COMPUTER SIMULATION AND BIOFIDELITY CONSIDERATIONS OF EUROSID

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ABSTRACT

In 1989 the ERGA-Passive Safety ad-hoc group finished a Draft Directive on the protection of car occupants in side-impact collisions. The document describes a 90 degree full-scale test for EC-type approval purpose. To assess injury the European Side Impact Dummy (EUROSID) is proposed.

EUROSID has been available in a production prototype form for two years. The dummy has been evaluated for biofidelity and in full-scale side-impact tests. A measurement program at the dummy with respect to the most important mass distribution data, joint properties and component stiffness data has been carried out at TNO. These measurements served as a basis for a three-dimensional model of the EUROSID for the MADYMO 3D Crash Victim Simulation program. Results of biofidelity tests were used for validation.

The objective of the presented model is to contribute to the insight in the dynamic behaviour of and the injury suffered by an occupant in a side-impact collision. The paper describes the set-up of the dummy database and compares simulations with test results. Most of the model simulations appeared to correlate well with the dummy test results. Deviations of the dummy response from the ISO biofidelity requirement corridors were also indicated by the model. The arm/shoulder assembly of the model needs further evaluation since the complex interaction observed in reality is not completely represented correctly in the model yet. Further improvement of the model should take place as soon as performance results of the latest dummy version become available.

INTRODUCTION

MADYMO is a computer program particularly developed for Crash Victim Simulations [1]. This paper is related to the development and application of a MADYMO 3D dummy database for occupant simulation in a side impact crash environment. A mathematical model of the European Side Impact Dummy - EUROSID - will be presented.

EUROSID has been designed, constructed and improved by a group of European research laboratories. Since 1987 production prototypes of this dummy have been evaluated in Europe, the United States of America, Canada and Japan. After this evaluation improvements were proposed and incorporated in the dummy.

The mathematical model is still based upon a prototype dummy (no. 1-011 1988), as far as dimensions, masses, moments of inertia and joint properties are concerned. Anticipating the latest arm design it was decided to model the upper arms only. The model consists of a number of elements representing the dummy body, with additional elements for the three ribs and the abdomen.

Impactor tests were used to validate the shoulder, the thorax, the abdomen and the pelvis model. The response of the complete dummy model was validated against the results of drop tests and rigid/padded wall sled tests. Where possible, the simulation results as well as the dummy responses will be presented together with ISO biofidelity requirement corridors [2].

GENERAL MODEL SET-UP

EUROSID is designed to assess injuries in side impact collisions, in particular at the head, the thorax, the abdomen and the pelvis. Injuries are determined by parameters such as head acceleration, rib deflection, abdomen impact force and pubic symphysis force. For these parameters injury tolerance levels have been defined [3]. Beside these parameters also optional quantities like spine-, rib- and pelvis accelerations can be measured for instance to study sensitivity and repeatability of the dummy.

The main part of the dummy model consists of a linkage system of 12 elements, i.e. head, neck, spine, pelvis, legs, clavicles and arms. The feet have been included in the lower legs. The ribs and abdomen insert are modelled by separate elements connected to the main part of the dummy model by springs-damper elements. The model of the seated dummy is shown in Figure 1. The elements used in the model are summarized in Table 1.

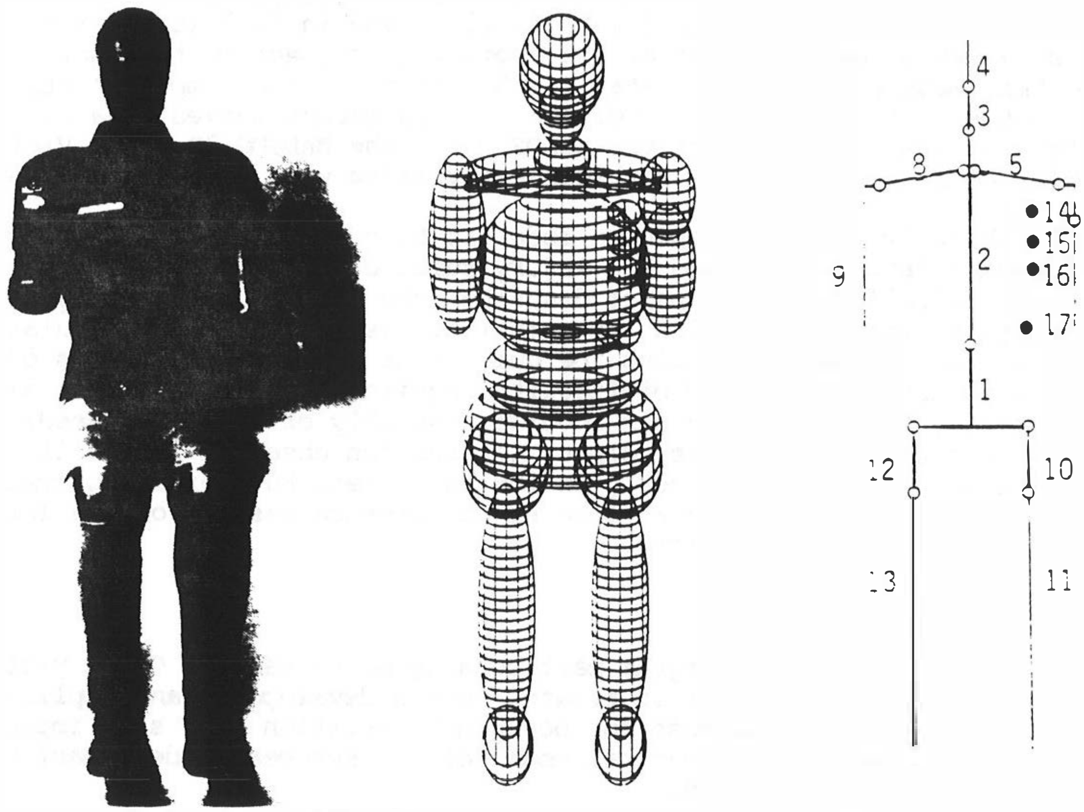

Figure 1: EUROSID: dummy, model and joint locations.

For all elements the mass, the location of the centre of gravity and the moments of inertia were measured. Except for the head it is assumed that the deviation in orientation between principal moments of inertia axes and local coordinate system axes is small so that these orientations are taken identical. Moments of inertia and orientation of the principal axes of the head are based on measurements reported elsewhere [4].

The joints in the model have been defined on locations identical to the locations of the hinges in the dummy (Figure 1). MADYMO allows for using two types of joint models. The cardan joint model was used in shoulder, arms and legs. The flexion-torsion joint model was used in lumbar spine and neck. The hip and knee joint characteristics originate from the HYBRID II dataset [5]. The clavicle/spine joint only allow for rotation in forward direction; the characteristic is prescribed in the EUROSID User's Manual [6]. Free ranges of motion and joint stops have been defined for the shoulder joints. The lumbar spine joint characteristics were defined according to the measurement of force and rotation during bending of the pelvis/abdomen/spine combination in frontal and lateral direction. The neck joints will be discussed lateron when describing the separate dummy elements.

Contact ellipsoids were defined in accordance with the various dummy segments: dimensions and locations were derived from technical drawings of EUROSID. Force/penetration characteristics were measured statically and dynamically, from which loading and unloading curves as well as estimations for hysteresis and damping were obtained.

