



## PRELIMINARY DESIGN OF THE “SUPERBUS”

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### SUMMARY

The present paper presents the structural design of the *Superbus*. First the overall requirements are described and analyzed, with respect to loads (static and dynamic), stiffness and functional requirements. In order to fulfil the relative targets, two different solutions have been defined and analyzed in the preliminary design. From those, the best option is described. Finally, the description of the production of the vehicle is presented.

### 1. INTRODUCTION

The Superbus is a concept from TU Delft [1] for the development of an innovative public transport system.



Figure 1

The main characteristics of the *Superbus* are the following. The superbus is sustainable, thus uses low power per passengers, produces no emissions and uses a number of recyclable materials; it runs at competitive speeds with respect to current high speed transports; it is lightweight and aerodynamically efficient; it is very safe by the use of an outstanding navigation and control system; it is silent, innovative, comfortable, appealing and provides flexible transportation on request for people and goods. At cruising speed (250 km/h) it runs on its dedicated and relatively cheap infrastructure, and at lower speed it leaves the special high speed track and runs in city centres and on highways at conventional speeds.

Due to such features, it was introduced as one of the option for the Zuiderzeelijn, a programme of the Dutch Ministry of Transport and Water Management aimed at identifying the best public transport system for the connection between Amsterdam and Groningen; the options being 5: three different type of high speed train, the magnetic levitation train and the *Superbus* [2].

The *Superbus* resulted as the best option, but it is new and only in its conceptual phase, unlike the other options. Thus, the Ministry of Transport has decided to sponsor the realisation of a demonstrator for evaluation of the feasibility of the



system within the “three-stage-rocket” plan [3]. The latter consists in three subsequent phases for the realisation of respectively the demonstrator, the prototype & market readiness and the production type. This is expected to take place in a time frame that spans from 2006 to 2020 and that sees industry to take the lead on the design and manufacturing of the third phase with TU Delft providing one part of the R&D.

The launch of the vehicle will be at the Beijing Olympics Game in August 2008.

The design and manufacturing of the Superbus is managed, coordinated and integrated by a dedicated team at TU Delft, which works with a number of other Universities, Institutions and Companies.

In order to be as efficient as possible, and thus minimizing the losses in the power chain, the vehicle structure must be as light as possible. As a result, the *Superbus* has a composite chassis, which preliminary design is described in this paper. Lightweight composite structures form an important research and development topic at Delft University of Technology, faculty of Aerospace Engineering [4], [5].

## 2. LIST OF REQUIREMENTS

The list of requirements (LOR) of the structural design for the whole vehicle is very wide and it is divided and highlighted in this paper into the various areas predominantly impacted. With regard to this it should be stressed that the requirements evolve, within the timeframe of realization, when designing such a complicated and new project. The main requirements for what concerns the structure can be summarized in the following:

### **Maneuverability**

As the vehicle will drive at a cruising speed of 250 km/h, it has to be able to be easily maneuverable, and thus to respond to the torsion stiffness of 30 kNm/°.

### **Driving conditions**

Most of the dynamic driving conditions are translated into static Loads. This conditions include a vertical bump, cornering, abrupt stopping, roll over and frontal impact.

### **Minimum weight**

The total weight of the vehicle, including payload is set to 8.5 T. The share of the structural weight is set to 3.5 T, including payload.

### **Payload**

The vehicle will carry 24 passengers plus driver. Per passenger a weight of 110 kg is considered, including luggage.

### **Exterior shape**

The exterior shape is illustrated in fig 1. Given a total number of 24 passengers, 8 rows of three passengers are envisioned, with each rows having its own door, thus 8 doors per side are wished.

## 3. DESIGN OPTIONS

On the basis of the list of requirements, the large amount of openings in the structure and the very high torsion stiffness, two concepts are considered. The latter are shown in Figure 2.

The first option consists of a standard layout with straight frames and therefore squared doors, whereas the second layout consists of inclined frames and octagonal doors. The second option is definitely the best option with respect to torsion stiffness and therefore weight reduction, especially when the frames are close to the ideal  $\pm 45^\circ$  orientation. Due to the amount of doors with respect to the overall chassis dimensions, the implementation of the second option allows only an inclination of about  $\pm 20^\circ$ .

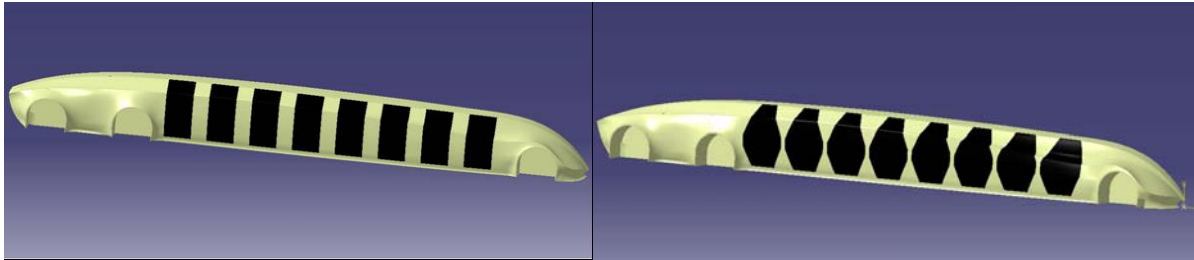


Figure 2 Design options.

