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LOW NOISE PANTOGRAPH ASP - RECENT DEVELOPMENTS

W. Behr*, T. Lölgen*, W. Baldauf*, L. Willenbrink*, R. Blaschko, K. Jäger**, J. Kremlacek****

* Deutsche Bahn AG (FTZ 811, 83, 52), Voelckerstrasse 5, 80939, Muenchen, Germany

** DaimlerChrysler Rail Systems GmbH, Am Rathenaupark 1, 16761, Hennigsdorf, Germany

Tel.: ++49-89-13087344 / Fax: ++49-89-13087311 / Email: wolfgang.behr@bku.db.de

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ABSTRACT
The aeroacoustic noise of a pantograph increases dramatically with the train speed. Especially at a very high speed of 300 km/h and above the aeroacoustic noise of the pantograph may exceed the rolling noise of the wheels. Since it is inappropriate and expensive to build high noise barriers to screen the pantograph, a new design of pantographs is necessary for future high speed trains. In cooperation with DaimlerChrysler Rail Systems an actively controlled single-arm pantograph (ASP) will be developed until next year in order to improve the quality of the contact force fluctuation and to reduce the aeroacoustic noise emission using computer simulation to estimate the aeroacoustic noise. These simulations are very helpful when developing an optimized design and avoiding unacceptable designs in an early state of development. First simulation results of the recent developments of the pantograph head will be presented.

1 - INTRODUCTION
The aeroacoustic sound of a pantograph results from the interaction between the single parts of the pantograph with the air. This interaction is not dependent upon the body vibrating, although parts capable of vibrating may cause a higher noise level compared to rigid parts. However, the additional sound due to body vibration will not be discussed in this investigation.
Since a pantograph can be composed of a number of single parts like slender cylinders or cuboids, the overall noise emission can be derived by summing up the emitted sound of those single parts. Varying the form and the dimension of certain parts of the pantograph leads to an optimal shape of this part with respect to a minimized aeroacoustic noise level. These simulations will help to abate the pantograph noise. Thus a new ASP-pantograph is just in development considering the guide lines [1]. Some of the most efficient rules to decrease the sound emission of the pantograph are to decrease the numbers of parts of the pantograph and to use parts with circular or elliptical cross-section instead of angular parts like cuboids. In addition, the elements of the pantograph should be conical with a rough surface.

2 - THE ASP-PANTOGRAPH (RECENT PROTOTYPE)
Taking the guide lines into account, a novel pantograph was designed, also with respect to aerodynamic and mechanical aspects. The FE-model that pantograph head is shown in Fig. 1. It can be seen clearly that the number of components was reduced to a minimum. Some of the most critical parts are the horns, because these elements are orientated vertical and at the same time perpendicular to the forward direction (Fig. 2).

3 - THEORY OF AEROACOUSTIC NOISE EMISSION
The overall sound level of the pantograph can be estimated by the addition of the levels of the single elements. The noise emission of various structures by different flow conditions is well known from

