Effective Aircraft Seat Development for Row to Row HIC test

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Agenda

1. Background

- Current aircraft seat dynamic qualification tests use the **H**ead **I**njury **C**riteria (**HIC**) to evaluate head protection. Difficult to understand which characteristics contribute the HIC value.
- Seat supplier must satisfy HIC with overall seat system, but the parts other than those of the seat supplier may be incorporated to the seat.
- Development verified by detailed seat model as conventional manner is costly and it takes time to complete the analysis.

Our Target

Clarifying the correlation of each characteristics of component items by using Model Based Development, then define target characteristics for product design.

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Application of Model Based Development to row to row HIC test

・Row to row HIC test (Zone C)
To confirm whether the occupant's head injury, femur load and post-test seat deformation condition within the limit or not, in case the inertia load of emergency landing occurred with multiple row layout.

HIC ≦ 1000
Femur compression Load ≦ 2250 lbf
Deformation: within the limit,
no harmful edge or injurious protrusion

HIC is calculated by following formula with Head Acceleration

$$HIC = \left\{ \left[\frac{1}{(t_2 - t_1)} \cdot \int_{t_1}^{t_2} a(t)dt \right]^{2.5} (t_2 - t_1) \right\}_{max}$$

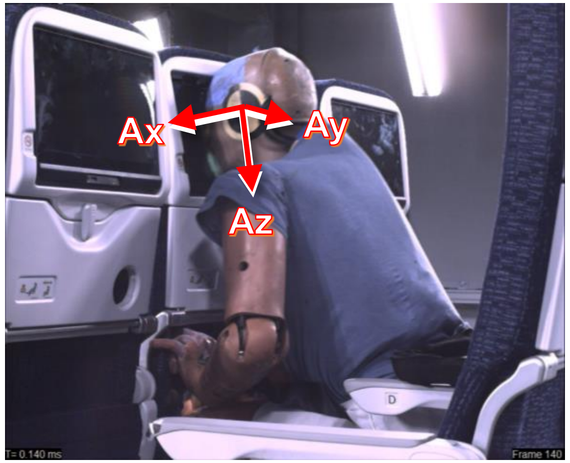
Extracted from AC 25.562-1B

Where a(t) is the resultant acceleration of the CG position of anthropomorphic test device head in g's, and t_1 and t_2 are times in the response that maximize the function.

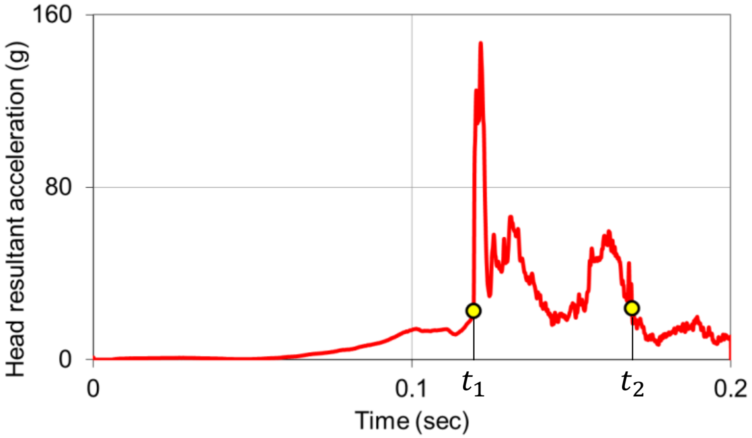
Before test

Head impact during test

Head Acceleration element



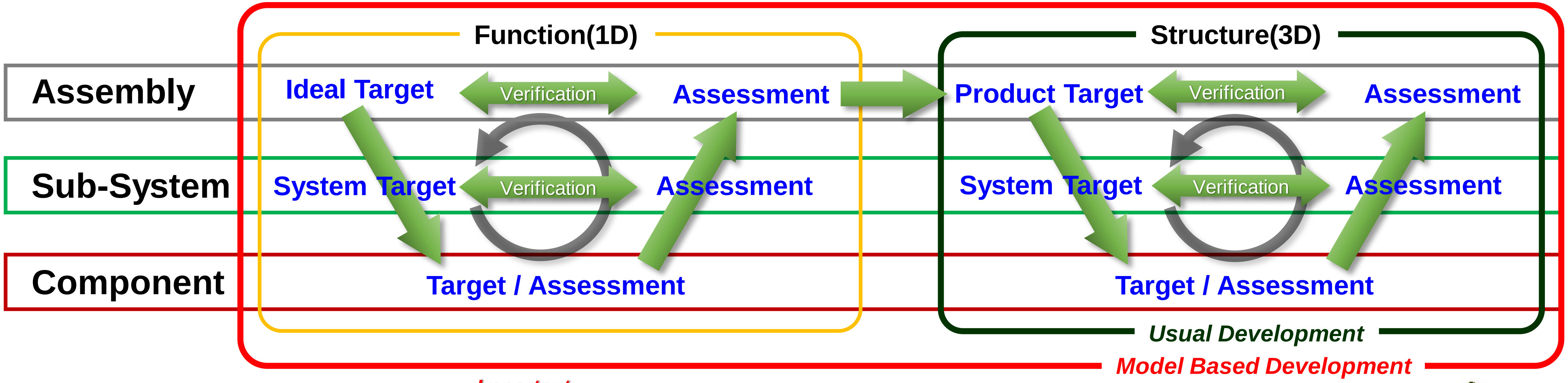
Sample of Head resultant acceleration graph

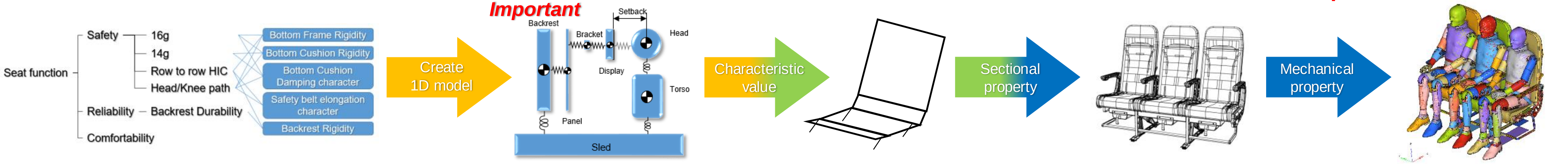


1. Background

- What's Model Based Development?

To develop a product from functional perspective in prior to structural verification phase.



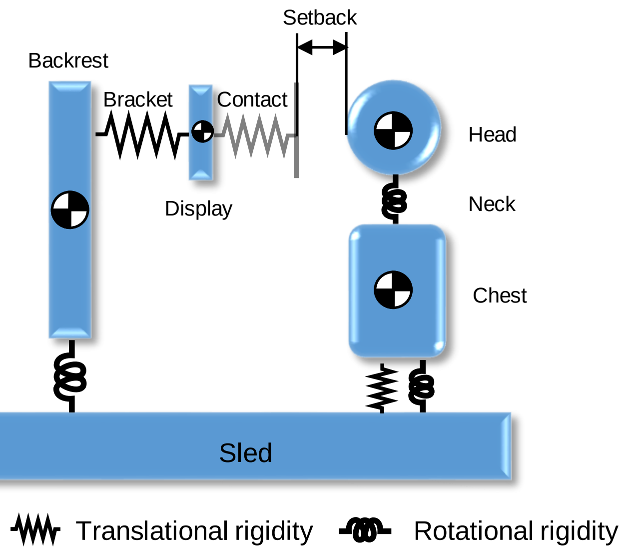


1. Background

- What's 1D CAE?

