6th International Conference on Mechanical Models in Structural Engineering
CMMoST 2021
01-03 DIC 2021 Valladolid SPAIN

NUMERICAL MODEL FOR THE PARAMETRIC ANALYSIS OF THE IMPACT BALL-PADDLE RACQUET.

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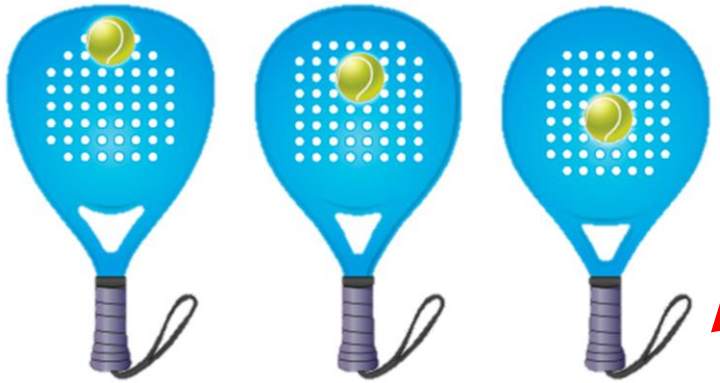
Mecánica de Medios Continuos y Teoría de Estructuras

UNIVERSIDAD DE MALAGA.

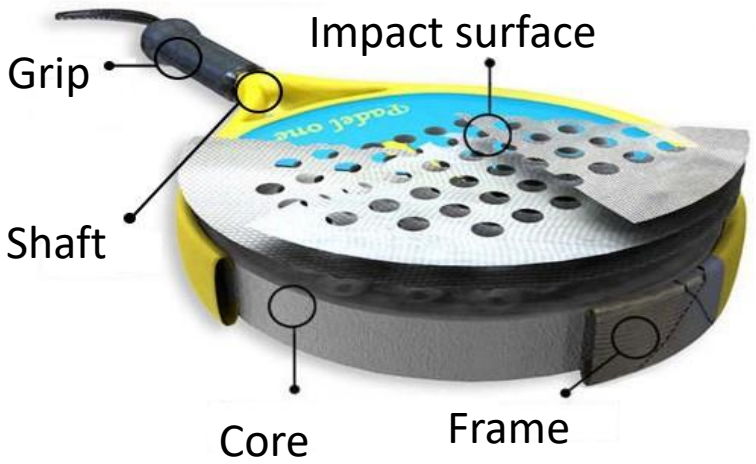
Outline

DESIGN PARAMETERS



Diamond Teardrop Round

Source: https://www.webconsultas.com/ejercicio-y-deporte/material-deportivo/como-elegir-la-pala-de-padel-adecuada- 14616.



Source: https://www.padelshack.com/how-to-choose-a-padel-racket/

SHARK PADEL

Small company from Málaga

PLAYER'S SENSATIONS

Source: http://www.hellopadel.org/padel/new/Jeremy-Gala-Belgian-WPT-Padel-player

DESIGN PARAMETERS

SHARK PADEL

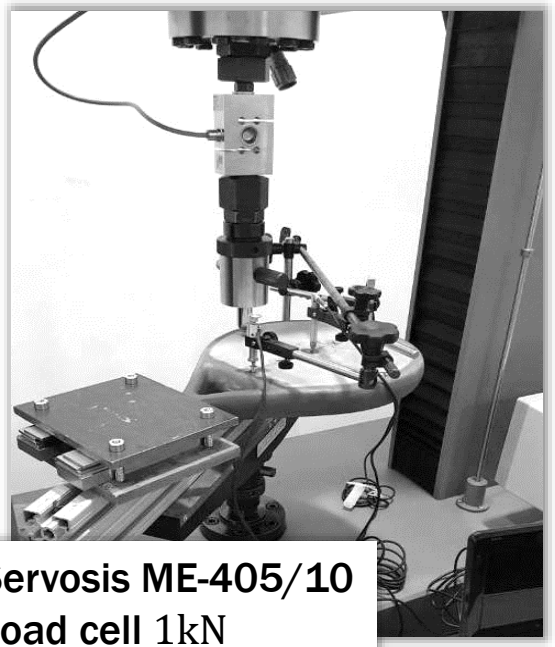
Small company from Málaga

NUMERICAL SIMULATION MECHANICAL PARAMETERS

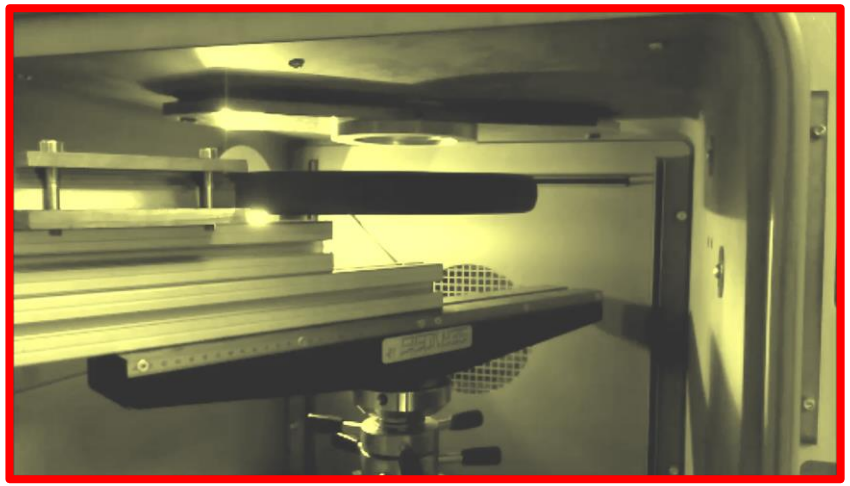
PLAYER'S SENSATIONS

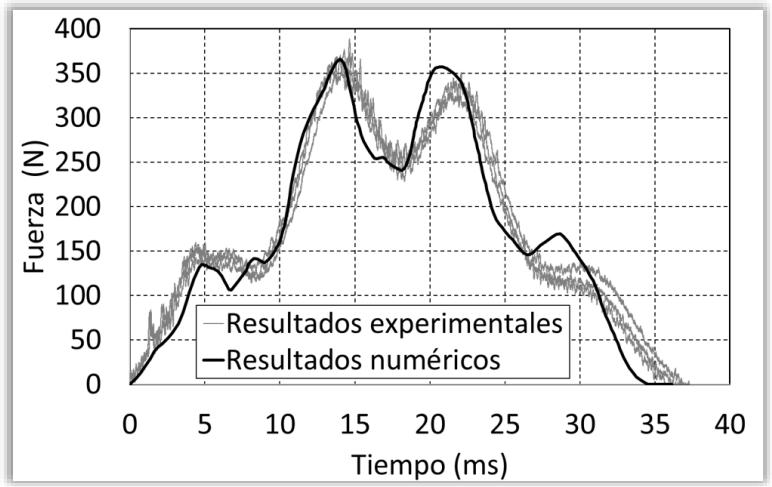
Source:
http://www.hellopadel.org/padel/new/Jeremy-Gala-Belgian-WPT-Padel-player

