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A HIGHLY CONSTRAINED GEOMETRIC PROBLEM: THE INSIDE-OUT-HUMAN-BASED APPROACH FOR THE AUTOMOTIVE VEHICLES DESIGN

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ABSTRACT

The traditional automotive design process that starts from the sketches and the 2D drawings has been superseded by the modern CAD modeling tools. The step through the clay model and the following digitalization problems can be superseded. It is now possible to construct the inside and to define the ergonomic boundaries of the vehicle in an inside out process. This approach greatly reduces the time to market of the final product by including all the parts and the components that comes from other projects or from outsourcing. However a 1:1 (true scale) physical mock up of the vehicle is, in most the cases, still necessary. In fact the evaluation of the real aesthetics of the new project should be made in a true 3D environment. The inside-out approach optimizes the standardization, the outsourcing, the multi powertrains and the unified "platform" concepts.

Keywords: automotive design, methodology to design, optimization.

INTRODUCTION

As it is simple to inform us, Wikipedia quotes: "Automotive designs are the profession involved in the development of the appearance, and to some extent the ergonomics of motor vehicles or more specifically road vehicles. This most commonly refers to automobiles but also refers to motorcycles, trucks, buses, coaches and vans. The functional design and development of a modern motor vehicle is typically done by a large team from many different disciplines included in automotive engineers. Automotive design in this context is primarily concerned with developing the visual appearance or aesthetics of the vehicle, though it is also involved in the creation of the product concept. Automotive design is practiced by designers who usually have an art background and a degree in industrial design or transportation design".

The development process is described as including the following steps: clay modeling, scale model, prototype development, computer-aided design, computer modeling, computer simulation, powertrain engineering, and manufacturing process design. This approach seems to be very theoretical. In fact the primary objective of automotive design is to deliver in the shortest time possible a beautiful car with a specific customer target. This car should be homologated in many countries following many different rules. It should be easy to use, easy to manufacture, economical, easy to maintain and, above all, safe. In fact the automotive design should be based on ergonomics, crash worthiness, manufacturing costs and adaptability to the brand. Platforms, engines, transmissions and safety components should be designed to include low cost mid-life updates. The targeted customer should feel beauty and friendliness of the product. The car has to use as many commercial components as possible. It should be modular in order to give the possibility to outsource. The design or of the car is what is perceived by the costumer and should include the exterior design or "first glance", the "interior design" and the accessories. The normal customer is not able to evaluate technical details as dynamic behavior of the car, crashworthiness etc. Many car owners never open the hood. Usually a car is barely classified by the customer as economic, family-oriented, SUV, sportive, luxury. All these models may be based on the same platform, with minor modification on settings, engines tuning, transmission types, gear ratios and software. For the customer the cars are very different, for the manufacturer and for the engineer they are very similar with minor modifications in components. The true difference is made by the design and the designer. The old approach form sketches to clay model are unreasonable in actual CAD world, in which the designer has all the CAD of the components. In CAD the "handmade sketch" should be digitally introduced in an extremely constrained environment. For example, if the designer has to make a sport utility vehicle (SUV), he must use larger tires along with the light alloy wheels design that is a "must" in the modern costumer view. In fact a SUV is a vehicle similar to a station wagon, optionally equipped with four-wheel drive for occasional and improbable off-road capability. Originally SUVs were considered light trucks in North America and Europe, and often shared the same platform with pick-up trucks. In the old times they were regulated less strictly than passenger cars under the two laws in the United States, the Energy Policy and Conservation Act for fuel economy, and the Clean Air Act for emissions. However, starting from 2004, the US Environmental Protection Agency (EPA) began to hold sport utility vehicles to the same tailpipe emissions standards as cars. In Europe and in the US not all SUVs have four-wheel drive capabilities. Moreover, although some SUVs have off-road capabilities, they often play only a secondary role, and the daily use of SUVs is largely on paved roads. The original SUV is gradually being supplanted by the

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crossover SUV, which uses an automobile platform for lighter weight and better fuel efficiency, as a response to increasing gas prices. So the platform may be the same of an A, B, C and G class vehicle. In this paper this highly constrained approach will be discussed with practical examples that will show that car design is a most difficult task, due to the multiplicity of constrains. [1]

Basic concept and simplified car example

A very simple electric car designed by Luca Sportiello, a student of the Forli Engineering Faculty is depicted in Figure-1:

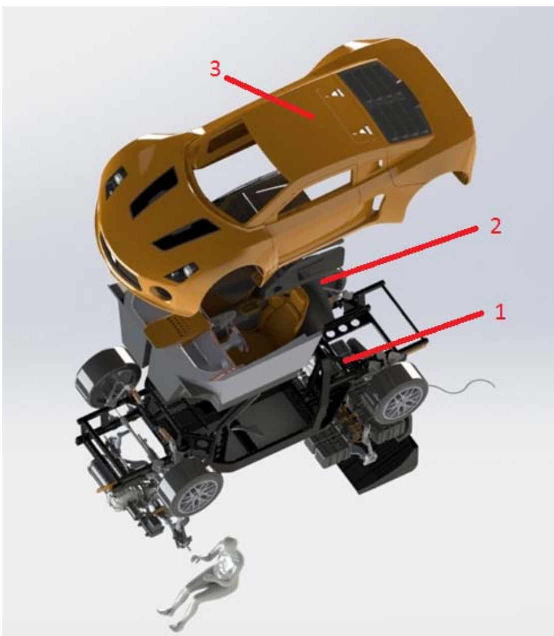

Figure-1. Electric self recharging car [2].

In the technical definition, a platform includes: underbody and suspensions (with axles) - where the underbody is made of front floor, underfloor, engine compartment and frame (reinforcement of underbody). Many other key mechanical components are included in the definition as:

- the floorpan (basic structure for the chassis and the other structural and mechanical components) [3];
- the wheelbase (that may be varied with additional floorplan components),
- the steering mechanism and type of power steering;
- the front and rear suspensions [4];
- the installation and choice of engine(s) and other powertrain components/systems. ECUs (electronic central units) and the related accessories [5].

Also well defined set(s) of user interface components are switches, instruments, control panels and many safety devices as airbags. (See element 1, in Figure-1).

On the platform, seats should be added. Seats usually are a set of possibilities: there are basic, comfort and sport models. On these seats the 95% percentile of the human population should be seated, with the required comfort and safety. The human interfaces should be added around the seats and the occupants (see element 2, in Figure-1).

It is necessary to verify the possibility to reach the knobs, switches and touch screens. The Graphical User Interface (GUI) should be also checked, and all the internal ECUs and wiring should find a suitable accommodation and cooling. Easy plug and play installation should be possible. Maintenance accessibility should be also taken into account.

External chassis (class A surfaces, see element 3, in Figure-1) and internal design should be then performed to see the outside, the car boundaries, all the indications, the mirror images.

Crashworthiness requirements will be also a major issue. Passive systems reduce the severity of injuries when a crash is happening. These include seatbelts that limit the forward motion of an occupant, Airbags that inflate to cushion the impact of a vehicle occupant with various parts of the vehicle interior. Crumple zones should be included to absorb and dissipate the force of a collision, displacing and diverting it away from the passenger compartment and reducing the deceleration impact force on the vehicle occupants. Vehicles may include front, rear and maybe side crumple zones too. A safety cell should guarantee survival space for the vehicle occupants. A pedestrian protection system should be included. Padding of the instrument panel and other interior parts, on the vehicle in areas likely to be struck by the occupants during a crash, and the careful placement of mounting brackets away from those areas. Cargo barriers may also be included to help prevent injuries caused by occupants being struck by unsecured cargo. Last but not least, the air-conditioning, heating and cooling systems for occupants, powertrain and electronics should be included [5]. Sound barriers are also installed to reduce the noise inside and outside the vehicle. The chassis should be easily producible with the available machinery. With all these constraints an original design concept is required to avoid the "similarity" with other cars. The car design is then, by definition, highly constrained.

The design process

The design process starts from the eye of the driver (see Figure-2).

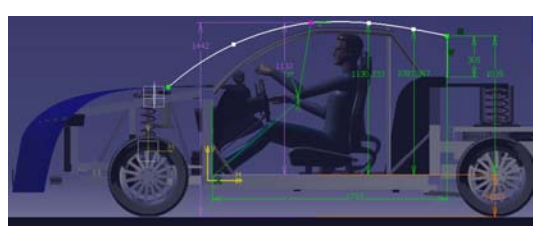

Figure-2. Ergonomics of the car (from Simone Marcoppido Master Thesis [6]).

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View direction and view angles are the starting point of the project. Then seat position should be chosen (see Figures 3, 4 and 5) depending on vehicle type [4, 7].

Equation (1) and (3) guarantee the head space for the tallest and smallest driver, (2) and (4) describe the pedals reach ability.

$$H \geq t_{\max} \cos \alpha + h_{\max} \cos\beta + h_{s_{min}} + h_{space} \quad (1)$$

$$L_{max} \geq \left(Leg_{upper} \cos \gamma_{min} + Leg_{lower} \cos \delta_{\min}\right) \cos\left(\tan^{-1}\left(\frac{h_{s_{min}}}{\left(Leg_{upper} \cos \gamma_{min} + Leg_{lower} \cos \delta_{\min}\right)}\right)\right) \quad (2)$$

$$h \leq t_{\min} \cos \alpha + h_{\min} \cos\beta + h_{s_{max}} \quad (3)$$

$$L_{min} \leq \left(leg_{upper} \cos \gamma_{max} + leg_{lower} \cos \delta_{\max}\right) \cos\left(\tan^{-1}\left(\frac{h_{s_{max}}}{\left(leg_{upper} \cos \gamma_{max} + leg_{lower} \cos \delta_{\max}\right)}\right)\right) \quad (4)$$

Initially the tallest possible driver is considered, and then the smallest one is introduced with his ergonomics. Both should see, drive and use switches and toggles properly.