The advantages of the first configuration are:

1. accessibility, as in the second option the top and bottom part of the door are smaller
2. there are no cross-connections which make the production easier
3. although the cross section varies though the vehicle, the doors have all the same width and therefore are easier to produce.

However, the second option offers the freedom to explore more appealing design options and has the potential of being more structurally efficient, which, in turn, allows a lighter structure.

#### 4. FINITE ELEMENT ANALYSIS

In order to establish the torsion stiffness of the structure and to be able to make a comparison between the two concepts a number of analyses were carried out, with particular attention on the influence of the single elements.

The analyses considered:

- an identical floor for the two models, 120 mm in thickness, 3 mm thick, with six internal stiffeners, as shown in Figure 3;
- a framework made of hollow beams 100 x 100 mm cross section, 3 mm thick;
- a 3 mm thick skin

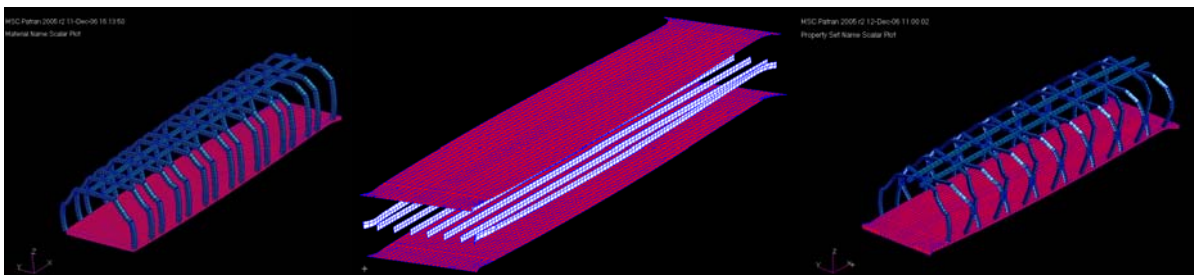


Figure 3 Definition of the components in the FE-analysis.

Carbon fibre reinforced plastic material is used, quasi isotropic, whose material characteristics are defined in Table 1:

Carbon					
Fibre orientation.	$v_f$	$E_x$ [GPa]	$E_y$ [GPa]	$G_{xy}$ [GPa]	$v_{xy}$
0/90	0.5	62.2	62.2	4.4	0.04
+/-45	0.5	15.5	15.5	29.8	0.76
Quasi Isotropic	0.5	44.9	44.9	17.1	0.31

Table 1 Material characteristics.

The results of the preliminary calculations are shown in Table 2:

Stiffness [kNm/deg]	Target 30kN/deg	Octagonal doors	Rectangular doors 700 mm width
Floor only		6.3	6.2
Floor and Framework only		<b>29.8</b>	7.2
Floor, Framework and skin, excluding doors		59.2	28.3

Table 2 Preliminary results.

The octagonal door solution is clearly superior to the rectangular door solution. The weight of the respective models differs only little (i.e. 10% of the weight of floor and framework only) prior to optimization of the material. Indeed, the combination of the cross beam frames with the floor and roof beams reaches the torsion stiffness target without the addition of the exterior panels (bold).

In order to determine the potential weight of the whole structure few configurations have been tested so to verify the difference in weight of the two structural options when complying with the target torsion stiffness (30kN/°). In fact, in both cases a minimum thickness in the structure is needed to avoid unwanted vibrations and obtain the desired strength of all components.

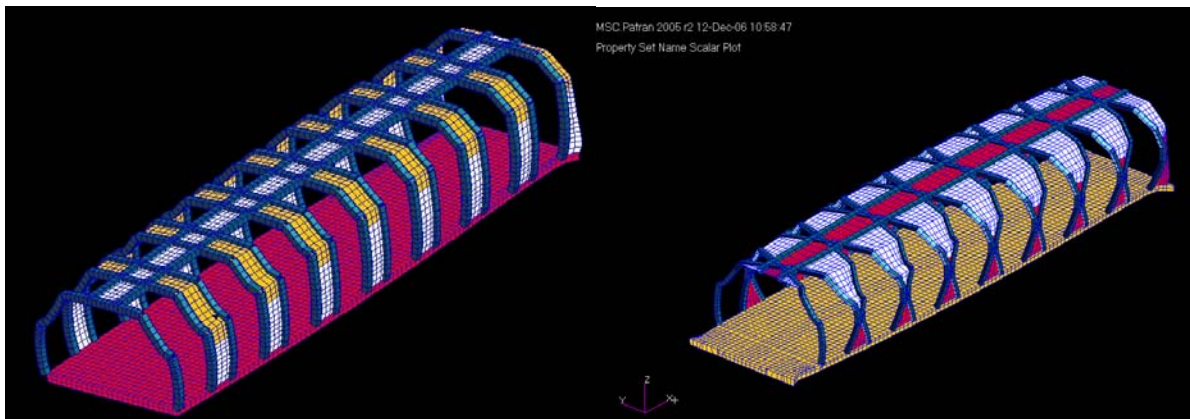


Figure 4 Layout of the two analysed models.