Table 1: Element names of EUROSID model

	Element number	Element name
Body	1	Pelvis
	2	Spine
	3	Neck
	4	Head
	5	Clavicle left
	6	Shoulder left
	7	Arm left
	8	Clavicle right
	9	Arm right
	10	Upper leg left
	11	Lower leg left
	12	Upper leg right
	13	Lower leg right
Thorax	14	Upper rib
	15	Middle rib
	16	Lower rib
Abdomen	17	Abdominal insert

ELEMENT DETAILS

NECK - The EUROSID neck is composed of a neck/thoracic spine interface, a head/neck interface and a rubber made central section which links the two interfaces (see Figure 2). The model is set up with two joints. Assuming the head/neck joint to coincide with the rotation centre of the head/neck interface, the location of the neck/spine joint can be approximated from head trajectories obtained in pendulum tests. These tests were carried out with a special bi-symmetrical head to avoid neck torsion during lateral pendulum impact. The head centre of gravity showed a circular trajectory; the radius was ascribed to the distance between head centre of gravity and neck/spine joint. Figure 2 shows the EUROSID neck and the neck model.

The bending stiffness of the neck was obtained from a neck bending test and distributed over the model joints in accordance with the theory explained below. Consider the model as a rigid beam with two joints having stiffnesses Ka and Kb and consider the neck as an elastic beam with uniform stiffness. By equating deflections and rotations of both systems as a result of an applied bending moment, the relationship between Ka and Kb can be calculated. The definitive values of Ka and Kb can now be determined from the torque/rotation characteristic obtained in the neck bending test. The rotations of both the head/neck interface and the neck/spine interface are physically limited to 13°. Therefore, a joint stop in the model was defined by using a relatively stiff characteristic for the head/neck joint after reaching this value. The torsional stiffness was obtained from the HYBRID II database [5]. Damping was set to a value of 25% of the critical value.

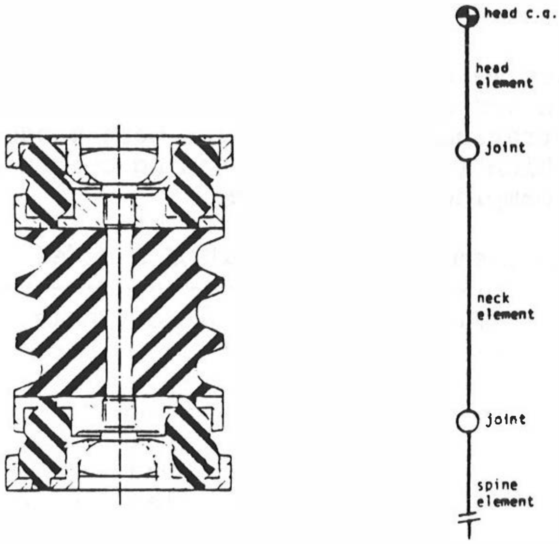

Figure 2: EUROSID neck and MADYMO neck model.

THORAX - The EUROSID thorax consists of a rigid thoracic spine box and three identical rib modules. A rib module (see Figure 3) consists of a rib of spring steel covered with sorbothane, a piston/cylinder assembly to guide the rib during deflection, a spring to tune the rib module stiffness and a stiff spring in series with a damper (Maxwell element). The MADYMO rib model consists of a mass connected to the spine by two spring damper combinations. One combination accounts for the metal rib, the tuning spring and the structural damping, both assumed to act parallel (Kelvin element). The other combination accounts for the spring and damper in series (Maxwell element).

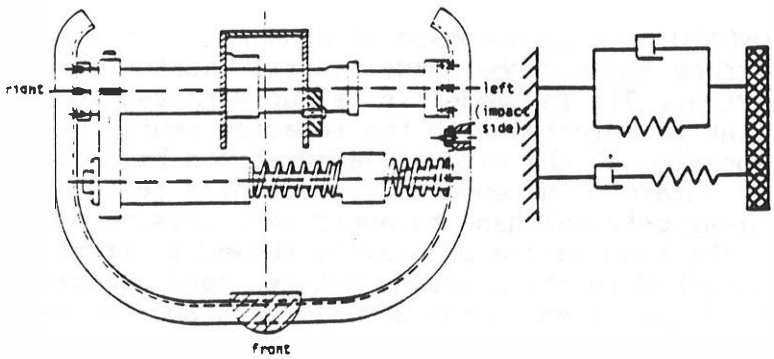

Figure 3: EUROSID rib module and MADYMO rib model.

Each rib module has a mass of approximately 2.5 kg. Most of this mass is assigned to the cylinder and the damper. It is assumed that only the piston, a part of the rib on impact side and the stiff spring are involved in the rib motion relative to the spine. This accounts for approximately 0.5 kg for each rib. The mass is guided by point restraints to imitate the piston/cylinder action. The stiffnesses of the springs in the Kelvin and Maxwell elements were obtained from static tests. The damping characteristics were determined from two dynamic impact tests, the first being applied to a single steel rib and the second to a complete module. By comparing the static and dynamic stiffnesses of the first test, the damping characteristic in the Kelvin element can be estimated. In the same way for the complete module the damping characteristic in the Maxwell element can be estimated. Three of these rib models add up to the complete thorax model.

ABDOMEN - The EUROSID abdomen (see Figure 4) consists of a metal drum and a foam covering in which at both sides lead-pellets have been integrated to obtain the required inertial mass. On the metal drum force transducers have been installed which measure the induced force during (mainly lateral) impact. The MADYMO abdomen model consists of a single mass which is attached to the spine by a Kelvin element. The mass represents that part of the lead-pellets which contributes to the force transmission. This mass was estimated to be 0.3 kg. The spring characteristic was determined in a static force/intrusion test. The damper characteristic was estimated from a dynamic impact tests. Part of the total spring force is allocated to predict the internal force level during dynamic impact.

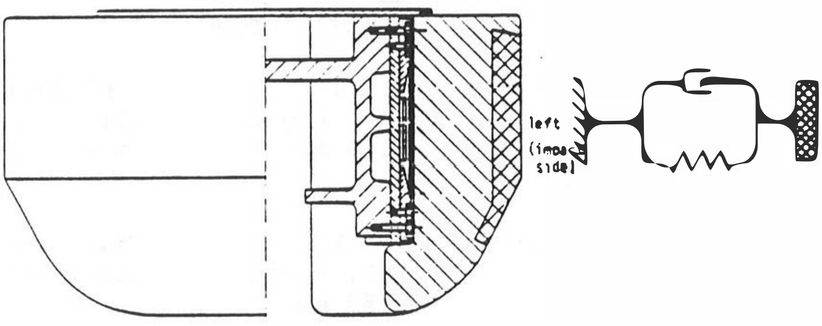

Figure 4: EUROSID abdomen and MADYMO abdomen model.

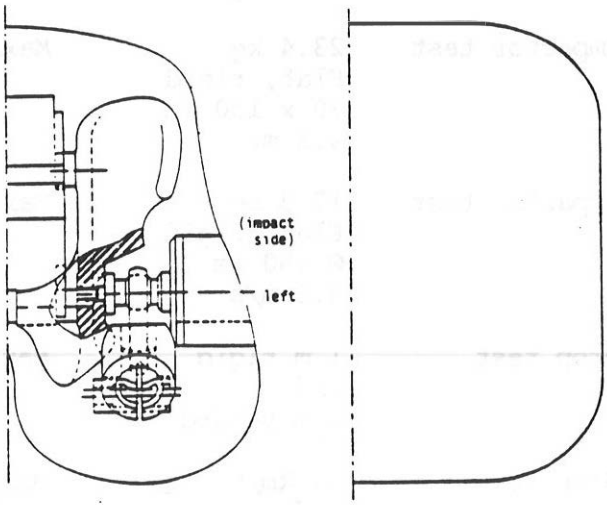

Figure 5: EUROSID pelvis and MADYMO pelvis model.

