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In-Vehicle Sliding Door System Finite Element Analysis and Experimental Verification

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Abstract
A sliding door system is used in commercial vehicles and passenger automobiles to provide more access to the inside for loading and unloading. Mechanisms and tracks with a particular cross-section created by roll forming and stretch bending ensure the movement of a sliding door on a vehicle body. On a sliding door system, there are three tracks and three mechanisms known as upper, central, and lower. To verify these goods, static criteria such as strength in multiple directions, mechanism stiffness, door drop off, and door sag must be met, as well as dynamic requirements such as high energy slam opening-closing and durability. Furthermore, there is a kinematic requirement to determine force values from the door handle during manual operation. In this work, the finite element analysis and physical test results for sliding door systems will be compared.

Keywords: *Sliding Door, Experimental, Finite Element Analysis, Vehicle Tests, Verification.*

INTRODUCTION
Wilbur W. Ellis patented the first sliding door used in a vehicle in 1913. It is comparable to the existing system. Mechanisms transport the door along rails [1].

Mechanisms and tracks ensure the movement of a sliding door on a vehicle body. On a sliding door system, there are three tracks and three mechanisms known as upper, central, and lower. Sliding door systems are made out of steel, plastic, and rubber pieces that are formed cold and hot.

The Finite Element Method is increasingly being utilised for engineering application analysis. Despite the introduction of user-friendly finite element applications, it is challenging to establish a suitable model that allows for a realistic understanding of the physical processes involved in a real-world project and delivers a reasonable forecast of design quantities (i.e. displacements, stresses, structural forces, bearing capacity, safety factor, etc.) [3]. A sliding door system's initial design validation stage is finite element analysis. As inputs for finite element analysis, CAD data and well-defined boundary conditions are required. Design engineers finalise CAD data during the design process. The system requirements of a sliding door aid in understanding the boundary conditions of finite element analysis. Physical testing are another key design validation phase for a sliding door system. The outcomes of finite element analysis and physical tests must be compared.

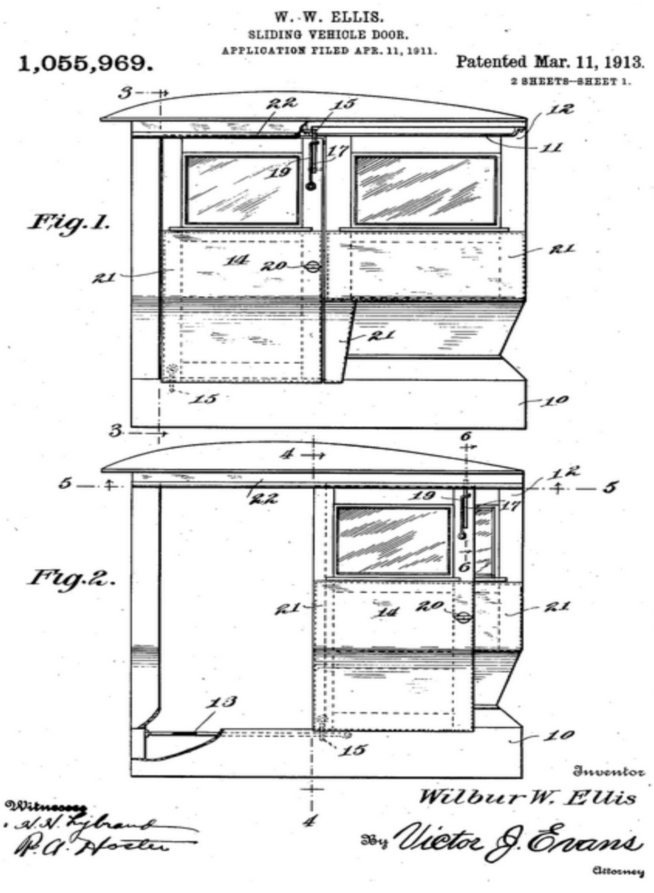

Figure:- 1 First sliding door patent [2]

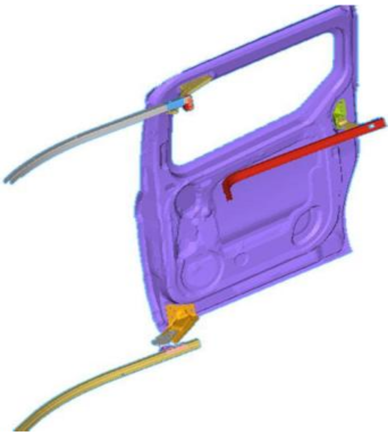

Fig. 2 Sliding door system

VALIDATION PROCESS WITH RESULTS

The validation approach for the design of a sliding door system is depicted in Fig. 3. Many conditions must be met by the design of a sliding door system. Some of these prerequisites are given below.

