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Fully Automatic Determination of the Trunk Volume

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The volume of a car trunk is an important purchase criterion. According to common DIN, ISO and SAE industrial standards, it is determined by filling up the trunk with special boxes. In addition to using the trunk of a real car, this process is more and more performed with virtual models in a CAD system. Both practices require time-consuming manual work. However, with the TrunkPacker software from Rmags the trunk volume of a car can now be computed fully automatically. Moreover, the software also features packing studies with arbitrarily shaped objects such as golf bags, buggies or suitcases.

STANDARDS FOR DETERMINING THE LOADING VOLUME

The declaration of the volume of a trunk in a catalogue is done in litres, according to standards ISO 3832 and DIN 70020. The sole measuring equipment permitted is a one-litre box (cuboid) with spatial dimensions 200×100×50 mm³. The maximum number of named boxes that can be placed inside the luggage compartment without deformation specifies its volume in litres. This defines a comprehensible and reproducible method to determine the usable cargo space of a passenger car and facilitates comparing different automakers. This measurement method was originally published by the German Association of the Automotive Industry (Verband der Automobilindustrie, VDA). It was later incorporated into the international ISO 3832 standard and is part of the German standard DIN 70020, which generally specifies the dimensions and weights of a vehicle. Given an open luggage compartment, the DIN standard distinguishes between several sectors for volume determination. That are behind the backseats and behind the driver and co-driver seats. Includied in this is also the maximum trunk, **FIGURE 1**.

The US-American standard SAE J1100 also specifies packing with boxes. However, the boxes used shall represent differently sized suitcases, **FIGURE 2**. They range from suitcases with 67 l of volume to small shoeboxes with just under 6 l. Additionally, there is a unit module, styled in the form of a golf bag, which can also be packed. The SAE standard also defines exactly how many boxes of which type may be used and in which order they are to be packed.

NEED FOR FULLY AUTOMATIC VOLUME DETERMINATION

The trunk volume of new car lines is nowadays already determined and optimised during an early development process, based on the digital vehicle model. Up to now this has been a rather laborious task in manual work: The engineer had to place each box manually using a CAD system and visually check the packing density and ensure that no boxes interpenetrate each other or the surrounding trunk geometry.

This manual approach usually takes an enormous amount of time, considering that the trunk size of a sedan is about 500 l, the maximum loading capacity of a station waggon about 1400 to 1900 l and the size of a van more than 2200 l. Thus there is a tremendous number of possible arrangements of the boxes. If a prototype already exists, the volume capacities resulting from CAD are usually verified on the physical model using plastic or expanded polystyrene blocks. This review process also generates heavy workload.

In both named manual methods, the value determined for the trunk volume can vary greatly, depending on the experience of the engineer and the time invested. In order to find an optimal packing one would have to check a vast number of different arrangements of the boxes.

The aim of the development of the TrunkPacker software by Rmags was the fully automatic determination of a nearly optimal packing to achieve a consistently high packing quality while simultaneously saving time. Using the software, one can determine the volume of a trunk automatically on the virtual model, according to common industrial standards ISO 3832, DIN 70020 and SAE J1100.

AUTOMATIC PACKING FROM THE PERSPECTIVE OF THE SCIENTIST

Mathematically speaking, packing a trunk (with boxes) is a provably hard problem from the complexity class „NP-hard“. If one were to find a simple solution to the trunk packing problem, one could (at least theoretically) solve

