

# University of Wales Trinity Saint David

Wales Institute of Science and Art



**Prifysgol Cymru**  
Y Drindod Dewi Sant  
**University of Wales**  
Trinity Saint David

A Technical analysis of the Audi TT

Harry Rogers

2205525

Automotive engineering (BEng)

23/04/2023

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Introduction To Automotive Engineering ACHA4009

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## 1 – Introduction

The German company Audi has been making the Audi TT sports car for more than 20 years. It was originally released in 1998 as a small, sporty coupe. The TT has gained popularity among sports car enthusiasts all over the world thanks to its distinctive appearance, innovative technology, and value for money. The TT has experienced several important changes over its production history as well as having multiple special edition versions made, in order to satisfy changing consumer preferences and governmental requirements. This report will look at the technical details, design principles, and performance of the Audi TT, and aims to provide a comprehensive overview of this iconic sports car as well as look at its position in the industry overall.

## 2 – Impact of the topics

### 2.1 – Materials

(Wan, 2009) discusses how the mark 2 Audi TT uses a hybrid of ASF (aluminium space frame) and steel in its chassis with most of it being made from stamped aluminium (31%). Aluminium was largely used due to its weight saving over steel. Using steel instead of aluminium would have increased the weight of the chassis by over 100kg. Stamped steel is also used for the rear floor pan for durability reasons. This material choice resulted in a chassis weight of 206kg. Details are shown in figure 1.

Figure 1



The mark 1 uses much more aluminium in the chassis compared to the mark 1, which had a steel monocoque with a bonded aluminium front end. Advanced materials technology (2014) says the weight saving has many positive impacts on the car. For example, it makes the car handle better as reducing the mass allows the car to change direction quicker, as well as helping it accelerate and decelerate faster, which for a small sports coupe, is very important. Aluminium is also very corrosion resistant and is easy to machine and shape meaning it lends itself well to being an ideal choice for Audi to use in the TT.

## 2.2 – Engineering interpretation

Chechurin & Borgianni (2016) explains that TRIZ (Theory of Inventive Problem Solving) was originally developed by the Russians during the space race. The goal of TRIZ is to find a solution to any engineering problem by categorising that problem under a set of parameters defined by TRIZ and comparing those parameters to find contradictions. Those parameters can then be matched up with principles set out by TRIZ to generate possible solutions. It is a structured, analytical approach that is designed to help solve problems using existing ideas that can be adapted to suit the situation.

Figure 2 showing the parameters and principles of TRIZ.

| The 39 Engineering Parameters |                                   |     |                                  | TRIZ – 40 Principles            |                                   |
|-------------------------------|-----------------------------------|-----|----------------------------------|---------------------------------|-----------------------------------|
| 1.                            | Weight of moving object           | 21. | Power                            | 1 Segmentation                  | 21 Skipping                       |
| 2.                            | Weight of non-moving object       | 22. | Waste of energy                  | 2 Taking out                    | 22 Blessing in disguise           |
| 3.                            | Length of moving object           | 23. | Waste of substance               | 3 Local quality                 | 23 Feedback                       |
| 4.                            | Length of non-moving object       | 24. | Loss of information              | 4 Asymmetry                     | 24 Intermediary                   |
| 5.                            | Area of moving object             | 25. | Waste of time                    | 5 Merging                       | 25 Self-service                   |
| 6.                            | Area of non-moving object         | 26. | Amount of substance              | 6 Universality                  | 26 Copying                        |
| 7.                            | Volume of moving object           | 27. | Reliability                      | 7 Russian dolls                 | 27 Cheap short-lived objects      |
| 8.                            | Volume of non-moving object       | 28. | Accuracy of measurement          | 8 Anti-weight                   | 28 Mechanics substitution         |
| 9.                            | Speed                             | 29. | Accuracy of manufacturing        | 9 Preliminary anti-action       | 29 Pneumatics and hydraulics      |
| 10.                           | Force                             | 30. | Harmful factors acting on object | 10 Preliminary action           | 30 Flexible shells and thin films |
| 11.                           | Tension, pressure                 | 31. | Harmful side effects             | 11 Beforehand cushioning        | 31 Porous materials               |
| 12.                           | Shape                             | 32. | Manufacturability                | 12 Equipotentiality             | 32 Colour changes                 |
| 13.                           | Stability of object               | 33. | Convenience of use               | 13 "The other way round"        | 33 Homogeneity                    |
| 14.                           | Strength                          | 34. | Repairability                    | 14 Spheroidality - Curvature    | 34 Discarding and recovering      |
| 15.                           | Durability of moving object       | 35. | Adaptability                     | 15 Dynamics                     | 35 Parameter changes              |
| 16.                           | Durability of non-moving object   | 36. | Complexity of device             | 16 Partial or excessive actions | 36 Phase transitions              |
| 17.                           | Temperature                       | 37. | Complexity of control            | 17 Another dimension            | 37 Thermal expansion              |
| 18.                           | Brightness                        | 38. | Level of automation              | 18 Mechanical vibration         | 38 Strong oxidants                |
| 19.                           | Energy spent by moving object     | 39. | Productivity                     | 19 Periodic action              | 39 Inert atmosphere               |
| 20.                           | Energy spent by non-moving object |     |                                  | 20 Continuity of useful action  | 40 Composite materials            |