Representing the entire target product on function basis without omission and evaluating them. It is possible to design overall appropriately at the upstream stage of product development.

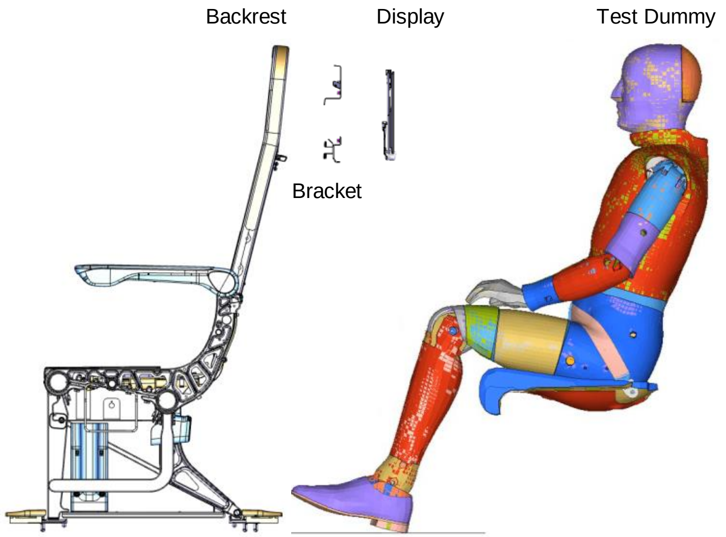
Physical Model (1D CAE model)



Represent physical phenomenon as simple model (can be replaced by mathematical formula), then verify the functional target

Functional target (Characteristics)

Product (3D CAE model)



Design the shape of structure that satisfies the functional target

1. Background

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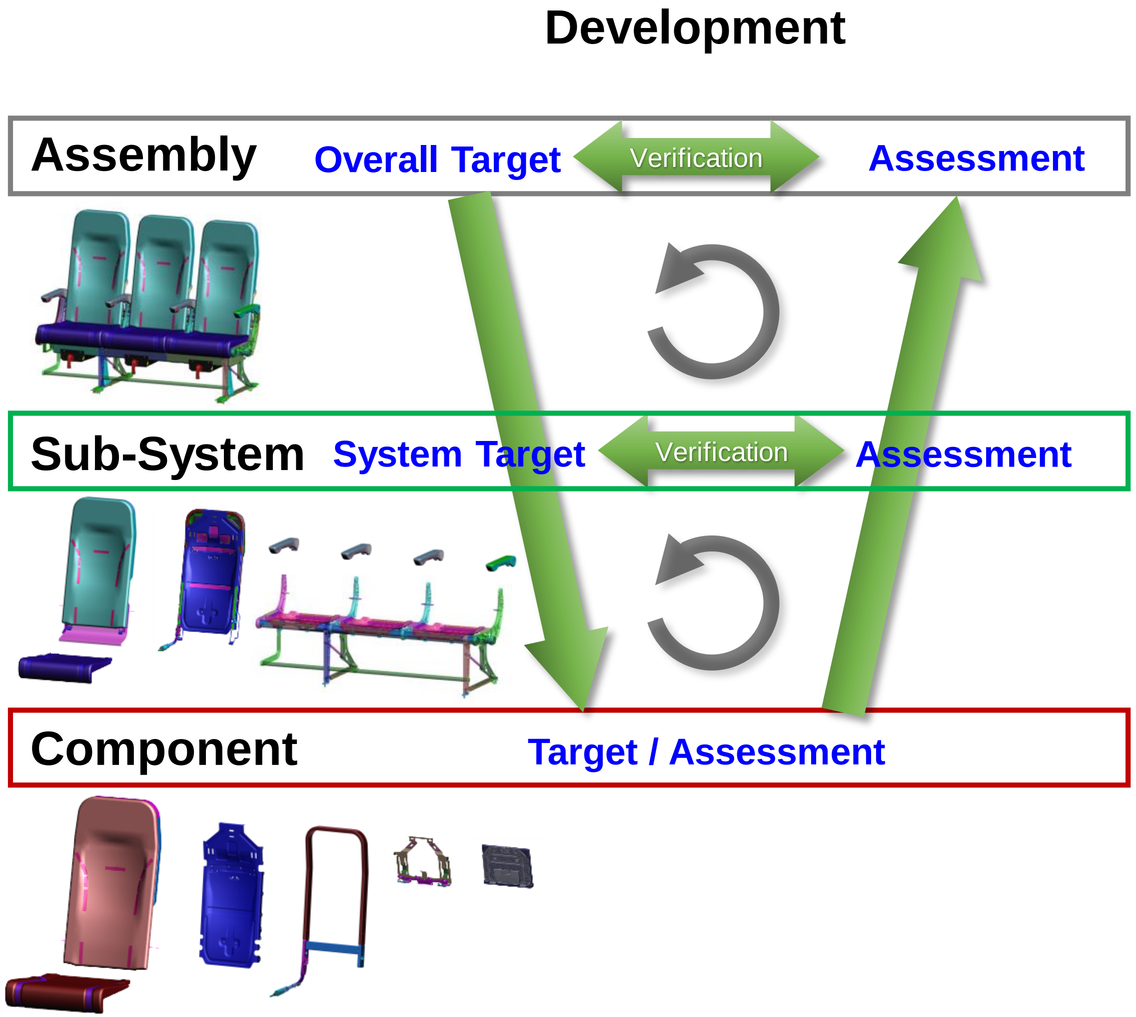
- Procedure of model based development

1. Consider the ideal performance of seat
(Value design/conceptual design/statement)
Determine what kind of seat to design and where to put the value into.

2. Generate function tree and clarify the interaction among each characteristics.
Breaking down overall target into types of functions. Make what the target consists of visible.