- Manual Operating Effort
- High Energy Slam
- Door Drop Off
- Door Stiffness
- Mechanism Stiffness
- Durability
- Packaging

It is critical to use finite element analysis to detect design flaws. Otherwise, the validation procedure takes longer. If a design flaw is discovered during physical testing following prototype production, the validation procedure is repeated.

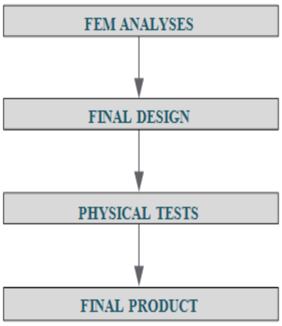

Fig. 3 Validation process

A. Manuel Operating Effort

The sliding door's maximum manual operating efforts must be less than the effort profile stated standard. Hyperworks Motionview is used to create the kinematic model. The mass, centre of gravity, and inertia of all sliding door system components are loaded into Motionview. Joints provide mechanisms with degrees of freedom. The door's centre of gravity and handle point are identified for study. The door is opened at a consistent speed. Hyperworks Motionsolve solves the final kinematic model. The effort results for the door handle are computed. Figure 4 depicts a kinematic model of a sliding door. Table I compares the test and analytical findings for the manual operating effort of a sliding door.

B. High Energy Slam

This criterion replicates the action of a sliding door under gravity on a 30% inclination. To slam the door open, the door must be allowed to free fall from a fully closed to fully open position by unlatching. The door must be allowed to free fall from the fully open to fully closed position before slamming shut. The door must still meet additional functional criteria after passing the test.

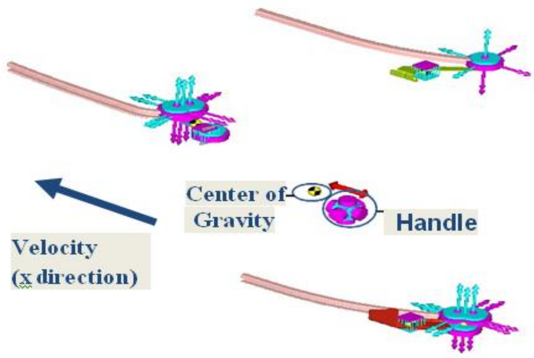

Fig. 4 Kinematic sliding door model

Table I: Effort Results from Test and FEA

	Curve Section Opening	Linear Section Opening	Linear Section Opening	Curve Section Opening
FEA	37,00 N	20,00 N	4,00 N	-19,00 N
Test	33,08 N	14,9 N	0,00 N	-13,09 N

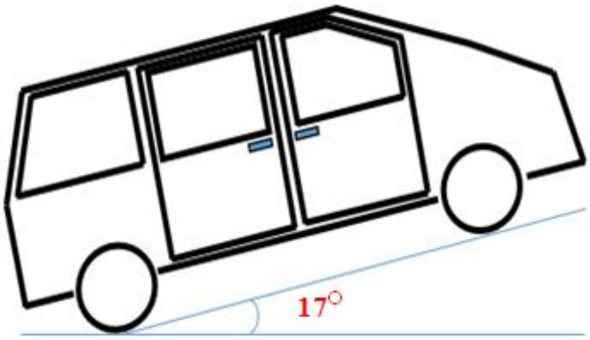

Fig. 5 High energy slam opening requirement [1]

The FEA model is being developed as the sliding door nears completion of its motion. It is modelled near the conclusion of the track for high energy slam opening analysis. The analysis begins with the initial velocity of the hit, which is computed using conservation of energy or evaluated using a physical test. Mechanisms collide with the rubber bumpers at the track's finish. As a consequence of the study, stress and strain measurements are acquired in order to detect damage to the parts. The door velocity, which varies on the track length, is 10 km/h. As a result, one of the most demanding criteria for a sliding door system is high energy slam. Damage examples from test and analysis are provided in Fig. 6 and Fig. 7 for high energy slam requirements.

C. Door Drop Off

The drop-off of the fully trimmed sliding door must not exceed the limit established by the door's own weight. Table II shows the displacement findings of the door drop off study and test. Figure 8 depicts the displacement pattern of a sliding door based on door drop off analysis.