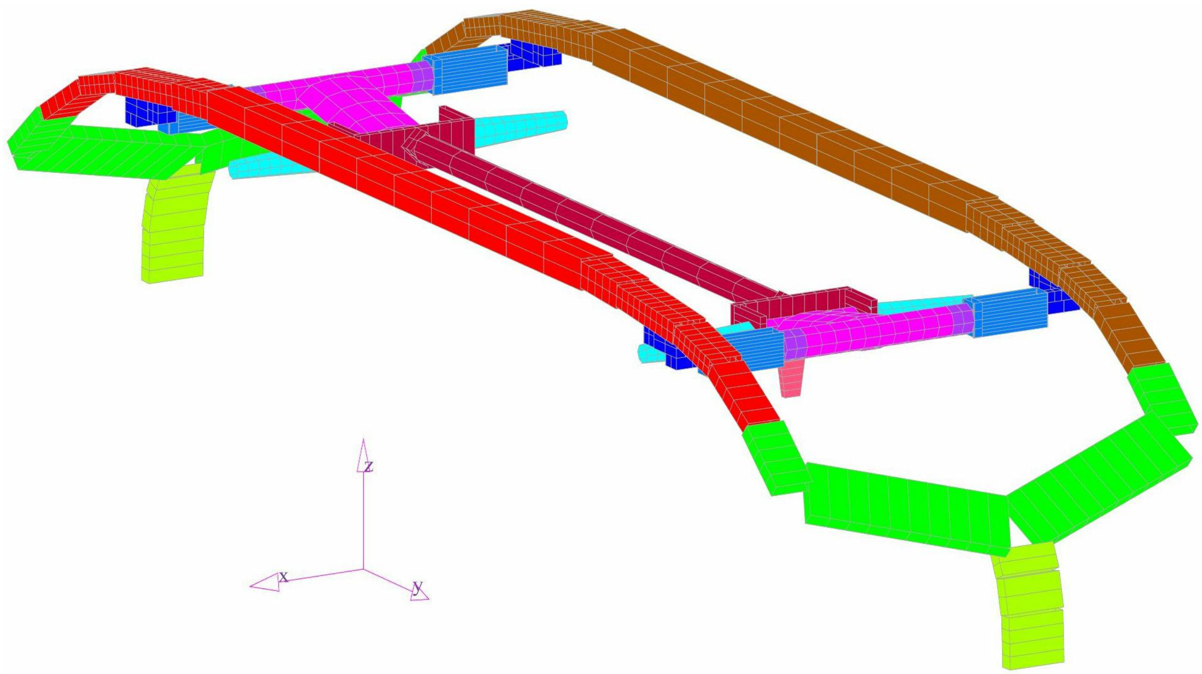

Figure 1: The model of the new developed pantograph ASP (iso-view).

Figure 2: The model of the pantograph ASP (front view); the horn ends are vertical orientated.

experimental investigations in wind tunnels. The researched elements were cylindrical structures with circular, elliptical, quadratic and rectangular cross sections [2,3].

Moving a cylinder through a fluid flow causes a wake behind this cylinder containing vortices shed from the body. The Reynolds number characterizes the flow field and is defined by

$$\mathrm{Re} = \frac{U \cdot l}{\nu} \tag{1}$$

with U = flow velocity, l = characteristic length of the element (e.g. the diameter of the cylinder if the length axis of the cylinder is perpendicular to the flow velocity) and $\nu = \mu/\rho$ kinematic viscosity (μ=dynamic viscosity, ρ=density).

Reynolds number can be interpreted as the ratio between the vis inertiae and the friction force. Additional cause variables are the ratio l/d (l = structure length, d = structure diameter) and the aspect ratio b/d of the cross-section of the structure (b/d = 1 for circles). Depending on Reynolds number and the geometry (l/d, b/d), the shedding frequency (which is the peak frequency as well, expressed as the Strouhal number St), the instationary lift value c_A and the correlation length l_C are resulting. The sound pressure p at the observer position can be expressed by

$$p^2 = \frac{c_{A\beta}^2 St_{d\beta}^2 \rho^2 L l_{c\beta} U_N^6 \sin^2\theta \mathrm{c\ os}^2\varphi}{16 a^2 R^2 \left(1 - M \cos\theta\right)^4} \tag{2}$$

where ρ denotes the density, L the structure length, U_N the normal component of the stream speed, θ the angle between the stream direction and the observer position, φ the angle between the axis of the structure and the observer position and a the sound speed. R denotes the distance between the center of the described structure and the observer, M the Mach number U/a.

4 - THE USED SIMULATION TOOL "DB-AERO"

To predict aeroacoustic noise, we use the internal DB − simulation tool DB-Aero which calculates the sound levels according to equation (2). Thereby the software uses a link on a database which contains the values of Strouhal's number St, c_A and l_C as a function of Re, b/d and l/d. The sound level of each cylindrical structure can be calculated as well as the peak frequency. The overall sound emission can be obtained by a summation of the single levels of those structures. In addition to the geometry of the structure, some other properties like the turbulence of the stream, the end parameter of the structure (open end, rounded end) and the roughness of the surface can be taken into account.
This simulation tool has been validated for single cylindrical structures as well as for complex geometry composed of single structures by comparing calculated data with data measured in a wind tunnel [4]. The calculated values are very good (discrepancy up to 1 dB(A)) for the described long cylindrical structures having a rectangular, circular or elliptical cross section.
For short structures (length $\leq$ cross section dimension) or for structures having other cross sections, the software is not yet valid. Nevertheless, qualitative predictions can be made to estimate noise level dependence on structure variation, e. g. variation of thickness or other geometrical parameters.