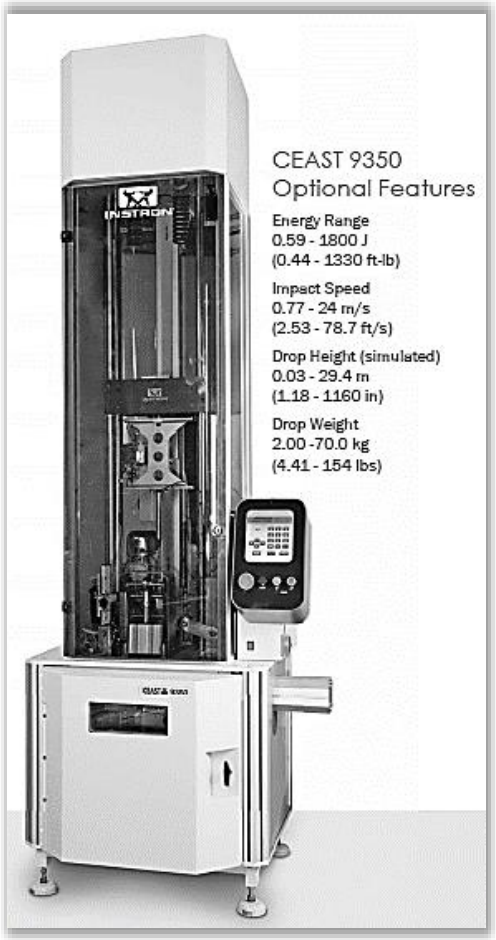
Static & Dynamic (impact) tests



Servosis ME-405/10
Load cell 1kN
Load$_{max}$: 50N

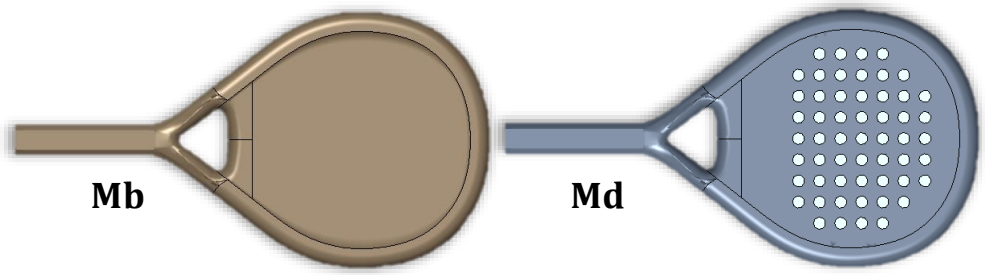




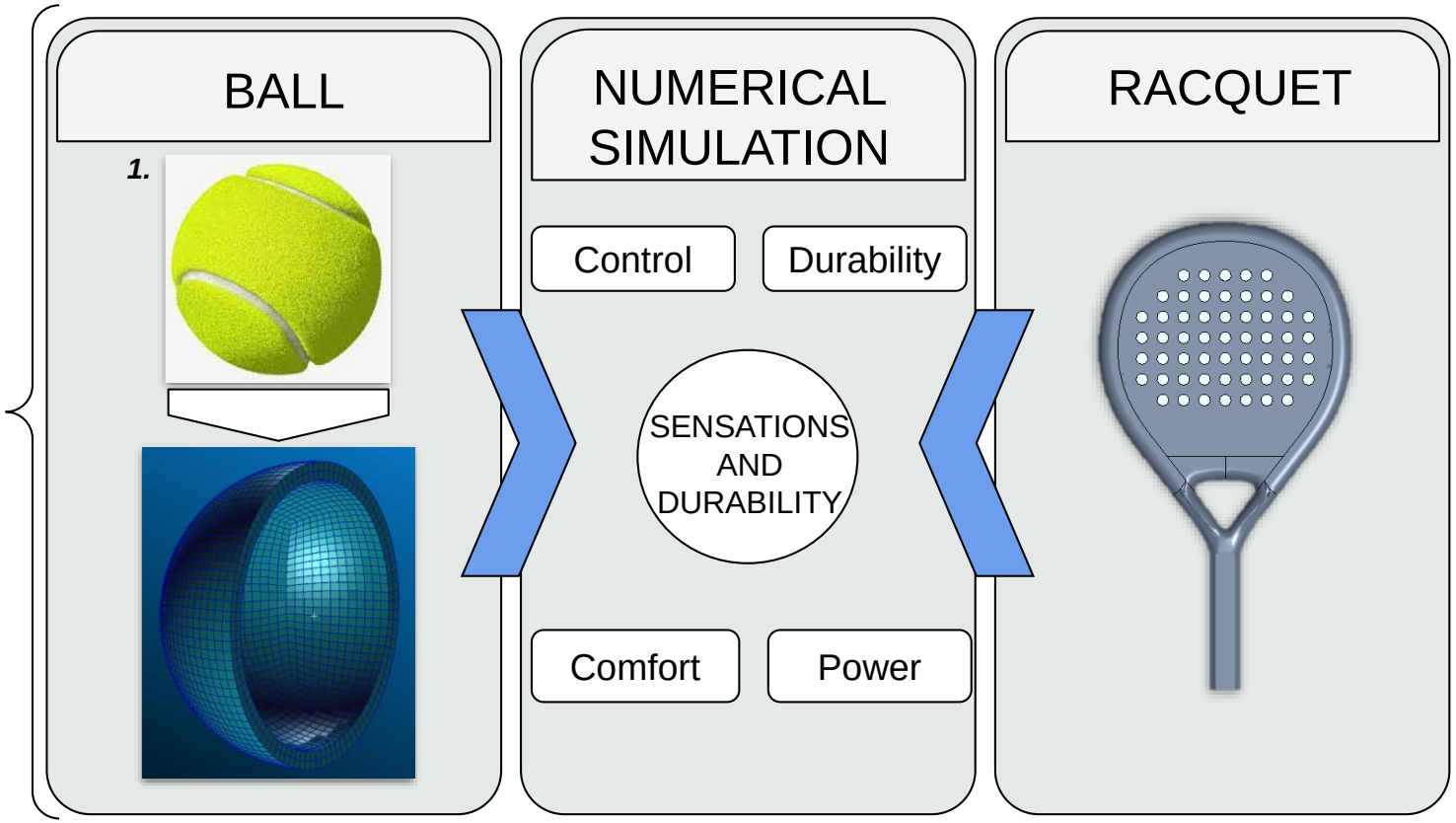


et al. Molí Díaz, Adrián Antonio, "Experimental numerical correlation of a padel racket subject to impact," in *CMMoST 2019: 5th International Conference on Mechanical Models in Structural Engineering*, 2019, pp. 351–368.

- Study of the influence of the holes.