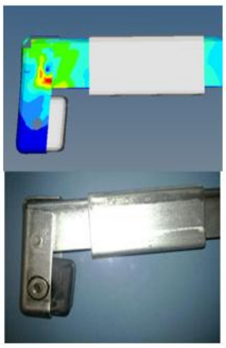

Fig. 6 Corresponded plastic deformation of bracket

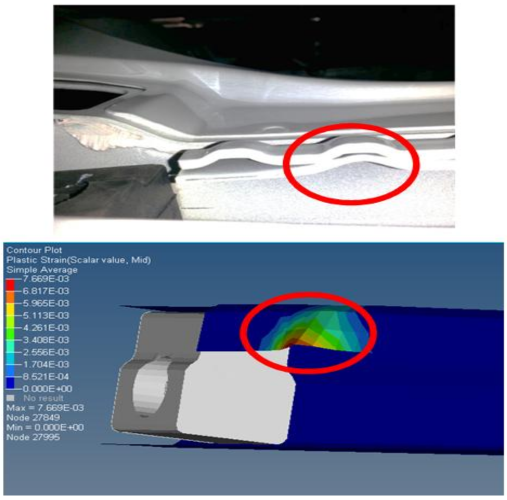

Fig. 7 Corresponded plastic deformation of track

D. Door Stiffness

For door rigidity requirements, tests and analyses are performed in both completely and partially opened positions. There are 14 distinct stiffness requirement conditions with;

- Different door positions,
- Different force values,
- Different force direction,
- Different applied points.

When the weight is removed, the door must not detach from the rails and must remain functioning. The stress and strain findings of the finite element analysis are used to assess disengagement and functioning.

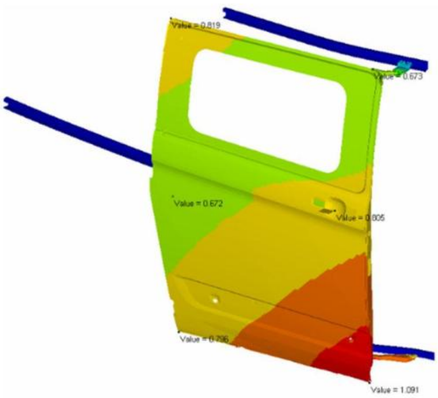

Fig. 8 Door drop off displacement results

TABLE II Displacement Results From Test and Analysis

Results	Ajar Position Displacement	Open Position Displacement
Analysis	1,291 mm	1,360 mm
Test	1,800 mm	1,920 mm

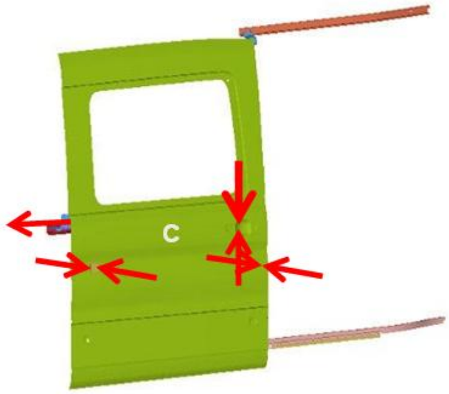

Fig. 9 Stiffness requirement load directions

E. Mechanism Stiffness

Door weight has an immediate impact on mechanisms via the contact between mechanisms' carrying rollers and tracks. This criteria is a simple technique to determine the robustness of the mechanisms. The carrying roller is subjected to force. Stiffness analysis yields stress, strain, and displacement findings.

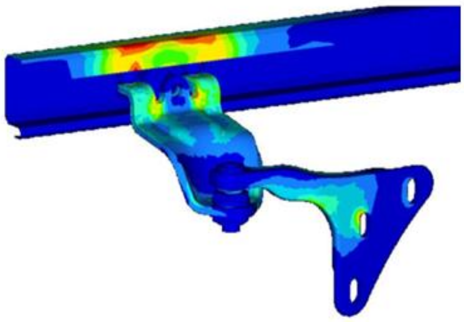

Fig. 10: Stress distribution of track and mechanism from stiffness analysis

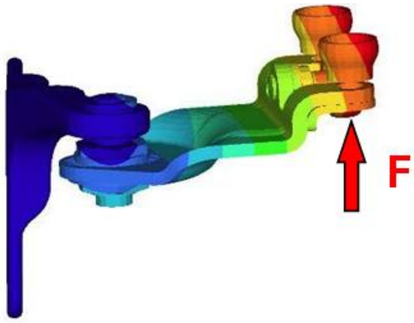

Fig. 11: Displacement distribution and force direction [4]