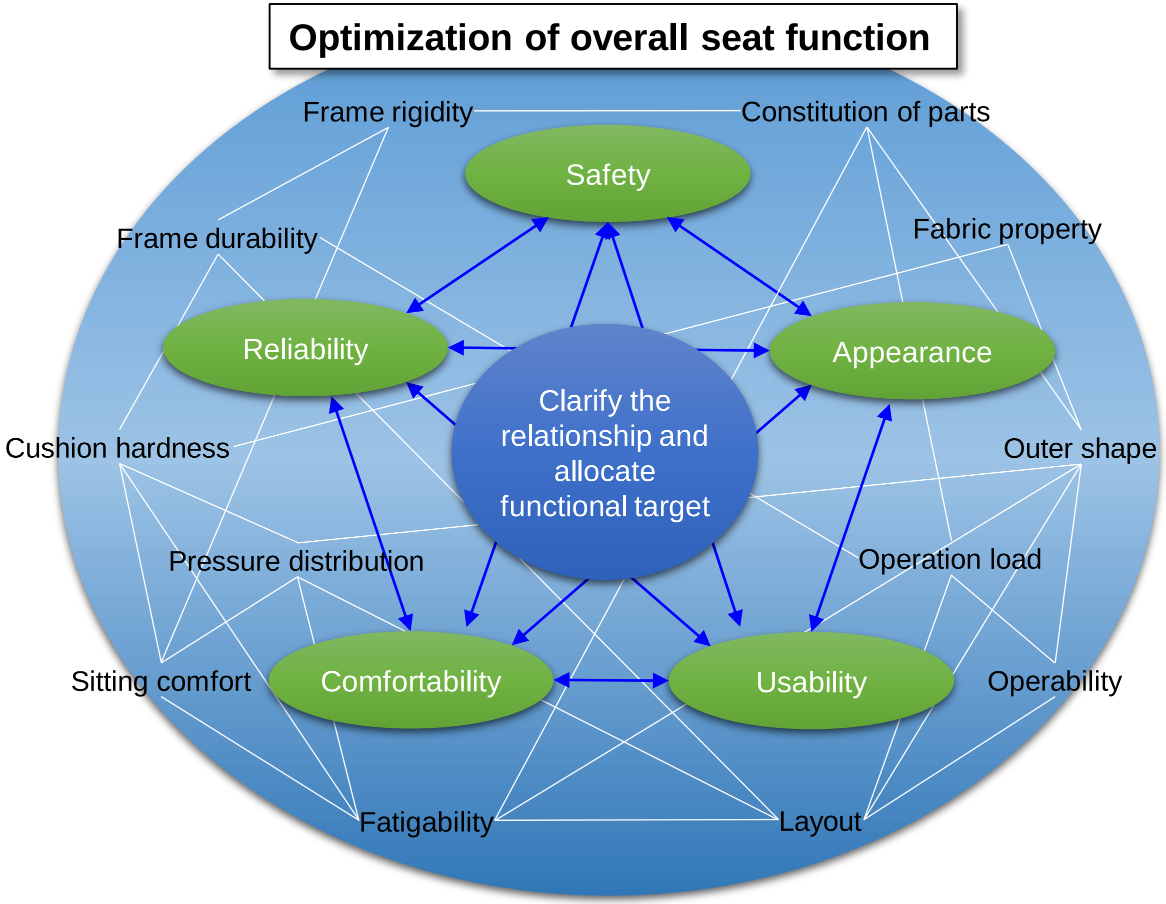
3. Generate function model
Make simple function model and understand the behavior.
Generate function model at necessary fineness level, then confirm the sensitivity.

4. Allocate functional target
Set target value of component part and predict performance.



1. Background

- From partial optimization to overall optimization



Characteristics have relationship beyond the type of function

- Seat function have many categories such as “Safety”, “Reliability”, “Comfortability” etc. And various component characteristics are closely related to their performance target.

- To achieve goals with overall seat in a well-balanced manner, it is necessary to clarify the relationships between each function and characteristics, then optimize and allocate the functional target.

1. Background

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- Advantage of 1D CAE

1. Front loading of development

Required characteristics can be drafted when shape is not determined yet, and the discussion can be conducted dynamically about the allocation of functional target.
Achievement scenario may be found by creating model based on physical principle.

2. Optimization of multiple functions

Overall non-defective condition can be found by confirming the interaction between multiple functions.
Easy to conduct verification with varied characteristics, and it may arrive to the new achievement scenario.

3. Shorten development duration

Compared with 3D CAE, calculation duration is short, so many variations of characteristic can be verified in a short period. In addition to this, the completed model can be utilized continuously by improving and updating.

2. Goals

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- Goals of this report

  - Construct a simple model that can confirm the behavior of each characteristic value with respect to HIC in row to row HIC test.

  - Find the better function allocation (amount of influence and sensitivity) among them by using created 1D CAE model.

Setting target Value of HIC

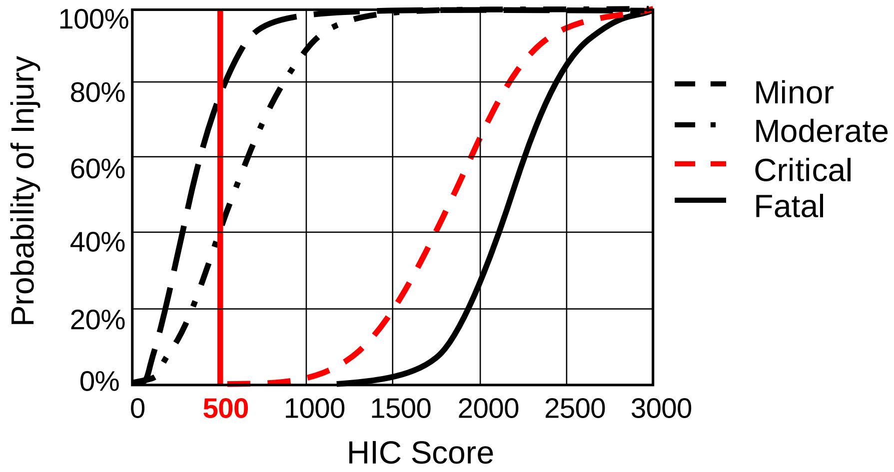
Which conditions are better?

Ideal ・No Head impact to front seat → Increase seat pitch upto enough space (Unrealistic in economy class)

Target ・Reduce head injury probability level → Make “critical” probability to 0% in Head injury risk curve

Head injury risk curve

Extracted from “*Expanded Prasad-Mertz Curves and relationship between the HIC score of head impact and the probability of an injury*”.



HIC 500 is estimated to represent a 0% risk of critical injury.

Rating of Automotive frontal impact about Head injury

Frontal Impact against ODB* with 40% Overlap at 64km/h

Indicator	Good	Acceptable	Marginal	Poor
HIC_{15} **	< 560	< 700	< 840	> 840

Extracted from “*IIHS rating*”

*ODB: Offset-Deformable Barrier

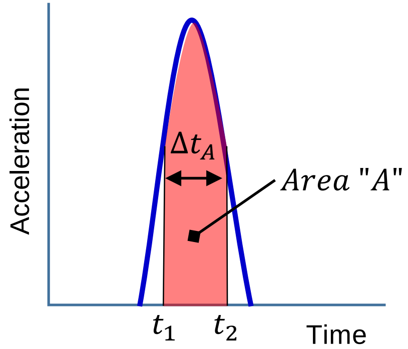
**HIC_{15}: HIC calculation result value which time duration $(t_2 - t_1)$ is limited to a maximum value of 15 msec.