PELVIS - The EUROSID pelvis (see Figure 5) consists of a sacrum block, two iliac wings, two hip joints and a foam covering. The iliac wings are connected to the sacrum block and linked together by a pubic symphysis force transducer. Loading on the hip joint (H-point) results in force transmission through sacrum block and pubic symphysis. In MADYMO the pelvis was modelled as one single rigid element where the outside was represented by a hyper ellipsoid. By defining a contact characteristic it is achieved that the right amount of energy will be transferred to the dummy. As a consequense of the simplicity of this model no pubic symphysis force can be predicted so that the model is limited to predict pelvis accelerations only.

Table 2: Validation test program

Test object	Type of test	Test details	Measurements
Neck test	Pendulum test		Max. lateral acc. and head c.g. displacement
Thoracic test no.1 (Figure 7a and b)	Drop test	1 m rigid and 2 m padded	Max. impact force and average max. rib defl.
Thoracic test no.2 (Figure 8a and b)	Sled test	32 km/h rigid and 32 km/h padded	Max. impact force
Thoracic test no.3 (Figure 6a)	Impactor test	23.4 kg Flat, rigid Ø 150 mm 4.3 m/s	Rib deflections and max. impactor acc. and max. upp. spine acc.
Shoulder test (Figure 6b)	Impactor test	23.4 kg Flat, rigid Ø 150 mm 4.3 m/s	Max. impact force and max. deflection
Abdomen test (Figure 7c)	Drop test	1 m rigid and 2 m rigid	Max. impact force and max. low. spine acc. and max. low. rib acc.
Abdomen test (Figure 6c)	Impactor test	23.4 kg Flat, rigid 70 x 150 mm 4.3 m/s	Max. impact force
Pelvic test no.1 (Figure 6d)	Impactor test	17.3 kg Flat, rigid Ø 150 mm 5.6 m/s	Max. impact force
Pelvic test no.2 (Figure 7a and b)	Drop test	1 m rigid and 2 m padded	Max. pelvic acc.
Pelvic test no.3 (Figure 8a and b)	Sled test	32 km/h rigid and 32 km/h padded	Max. impact force and max. pelvic acc.

VALIDATION TESTS

The model was validated against the results of a number of different standard tests (summarized in Table 2) consisting of impactor tests, a pendulum test, drop tests and sled tests. The impact tests concern impact at a certain body part of the assembled dummy. The pendulum test deals with the performance of the head/neck combination. The drop tests are more or less an extension of the impact tests: just one single body part is impacted. The sled tests account for the response of the dummy as a whole, including the interaction between the various body segments.

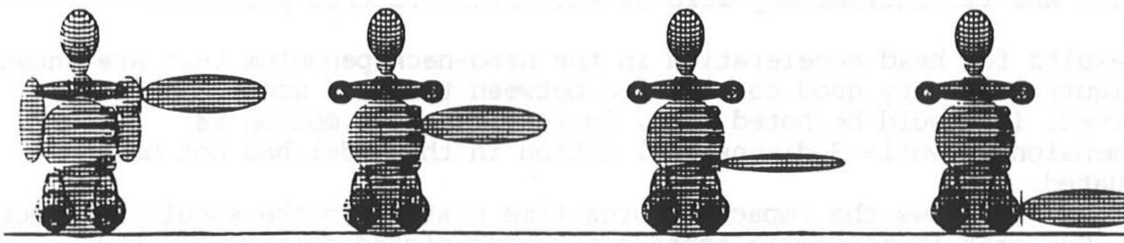

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Figure 6: Shoulder, thorax, abdomen and pelvis impactor tests.

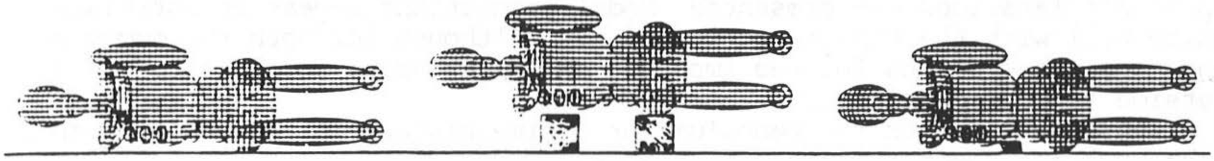

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Figure 7: Thorax/pelvis (rigid and padded) and abdomen drop tests.

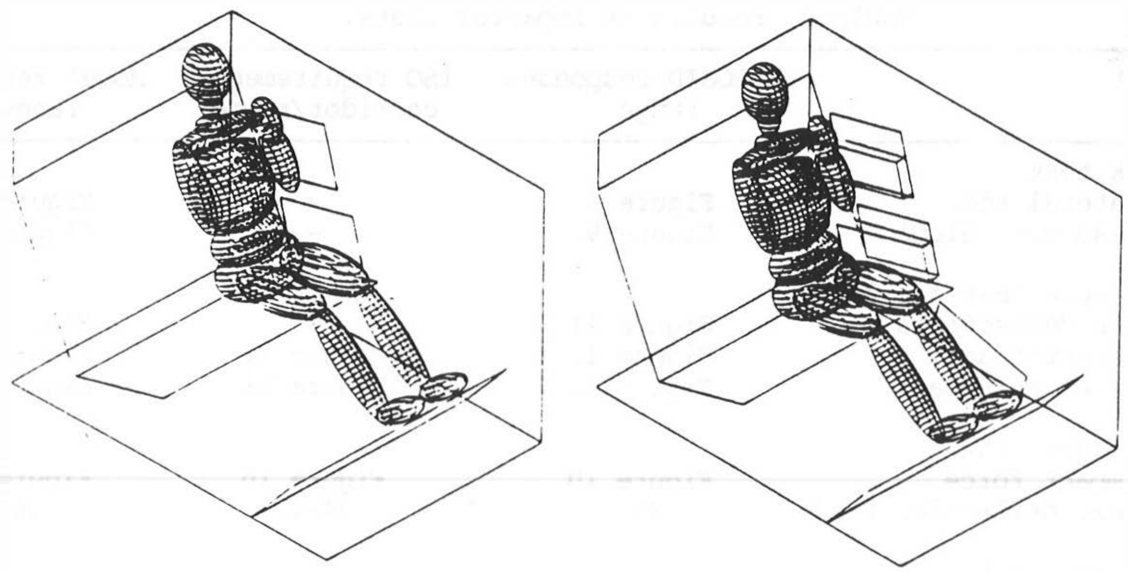

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Figure 8: Rigid and padded sled tests.

SIMULATION RESULTS

IMPACTOR TESTS - A series of impact tests on all relevant body parts of EUROSID has been performed. The tests were based on ISO requirements described in documents ISO/DP 9790-1 to 9790-6 [2]. In [8-9] the test set-up and test results have been presented. In the Figures 9-13 and in Table 3 the simulation results are compared with the test results and, if available, with the ISO corridors. It should be mentioned that the experimental data have been normalized according to the requirements in [2] in order to adjust for changes in effective mass due to slight differences in the position of the dummy on impact. So differences between experimental results and simulations may also be attributed to this procedure.

Results for head acceleration in the head-neck pendulum test are shown in Figure 9. A very good correlation between test and model can be observed. It should be noted that, in reality, neck motion is 3-dimensional, while 3-dimensional motion in the model has not been evaluated.