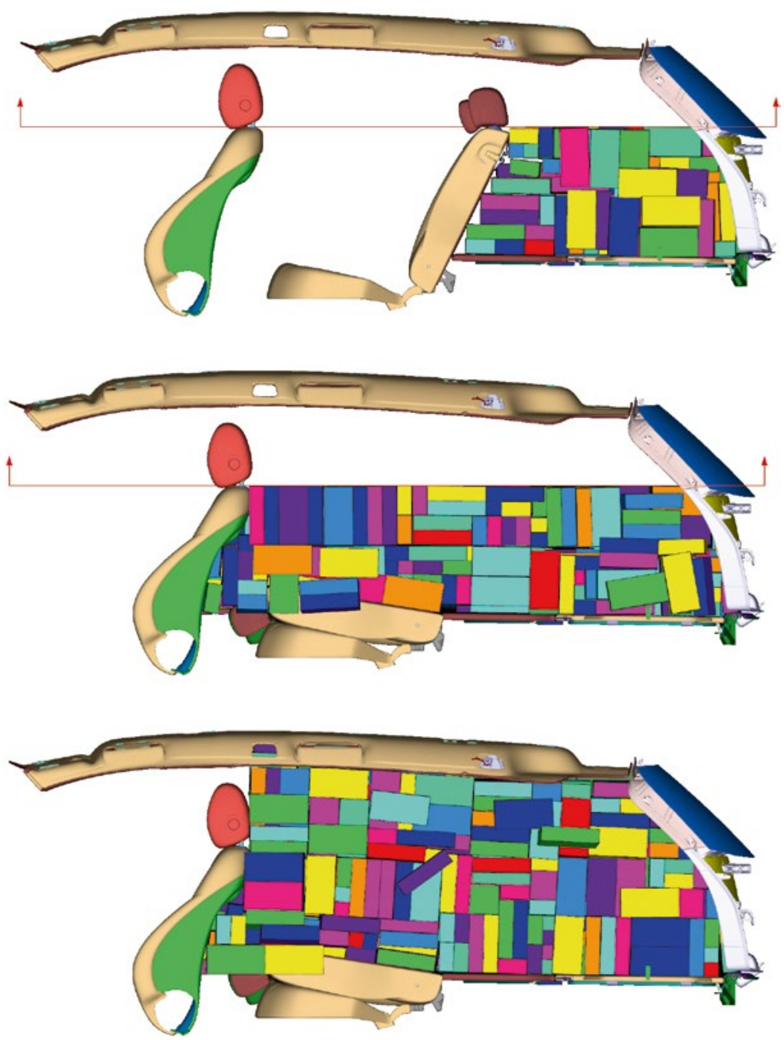

FIGURE 1 Volume determination in Europe with standard cuboids – given an open luggage compartment, the DIN 70020 standard distinguishes between several sectors for volume determination: behind the backseats (top), behind the driver and co-driver seats (centre) or the maximum trunk volume (bottom) (© Rmags)

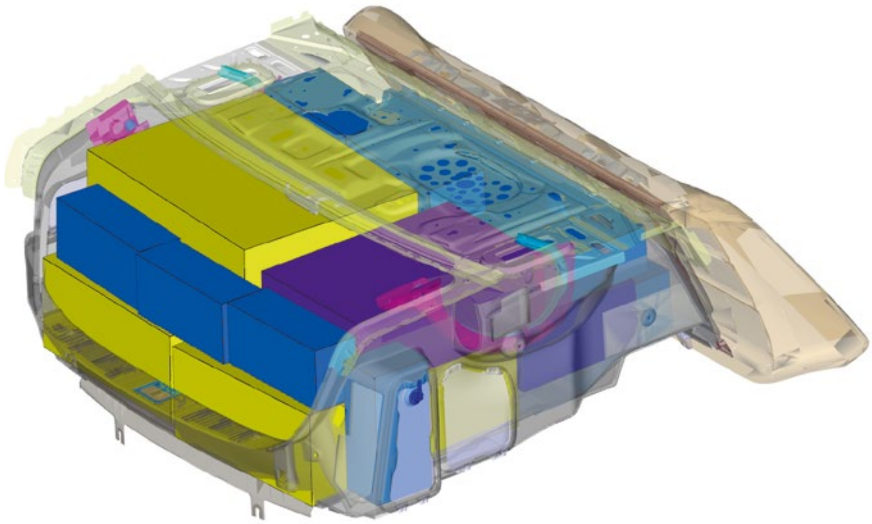

FIGURE 2 Volume determination in the USA with differently sized pieces of luggage – SAE volume of a trunk determined according to the norm SAE J1100 (© Daimler)

some of the most difficult problems in theoretical computer science with this knowledge. Practical approaches to solve these problems usually try to approximate the optimal solution.

A possible approach to find a near optimal packing is using a heuristic optimisation technique called simulated annealing. The algorithm makes random changes to the currently best packings, permanently trying to improve the packing, but occasionally also temporarily accepts worse packings. The algorithm "cools down" the search in the course of time, that is the changes become weaker and poorer packings are accepted less frequently. This process bears analogy to the freezing of water: If the cooling happens slowly enough, the molecules form long crystalline structures trying to obtain a state of global energy optimum.

The scientific experience and knowledge, which laid the foundation for the contemporary TrunkPacker, have emerged from a long-standing research cooperation, involving the developers of Rmags, Daimler, the University of Mainz and the Max Planck Institute for Computer Science (MPI) in Saarbrücken.

Since mid-2014 Rmags has taken over development, maintenance and distribution of the software to other automotive manufacturers and suppliers. Prof. Dr. Elmar Schömer from the University of Mainz supervised all research projects that have arisen in the context of this cooperation. He holds a chair for Computational Geometry and is an expert for solving packing problems. He used his expertise in this area for similar problems: for optimal layout of patterns, for the arrangement of cargo in containers and for the optimisation of cross-sections of submarine cables [1].