5 - THE MODEL OF THE PANTOGRAPH HEAD

The head (see Fig. 1) was fragmented in a minimum number of cylindrical elements where the original geometry of the pantograph head was modeled by using necessary simplifications. The plate elements the horns are built of, have an improved shape with a thickness of 17 mm (Fig. 3); the width of the upper plates is 48 mm, the width of the middle parts and the horn end is 72 mm.

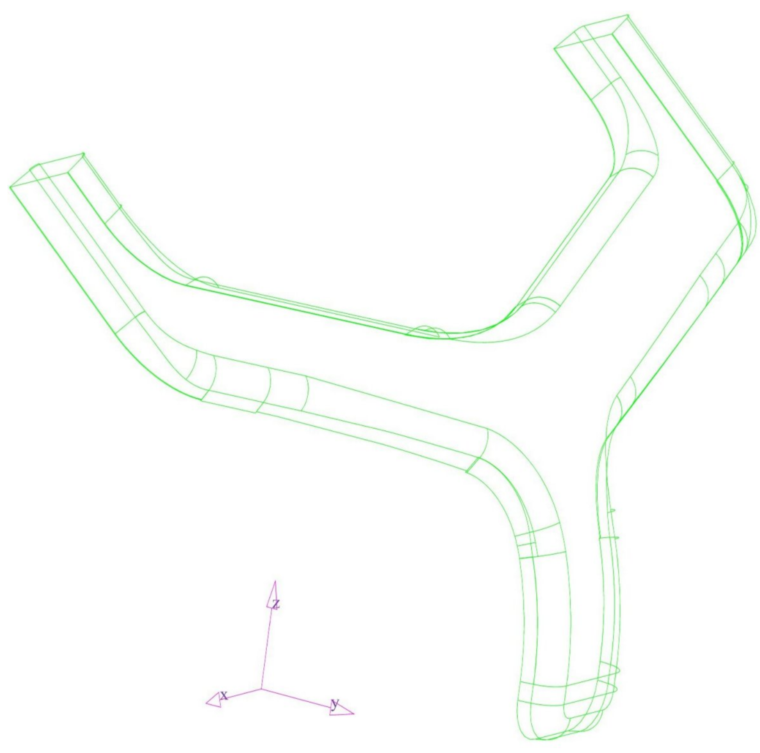

Figure 3: One horn of the pantograph (technical construction plot showing the special rounding).

The rounded horns were modeled by angular cylinders (Figs. 4 & 5). Of course, the sound radiation from the horns is underestimated with the software due to the rounded edges assumed.
Nevertheless, quantitative statements due to geometry changes are possible by the assumption that the rounded edges will cause the same (quantitatively unknown) noise reduction.
Even if the model of the horn, shown in figure 6, regards the curvature of the end of the horn, this model will not give appropriate results because the elements do not fulfil the requirement for the simulation tool. Due to limitations of the simulation tool DB-Aero (element length >> cross section dimension), the horn end was modeled by one long element (Fig. 7).

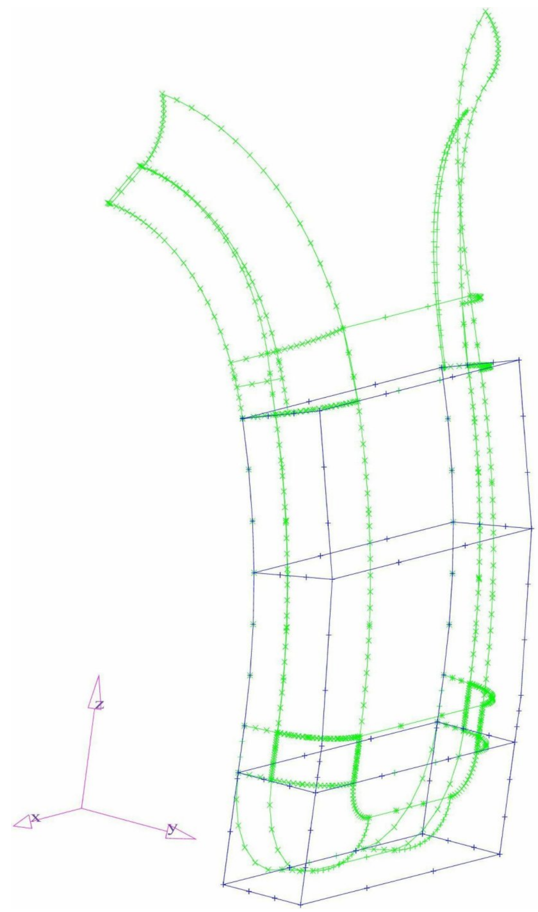

Figure 4: Cuboids (blue) to simulate the horn end.

