

Vehicle Spaciousness and Packaging Efficiency

Rajiv Mehta and Mark Hadley
General Motors Co.

ABSTRACT

With the ever increasing pressure to improve the fuel economy of vehicles, there has been a corresponding interest in reducing the mass and size of vehicles. While mass is easily quantifiable, vehicle size, particularly the notion of "interior space" as perceived by the customer, is not. This paper explores different ways in which vehicle spaciousness can be quantified and explores new metrics based on customer verbatims. A novel 'spaciousness calculator' combines individual metrics to provide a singular holistic rating for spaciousness, useful during vehicle development. Beyond spaciousness, the paper discusses techniques to quantify the 'packaging efficiency' of a vehicle; this allows engineers to maximize the interior space for a given exterior size.

CITATION: Mehta, R. and Hadley, M., "Vehicle Spaciousness and Packaging Efficiency," *SAE Int. J. Passeng. Cars - Mech. Syst.* 7(1):2014, doi:10.4271/2014-01-0348.

INTRODUCTION

A key attribute of any vehicle is the amount of space it provides for the occupants. Research [1] shows spaciousness ranks high on the list of attributes considered during vehicle purchase and also contributes to a positive ownership experience. Thus, it is important for vehicle manufacturers to know how a vehicle performs in terms of delivering space for its occupants.

For Engineers it has been a challenge to try and quantify spaciousness. Unlike other vehicle design parameters, such as 0-60 mph acceleration or torsional stiffness which are based on physics or engineering principles, spaciousness is not easily quantifiable. This is due to the experiential (sensory) nature surrounding the perception of space. Today many single dimensional metrics exist (such as headroom) however no single metric exists which captures the entire customer experience. This makes it difficult to monitor this important vehicle attribute through the development process, making decisions involving spaciousness more complex and oftentimes subjective.

This paper discusses different ways in which spaciousness can be quantified and explores new metrics which can be aggregated to create a single metric that relates to the customer experience.

While a vehicle can be spacious, it does not mean it is packaged efficiently, hence the notion of 'space efficiency'. With the pressure to reduce vehicle mass, it has been suggested that 'downsizing' is needed, however no customer wants less interior space. Thus it is important to look at interior spacious in relation to the exterior size of a vehicle. By

providing a methodology for assessing space efficiency, we can gauge progress during the development phase of a vehicle and take steps to improve the packaging efficiency of the vehicle as it is being designed.

CUSTOMER NOTIONS SURROUNDING SPACIOUSNESS

In order to quantify any metric or attribute in a meaningful way, we need to understand what it means to the end user or customer. [Figure 1](#) shows verbatims emanating from vehicle owners when asked what 'spaciousness' means to them. Frequently, common language expressions such as "I can spread-out and move around" are used rather than engineering terms such as 'legroom'. This is important as we must not assume there is direct translation between commonly used SAE or ISO metrics and what the customer experiences.

Comprehensive learning reports show that customers view spaciousness rather holistically - see [Figure 2](#). For example, how easy it is to enter and exit a vehicle influences how one feels about interior spaciousness. The amount of visibility experienced by the occupant influences the perception of space. We have heard the expression: the more light we have coming into the living room, the larger the room will appear to look and feel.

What is Spaciousness?

Typical perceptions based on Customer Research

Roominess/visibility combined map – linkage between pathways

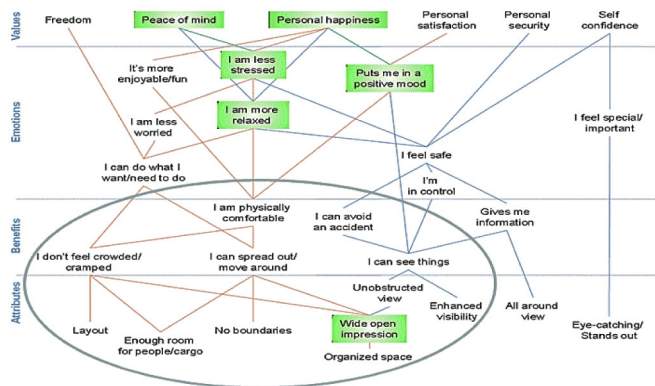


Figure 1. Typical perceptions of Spaciousness based on customer research. The area circled relates specifically to spaciousness.