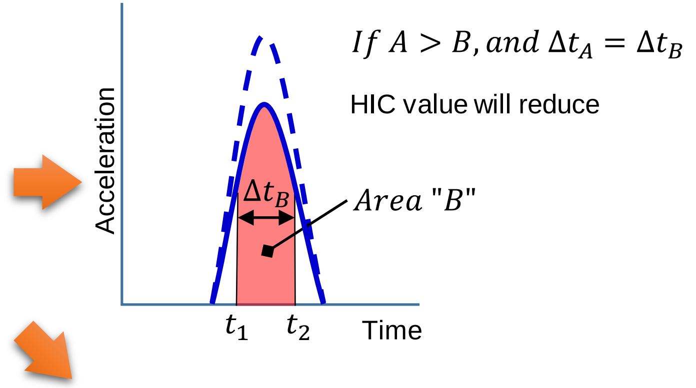
HIC score 500 is a target comparable to automotive rating.

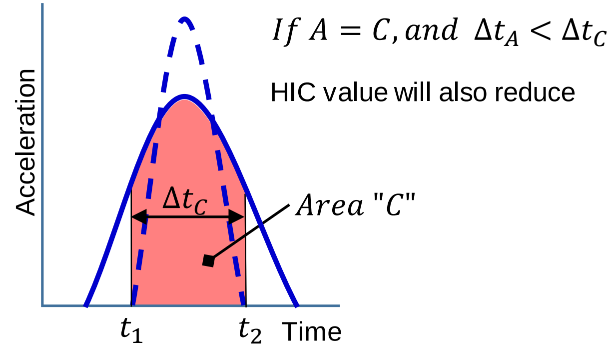
From the above, the target value of HIC is set at 500 or less.

Relationship between HIC value and Head acceleration

Condition: If pulse shape of head acceleration of 1st collision is comparatively large, HIC value may be determined by 1st collision pulse magnitude only.
In such case, HIC value may be reduced by changing pulse shape of head acceleration as below.







Expanding the HIC calculation formula for clarify, we get

$$HIC = \left\{ \frac{1}{(t_2 - t_1)^{1.5}} \cdot \left[\int_{t_1}^{t_2} a(t)dt \right]^{2.5} \right\}_{max}$$

HIC value will be decreased if $\Delta t\ (t_2 - t_1)$ increased or integral of acceleration (i.e. area) is decreased.

Our approach: Verify the response against each characteristics by using 1D CAE, because Δt is variable which is determined from the pulse shape of acceleration.

Relationship between HIC value and Head acceleration

Condition: There are cases when Δt will become long and include the acceleration of 2nd collision to HIC value calculation, because $\Delta t \ (t_2 - t_1)$ is determined so as to maximize the HIC value.
In such case, HIC value may be reduced if the time interval of collisions can be increased.

Our approach: It is also verified by using 1D CAE how the response against each characteristics indicate.

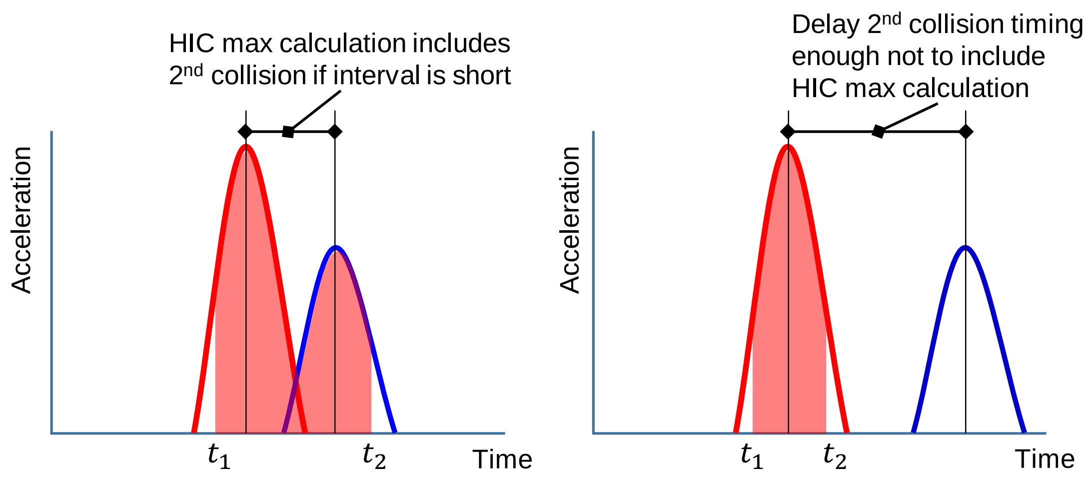
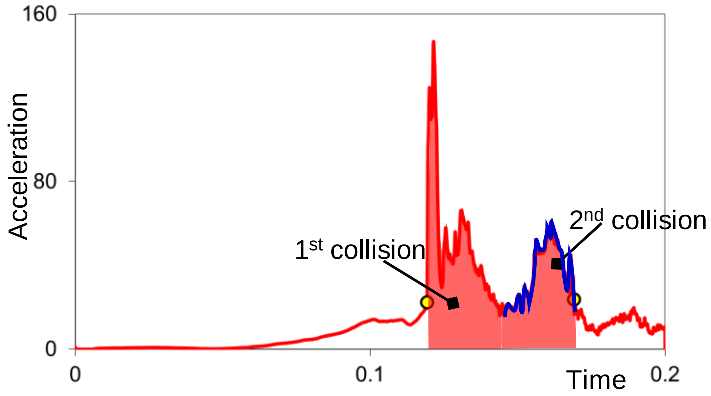
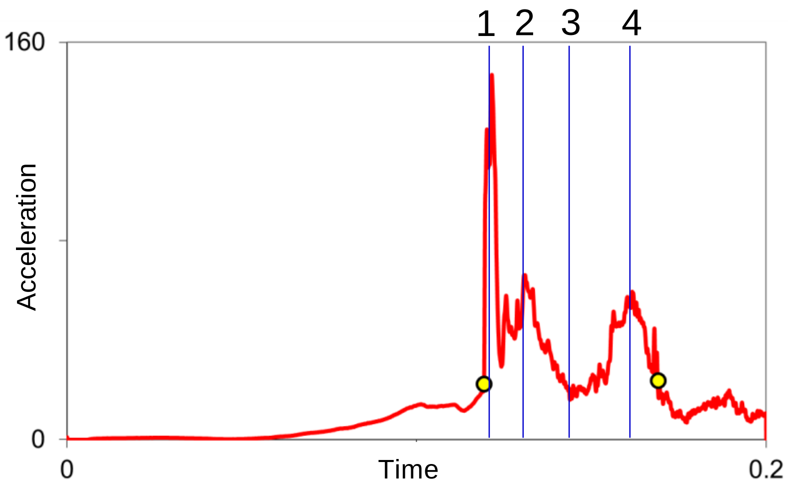