The layout of the two models is shown in Figure 4. In both models, the floor and the frames are considered as structural parts whereas the body consist of a structural part (the bodywork) and a non-structural part (the transparencies).The door openings are kept open in the analysis, as their load carrying capacity are considered additional.

Several configurations with different thickness and cross sections for the different parts have been analysed, from which the best results are summarized in Table 3:

Frames	Torsion Stiffness (kNm/degree)	Weight (kg)	Penalty
Inclined	32.1	<b>321</b>	-
Straight	33.2	447.1	<b>40 %</b>

Table 3. Weight comparison.

Also in this case the inclined doors perform better, as expected, achieving the desired stiffness with less material, therefore weight.

To verify the influence of the doors to the overall stiffness of the vehicle the doors are introduced. They are connected to the structure only in a few points, where they locally transfer loads. The connecting points are shown in Figure 5 (circles).

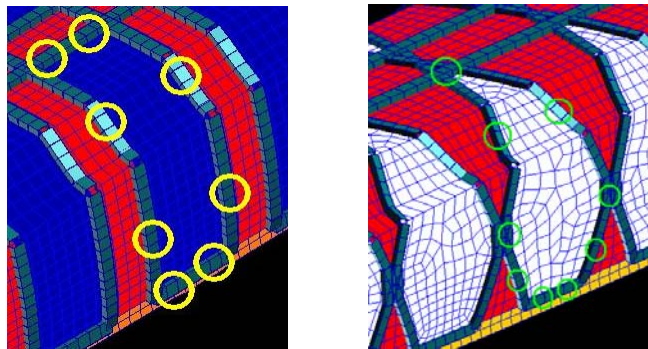


Figure 5 Doors with connections.

The results are presented in Table 4. The torsion stiffness increases in both cases by a factor ten. Thus, even if the doors will be connected in fewer points the stiffness of the vehicle will improve considerably.

Frames	Doors open	Doors Partially closed
Inclined	32.1 kNm/°	312 kNm/°
Straight	33.2 kNm/°	320 kNm/°

Table 4 Influence of doors in the torsion stiffness.

Finally, the dynamic load cases have been analysed. In this case, the suspensions have been schematized and attached to the load carrying structure as shown in Figure 6.

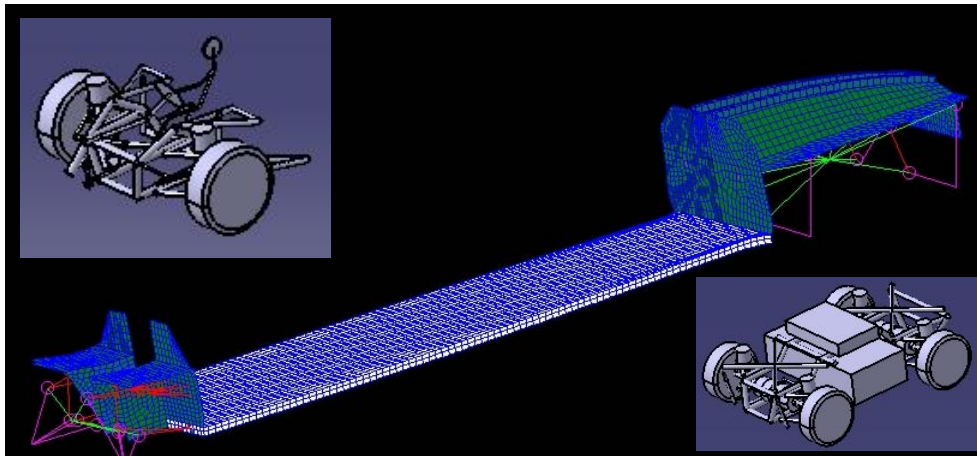


Figure 6 Suspensions attachment points and structural layout of the interior.



The load corresponding to the payload, the motors and the suspensions have been added to the structure, together with interiors, cables and all the non structural parts contained in the Superbus.

## 5. DESIGN AND MANUFACTURING CHOICES

The Superbus structure will be built in several elements and subassemblies. The design driver for such choice is due to fact that for the demonstrator phase the various subsystems will not be completed simultaneously. This will allow the freedom for late changes and for the improvement of the integration of the whole structural part.

As for the tooling, they should be affordable; therefore repetitive elements shall be used where possible.

To account for the foreseeable late finalization of the interior concept and the relative details, the aim is to use one uninterrupted interior living volume without separations and equidistant spaced seat rails to enable various seating configurations without structural changes. A second important element is to use the interior structural elements facing to the inside to be tooling side. This will result in a relatively clean interior appearance.

For what concerns production and assembly, the following choices have been made:

- Vacuum infusion (large) structural elements (floor, beams, frames)
- Wet fibre laminate local elements (frame intersection internal structure)
- 'Dry' mechanical assembly (bolted structure) until all subsystem integration has been achieved
- Final adhesive bonded assembly

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