Factors influencing the Perception of Space

External Influences

- Segment & brand expectations
- Customer (occupant size, etc)
- Intended vehicle use
- Global / Regional preferences

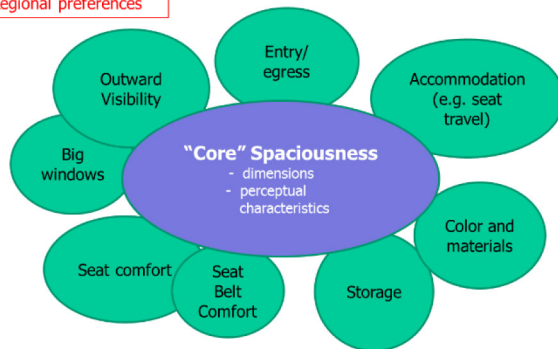


Figure 2. Spaciousness is influenced by external influences as well as other product attributes such as visibility.

METHODS TO QUANTIFY SPACIOUSNESS

Today the industry uses a variety of methods to measure the spaciousness of a vehicle. Each has some positive aspects as well as limitations.

Dimensional Assessment

Perhaps the most common way of expressing spaciousness is through the use of singular dimensions such as headroom, legroom, etc. Some of these are shown in Figure 3. These dimensions are typically represented by SAE [2] or ISO codes, making them useful for relative comparison between vehicles. These dimensions are typically point-to-point measurements and pertain to a select area of the vehicle. We are reminded that these are simply measurements of interior distances using standard tools and do not necessarily relate to the customer experience. One such example is 'shoulder room', a fundamental cross-car dimension used in the packaging world.

It is measured vertically above the occupant's Hip-point and not adjacent to the where the shoulders of a seated person typically reside.



Figure 3. There are a multitude of SAE dimensions that are used to "measure" spaciousness.

EPA Volume Index

EPA Volume Index [3] is used in the United States to classify vehicles according to their size. For example, cars having an EPA Volume Index of 110-119.9 cu.ft. are classified as "midsize". In the case of 'notchback' cars, i.e. vehicles with a trunk, the EPA volume Index is the sum of the 'passenger compartment' volume and the 'trunk' volume. The 'passenger compartment' volume is calculated by multiplying selected length, width and height-related interior dimensions; the 'trunk' volume is calculated using a standardized SAE luggage kit.

At a high-level, the EPA 'passenger compartment' volume provides some indication of interior space. However, many *shape-related* elements of the vehicle are not represented by the dimensions used for the calculation, an example being the 'tumblehome' of a vehicle (amount of tip-in of the side glass adjacent to the occupant's head). Neither are 'encroachments' from interior components such as the instrument panel or console considered.

Math-Based Interior Volume

The idea of calculating the total interior volume in math is akin to filling up the interior of the vehicle with say, water or marbles, and then measuring the occupied volume. Unfortunately this method is not easy to execute in math (and certainly not physically!) due the presence of discontinuous surfaces, such as the gap between the front seat and console. These 'discontinuities' make volume calculations difficult in CAD. Moreover, the total volume of the cavity of space is less meaningful when you consider certain parts of the vehicle (such as the space above the package shelf) are of limited value from a spaciousness perspective. In other words, all space is not created equal.

Occupant Models

There are several different occupant models available in the Industry. One such model is the 3D CAD manikin RAMSIS shown in [Figure 4](#). These occupants come in different sizes and can be positioned in a variety of ways. Occupant models are fundamentally 'accommodation' tools, useful for studying 'clearances'. For example, is there sufficient clearance between an occupant's head and the headliner surface? It is not within the scope of most models to suggest *how much* clearance is needed. As such these tools are useful for assessing if an occupant 'fits' in the environment and are not ideally suited for predicting spaciousness.