Shortly after the launch of the mark 1 Audi TT, there were a series of high-speed crashes recorded, mostly from the autobahn in Germany. The car suffered with rear end instability at high speed which was largely due to the shape of the car causing lift on the rear end of the car (Dymott, 2022). Rather than completely redesigning the aerodynamics of the car, a small rear wing was installed to disrupt the airflow. This solution gives an example of how processes like TRIZ can be used to find a solution using existing knowledge. Looking at Figure 2, the parameters 30 (harmful factory acting on object) and 9 (speed) apply to the problem Audi faced. Putting this into a TRIZ calculator provided by Firefly Consulting (2009) gave us principle 35 which refers to changing the parameters of the object, in this case the shape. This is consistent with Audi's solution which was to change the shape of the car by adding the rear wing.

## 2.3 – Simulation

The use of computational simulations in engineering has become an essential part of engineering in general, especially in the automotive sector. Tools such as CFD (computational fluid dynamics) and FEA (finite element analysis) have changed the way vehicles are developed during the design and manufacturing phase. These tools allow manufacturers to have a better understanding of how the part will behave and work before any physical prototypes are made. It does this by simulating it in various virtual environments. This speeds up the development of parts and assemblies via rapid prototyping as they can be optimised from the first stages of the design process. As mentioned previously in section 2.2 – Engineering interpretation, the first-generation Audi TT suffered from lift being generated at the rear of the car at higher speeds. Dymott (2022) conducted a CFD analysis of the TT with and without the spoiler. The results are shown in table 1.

*Table 1 showing the aerodynamic values of the Audi TT (Dymott, 2022)*

|                                   | <b>Without spoiler</b> | <b>With spoiler</b> |
|-----------------------------------|------------------------|---------------------|
| Drag Coefficient, $C_d$           | 0.305                  | 0.265               |
| Total Lift Coefficient, $C_l$     | 0.098                  | -0.018              |
| Front Lift Coefficient, $C_{l,f}$ | -0.063                 | -0.072              |
| Rear Lift Coefficient, $C_{l,r}$  | 0.161                  | 0.053               |

It shows that the lift coefficient of the car is reduced from 0.098 to -0.018. This shows how tools like CFD can be very useful in developing vehicles because issues like the lift generation can be discovered early in the design phase. In a situation like this, that could have meant the first-generation TT being launched as a safer car and could have helped avoid the early model crashes, and in general make a better performing car.

## 2.4 – Automotive chassis

The standards for a new vehicle to be considered safe have risen rapidly over the last 30 years. This has driven manufacturers to increase safety features in their vehicles as well as develop how crash worthy they are in order to sell well on the market. Euro NCAP (n.d.) discuss that one factor pushing the development of crash worthiness in cars is the growth of Euro NCAP crash testing. Euro NCAP was founded in 1970 and had a full crash testing procedure by the 1990's. The results were first published from tests in 1997. It is not required for a manufacturer to get their new vehicles tested with Euro NCAP, although Euro NCAP does pressure manufacturers to do so. Many manufacturers sponsor their own models to be tested voluntarily to prove to customers how they perform in a crash. Euro NCAP works using a 1-to-5-star rating with 1 being the lowest and 5 being the highest. The 2003 model Audi TT was first tested in 2009 and received a 4-star rating for safety and a score of 28. It was then retested in 2015 and again received a 4-star rating. Euro NCAP (n.d.) explain that a 4-star rating means "overall good performance in crash protection and all round; additional crash avoidance technology may be present". The crash test results for the Audi TT have always been good which could have contributed to the popularity of the car and how well it has sold. Full Euro NCAP results can be found via <https://www.euroncap.com/en> (Euro NCAP, n.d.)