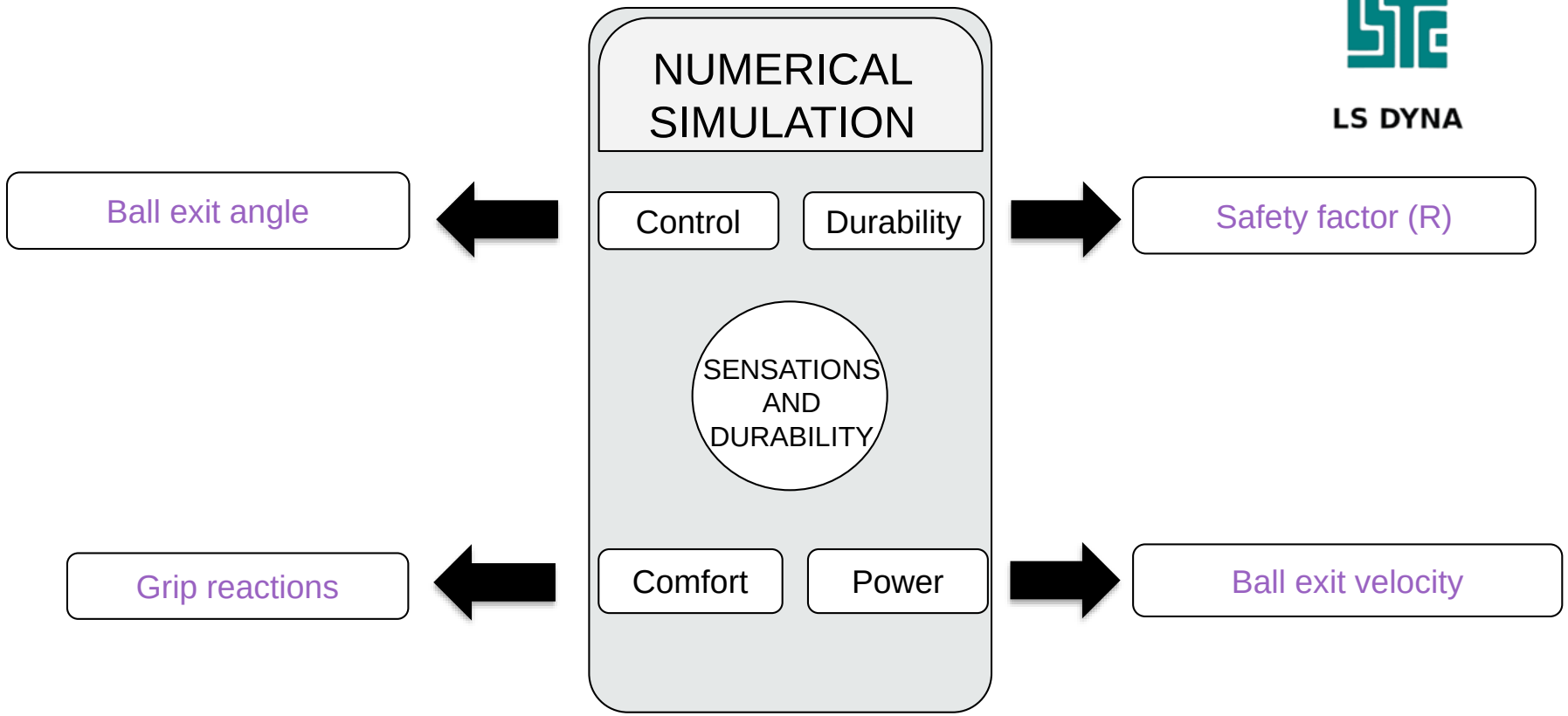


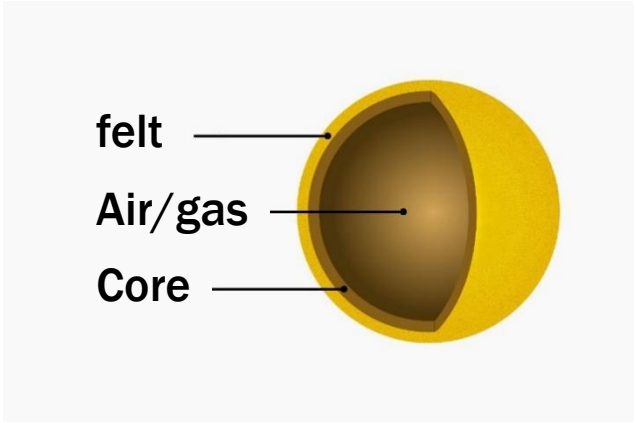
- Engineering parameters versus player's sensations and racquet durability.



1. https://www.pinterest.es/pin/844776842591064746/
2. Molí Díaz, A. A. (Junio 2017). *Correlación numérico-experimental del comportamiento ante impacto de una pala de padel.* TFG

- Numerical simulation → Explicit Finite Elements analysis.
- Engineering parameters definition.

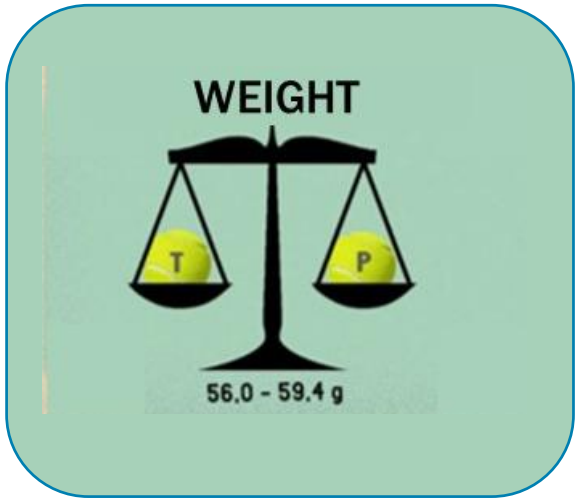


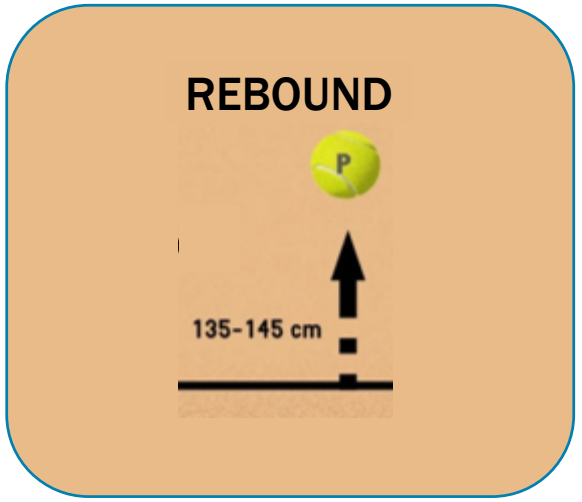


Internal relative pressure: 0.82 bar

Regulatory rebound height when launching from a height of 2.56 m: 1.35-1.45 m.

https://padelstar.es/reglas-de-padel/reglamento-la-pelota/ (24-1-2021)