6 - VARIATIONS OF HORN PARAMETERS

Based on the horn model, displayed in Fig. 7, the following variations has been done:

■ Variation of thickness and width of the horn plate

- Var_1a: Increase of the thickness from 17 mm to 22 mm (Fig. 8)
- Var_1b: Reduction of the thickness from 17 mm to 15 mm
- Var_2a: Increase of the width (lower parts) from 72 mm to 88 mm
- Var_2b: Reduction of the width (lower parts) from 72 mm to 50 mm (Fig. 9)

■ Variation of horn geometry shape

- Var_3: larger middle part angle, horn-end longer (Fig. 10)
- Var_4: replacing the original horn envelope shape with a round envelope shape (in order to avoid a vertical horn end perpendicular to speed direction) (Fig. 11)
- Var_4a: Similar to Var_4, all plates have the width of 48 mm
- Var_4b: similar to Var_4, all plates have the width of 72 mm
- Var_4c: similar to Var_4b, but elliptical cross-section (Fig. 12)

7 - RESULTS

The sound levels of the pantograph head have been simulated at a train speed of 300 km/h. The distance between the middle of the pantograph head and the observer position was chosen to 25 m.
At that distance, the aeroacoustic radiation of the complete pantograph head as shown in figure 1 was calculated to 81.8 dB(A). In that calculation, the sound pressure of the two horns was 79.6 dB(A), the

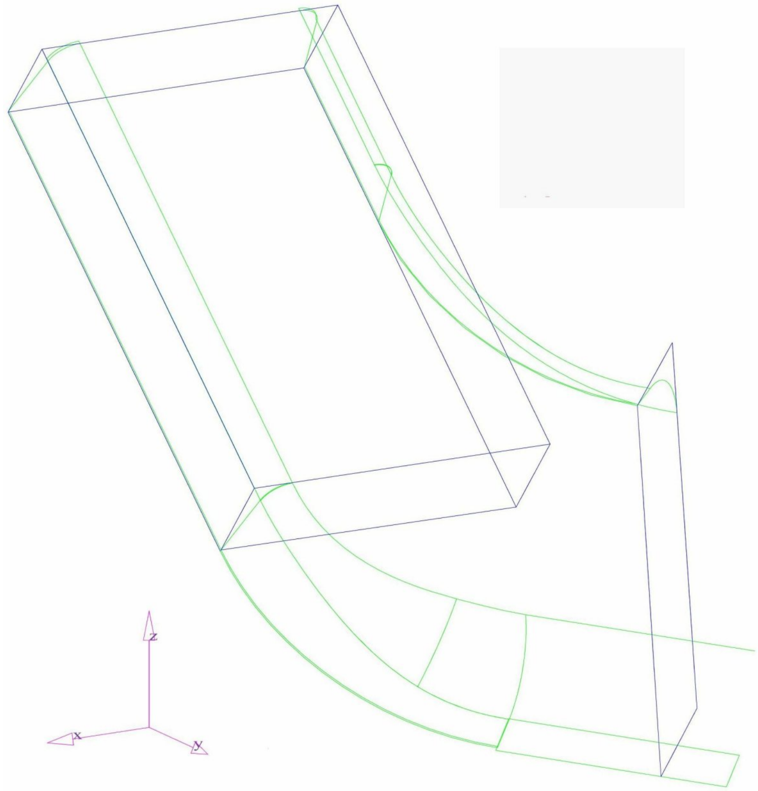

Figure 5: Cuboids (blue) to simulate the upper part of the horn next to the conductor strip.

sound pressure of all the other parts of the head ranged between 70.5 dB(A) and 74.7 dB(A). So assuming the horns as cuboids, the horns generates much more sound than other parts. This indicates possible improvements of the horn shape. The calculated sound levels of these variations are listed in table 1.

horn type	Original	Var_1a	Var_1b	Var_2a	Var_2b	Var_3	Var_4	Var_4a	Var_4b	Var_4c
dis-played in	Fig. 7	Fig. 8			Fig. 9	Fig. 10	Fig. 11			Fig. 12
Lp / dB(A)	79.6	79.0	80.0	79.3	81.4	80.9	77.6	78.0	75.8	66.0

Table 1: Composition of the sound levels of the horn variations with the original horn type; the type of variation is explained in the paragraph above.