Figure 10 shows the impactor force time history in the shoulder impact test. The peak impact force appears to be predicted quite well; the duration, however, is too short, indicating that in the model the shoulder/arm assembly is too stiff. The shoulder deflection is predicted quite well compared to the requirements, as can be seen in Table 3.

Results for the thoracic impact are shown in Figure 11. The arms are not involved in these tests. Rib deflections, impactor accelerations as well as spine accelerations are presented. Model predictions appear to correlate quite well with the experimental findings, although for both the dummy and the model the results for the impactor and upper spine accelerations are outside the ISO corridors.

Figure 12 presents the pendulum force time history in the abdomen impact test. The agreement is quite reasonably.

Finally, in Figure 13, the pendulum force versus impact velocity in the pelvic impact test is shown. The dummy results as well as the simulation results are outside the ISO corridor, while both the dummy and the model show the same stiff behaviour.

Table 3: Results of impactor tests.

Test	EUROSID responses range	ISO requirements corridor/range	Model responses range
Neck test			
- lateral acc.	Figure 9	-	Figure 9
- head c.g. displ.	Figure 9	-	Figure 9
Thoracic test no. 3			
- rib deflections	Figure 11	-	Figure 11
- impactor acc.	Figure 11	Figure 11	Figure 11
- upper spine acc.	Figure 11	Figure 11	Figure 11
Shoulder test			
- impact force	Figure 10	Figure 10	Figure 10
- max. deflection [mm]	95	34-41	48
Abdomen test			
- impact force	Figure 12	-	Figure 12
Pelvic test no. 1			
- impact force	Figure 13	Figure 13	Figure 13

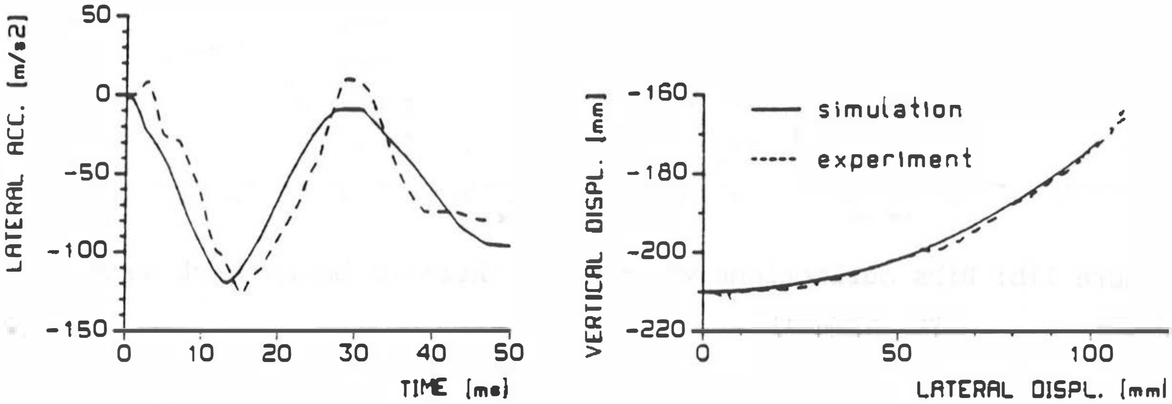

Figure 9: Head centre of gravity lateral acceleration vs. time and head centre of gravity trajectory in neck pendulum test.

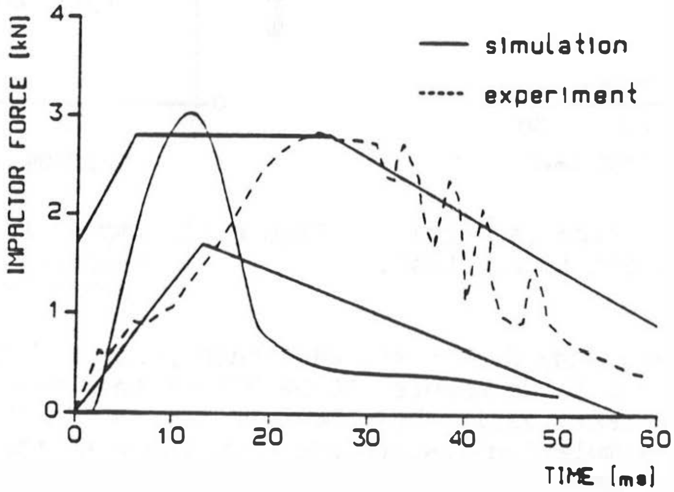

Figure 10: Impactor force vs. time in shoulder impact test.

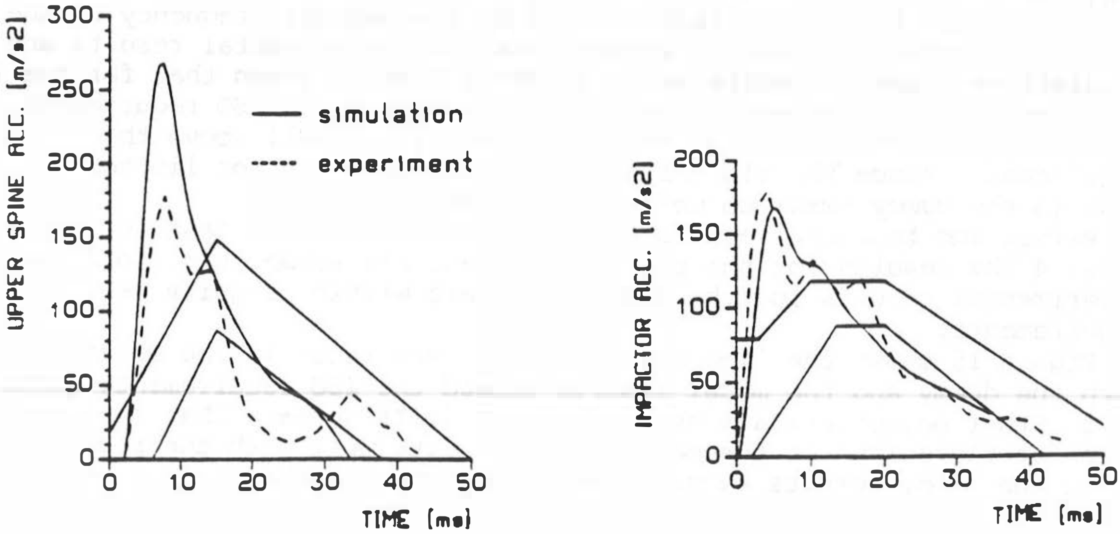

Figure 11a: Lateral upper spine resp. impactor acceleration vs. time in thoracic impact test no.3.

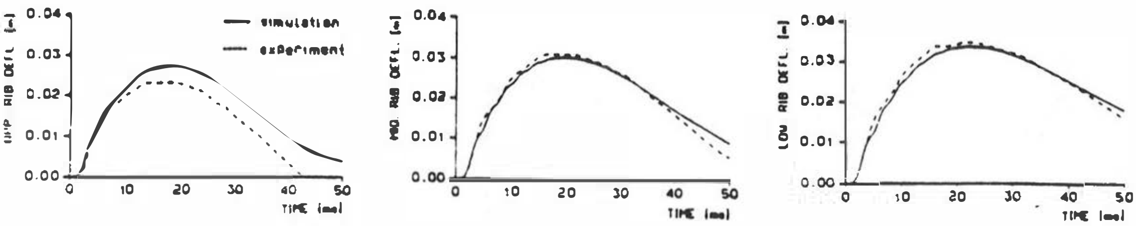

Figure 11b: Ribs deflections vs. time in thoracic impact test no.3.