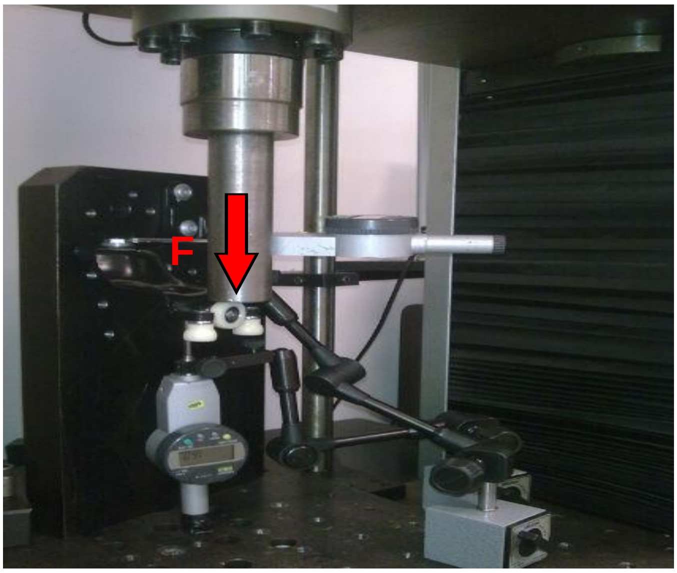

Fig. 12: Physical test set up for mechanism stiffness

This criteria is met by a physical test. Table III compares the displacement findings of stiffness study performed on an upper mechanism [5].

TABLE III: Displacement Results From Test and Analysis

Results	Displacement from Test	Displacement from CAE
Specimen No 1	2.90 mm	2.97 mm
Specimen No 2	3.38 mm	2.97 mm
Specimen No 3	3.55 mm	2.97 mm

F. Durability

Durability is an important factor in the functioning of a sliding door. This requirement was met by a physical test in a climatic chamber under varying conditions depending on the kind of sliding door. Need elements include cycle, opening speed, closing speed, temperature, and moisture.

The door must still satisfy the fit-finish requirement, the opening effort requirement, the closing effort requirement, the squeak and rattle requirement, and the door closing sound quality requirement after passing the test. Furthermore, there must be no sheet metal fractures, discolouration, fracturing, or attachment loosening.

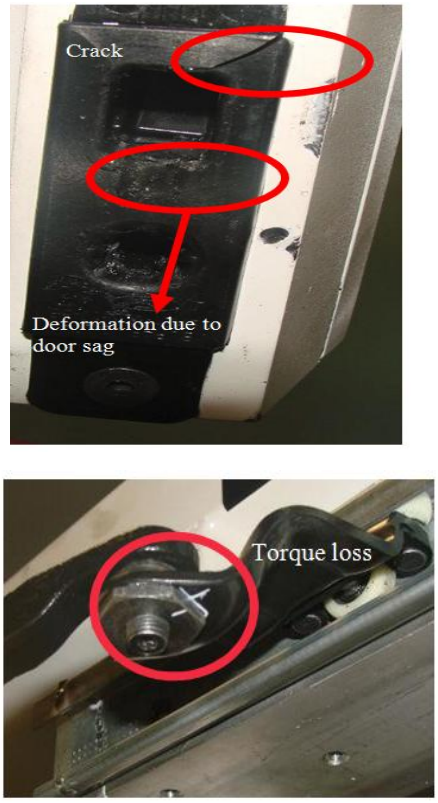

Figure: - 13 Part fails from durability test [6]

G. Packaging

Minimum clearances are checked using kinematic analysis while the sliding door is in motion.

CONCLUSION

A sliding door mechanism utilised in the automobile sector was investigated through experimental verification and finite element analysis. Finite element calculations and physical testing were carried out in accordance with the specifications.

To begin, the goal is to create a sliding door mechanism that will not fail. Then, if there is a design flaw, finite element analysis is preferable to physical tests. The worst case scenario is seeing failures with physical testing on prototypes from the validation phase.

Our testing and analytical skills continue to evolve in relation to the sliding door design validation process. Measurements of new parameters (stress, strain, residual stress, and so on) with physical testing allow for additional parameter comparisons between tests and analyses. It contributes to the precision and correlation of finite element analysis. Our research focuses on fatigue and durability. These studies are critical in terms of design life and customer satisfaction.

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