8 - DISCUSSION

An element with rectangular cross section will radiate more sound as the one with elliptical cross section. The database of the software DB-Aero contains data only for cylinders with rectangular, circular or elliptical cross section. The cross section of the plate used for the original horn is something between (see Figs. 4 & 5). Thus the real sound levels will be significantly lower than the calculated (table 1, variations 1a through 4b), but will be higher than results for elements with elliptical cross section, which cause the least (Var_4c). Although elements with elliptical cross-section would be best regarding noise emission, they will be unacceptable for other reasons (e. g. aerodynamic behavior). Taking that into account, the presented data have to be weighted and interpreted qualitatively, but noise differences can be seen quantitatively:

The Variations Var_1a/b show that choosing thinner plates causes more sound, thicker plates however causes a little less sound pressure; it has to be taken into account that thicker material will have more weight however. So the chosen thickness may be optimal.

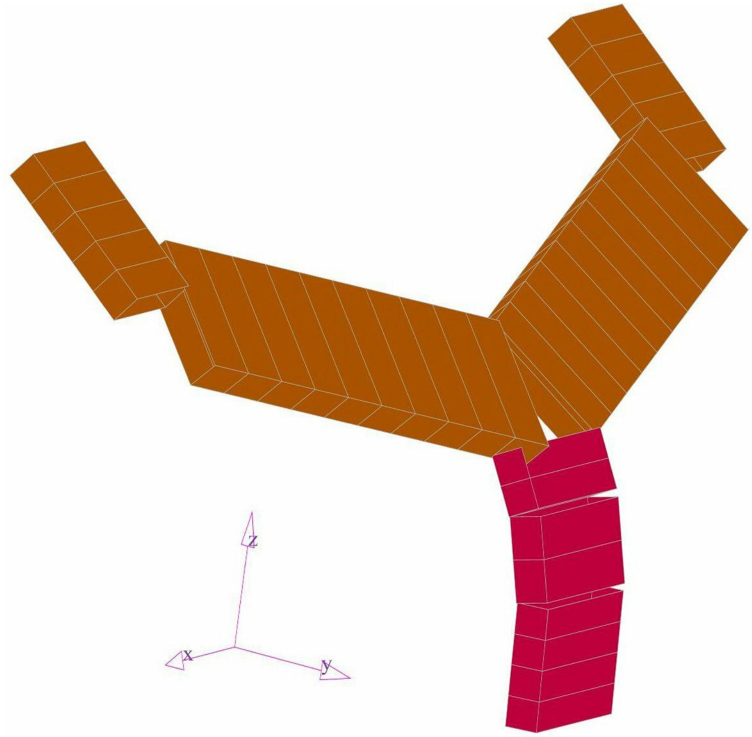

Figure 6: Model of the horn where the curvature of the horn end has been taken into account.

Variations Var_2a/b show that wide plates cause some reduction of sound (0.3 dB(A)), but plates with a reduced width lead to an significant increase of 1.8 dB(A). So the chosen plate width may again be optimal.
The aeroacoustic behavior of cuboids with varying width is qualitatively known [2]. But calculations (variation 1 and 2) give an quantitative idea of the importance of the changes.
Also, the results (variations 3 and 4) show that a vertical horn end, perpendicular to the train speed, will cause much more sound than horn ends with other shapes. However, beside the aeroacoustic aspects of a pantograph other aspects concerning the mechanics, the aerodynamic or the weight have to be taken into account when designing a new pantograph. The results (variation 3 and 4) help to find an optimum compromise. While a longer horn end (variation 3) leads to a 1.3 dB(A) increase, an avoidance of vertical horn ends will reduce the sound by 2 dB(A) (variation 4). Starting from that variation, variations 4a and 4b show the influence of the plate width. While a smaller plate width will cause only a little bit more sound, that solution might be interesting for weight reduction. However, choosing variation 4 with wider plates in the upper part of the horn (variation 4b), a significant reduction of about 2 dB(A) can be obtained if the increase in weight linked with that aeroacoustic improvement can be accepted. Finally variation 4c points out the quantitative difference between the aeroacoustic sound of the horn end made out of elliptical cylinders instead of cuboids. That theoretical abatement (about 10 dB(A)) cannot be realized due to aerodynamic behavior of the elliptical cylinders.