*Figure 3 photograph of a Mark 1 Audi TT during its Euro NCAP testing (Euro NCAP, n.d.)*



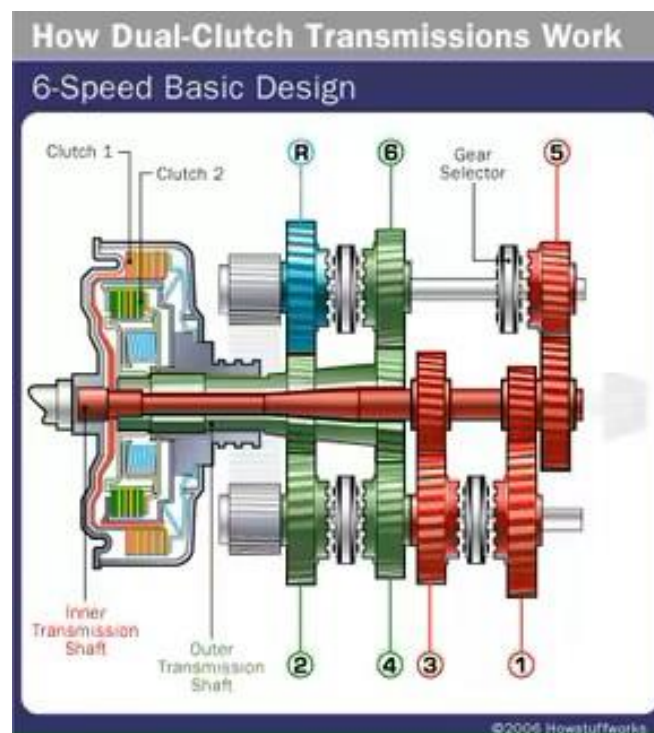
## 2.5 – Sustainability

LeaseCar (2020) says that transport makes up around 30% of global carbon dioxide output with 72% of that being from vehicles on the road. Due to the tighter restrictions on the emissions output of modern vehicles, a lot of manufactures are looking for new ways of powering their vehicles. Some examples of this are hybrid vehicles (use 2 distinct types of power) and electric vehicles which run off electricity stored in a battery. Audi make many hybrid versions of other cars in their line-up but have never made a hybrid or electric version of their TT models. Autoevolution (2020) explains that the TT was built to be an accessible sport car which was meant to be fun to drive, rather than a tool to be used day to day. For this reason, the Audi TT has been built around internal combustion engines. When Audi brought out the mark 2, the whole life emissions of the vehicle were reduced by 800kg over the original mark 1, showing that Audi were keeping the emissions of the TT as low as possible while trying to retain the cars' goal of being a fun sports car. Due to the new rules on the production of petrol and diesel in 2030, the current mark 3 Audi TT will be the final version of the coupe as they have no plans to convert it to either electric or hybrid.

## 2.6 – Engine and transmission

Research from DLG Corporate (2022) shows that cars with automatic transmissions are becoming more common than manual cars. They state that with the shift towards electric and hybrid vehicles, there is less need for people to learn how to drive manual, which explains why automatic tests rose 42% in 2020/2021. Zhang & Mi (2018) explain that DCT (dual clutch transmission) gear boxes are better for performance cars because they can change gears faster and smoother and the design lends itself to holding a lot of torque from the engines. The current models of the Audi TT are only available with Audis S-Tronic 7 speed dual clutch transmission. Zhang & Mi (2018) also state that a DCT is effectively 2 manual gear boxes set up in parallel, one with the odd number gears and the other with the even gears. It works by having the next gear that is needed ready to be engaged with its clutch disconnected. When the next gear is needed, the transmission disengages the currently applied clutch and engages the other bank with the next gear. They can be used as fully automatic or manually using paddles positioned behind the steering wheel in the case of the TT. These transmissions lend themselves to making the vehicle have the ease of use and comfort of an automatic vehicle, as well as the efficiency of a manual vehicle. This explains why Audi have only fitted their current model TT with this style of transmission.

*Figure 4 diagram of a DCT Transmission*



### 3 – Current state of the industry

Looking back at the automotive industry over the last 30 years compared to the vehicles produced today, there have been many areas in which vehicles have developed and changed. Some examples of this are the technology and driver aids, the security of vehicles and overall size and power. However, the largest area in which vehicles have changed and adapted to the modern world is the emissions standard they must meet. The RAC (2018) says that 1992 saw the first standardised emissions regulations imposed by the European union. This new regulation meant that catalytic converters effectively became compulsory on new cars. Since then, they have been updated with the aim of lowering the overall emissions output of cars with a goal of Zero emissions transport. An overview of their criteria and standards are shown in table 2.