Image of HIC including 2nd collision and not including 2nd collision



Head acceleration pulse shape with 2nd collision

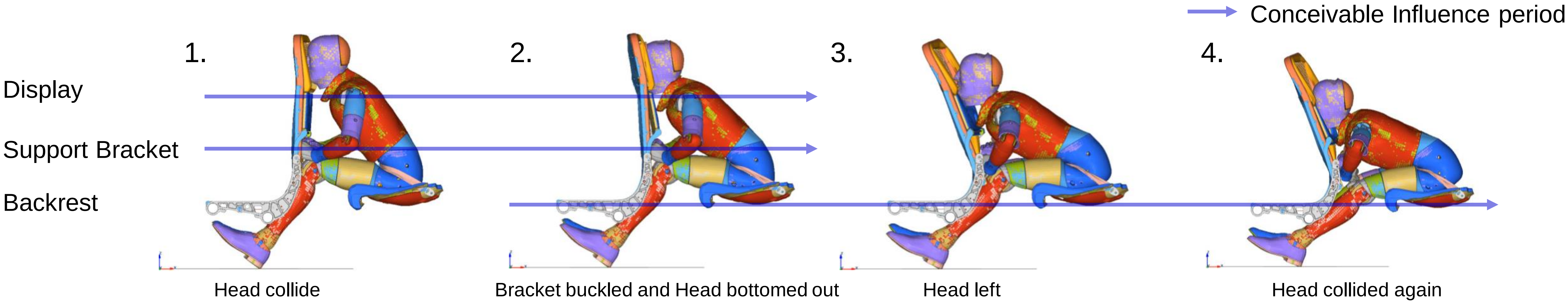
Confirmation of Head Acceleration occurrence mechanism



By observing the behavior during the test, the collision phenomena 1 to 4 can be confirmed, and extract the items that are thought to affect the head acceleration in each state.

1. Head collide with display and head acceleration have highly raised.
2. Display support bracket have buckled and bottomed out, then head acceleration have raised again.
3. Backrest have leaned forward and head left backrest.
4. Backrest have leaned rearward and head collide with backrest again.

From the above, at least the head, display and backrest must be represented as mass points, and the collision rigidity between head and display, the rigidity of bracket that support display, and rotational rigidity of backrest are necessary.



4. Creation of simple model

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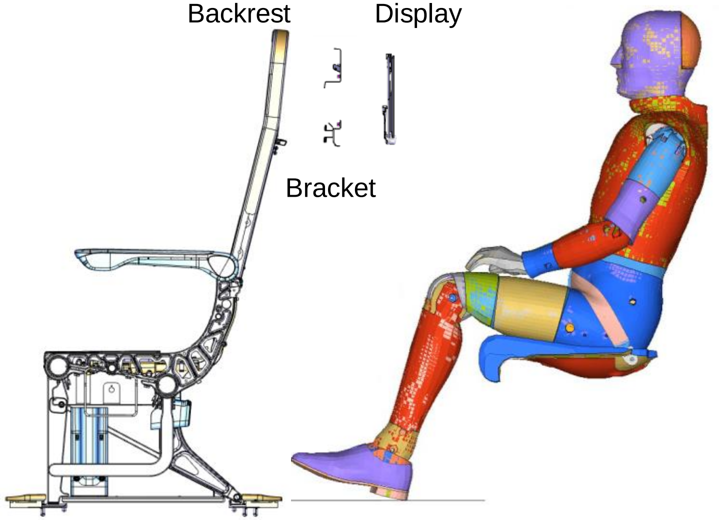
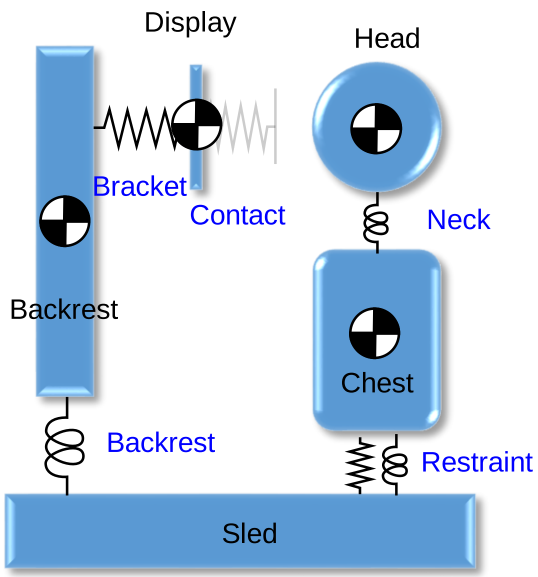
Summary of simple 1D model





Use “Simulation X”, a physical modeling software developed by ESI ITI, for creating and analyze 1D CAE model.

Create simple model with Backrest, Display and Head as mass points.
Since the head trajectory is not a translational motion but a rotational motion, the chest mass point have been also incorporated. The each rigidity values between each mass points have been also incorporated.
Each characteristic value and position are acquired from existing seat parts and test dummy in order to increase reproducibility.

Input parameter:

Item	Mass	Inertia moment	Location	Rigidity	Acceleration from sled
Hinge	-	-	X	-	X
Backrest	X	X	X	Rotate	-
Bracket	-	-	-	Translation	-
Display	X	X	X	-	-
Contact	-	-	-	Translation	-
Head	X	X	X	-	-
Neck	-	-	-	Rotate	-
Chest	X	X	X	-	-
Restraint	-	-	X	Translation & Rotate	X

4. Creation of simple model

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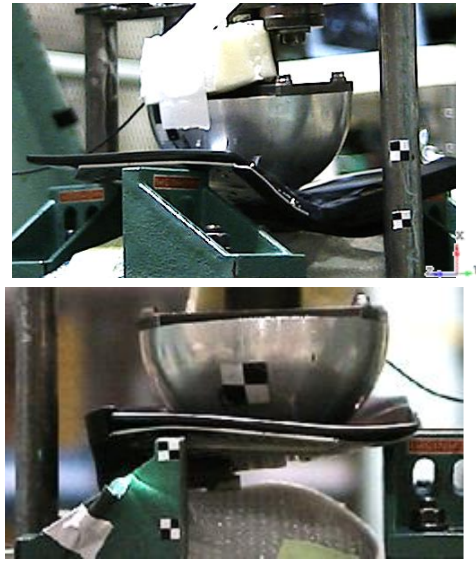
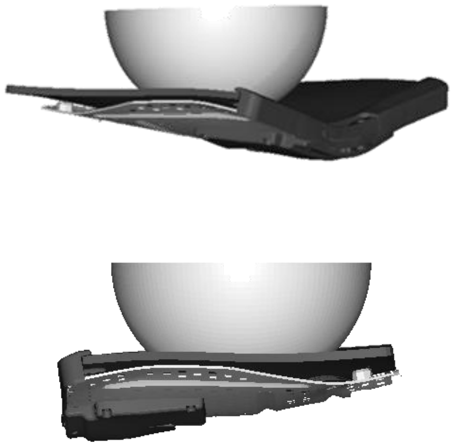
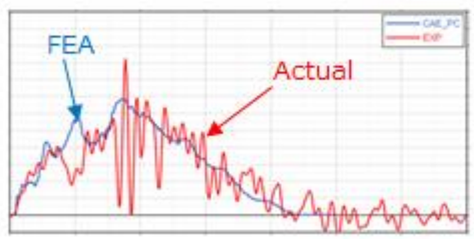
Validation of Display linear rigidity





