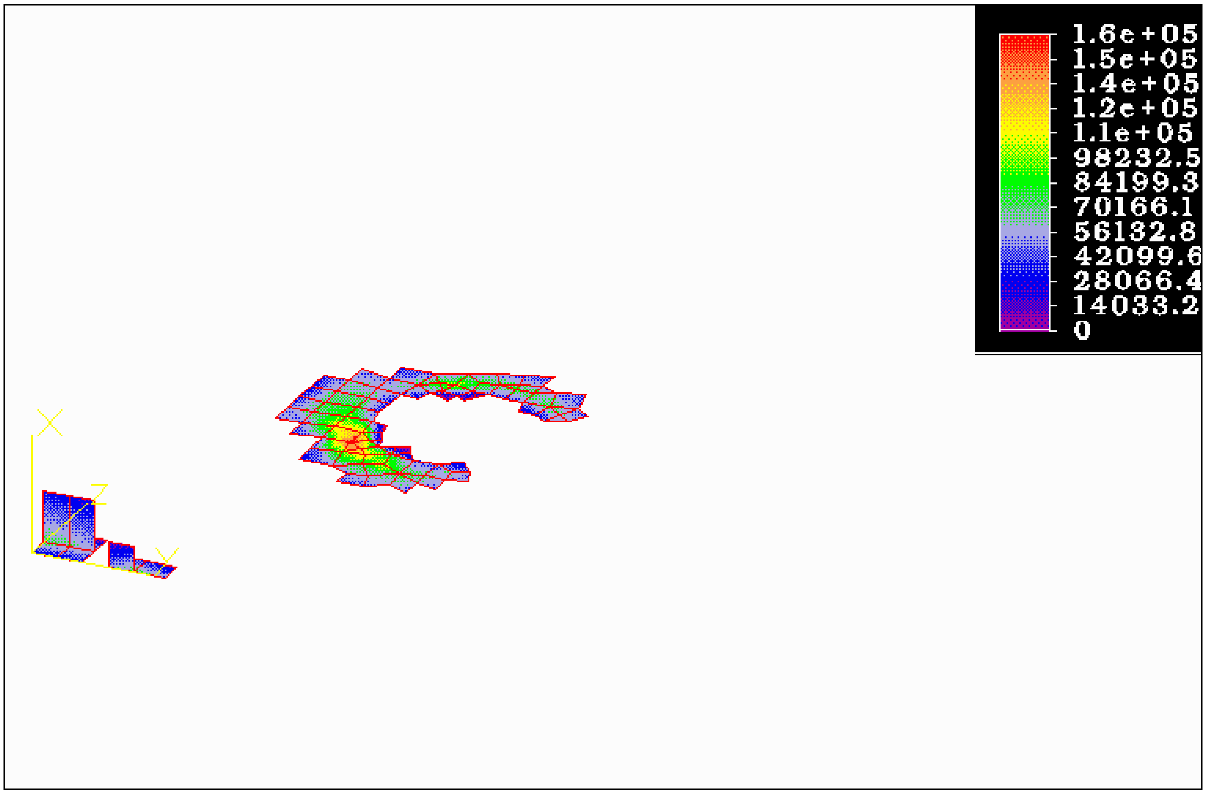

Figure B3. Mounting Plate, Final Variant, Threshold Set At 60,000 PSI

B3. Guide Rails

To assess the performance of the guide rails used in the under carriage of the Braun model 13085A six-way transfer seat base, a finite element model was created in ALGOR® software. The model consisted of 2D beam elements with material and sectional properties corresponding to guide rails used in the Braun transfer seat base. The loads imparted to the model were derived from a rigid body analysis of a simplified six-way transfer seat base which had the following loads applied:

Inboard seat anchor location, fore/aft direction:	8451 N (1900 lb)
Inboard seat anchor location, vertical direction:	11.4 kN (2560 lb)
Inboard seat anchor location, transverse direction:	5782 N (1300 lb)
Centre of Gravity location, fore/aft direction:	10.9 kN (2440 lb)

The reaction loads resulting from the aforementioned load situation were then applied to a model of the guide rails. Figure B4 shows the guide rails with the stresses shown in units of pounds per square inch (psi). The stresses are below the yield strength (45,000 psi) for the material (2024-T3 aluminum). Figure B4 shows the model in its “displaced” configuration. The bottom rail in the figure corresponds to the right hand side rail.