| Year of Regulation | CO (g/km) | HC & NOx (g/km) | HC (g/km) | NOx (g/km) |
|--------------------|-----------|-----------------|-----------|------------|
| 1982               | 20.7      | 5.8             | -         | -          |
| 1992 (Euro 1)      | 2.72      | 0.97            | -         | -          |
| 1996 (Euro 2)      | 2.2       | 0.5             | -         | -          |
| 2000 (Euro 3)      | 2.3       | 0.35            | 0.2       | 0.15       |
| 2005 (Euro 4)      | 1.0       | 0.18            | 0.1       | 0.08       |
| 2009 (Euro 5)      | 1.0       | 0.16            | 0.1       | 0.06       |
| 2014 (Euro 6)      | 1.0       | 0.16            | 0.1       | 0.06       |

*Table 2 outlines emission figured for different Euro standards. (Summerfield, 2023)*

Lowering emissions has meant that manufacturers have had to rethink the way in which they design vehicles. The stricter regulations have led to the development of hybrid and electric vehicles, as their design produced less or no emissions at the tailpipe. Car manufacturers have also had to make significant changes to engine concepts with more emphasis being put on combustion efficiency and vehicle aerodynamics to reduce drag.

Another overarching factor that has driven vehicle design is safety. Hyundai Europe (2018) states how different technology developments and regulatory changes during the past three decades has advanced vehicle safety in Europe significantly. Examples of this are airbags becoming mandatory in 2006 in the EU and anti-lock braking systems (ABS) started to appear in more cars around the beginning of the 1990s. Numerous advancements have been made since then, including the electronic stability control (ESC), blind-spot identification, lane departure warning systems, and pedestrian detection along with various other driver aids. The establishment of the Euro NCAP (European New Car Assessment Programme) in 1997 has also made a significant contribution to raising the bar for vehicle safety. Euro NCAP (n.d.) explains how the program evaluates new vehicles' safety features and

assigns them a rating, which has encouraged automakers to prioritize safety in their designs. Additional rules from the European Union such as stricter crash test requirements and seatbelts becoming mandatory have increased vehicle safety. Over the past 30 years, there has been a significant decrease in road fatalities and major injuries in Europe as a result of a combination of technology developments as well as stricter regulations.

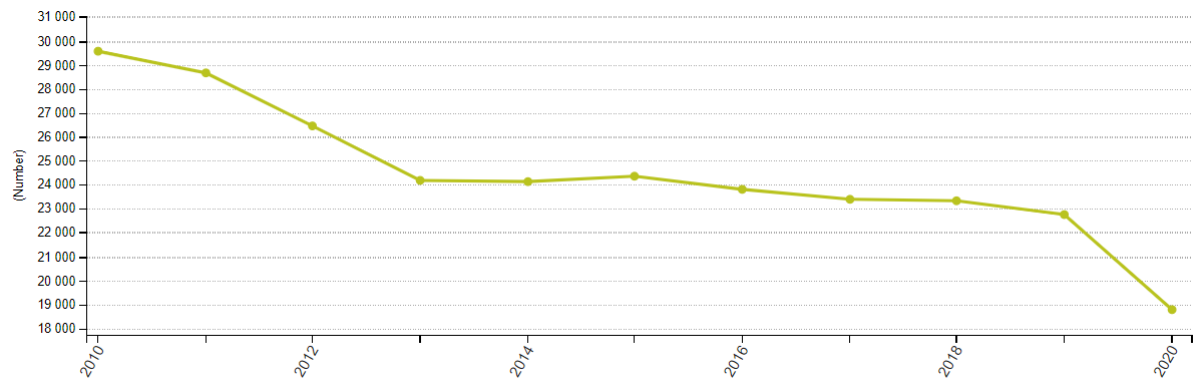


*Table 3 showing fatalities in road accidents between 2010 - 2020 in Europe.*

## 4 – Conclusion

In conclusion, the Audi TT is a well-engineered sports car that has utilised aluminium and steel in a way that provides a balance between weight and strength. This report has discussed how the use of CFD in the design process has enabled the car to overcome issues such as the rear lifting problem, ensuring optimal performance and safety. It has also highlighted how problems can be solved when they arise with the use of tools like TRIZ. Audis push to build a fun and easy to drive sports car explains the decision to use their S Tronic DCT gearbox. This transmission in the TT allows for improved fuel efficiency and performance, which enhances the overall driving experience. The Euro NCAP crash test results indicate that the TT has demonstrated reliability and is capable of protecting its occupants in case of a collision.

However, the absence of a hybrid or electric version of the Audi TT suggests that Audi is reluctant to pull the TT away from its roots. With the push toward more sustainable vehicles within the industry, Audi may be forced to make the current generation the last.

In conclusion, the Audi TT in all its forms is an impressive example of a practical sports car that emphasises the importance of innovation, safety, and sustainability in the design and production of performance sports cars.

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