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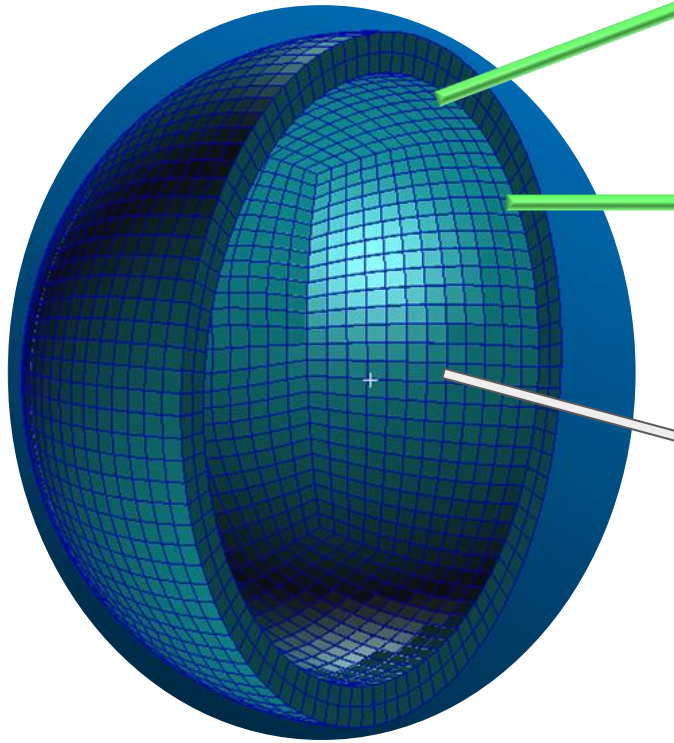


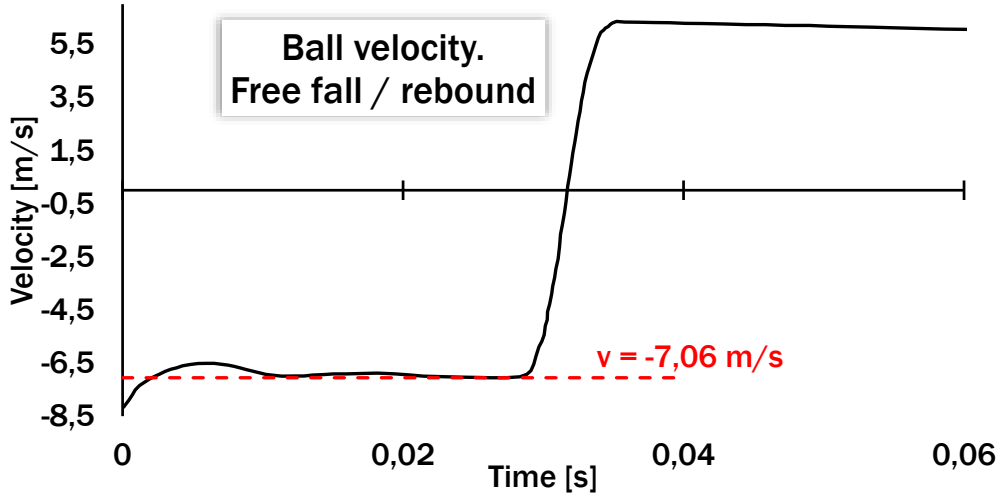
CONCRETE BLOCK

RUBBER
Hexahedral elements

AIRBAG SURFACE
Quad elements

Initial and boundary conditions

- ❑ Initial Velocity.
- ❑ Airbag internal pressure.
- ❑ Contact.



RUBBER → Ogden's hyperelastic model

Behavioral law defined by unitary deformation energy function

$$W = \sum_{j=1}^{j=N} \sum_{i=1}^{i=3} \frac{\mu_j}{\alpha_j} (\lambda_i{}^{\alpha_j} - 1) + K(J - 1 - \ln J)$$

Maxwell relaxation function (viscous behavior) Prony series (g(t))

$$g(t) = \sum_{i=1}^{i=n} G_i \, e^{-\beta_i t}$$

RUBBER (Ogden Model)			
	Density	$1.15\ kg/m^3$	
G	2.39 MPa	ν	0.49
μ_1	$-1.5 \cdot 10^{-2}$	α_1	−7.424
μ_2	1.552	α_2	−1.664
μ_3	2.149	α_3	3.28
G_1	$1.975 \cdot 10^{-4}$	β_1	25.675
G_2	$1.4491 \cdot 10^{-1}$	β_2	259.57

ALLEN, Thomas Bruce (2009). Finite element model of a tennis ball impact with a racket. Doctoral, Sheffield Hallam University. element model of a tennis ball impact with a racket," Sheffield Hallam University, 2009.

Where:

K is the volumetric modulus of compressibility.

J is the unit volume change.

λ_i are the principal deformations.

μ_j and α_j are the material constants.

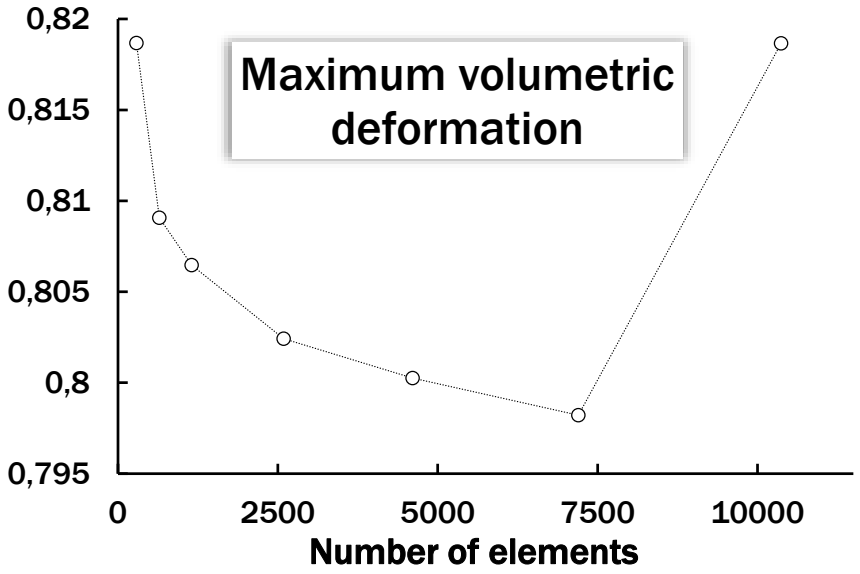
N is a number, eligible, of terms that can be used for the definition of this function. In this work, three terms have been considered.

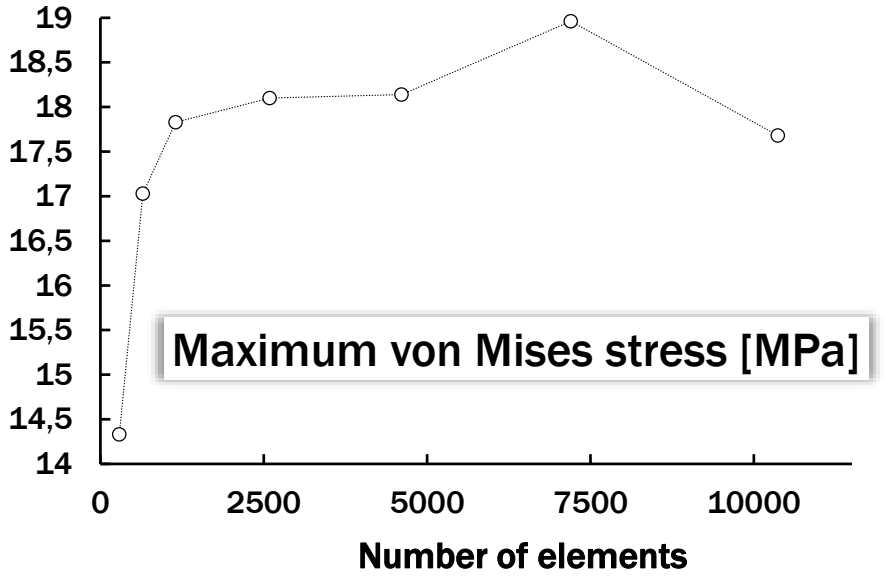
G_i are shear moduli.