Actual test

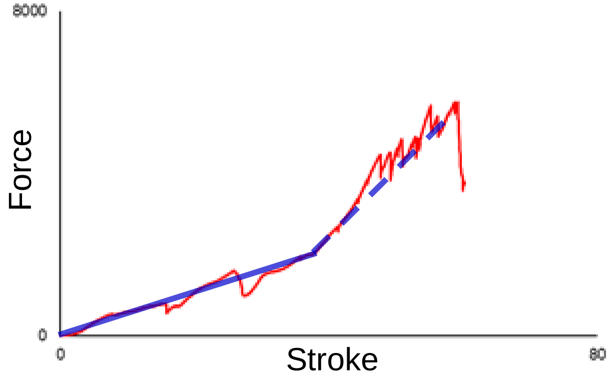
FEA model



Identify the equivalent display stiffness by reproducing the test with FEA model

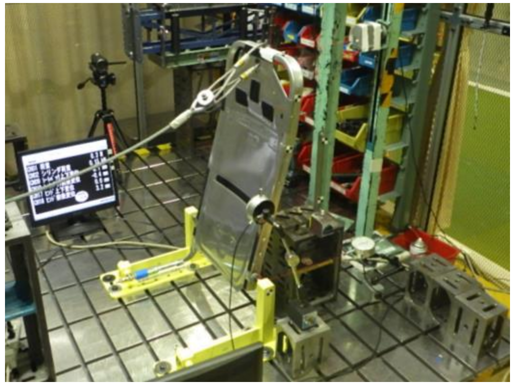
Validation of Display support bracket linear rigidity

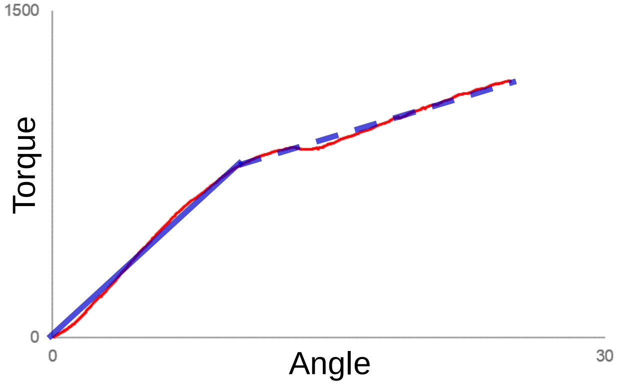
Obtain Force-Stroke graph with component configuration



Validation of Backrest rotational rigidity

Obtain Torque-Angle graph with component configuration





4. Creation of simple model

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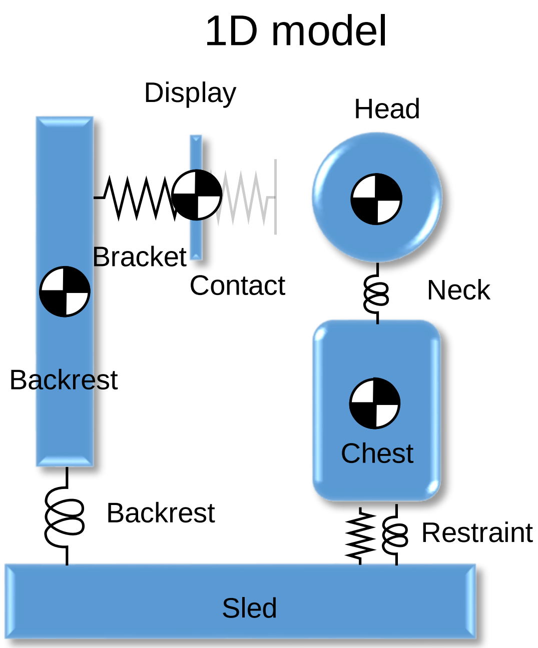
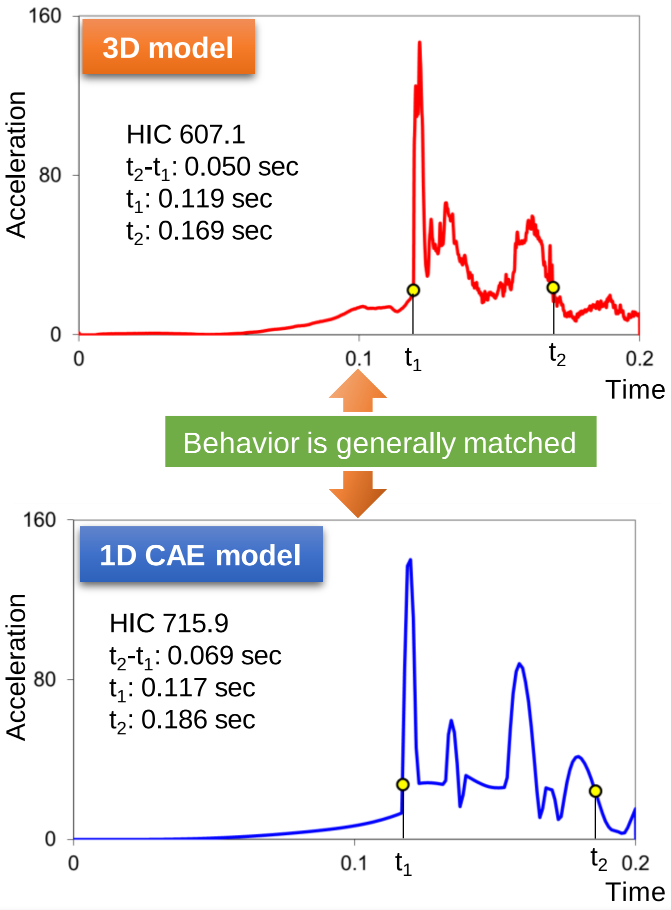
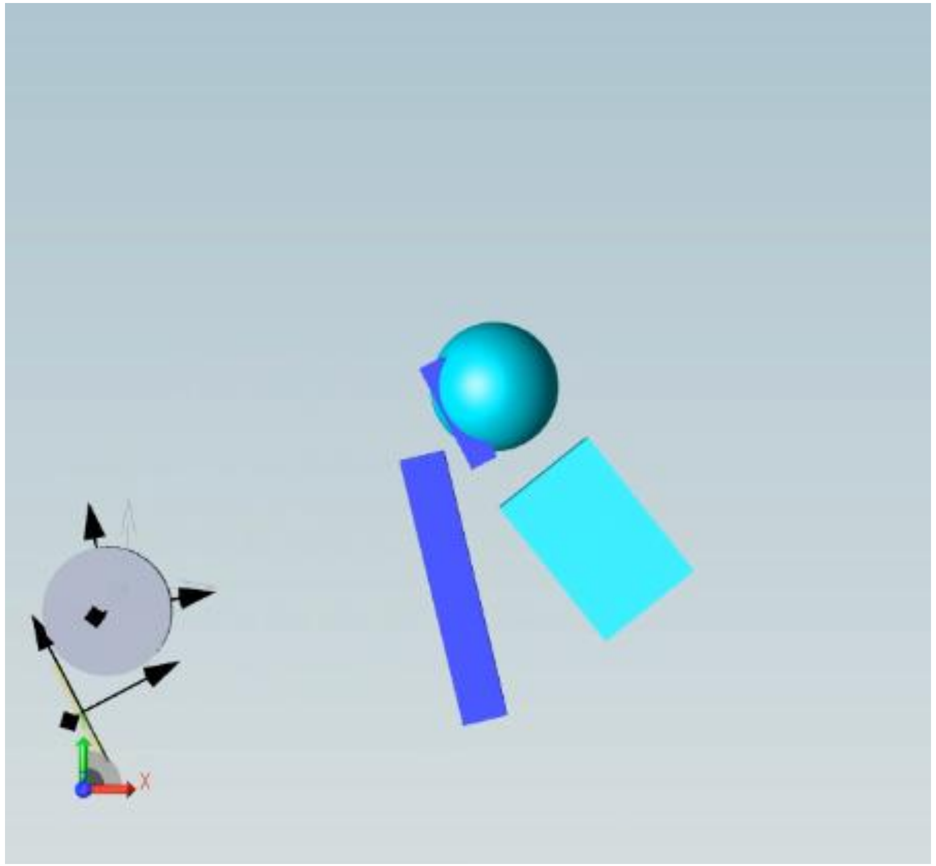
Confirmation of reproducibility



The pulse shape of head acceleration can be reproduced by 4 mass points.