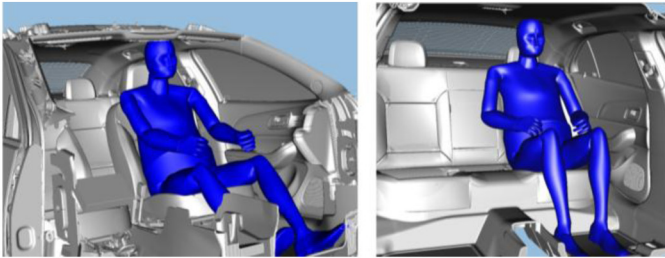


Figure 4. 3D CAD Manikins such as RAMSIS are used to study Occupant Accommodation, e.g. does the occupant 'fit'.

CUSTOMER-BASED METRICS

Over the years, numerous spaciousness clinics have been conducted by General Motors in different parts of the world, across a broad range of vehicles. These clinics have provided valuable insight into how customers perceive space. Whereas Engineers speak in terms of headroom and legroom, clinic participants express themselves in terms of observations and experiences:

- "I hit my knee on the side of the console"
- "The Instrument Panel looks tall and intrusive"
- "There is a lot of space for my feet to move around"

Despite the availability of many SAE metrics, few correspond directly to customer verbatims. This is probably due to a combination of factors:

- Customers think in holistic terms and generally don't hone-in on a specific localized area of the vehicle.
- Perceptual characteristics such as shape, color, and clutter, which can influence one's perception of space are not comprehended.
- Dimensions such as 'legroom' have a broader meaning to the customer; in the case of legroom, it can mean fore-aft leg room, side-to-side leg room, clearance of the leg to the instrument panel, or a combination of the above.
- SAE metrics have not evolved to include more complex geometry.

Therefore in order to create a holistic metric for spaciousness, it becomes necessary to define additional metrics which relate to the customer experience. A total of 10 new metrics have been created using the customer as a guiding compass. Two of these new metrics are illustrated in [Figures 5a](#) - Instrument Panel Spaciousness and [Figure 5b](#) - Under-seat Footroom. (Please note, it is not within scope of this paper to share all of the new metrics that have been developed).

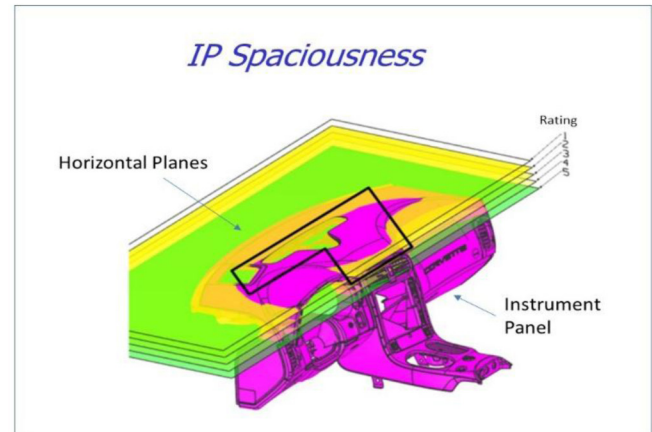


Figure 5a. Newly developed metric to quantify IP spaciousness.

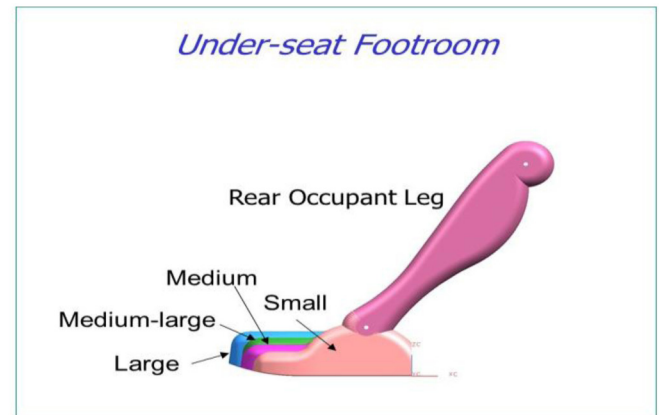


Figure 5b. Newly developed metric to quantify Under-seat Footroom.

MULTI-DIMENSIONAL APPROACH TO SPACIOUSNESS

Using the building blocks of dimensional and attribute characteristics, including the 10 newly developed customer-based metrics, we can start thinking of spaciousness in more holistic terms.

A total of 26 metrics have been combined to create a proprietary "Spaciousness Calculator", shown conceptually in [Figure 6](#).