9 - CONCLUSION

The calculations demonstrate possible sound reductions due to geometrical changes of the horn of the new ASP-pantograph in comparison with the recent prototype. Exact quantitative acoustic values for the special form of the horn plate can be obtained by aeroacoustic measurements in a wind tunnel which will be performed next. The results of those measurements will supplement the data base of DB-Aero so that in the future DB-Aero can handle more complicated cylinders, too.

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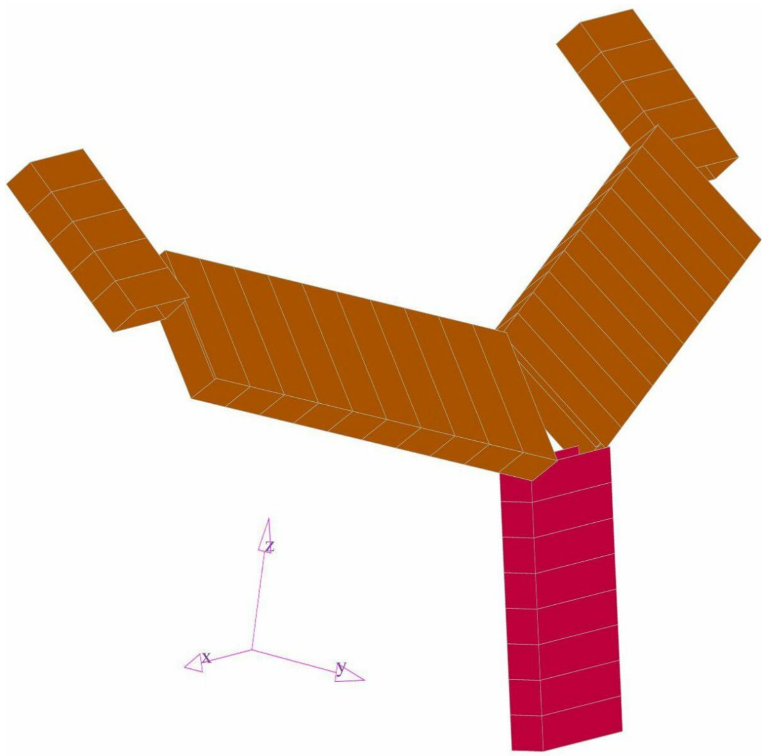

Figure 7: Appropriate model of the horn where the horn end is simulated by one long cuboid.

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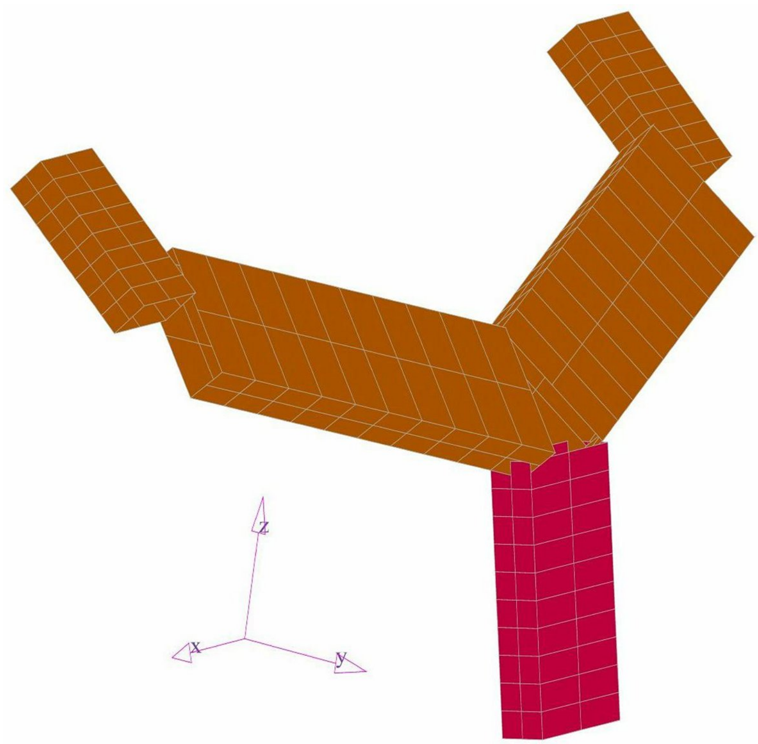

Figure 8: The thickness of the horn plate has been enlarged from 17 mm to 22 mm.