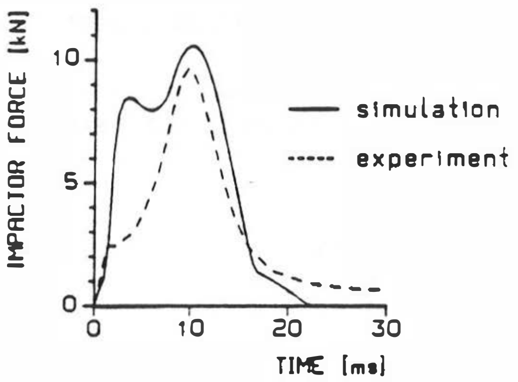

Figure 12: Impact force vs. time in abdomen impact test.

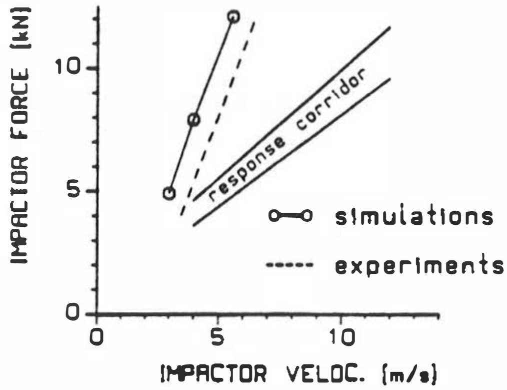

Figure 13: Impact force vs. impact velocity in pelvic impact test no.1.

DROP TESTS - Free dummy drop tests have been performed based on ISO requirements described in documents ISO/DP 9790-1 to 9790-6 [2]. In [8-9] the test set-up and test results have been presented. In the Figures 14-15 and in Table 4 the simulation results are compared with the test results and with the ISO corridors. Also in this case the experimental data have been normalized for reasons already mentioned.

Results for the thoracic impact force for the 1 m rigid and 2 m padded tests are shown in Figure 14. Omitting the first peak in the experimental results in the rigid drop test (caused by the natural frequency of the rib/load platform system) it appears that the experimental results and the simulations correlate quite well. In Table 4 it is shown that for the 1 m drop test the calculated rib deflection is within the ISO requirement. The calculated rib deflection in the 2 m drop test is well above the requirement, since the rib deflection in the model is not limited as is the case in the dummy (maximum deflection 50 mm).

Pelvic and thoracic results are obtained in the same test set-up. In Table 4 the results for the pelvic drop test are summarized. Both the experimental results and the simulations are within or quite near the ISO requirements.

Figure 15 shows the impact force on an 'arm rest' in the abdomen area. Both the dummy and the model results exceed the ISO requirements quite well. Other parameters are shown in Table 4. It appears that the lower spine accelerations in the model compare quite well with the requirements, while the dummy results exceed these requirements. The requirements on the lower rib accelerations are exceeded significantly by both the experimental results and the simulation results.

Table 4: Results of drop tests.

Test	EUROSID responses range	ISO requirements corridor/range	Model responses range
Thoracic test no.1			
- impact force			
* 1 m rigid	Figure 14	Figure 14	Figure 14
* 2 m padded	Figure 14	Figure 14	Figure 14
- average max. rib defl.			
* 1 m rigid [mm]	43.4	25-35	34.8
* 2 m padded [mm]	50.0	38-48	63.0
Abdomen test			
- impact force			
* 1 m	Figure 15	Figure 15	Figure 15
* 2 m	Figure 15	Figure 15	Figure 15
- max. lower spine acc.			
* 1 m [g]	65.6	29-35	52.0
* 2 m [g]	128.1	75-92	86.4
- max. lower rib acc.			
* 1 m [g]	282.2	100-125	185.
* 2 m [g]	333.2	160-200	600.
Pelvic test no. 2			
- max. pelvic acc.			
* 1 m rigid [g]	74.7	63-77	50.9
* 2 m padded [g]	38.1	39-47	45.0

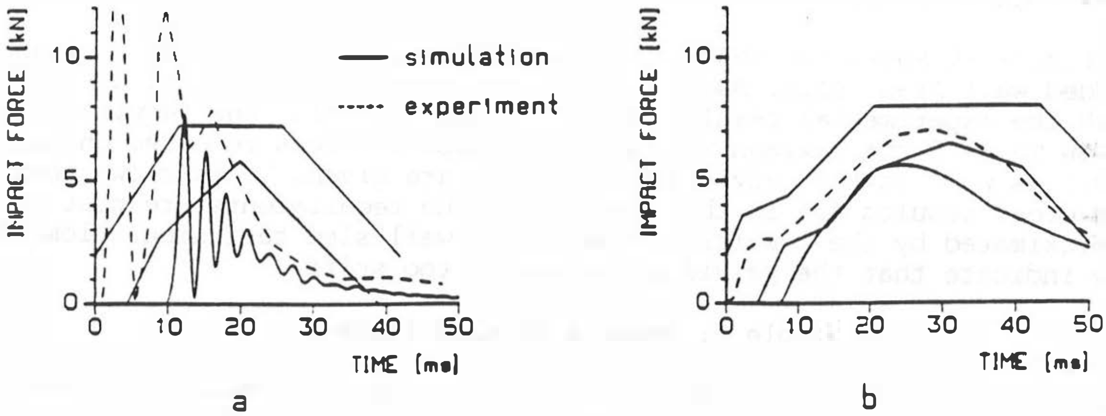

Figure 14: Thoracic impact force vs. time
in a) 1 m rigid thoracic drop test no.1,
b) 2 m padded thoracic drop test no.1.

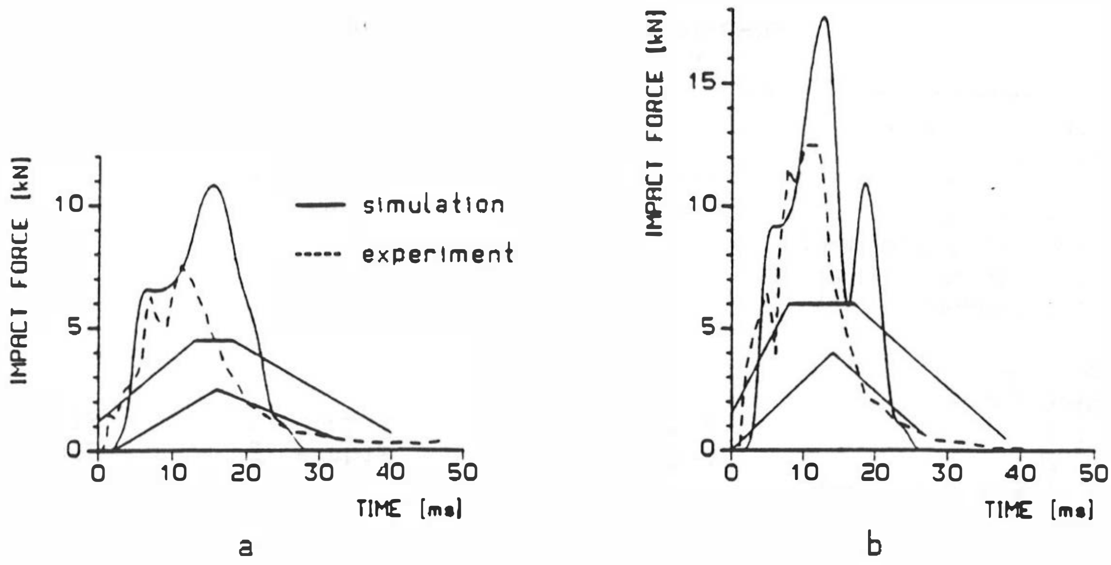

Figure 15: Abdomen impact force vs. time
in a) 1 m rigid drop test,
b) 2 m rigid drop test.