β_i relaxation factors.

n is the number, eligible, of terms in the Prony series, two in this paper.

CONVERGENCE ANALYSIS





The time step is performed automatically by SOL 700 of MSC Nastran, to ensure that the Courant-Friedrichs-Lewy condition is satisfied.

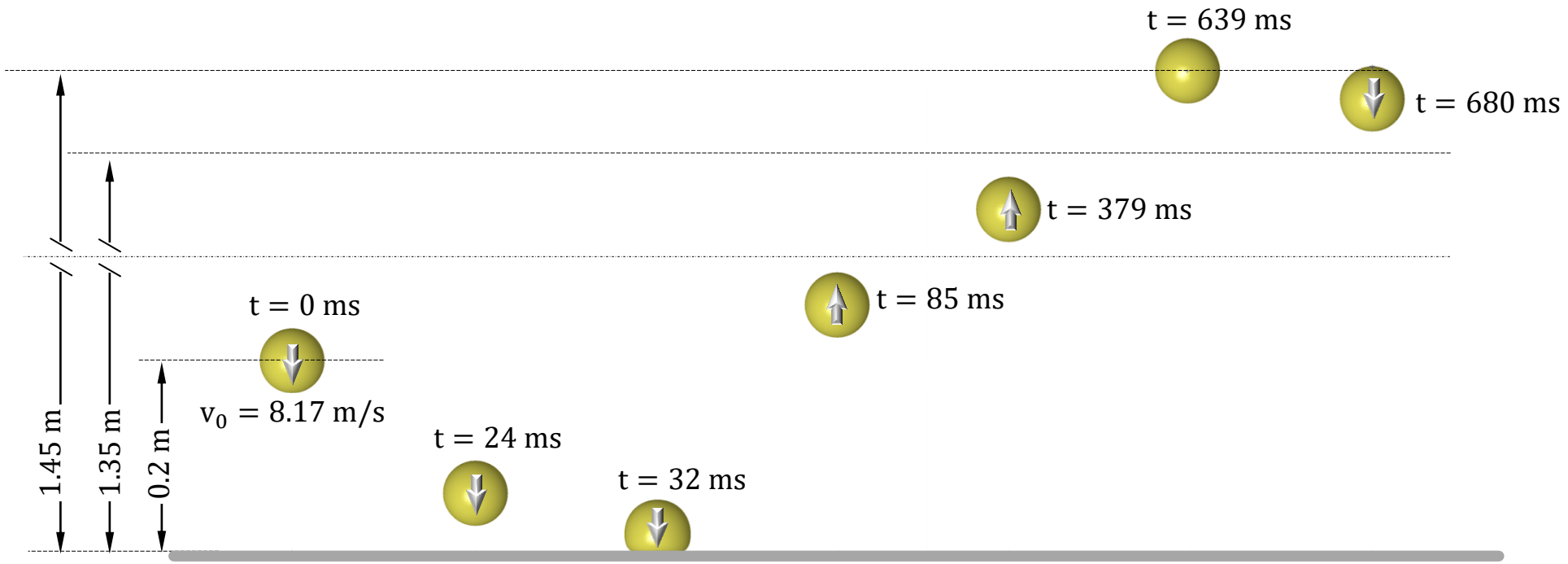
$$\Delta t < \Delta t_{crit} = \frac{h}{c} = \frac{2}{\omega_{max}}$$

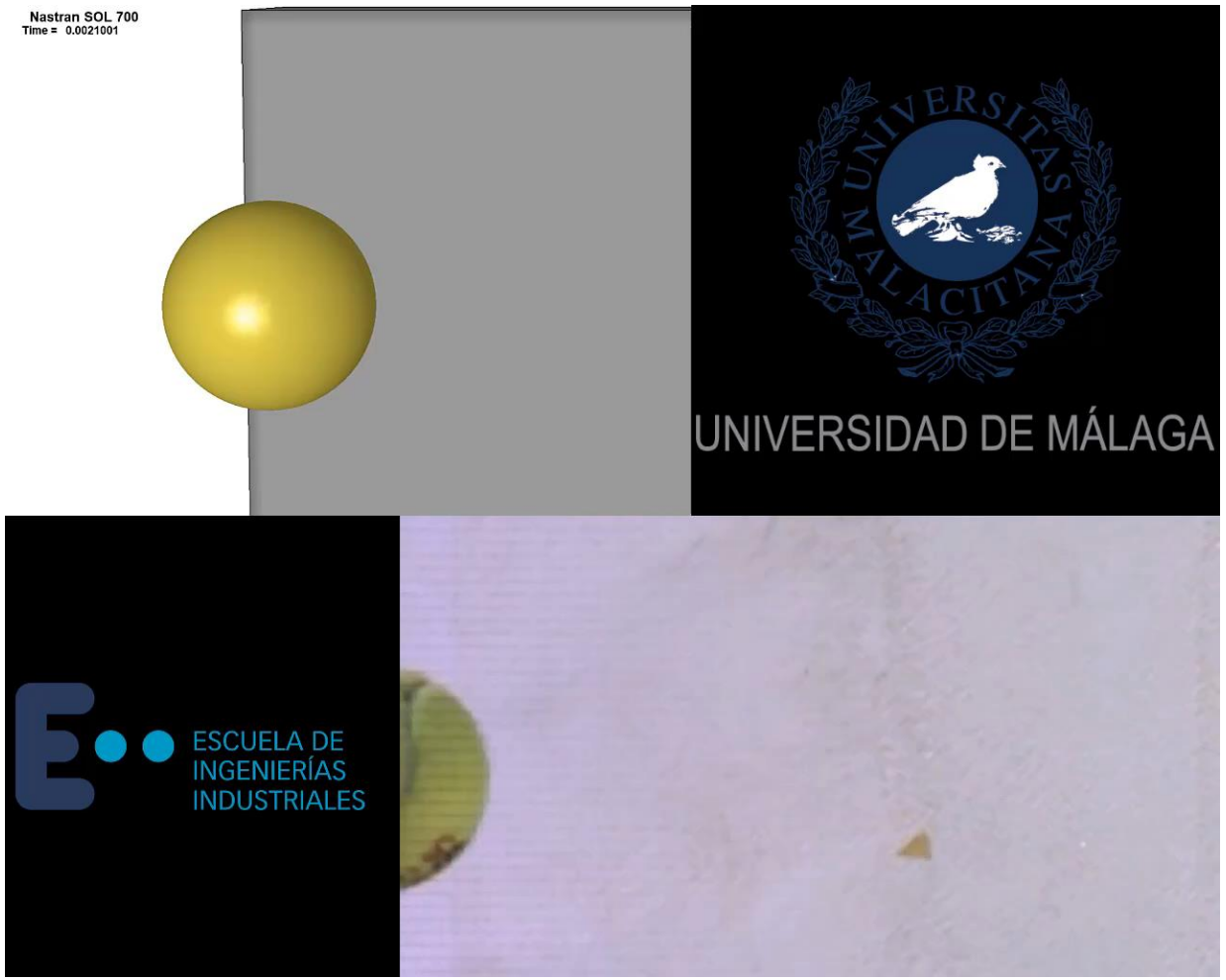
Where:

h is the element size.

c maximal wave speed.