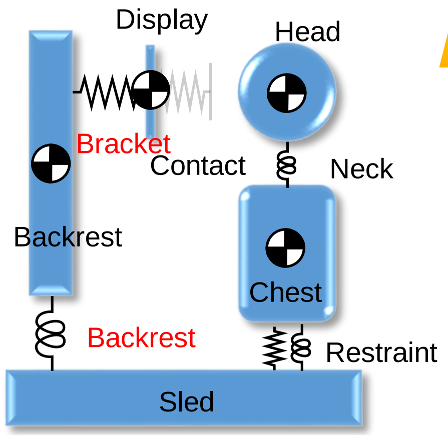
Simulated behavior image by using software (Simulation X)

The model can be used for parameter study.

5. Application example

Verification of changes in characteristics values

1D model



The higher the rigidity, the lower the HIC Value

The lower the rigidity, the lower the HIC Value

Backrest Rigidity \ Bracket Rigidity	50%	60%	70%	80%	90%	100%	150%	200%
50%	609.0	512.7	503.6	500.9	503.2	503.1	528.9	537.9
60%	717.8	645.1	622.3	598.5	575.3	557.9	565.5	577.1
70%	809.2	767.0	730.9	718.9	696.1	655.5	615.7	622.3
80%	847.9	824.0	818.5	776.2	726.3	682.7	610.5	632.6
90%	903.6	855.7	813.3	783.7	729.6	703.8	604.8	615.3
100%	929.1	873.2	813.6	774.8	731.5	715.9	582.2	600.1
150%	946.5	942.9	814.8	788.5	728.4	654.3	607.0	595.0
200%	1290.3	1013.7	837.0	794.9	785.4	768.7	672.6	643.4

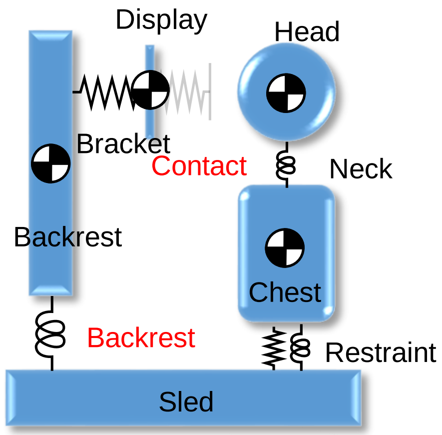
:HIC ~500 :HIC 500~650 :HIC 650~1000 :HIC 1000~

5. Application example

Verification of changes in characteristics values

The lower the rigidity, the lower the HIC Value

1D model



The lower the rigidity, the lower the HIC Value

Backrest Rigidity \ Contact Rigidity	50%	60%	70%	80%	90%	100%	150%	200%
50%	330.9	325.9	369.4	413.2	455.3	503.1	712.8	911.9
60%	367.3	395.4	436.3	477.2	521.0	557.9	800.1	1013.9
70%	416.3	472.0	522.9	571.4	612.9	655.5	879.5	1147.6
80%	451.1	503.1	559.4	602.9	657.3	682.7	889.1	1101.4
90%	459.2	518.2	570.2	621.7	661.4	703.8	953.2	1169.1
100%	460.3	515.6	558.2	613.8	649.5	715.9	954.4	1262.8
150%	436.4	491.1	541.0	599.0	630.9	654.3	1030.9	1333.2
200%	422.6	489.2	558.8	615.8	692.0	768.7	1070.7	1268.2

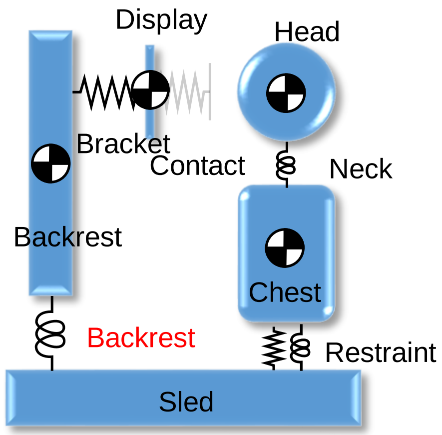
:HIC ~500 :HIC 500~650 :HIC 650~1000 :HIC 1000~

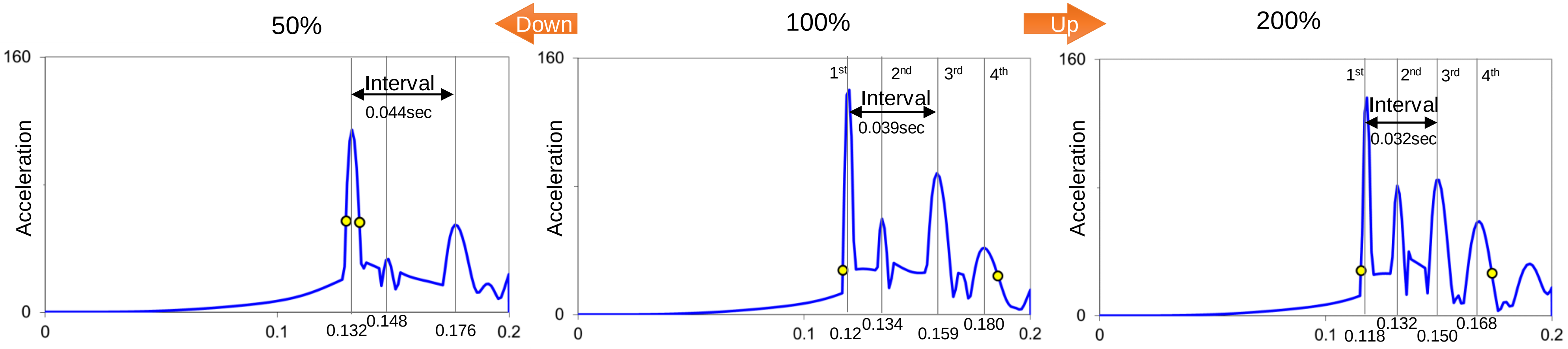
5. Application example

Verification of changes in characteristics values

Backrest rigidity

1D model





Backrest rigidity affects the first collision timing and time interval of collisions.
This is because the natural frequency was changed as a result of rigidity change.