SLED TESTS - A series of rigid wall and padded wall sled tests was carried out. These tests, based on requirements described in ISO documents [2], have extensively been described and analysed in [7]. In Figure 16 and in Table 5 the simulation results are compared with the experimental results and with ISO requirements. Note that the experimental data again have been normalized.

Figure 16 shows the thoracic impact force in 32 km/h rigid wall and padded wall sled tests. Model predictions appear to correlate quite well with the experimental results. Both compare well with the requirements.

In Table 5 the maximum values of the impact forces recorded on pelvis level as well as the pelvic accelerations are given. It is shown that dummy and model results are in the same range. The requirements are best approximated by the results of the padded wall sled test simulation. This may indicate that the pelvis structure is too stiff.

Table 5: Results of sled tests.

Test		EUROSID responses range	ISO requirements corridor/range	Model responses range
Thoracic test no. 2				
- impact force				
* 32 km/h rigid		Figure 16	Figure 16	Figure 16
* 32 km/h padded		Figure 16	Figure 16	Figure 16
Pelvic test no. 3				
- max. impact force				
* 32 km/h rigid	[kN]	54.5	22.4-26.4	42.0
* 32 km/h padded	[kN]	20.7	11.6-13.6	24.5
- max. pelvic acc.				
* 32 km/h rigid	[kN]	189.4	96-116	148.0
* 32 km/h padded	[kN]	64.7	61- 75	80.0

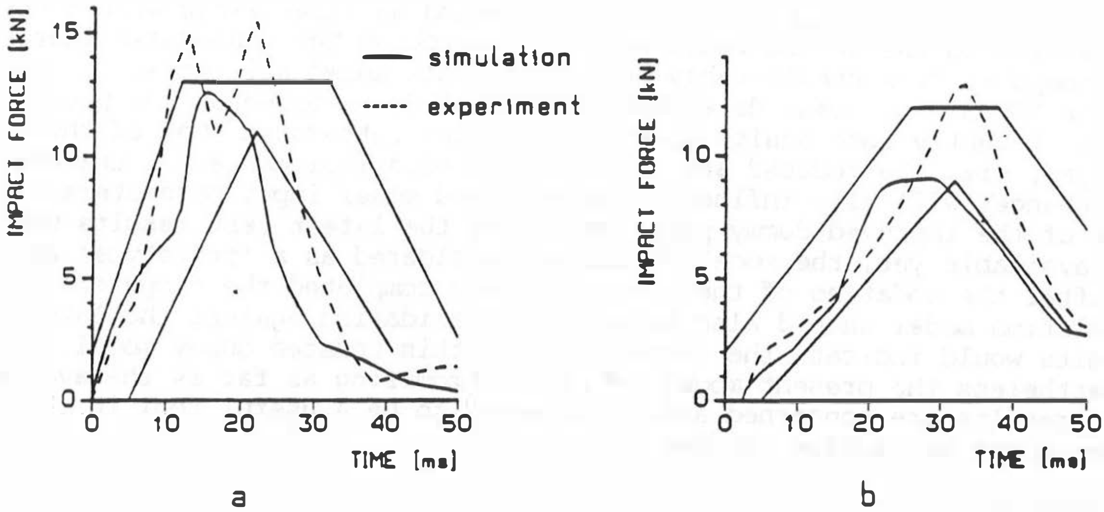

Figure 16 : Thoracic impact force vs. time
in a) rigid wall impact,
b) padded wall impact, thoracic test no.2.

DISCUSSION AND CONCLUSIONS

A computer model based on a prototype of the EUROSID has been developed. The model is formulated with the MADYMO 3D Crash Victim Simulation program and consists of 17 elements, connected by joints and spring-damper elements. With the model the same injury indicating parameters can be predicted as are measured in the real dummy. In a validation study the complete dummy response predicted by the model has been compared with results from impactor tests, drop tests and sled tests.

In general the simulation results are quite well comparable with experimental results. Especially the results of the impactor tests are rather good predicted by the model. In the drop test the largest deviation can be observed in the transmission of the thoracic force. Rib deflections and rib accelerations are different as soon as the dummy ribs reach their limits. There is a good comparison between pelvic responses in model and dummy. In the abdomen drop tests the differences between test and simulation are more explicit. In the sled tests the simulation results are of the same order as the test results.

An area of major concern is the representation of the arm/shoulder assembly. The contact interaction between impacting surface, arm and chest is very complex. Because of the flexibility of the arm and the complicated motion of the system during side-impact it is difficult to ascribe a certain behaviour to a certain phenomenon. In other words, the elasticity and hysteresis as well as the appearance of damping and friction are hardly to be localized unambiguously. A careful observation of the local behaviour under different impact conditions could contribute to a better understanding of the process and hence result in a better model.

The chest, represented by the three rib systems, shows a good behaviour. It is the advantage of this model that the rib deflection is not limited to physical values as is the case in the real dummy. Deflections of more than 50 mm can be calculated and thus give an impression of how much the full-scale test requirements are exceeded under certain circumstances.

In the pelvis area the prototype dummy appeared to be too stiff. In the present model the pelvis is described as a contact ellipsoid, which only accounts for force transmission to the spine. A disadvantage of this description is that the pubic symphysis force can not be calculated, because there is no load path defined in this model which correlates with this force. A more sophisticated model including iliac wings with a stiff connection to the sacrum would solve this problem but would also increase the computer time considerably because of this added stiffness.

The EUROSID database developed in this study is based on the prototype dummy. Recently some design changes have been introduced. One of the changes, viz. the reduced arm, has already been implemented in the model. The changes will also influence the selected model input parameters. As some of the improved dummy parts and hence the latest test results were not all available yet, the model should be considered as a 'prototype' as well.

After the updating of the dummy has been completed the computer simulation model should also be adapted. Validation against the latest test results would indicate the reliability of this updated dummy model. Nevertheless the present model is rather promising as far as the available test results are concerned and is expected to be a useful tool in side-impact protection studies.