AUTOMATIC PACKING FROM THE USER'S PERSPECTIVE

The average number of man hours necessary to determine the trunk volumes of all model series at Daimler has been reduced by 70 % thanks to the TrunkPacker software. This enormous time saving is possible because the software integrates seamlessly into the workflow of volume determination: One can directly transfer the trunk geometry from the CAD system to the TrunkPacker, do the calculations and easily export the packings produced back to the CAD system. Also volume determinations can now be carried out much more frequently, which enables a better influence on the product development and finally an optimal trunk design. On the part of Daimler, the research project was initiated by Matthias Kreutz and headed by Sascha Mudnic during all the time.

Especially for the packing algorithms according to ISO/DIN standards, a longer running time yields a higher packing

FIGURE 3 Packing study with arbitrary objects: The TrunkPacker automatically finds the only possible placement of the green golf bag using the lateral cavities; for the brown shopping basket and the pink buggy the requirements are met to only assume upright orientations (© Daimler)

quality. Depending on the size of the trunk, several hours computing time should be provided for optimal packings. Therefore, the user can use a job scheduler to plan multiple calculations and let them execute consecutively, for example over the weekend.

In order to improve the packing quality in the time available, all packing algorithms have been parallelised. Since the TrunkPacker is a stand-alone programme and not a plug-in for a CAD programme, it can utilise the full processing power available and does not bind a license of third-party software.

The user is given many possibilities to alter and optimise a packing. He can, for example, add, move or rotate boxes. This is assisted by a real-time collision detection and a snap function: the box is snapped to the desired position and cannot overlap other boxes or trunk geometry.

In the production process of real plastic blocks manufacturing inaccuracies are inevitable. The blocks can show abrasion after some time, typically at corners and edges. To take this into account, the ISO 3832 standard allows tolerances regarding the dimensions of the measuring cuboids. The blocks may be shortened at each edge by a maximum of 1 mm and the edges can be rounded with a radius of up to 10 mm. In order to fully implement the standard and to be able to produce results comparable with a physical volume determination on the actual vehicle, the algorithms can optionally use rounded and shortened measuring blocks.

In reality, panelling of the trunk is also not completely rigid, but allows some deformations. To simulate this in the virtual model, there are material properties that can be adjusted by the user and which are included in the collision calculation.

The TrunkPacker also offers packing in layers. These layer algorithms divide the trunk into (usually horizontally aligned) layers and fill these layers with standard blocks. The packages thus generated can later be better reproduced with the physical model because layer-wise packing corresponds to the human approach of packing blocks into a trunk.

FIGURE 4 Packing study with a luggage set consisting of differently sized suitcases: the suitcases are arranged fully automatically (© Daimler)

PACKING STUDIES WITH ARBITRARY OBJECTS

For the end customer the trunk volume alone is not necessarily a measure of the practicality of the trunk geometry. He might rather be interested in whether his new car will accompany him in the next few years, according to his life circumstances and habits. With the TrunkPacker software one can therefore also pack arbitrary objects such as golf bags, beverage crates or buggies, **FIGURE 3**. Different constraints may be imposed on the objects. For example, a maximum permissible angle of inclination can be specified, which is particularly useful for beverage crates or shopping baskets.

The end customer might also be interested whether his luggage set can be completely stowed in the boot, **FIGURE 4**, or whether he can transport the wrapped shelf from the furniture store to his home, after he has turned over the rear bench seat. With the help of such packing studies the carmaker can be sure that his customer will look forward to a well-thought trunk geometry. The packing studies feature is currently in the final testing stage of development and will be available to the users in the next release.

In addition to the determination of a purely static packing, one is often interested in the actual packability, that is the question of whether the objects can be successively placed into the cargo area without collision. To this end, Rmags is working on methods for automatic planning and verification of paths along which the objects can be placed into the trunk. The calculation of dynamic motion envelopes [2] (swept volumes, **FIGURE 5**) along these paths makes it possible for the engineer to better understand the ergonomics of the cargo space and optimise the trunk geometry.

The software developers of Rmags already encountered similar problems in other fields of automotive engineering, such as robot motion planning or safety distance checks between moving compo-

FIGURE 5 Packing study with a dynamic motion envelope: a golf bag is placed into a trunk; the swept volume of this motion is shown in blue; the motion as well as the swept volume are computed fully automatically (© Daimler)

nents [3]. The developed methods in these areas will help to further optimise the computer aided design of trunk geometry.

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