ω_{max} maximum system eigenfrequency.


t = 639 ms
t = 680 ms
t = 379 ms
t = 85 ms
t = 0 ms
v_0 = 8.17 m/s
t = 24 ms
t = 32 ms
1.45 m
1.35 m
0.2 m



Velocidad de Impacto

100 mph (aprox 161 km/h)

https://www.youtube.com/watch?v=FC8Tpi3U0H0&ab_channel=MattAnderson

12

Study case: Marvel racquet

Glass fiber $[0/90]_3$

Braiding

Foam EVA

Glass fiber $[0/90]_3$

Foam EVA

(Poly) Ethylene-vinyl acetate

Glass fiber $[0/90]_3$

Carbon fiber [0/90]

Braiding

Internal wall

Laminates

Fabric ply

Property	Carbon	Glass
$E_x = E_y$	32.5 GPa	12.2 GPa
E_s	2.6 GPa	1.9 GPa
ν_{xy}	0.04	0.09
$X = Y$	299 MPa	296 MPa
$X' = Y'$	414 MPa	228 MPa
S	73 MPa	222 MPa
V_f	29 %	25 %
Density	1270 kg/m^3	1430 kg/m^3
Thickness	0.39 mm	0.33 mm

Balanced glass fabric: 220 gr/m^2

Twill 3K carbon fibre 2×2: 200 gr/m^2

Multipurpose epoxy resin for manual lamination

Hybrid braiding

Property	Unidirectional ply	
	Carbon	Glass
E_x	59.5 GPa	20.25 GPa
E_y	5.3 GPa	4.04 GPa
E_s	2.6 GPa	1.9 GPa
ν_{xy}	0.28	0.26
X	621 MPa	590 MPa
X'	562 MPa	328 MPa
Y	40 MPa	93 MPa
Y'	246 MPa	354 MPa
S	68 MPa	216 MPa
Density	1270 kg/m^3	1430 kg/m^3
Thickness	0.099 mm	0.121 mm

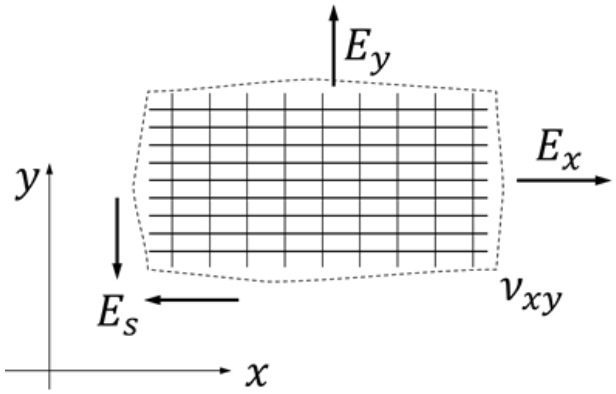
Hybrid braiding carbon/glass 40 mm:

39.8 gr/m

Core: EVA foam

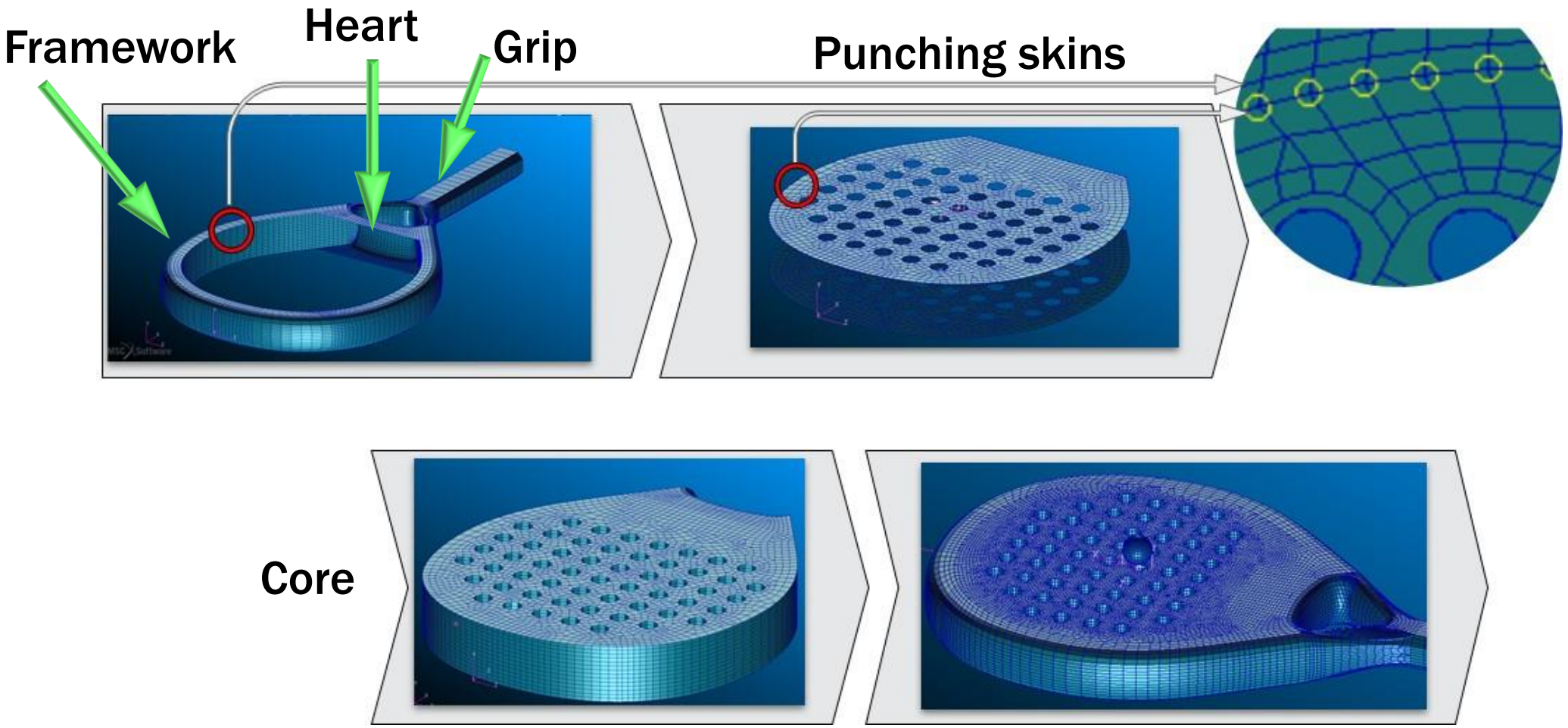
EVA foam (**Ethylene-vinyl acetate**).