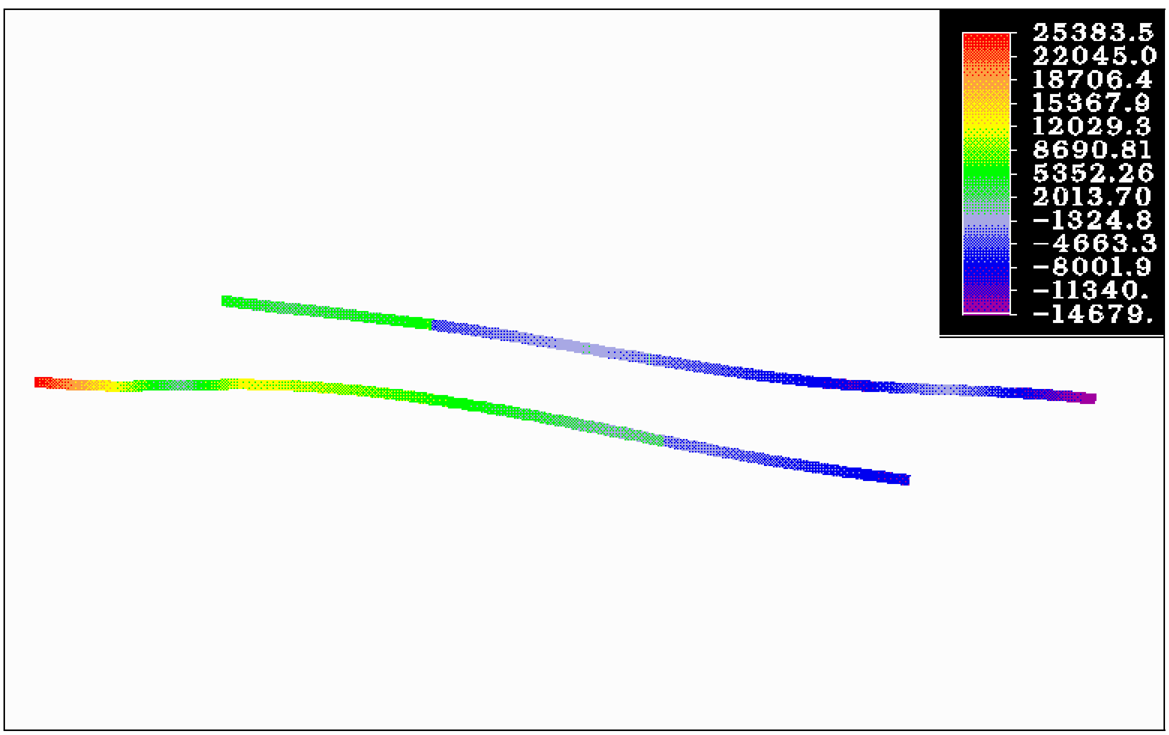

Figure B4. Guide Rail Stress Pattern, Stresses (Axial Plus Bending) In PSI

B4. Front Arm Link

Figure B6 shows the finite element model of the “front arm” link used to join the lower carriage to the upper carriage of the Braun model 13085A transfer seat base. The model was constructed in ALGOR® software using four (4) node plate elements having material and sectional properties corresponding to the Braun transfer seat base. The link model was constrained at the periphery of the circular cut-out at one end with the loads applied to the opposite circular cut-out. The total load was calculated as 18.5 kN (4150 lb) and was applied as a uniformly distributed load. The 18.5 kN force applied was the reaction force calculated for PIN 50 shown in Figure A1. The stresses shown in Figure B5 are “Von-Mises” stresses in the units of pounds per square inch (psi). The stresses are above the yield strength for mild steel and close to the tensile strength of structural steel. Failure or success of this part when subjected to full loading (in accordance with combined 207/210) loading cannot be confidently predicted.