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```
SYSTEM 1
BODY
CONFIGURATION
    4    3    2    1
    7    6    5    2    1
    9    8    2    1
   11   10    1
   13   12    1
-999
GEOMETRY
   0.000    0.000    0.000    0.023    0.000   -0.059       PELVIS
   0.000    0.000    0.088    0.029    0.000    0.089       SPINE
   0.073    0.000    0.445    0.       0.       0.042       NECK
   0.000    0.000    0.104    0.013    0.       0.051       HEAD
  -0.009    0.010    0.336    0.       0.0885   0.          CLAVICLE L
   0.105    0.147    0.000    0.       0.028   -0.020       UPP UPP ARM L
   0.000    0.028   -0.07     0.       0.      -0.090       LOW UPP ARM L
  -0.009   -0.010    0.336    0.      -0.0885   0.          CLAVICLE R
   0.105   -0.147    0.000    0.      -0.028   -0.105       UPPER ARM R
   0.068    0.100   -0.048    0.197    0.       0.          UPPER LEG L
   0.36     0.       0.       0.       0.      -0.278       LOWER LEG L
   0.068   -0.100   -0.048    0.197    0.       0.          UPPER LEG R
   0.36     0.       0.       0.       0.      -0.278       LOWER LEG R
-999
INERTIA
    11.9      0.11        0.076       0.111       PELVIS
    18.1      0.24761     0.17882     0.20652     SPINE
     0.5      0.003       0.003       0.0015      NECK
     4.8      0.0159      0.024       0.0221      HEAD
     0.4      0.002       0.001       0.0003      CLAVICLE L
     0.7      0.005       0.005       0.001       UPP UPP ARM L
     1.5      0.015       0.015       0.001       LOW UPP ARM L
     0.4      0.002       0.001       0.0003      CLAVICLE R
     2.2      0.020       0.020       0.001       UPPER ARM R
     9.2      0.017       0.159       0.159       UPPER LEG L
     4.4      0.147       0.147       0.005       LOWER LEG L
     9.2      0.017       0.159       0.159       UPPER LEG R
     4.4      0.147       0.147       0.005       LOWER LEG R
-999
ORIENTATIONS
 4 0 3  0.8943  0.0002  0.4475 -0.0001 -1.0000  0.0006 0.4475 -0.0006 -0.8943
-999
CARDAN JOINTS
   5  1  0   0.  0.  1  0   0.  0.  3  0   0.  0.  0.  0. 10.   0.  0.  1.0
   8  1  0   0.  0.  1  0   0.  0.  2  0   0.  0.  0.  0.  0.   0.  0.  0.
   6  4  0   0.  0.  4  0   0.  0. 10  0   0.  0.  0.  0.  0.   0.  5.  0.
   7  4  0   0.  0.  1  0   0.  0.  1  0   0.  0.  0.  0.  0.   0.  5.  0.
   9  4  0   0.  0.  4  0   0.  0. 10  0   0.  0.  0.  0.  0.   0.  5.  0.
  10  6  0   0.  0.  5  0   0.  0.  7  0   0.  0.  6.  6.  5.  39. 39. 12.
  12  8  0   0.  0.  5  0   0.  0.  7  0   0.  0.  6.  6.  5.  39. 39. 12.
  11  1  0   0.  0.  9  0   0.  0.  1  0   0.  0.  5.  7.5 4.   0. 12.  0.
  13  1  0   0.  0.  9  0   0.  0.  1  0   0.  0.  5.  7.5 4.   0. 12.  0.
-999
ORIENTATIONS
   5  5  1 2.  0.0873
   6  6  1 2. -0.0873
   8  8  1 2.  0.0873
   9  9  1 2. -0.0873
-999
FUNCTIONS
2
-1.000 -5000. 1.000 5000.
5
-1.000 -2000. 0. 0. 0.5 300. 1. 1000. 1.500 2000.
4
-1.000 -1000. -0.8 -80. 0. 0. 1.000 2000.
2
-1.000 -50. 1.000 50.
5
-3.280 -540. -2.280 -40. -1.570 0. 0.000 0. 1.000 500.
5
-1.880 -568. -0.880 -68. 0.000 0. 0.175 14. 1.175 514.
4
-2.000 -500. -1.000 0. 1.000 0. 2.000 500.
5
-1.175 -514. -0.175 -14. 0.000 0. 0.880 68. 1.880 568.
4
-1.000 -500. 0.000 0. 2.300 0. 3.300 500.
2
-1. -500. 1. 500.
-999
FLEXION-TORSION JOINTS
   2  1  2   684.   0.  3  0   0.   0.   3.0   0.   0  PELVIS-SPINE
   3  4  0     0.   0.  5  0   0.   0.   0.5   0.   0  SPINE-NECK
   4  6  0     0.   0.  5  0   0.   0.   0.6   0.   0  NECK-HEAD
-999
ORIENTATIONS
   3  2  1  2.  0.3491
-999
FUNCTIONS
```

```
2
-0.7046 -176. 0.7046 176.
2
-0.7046 -55. 0.7046 55.
4
-1.000 -126. -0.175 -40. 0.175 40. 1.000 126.
2
-1.0 -91. 1.0 91.
4
-1. -100. -0.2 -30. 0.2 30. 1. 100.
2
-1.0 -300. 1.0 300.
-999
ELLIPSOIDS
    1 0.110  0.175  0.110   0.060  0.      -0.052  4. 10  0        0.  PELVIS
    2 0.100  0.140  0.083   0.045  0.      -0.038  2.  1  0        0.  ABDOMEN
    2 0.120  0.155  0.160   0.050  0.       0.160  4.  2  0        0.  THORAX
    2 0.075  0.180  0.040   0.050  0.       0.355  2.  0  0        0.  SHOULDER
    2 0.060  0.050  0.040   0.050  0.       0.385  2.  0  0        0.  BRACKET
    3 0.040  0.040  0.070   0.     0.       0.042  4.  0  0        0.  NECK
    4 0.085  0.075  0.110  -0.011  0.       0.035  2.  3  0        0.  HEAD
    6 0.045  0.050  0.083   0.     0.028  -0.018  2.  4  5  250000.  UPP UPP ARM L
    7 0.045  0.050  0.125   0.     0.0    -0.090  4.  4  5  250000.  LOW UPP ARM L
    9 0.045  0.050  0.175   0.    -0.028  -0.110  3.  4  0        0.  UPPER ARM R
   10 0.2    0.075  0.075   0.2    0.      0.     2.  6  0        0.  UPPER LEG L
   11 0.050  0.050  0.25    0.     0.     -0.23   3.  7  0        0.  LOWER LEG L
   11 0.13   0.045  0.04    0.1    0.     -0.455  2.  8  0        0.  FOOT L
   12 0.2    0.075  0.075   0.2    0.      0.     2.  6  0        0.  UPPER LEG R
   13 0.050  0.050  0.25    0.     0.     -0.23   3.  7  0        0.  LOWER LEG R
   13 0.13   0.045  0.04    0.1    0.     -0.455  2.  8  0        0.  FOOT R
    5 0.100  0.030  0.015   0.058  0.082   0.     2.  9  0        0.  CLAVICLE L
    8 0.100  0.030  0.015   0.058 -0.082   0.     2.  9  0        0.  CLAVICLE R
-999
ORIENTATIONS
 13   0 1 2  0.1745
 16   0 1 2  0.1745
 17   0 1 3  0.951
 18   0 1 3 -0.951
-999
FUNCTIONS
5
0.000 0. 0.007 484. 0.018 901. 0.025 1495. 0.031 2297.
4
0.000 0. 0.002 331. 0.010 1000. 0.033 2514.
3
0. 0. 0.28 0. 1.28 218.3
2
0.000 0. 0.040 5000.
2
0.000 0. 0.040 2500.
4
0.000 0. 0.010 267. 0.019 778. 0.028 2111.
4
0.000 0. 0.007 221. 0.011 684. 0.013 1412.
4
0.000 0. 0.020 500. 0.050 2500. 0.100 10000.
2
0.000 0. 0.01 100000.
7
0. 0. 0.005 630. 0.010 1440. 0.015 2520. 0.020 4050. 0.025 5850. 0.030 9000.
-999
INITIAL CONDITIONS
    0.000   0.000    0.000    0.000    0.000    0.000
ORIENTATIONS
  1 -1  1 1.  0.
  2  1  1 1.  0.
  3  1  1 1.  0.      2.  0.3491
  4  1  1 1.  0.
  5  1  1 1.  0.      2. -0.0873
  6  1  1 1.  0.      2.  0.0873
  7  1  1 1.  0.
  8  1  1 1.  0.      2. -0.0873
  9  1  1 1.  0.      2.  0.0873
 10  1  1 1.  0.
 11  1  1 1.  0.
 12  1  1 1.  0.
 13  1  1 1.  0.
-999
END SYSTEM 1
SYSTEM 2
UPPER RIB
CONFIGURATION
  1
-999
GEOMETRY
   0.000    0.000    0.000   0.000    0.000    0.000  UPPER RIB
-999
INERTIA
   0.500   0.01   0.01   0.01   UPPER RIB
-999
```