Property	EVA
E	1,6 MPa
Density	27,8 kg/m^3

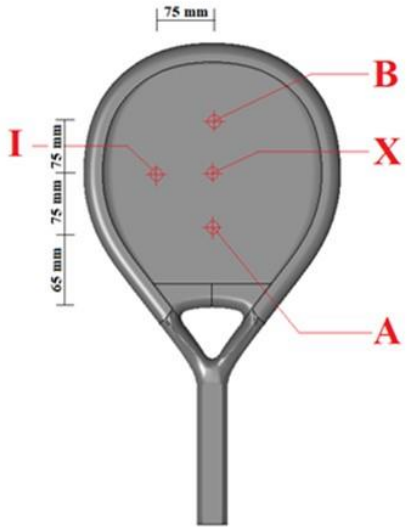


Manufacturing process: Hand-laminated and vacuum bag for hybrid braiding

TRI and Quad Shell elements

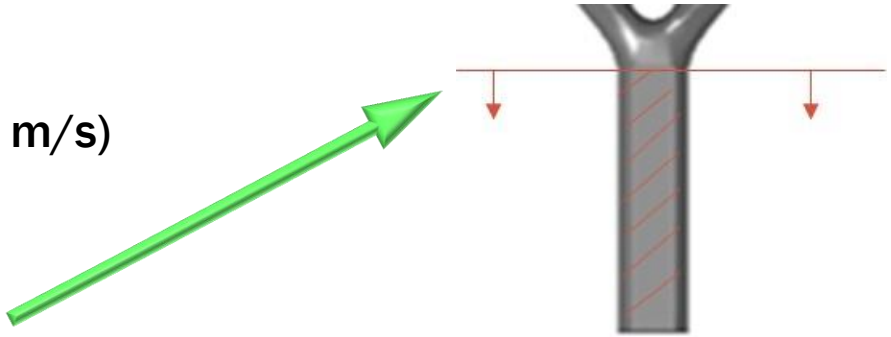


Hitting positions



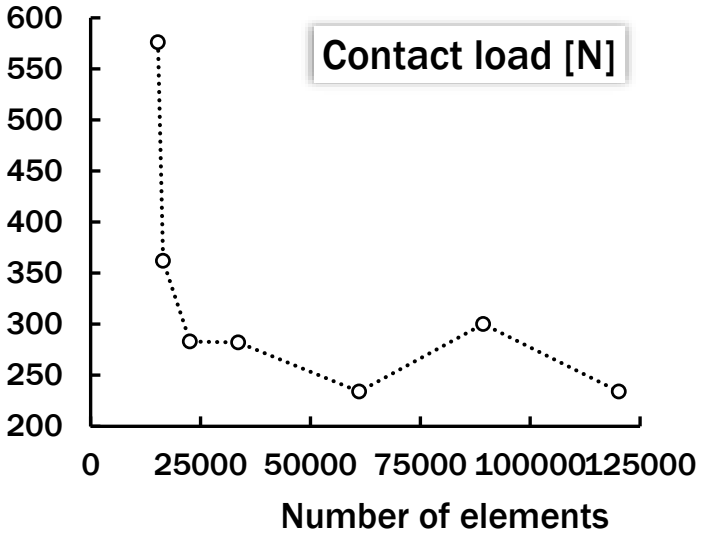
Initial and boundary conditions

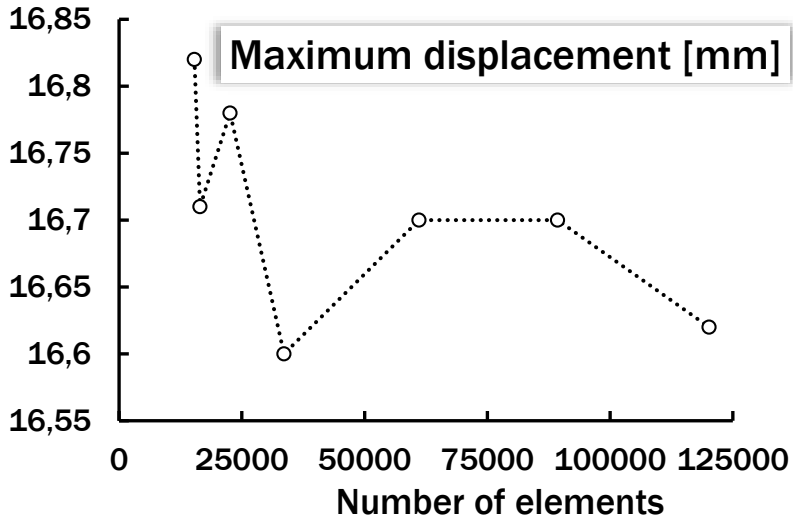
- Impact velocity (30 m/s)
- Grip embedding
- Ball-Racquet contact