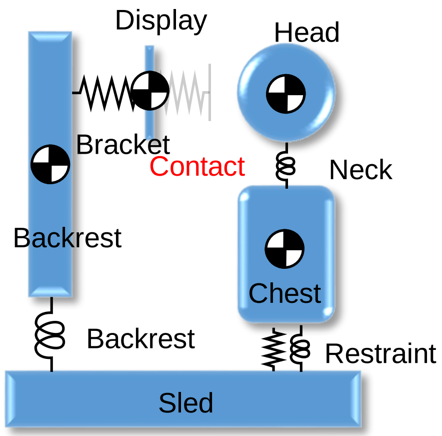
A natural frequency is obtained by a calculation formula $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$.

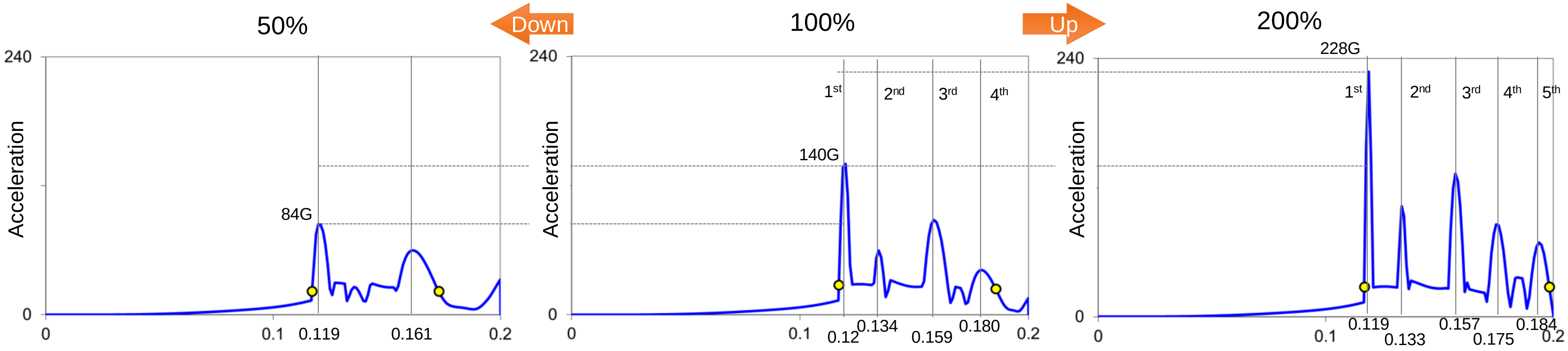
This behavior matches the theoretical formula, and it can be seen that it is able to be changed by rigidity and mass.

Verification of changes in characteristics values

Contact rigidity

1D model





Contact rigidity strongly affects the peak of collision acceleration.
According to equation of motion $ma + kx = 0$, the peak of acceleration was changed as rigidity change.
The time interval between collisions is linked to the natural frequency, just like Backrest case.

5. Application example

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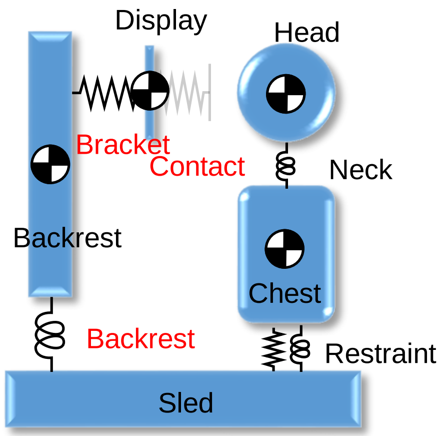
Verification of changes in characteristics values

1D model



Summary of the confirmation results

		Characteristics		
		Bracket	Backrest	Contact
Affect items	Time interval between collisions	X	XX	X
	Head acceleration peak value	—	X	XX
	1st collision timing	—	X	—

Legend - XX: Strong correlation, X: Correlation, —: No correlation

HIC value can be reduced mainly by the rigidity of Backrest and Contact.
Backrest rigidity contributes the time interval between collisions.
Contact rigidity contributes the peak value of Head acceleration.

5. Application example

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Verification result

		Bracket Rigidity							
		50%	60%	70%	80%	90%	100%	150%	200%
Backrest Rigidity	50%	609.0	512.7	503.6	500.9	503.2	503.1	528.9	537.9
	60%	717.8	645.1	622.3	598.5	575.3	557.9	565.5	577.1
	70%	809.2	767.0	730.9	718.9	696.1	655.5	615.7	622.3
	80%	847.9	824.0	818.5	776.2	726.3	682.7	610.5	632.6
	90%	903.6	855.7	813.3	783.7	729.6	703.8	604.8	615.3
	100%	929.1	873.2	813.6	774.8	731.5	715.9	582.2	600.1
	150%	946.5	942.9	814.8	788.5	728.4	654.3	607.0	595.0
	200%	1290.3	1013.7	837.0	794.9	785.4	768.7	672.6	643.4

Combination of Backrest and Bracket rigidity

No combination of parameter satisfying the target of HIC 500 or less could be found. To satisfy HIC 500 or less, reduction by other characteristic value is required.

		Contact Rigidity							
		50%	60%	70%	80%	90%	100%	150%	200%
Backrest Rigidity	50%	330.9	325.9	369.4	413.2	455.3	503.1	712.8	911.9
	60%	367.3	395.4	436.3	477.2	521.0	557.9	800.1	1013.9
	70%	416.3	472.0	522.9	571.4	612.9	655.5	879.5	1147.6
	80%	451.1	503.1	559.4	602.9	657.3	682.7	889.1	1101.4
	90%	459.2	518.2	570.2	621.7	661.4	703.8	953.2	1169.1
	100%	460.3	515.6	558.2	613.8	649.5	715.9	954.4	1262.8
	150%	436.4	491.1	541.0	599.0	630.9	654.3	1030.9	1333.2
	200%	422.6	489.2	558.8	615.8	692.0	768.7	1070.7	1268.2

Combination of Backrest and Contact rigidity

Multiple combinations satisfying HIC 500 or less were found, but all of them require reduction of contact rigidity. (Area surrounded by red frame)
Each parameter must be verified by the other related functions.

6. Conclusion

Summarizing this activity as follows:

- The simple model which can confirm the behavior of characteristics about row to row HIC test could be generated.
- The combination of characteristics which satisfy with the target HIC value could be found by 1D CAE.
- The hypothesis verification cycle by using 1D CAE is fast, so countermeasures can be verified in a short period.
- It is possible to know the amount of influence of characteristic value changes in the absence of actual components.
- 1D CAE is suitable for verification of changes in physical quantities (rigidity, mass, arrangement)
- Function models (1D model) are useful for checking the behavior of characteristic values. Also useful for understanding the interaction between component items.

7. Future work

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Summarizing future works as follows:

- Plan to create 1D CAE model about the other test items and sub-systems for increasing functions that can be optimized.

- Utilize this 1D CAE model for proposing required characteristics to the new design seat.

Thank you

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