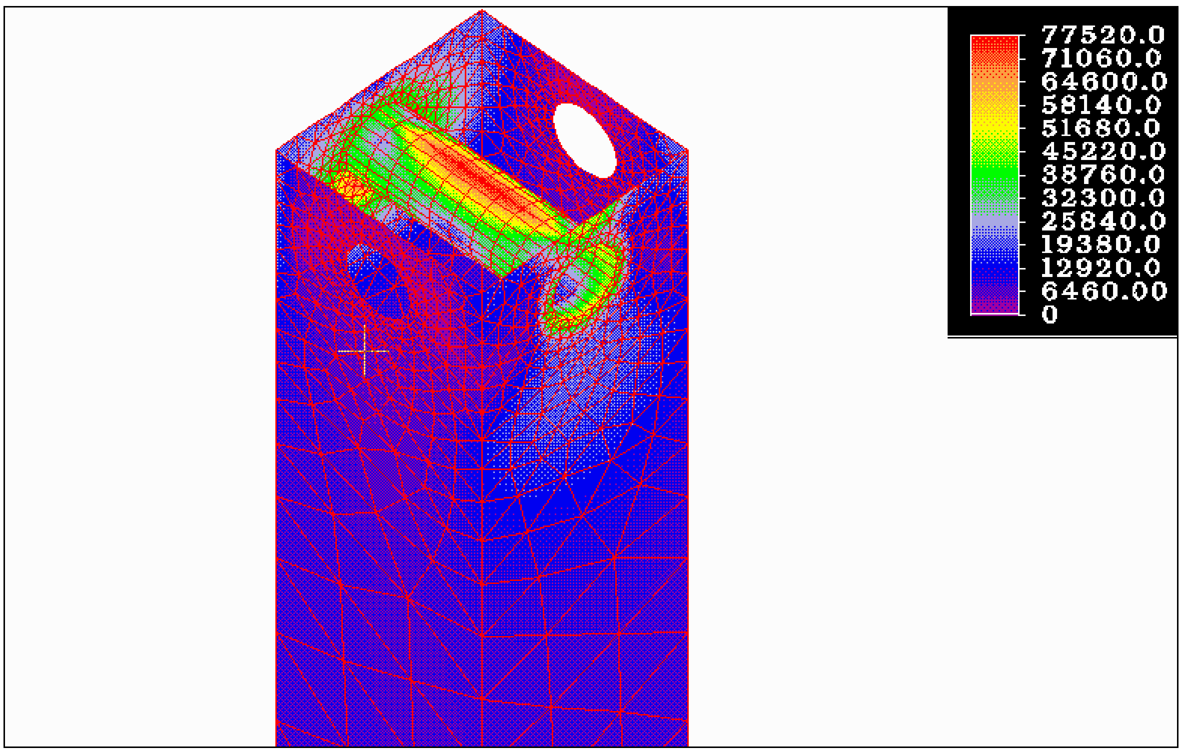

Figure B6. Front Arm Link Stresses (Von-Mises) In PSI

B5. Front Arm Link Pin

The front arm link shown in Figure B6 is connected to the upper carriage by a revolute joint, Pin 50 as shown in Figure A1 of Appendix A. From the kinematic stress analysis, the calculated shear load on this pin is 18.5 kN (4150 lb). The resulting average shear stress is 79,000 psi. Since the pin in question is actually a threaded rod, as opposed to a graded bolt, the proof load cannot be determined by a visual examination. Since the stresses occur at a point where there is existing stress risers, this component is susceptible to failure; however, performance (pass/fail) cannot be predicted with certainty.

APPENDIX C

TES210 TEST PROCEDURE

**(Not available in electronic format/
Non disponible en format électronique)**

APPENDIX D

TES210 TEST RESULTS

(Not available in electronic format/
Non disponible en format électronique)

APPENDIX E

FIGURES

(Not available in electronic format/
Non disponible en format électronique)

APPENDIX F

PRESSURE/LOAD CALIBRATION CHART

(Not available in electronic format/
Non disponible en format électronique)