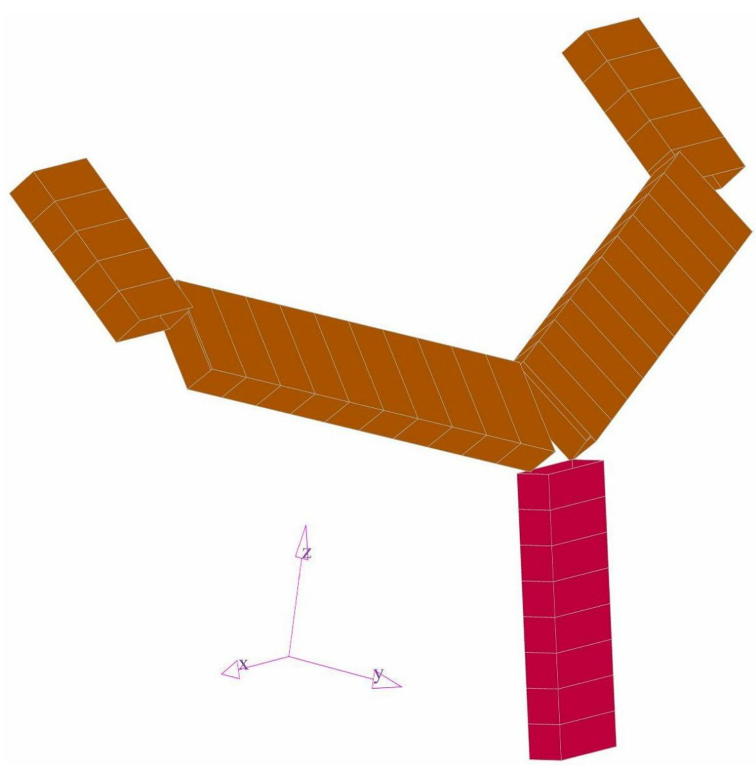

Figure 9: The width of the lower parts of the horn has been reduced from 72 mm to 50 mm.

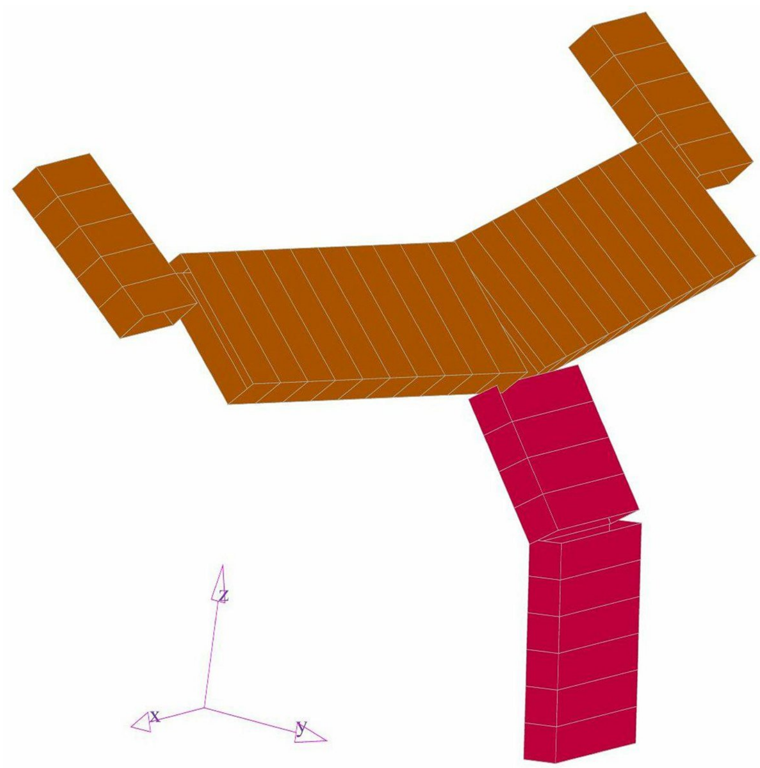

Figure 10: Variation of the horn with a larger middle part angle and a longer horn end.