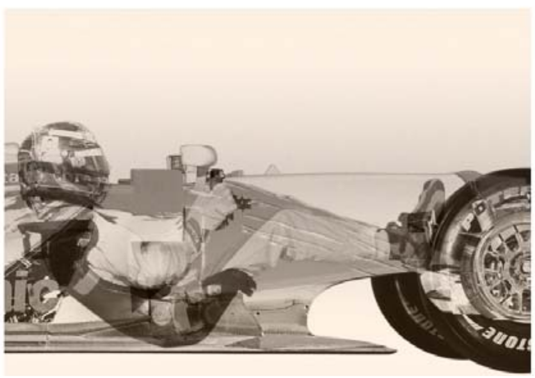

Figure-3. F1 driving position image (from Toyota F1 Goodby site).

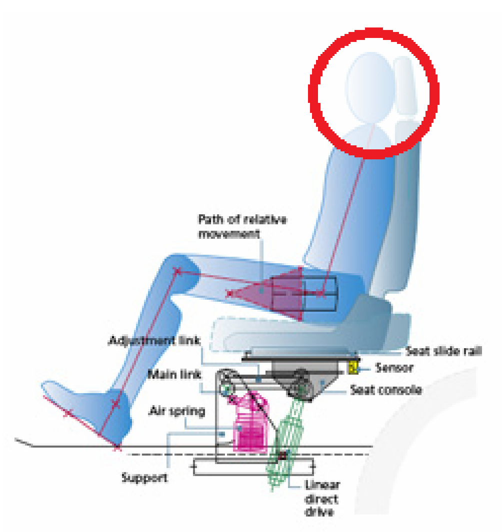

Figure-4. SUV driving position with circled room for driver's head.

Figure-5. Typical truck seat.

The tallest considered person is then assembled on the seat (see Figure-6)

The eye position for the virtual driver should then be selected along with the headspace, legs, pedals.

The 95% of the human population should use comfortably the vehicle (Figure-3), simply by adjusting the seat and the driving wheel.

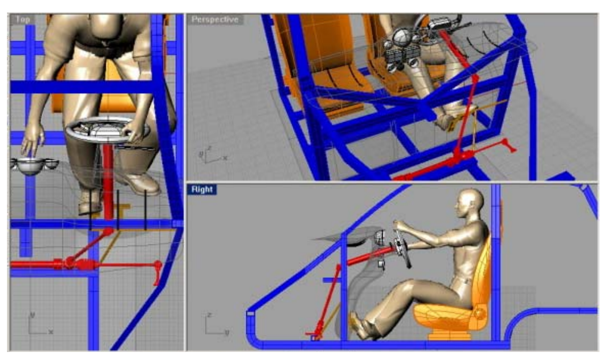

Figure-6. Ergonomics: initial checks on Danilo Donati's microcar [8]. The platform has a tubular structure.

The process should be repeated for the passengers. Once defined the seat and the main ergonomics, an initial geometry of the interiors (see Figures 6, 7 and 8) can be designed. It is then possible to

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install everything of the platform, with engines, transmissions and the suspension set [9].

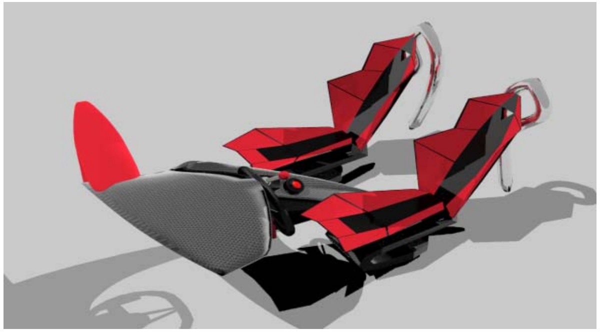

Figure-7. Preliminary internal design (from Luca Ercolani Bachelor Thesis [10]).

Figure-8. Knob and switches ergonomics (form Donati Master Thesis [8]).

With masses and intertia data of the main components it is then possible to have an idea of the dynamic of the car. Several simulators are available for this purpose. At this stage, it is still possible to take "painless" corrective actions if the car has stability problems. With the stability checked, the designer can define the exterior of the car (Figure-9). This phase closes the project and freezes the previous solutions.