```
ELLIPSOIDS
   1 0.045  0.030  0.020  0.000  0.000  0.000  4. 1  0  3.0E6  UPPER RIB
-999
FUNCTIONS
9
0. 0. 0.001 140. 0.002 320. 0.003 600. 0.004 880. 0.005 1200. +
      0.006 1700. 0.0065 2400. 0.007 5000.
-999
INITIAL CONDITION
    0.022  0.110  0.354  0.000  0.000  0.000  1  1  1
ORIENTATIONS
  1  -1  1  1  0.  2  0.  3  0.
-999
END SYSTEM 2
SYSTEM 3
MIDDLE RIB
CONFIGURATION
  1
-999
GEOMETRY
   0.000   0.000   0.000  0.000   0.000   0.000  MIDDLE RIB
-999
INERTIA
   0.500  0.01  0.01  0.01  MIDDLE RIB
-999
ELLIPSOIDS
   1 0.045  0.030  0.020  0.000  0.000  0.000  4. 1  0  3.0E6  MIDDLE RIB
-999
FUNCTIONS
9
0. 0. 0.001 140. 0.002 320. 0.003 600. 0.004 880. 0.005 1200. +
      0.006 1700. 0.0065 2400. 0.007 5000.
-999
INITIAL CONDITION
    0.022  0.110  0.298  0.000  0.000  0.000  1  1  1
ORIENTATIONS
  1  -1  1  1  0.  2  0.  3  0.
-999
END SYSTEM 3
SYSTEM 4
LOWER R IB
CONFIGURATION
  1
-999
GEOMETRY
   0.000   0.000   0.000  0.000   0.000   0.000  LOWER RIB
-999
INERTIA
   0.500  0.01  0.01  0.01  LOWER RIB
-999
ELLIPSOIDS
   1 0.045  0.030  0.020  0.000  0.000  0.000  4. 1  0  3.0E6  LOWER RIB
-999
FUNCTIONS
9
0. 0. 0.001 140. 0.002 320. 0.003 600. 0.004 880. 0.005 1200. +
      0.006 1700. 0.0065 2400. 0.007 5000.
-999
INITIAL CONDITION
    0.022  0.110  0.242  0.000  0.000  0.00  1  1  1
ORIENTATIONS
  1  -1  1  1  0.  2  0.  3  0.
-999
END SYSTEM 4
SYSTEM 5
ABDOMEN INSERT
CONFIGURATION
  1
-999
GEOMETRY
   0.000   0.000   0.000  0.000   0.000   0.000  ABDOMEN INSERT
-999
INERTIA
   0.300  0.01  0.01  0.01  ABDOMEN INSERT
-999
ELLIPSOIDS
   1 0.035  0.040  0.035  0.000  0.000  0.000  4. 1  0  0.  ABDOMEN INSERT
-999
FUNCTIONS
3
0. 0. 0.008 1500. 0.010 5000.
-999
INITIAL CONDITION
    0.048  0.099  0.138  0.000  0.000  0.00  1  1  1
ORIENTATIONS
  1  -1  1  1  0.  2  0.  3  0.
-999
END SYSTEM 5
FORCE MODELS
KELVIN
```

```
    2  1 -0.022    0.000   0.000    1  2  0.000   -0.030  0.266    +
                                 1  0         0.   0.  2   0.  0  UPPER RIB
    3  1 -0.022    0.000   0.000    1  2  0.000   -0.030  0.210    +
                                 1  0         0.   0.  2   0.  0  MIDDLE RIB
    4  1 -0.022    0.000   0.000    1  2  0.000   -0.030  0.154    +
                                 1  0         0.   0.  2   0.  0  LOWER RIB
    5  1  0.000    0.000   0.000    1  2  0.048    0.000  0.050    +
                                 3  0         0.   0.  4   0.  0  ABDOMEN
    5  1  0.000    0.000   0.000    1  2  0.048    0.000  0.050    +
                                 5  0         0.   0.  0   0.  0  ABDOMEN TUNING
-999
FUNCTIONS
3
-0.4545 -1050. 0.0 0. 0.4545 1050.
2
-20. 150. 20. 150.
6
-0.25 -5333. -0.227 -3000. -0.182 -1667. -0.137 -1000. 0. 0. 1.0 0.
2
-20. 1500. 20. 1500.
6
-0.25 -2667. -0.227 -1500. -0.182 -833. -0.137 -500. 0. 0. 1.0 0.
-999
MAXWELL
  1  2  0.000 -0.030   0.266 2  1 -0.022  0.000  0.000   +
                             1  0  0.  0.  2  0.3  0.3   UPPER RIB
  1  2  0.000 -0.030   0.210 3  1 -0.022  0.000  0.000   +
                             1  0  0.  0.  2  0.3  0.3   MIDDLE RIB
  1  2  0.000 -0.030   0.154 4  1 -0.022  0.000  0.000   +
                             1  0  0.  0.  2  0.3  0.3   LOWER RIB
-999
FUNCTIONS
3
-1. -5363. 0. 0. 1.0 100.
2
-20. 200. 20. 200.
-999
POINT-RESTRAINTS
  2  1 -0.022  1.000   0.000  1  2  0.000  1.110  0.266  +
               1  0  0  0  0  0  0  1  0  0  0    1.0 0.0  1.0   LAGER UPP RIB
  2  1 -0.022 -1.110   0.000  1  2  0.000 -1.000  0.266  +
               1  0  0  0  0  0  0  1  0  0  0    1.0 0.0  1.0   LAGER UPP RIB
  3  1 -0.022  1.000   0.000  1  2  0.000  1.110  0.210  +
               1  0  0  0  0  0  0  1  0  0  0    1.0 0.0  1.0   LAGER MID RIB
  3  1 -0.022 -1.110   0.000  1  2  0.000 -1.000  0.210  +
               1  0  0  0  0  0  0  1  0  0  0    1.0 0.0  1.0   LAGER MID RIB
  4  1 -0.022  1.000   0.000  1  2  0.000  1.110  0.154  +
               1  0  0  0  0  0  0  1  0  0  0    1.0 0.0  1.0   LAGER LOW RIB
  4  1 -0.022 -1.110   0.000  1  2  0.000 -1.000  0.154  +
               1  0  0  0  0  0  0  1  0  0  0    1.0 0.0  1.0   LAGER LOW RIB
  5  1  0.000  1.000   0.000  1  2  0.048  1.132  0.050  +
               2  0  0. 0. 0  0  0. 0. 2  0  0. 0.  20.  0.  20.   LAGER ABDOMEN
  5  1  0.000 -1.000   0.000  1  2  0.048 -0.868  0.050  +
               2  0  0. 0. 0  0  0. 0. 2  0  0. 0.  20.  0.  20.   LAGER ABDOMEN
-999
FUNCTIONS
2
-1. -2000000. 1. 2000000.
2
-1. -100000. 1. 100000.
2
-1. -15000. 1. 15000.
-999
END FORCE MODELS
END INPUT
```