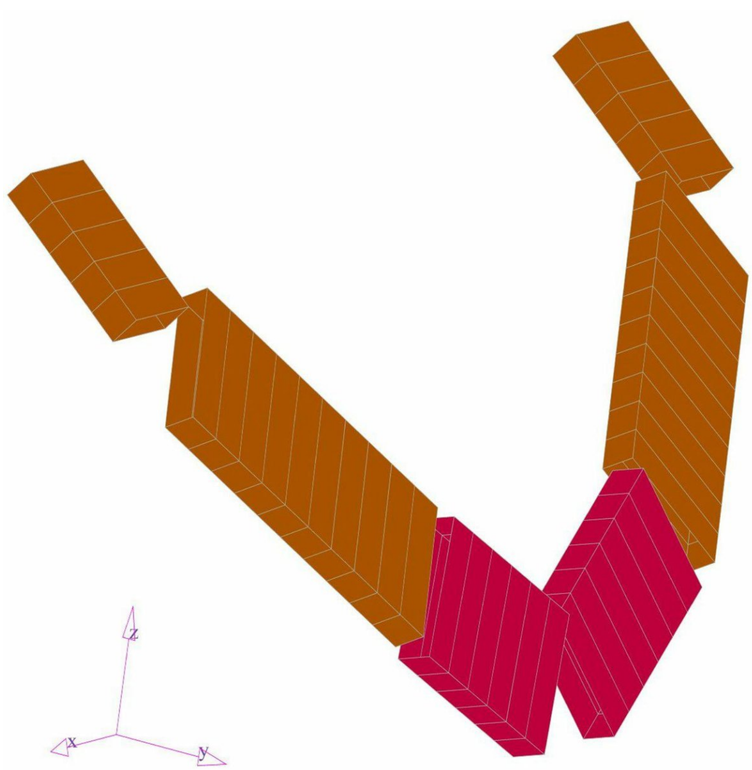

Figure 11: Variation of the horn envelope shape.

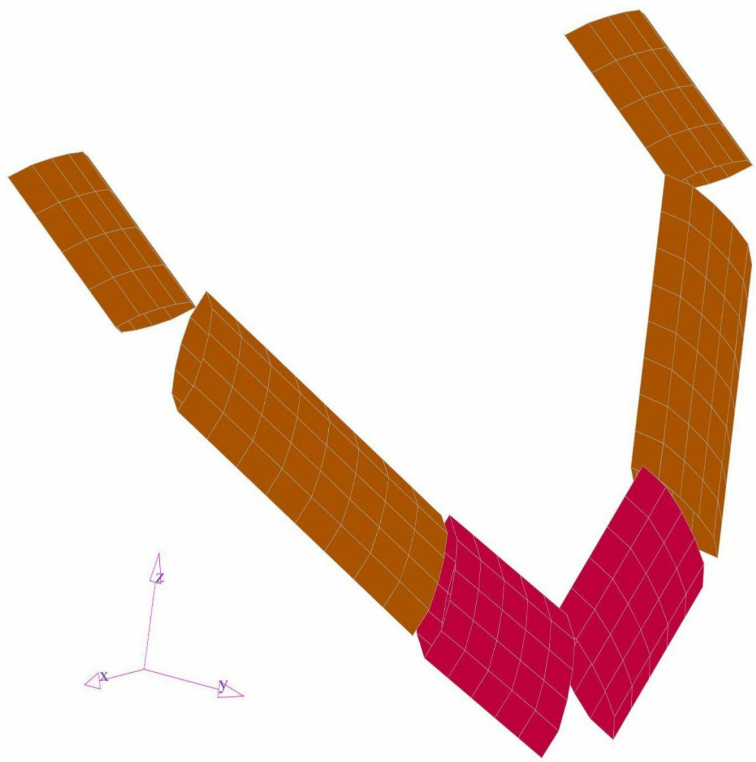

Figure 12: Variation of the horn envelope shape by using cylinders with elliptical cross section.