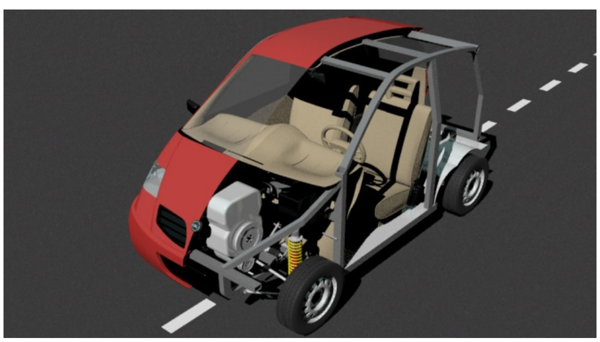

Figure-9. Danilo Donati's initial microcar design [8].

Then the necessary checks should be performed.

Figure-10. Inside out driver's view with wipes [8].

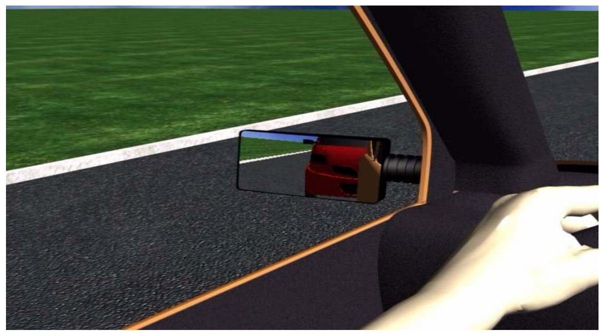

Figure-11. Checks on lateral mirror view [8].

It is then possible to check the inside-outside view (Figures 10 and 11) and then define a possible design (see Figure-12)

Figure-12. Possible exterior design and aesthetic evaluation [8].

If the result is not satisfactory it is necessary to travel through again the whole process until a satisfactory compromise is reached. Aesthetic is a matter of proportion and the refinement process may be tedious. Photo rendering helps the designer to obtain the right look. However a trained eye is necessary since photo rendering may be tricky. A 1 to 1, true scale, model of the car is more reachable to the average person. It can be made with relative ease if the whole process has been made by CAD modeling. The final aspect of the car will be the same of the photo rendering and of the 1 to 1 model since the mathematical model is the same. Again the various possibilities of colors (Figure-13), configurations and accessories should be evaluated along with at least a midlife update of the car.

Figure-13. Donati's "Koala" final design [8]. Since design is a matter of proportion, photorendering can be of great help.

Manufacturing feasibility tests should be performed to verify that the chassis can be produced with reasonable costs and quality. Maintenance feasibility simulations should also be carried out. Then crash tests should be performed. Finally the dynamic model can simulate accurately the behavior of the car from the driver point of view. A simulator can be used by the test pilot.

CONCLUSIONS

From the Eighties the introduction of CAD and CNC (Computer Numerical Control) to now has revolutionized the design process. Manual sketches, wall projections of components, tape design and clay modeling have been superseded by direct 3D CAD modeling. This simultaneous design approach includes already available commercial components and ergonomics. The designer can then behave appropriately in the highly constrained environment of automotive design where ergonomics, economics, manufacturing and safety dictate important boundaries to the creativity. The design process starts from the eye to the driver and ends on car outside with an inside out process that leads the designer to the fulfillment of the many boundaries and goals. Style and aesthetic considerations are greatly helped by video realistic rendering that however requires an expert eye for a proper evaluation. Once a 1:1 digital mock up is realized it is easy with CNC and 3D printing to realize a 1:1 physical mock up for style final evaluation and refinement [9, 11, 12].

Symbols

H floor to ceiling distance [m]
t_{max} maximum torso length [m]
α minimum torso/seat inclination from the vertical [-]
h_{max} maximum head-neck length [m]
β minimum head-neck inclination from the vertical [-]
h_{space} minimum vertical head space [m]
h minimum line of sight height [m]
t_{min} minimum torso length [m]
h_{min} minimum head-neck length [m]
h_{s_min} minimum seat height [m]
β minimum head-neck inclination from the vertical [-]
L_{max} max horizontal distance of hip joint to fully engaged pedal [m]
Leg_{upper} maximum femur length [m]
Leg_{lower} maximum tibia length [m]
γ_{min} minimum angle femur to horizontal [-]
δ_{min} minimum angle tibia to horizontal [-]
L_{min} min horizontal distance of hip joint to disengaged pedal [m]
leg_{upper} minimum femur length [m]
leg_{lower} minimum tibia length [m]
γ_{max} maximum angle femur to horizontal [-]
δ_{max} maximum angle tibia to horizontal [-]

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