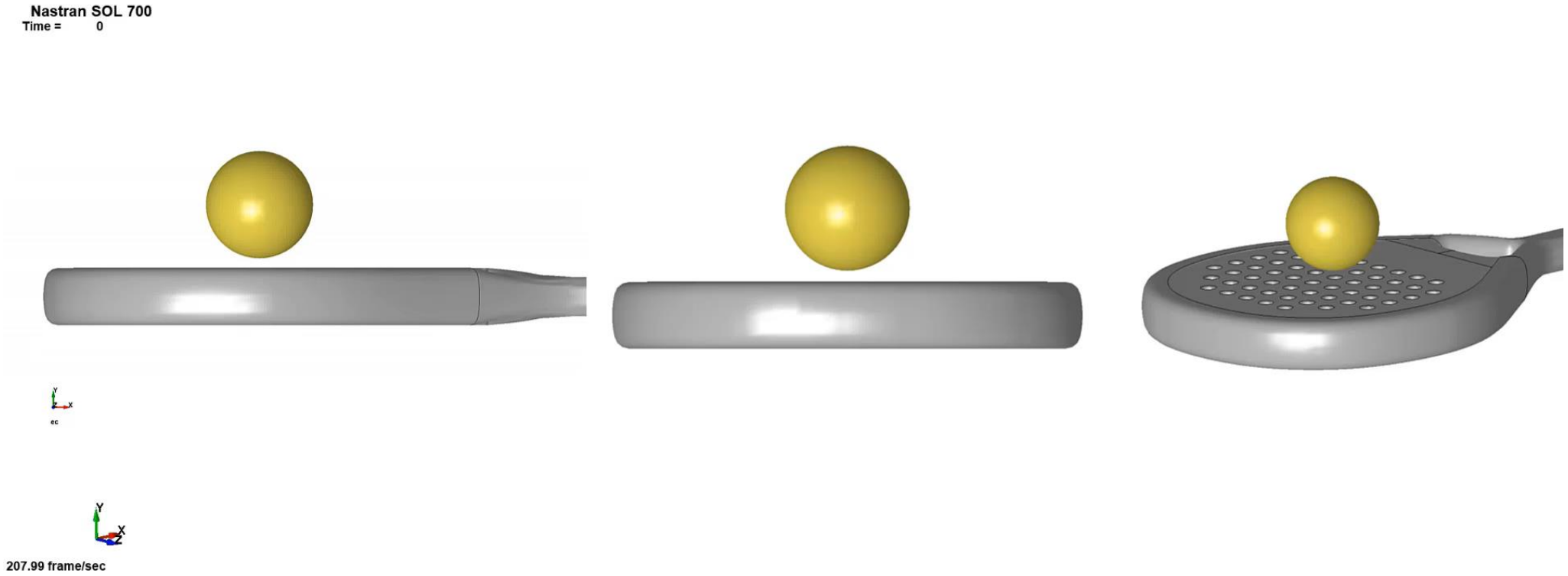


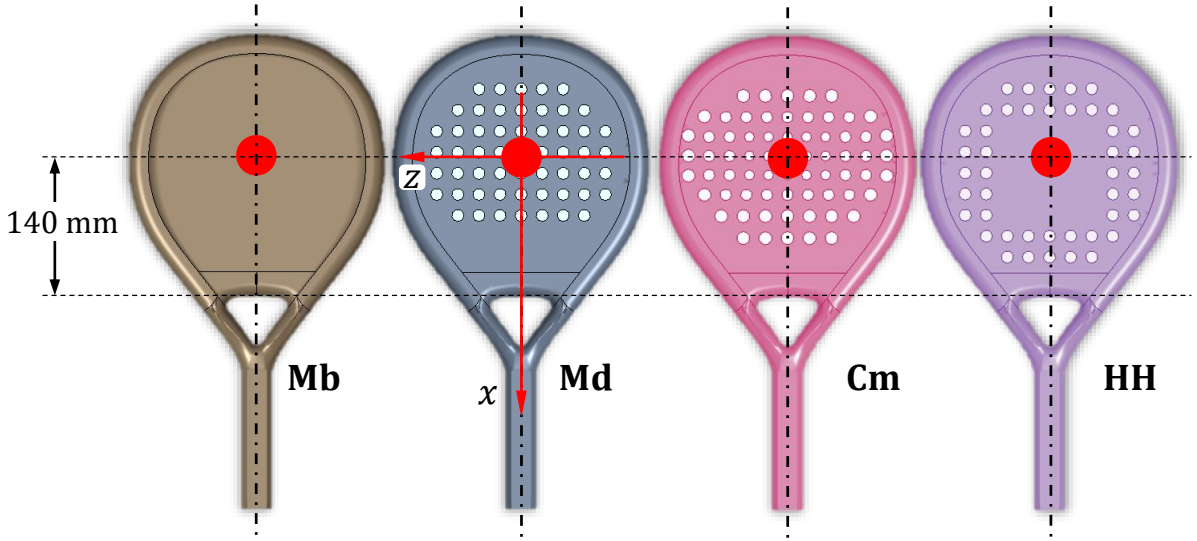
Convergence analysis

Time step performed automatically by SOL 700 of MSC Nastran, to ensure that the Courant-Friedrichs-Lewy condition is satisfied.

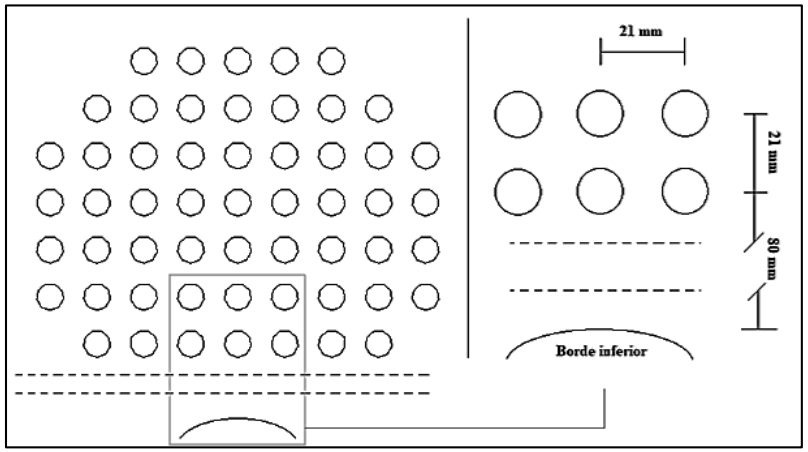




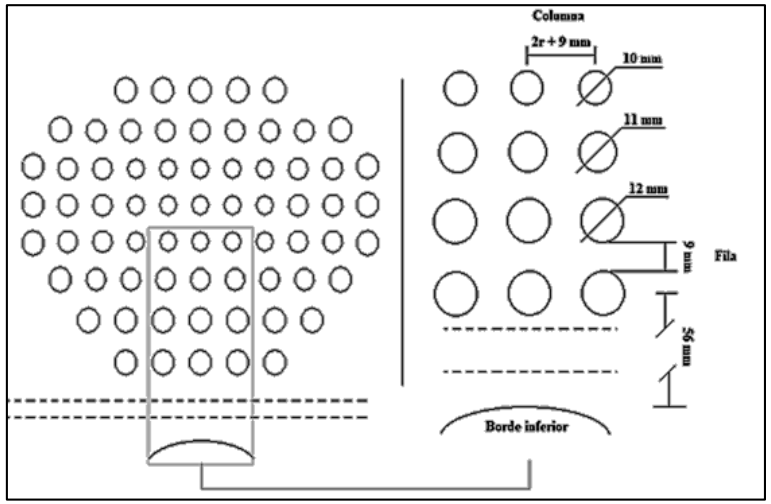

Nastran SOL 700
Time = 0
Y
X
Z
207.99 frame/sec



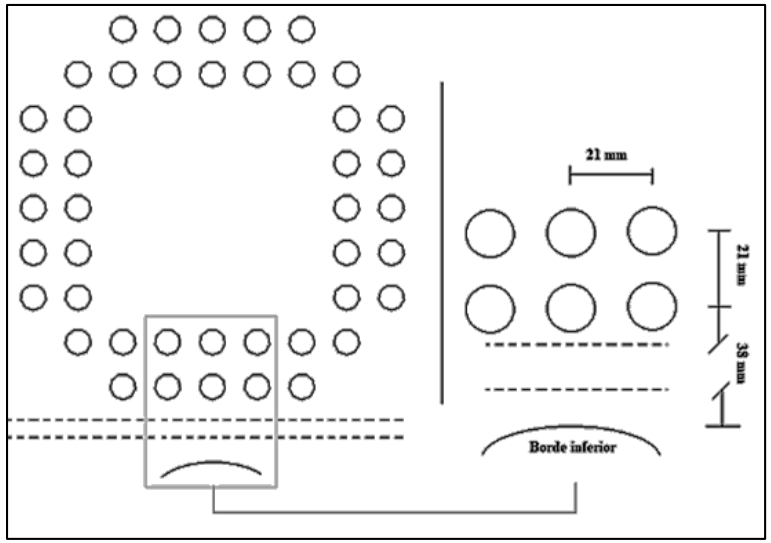
Md	Marvel (SHARK)
Mb	Rough racket
Cm	Commercial
HH	Huarte-Huera



Marvel (SHARK)



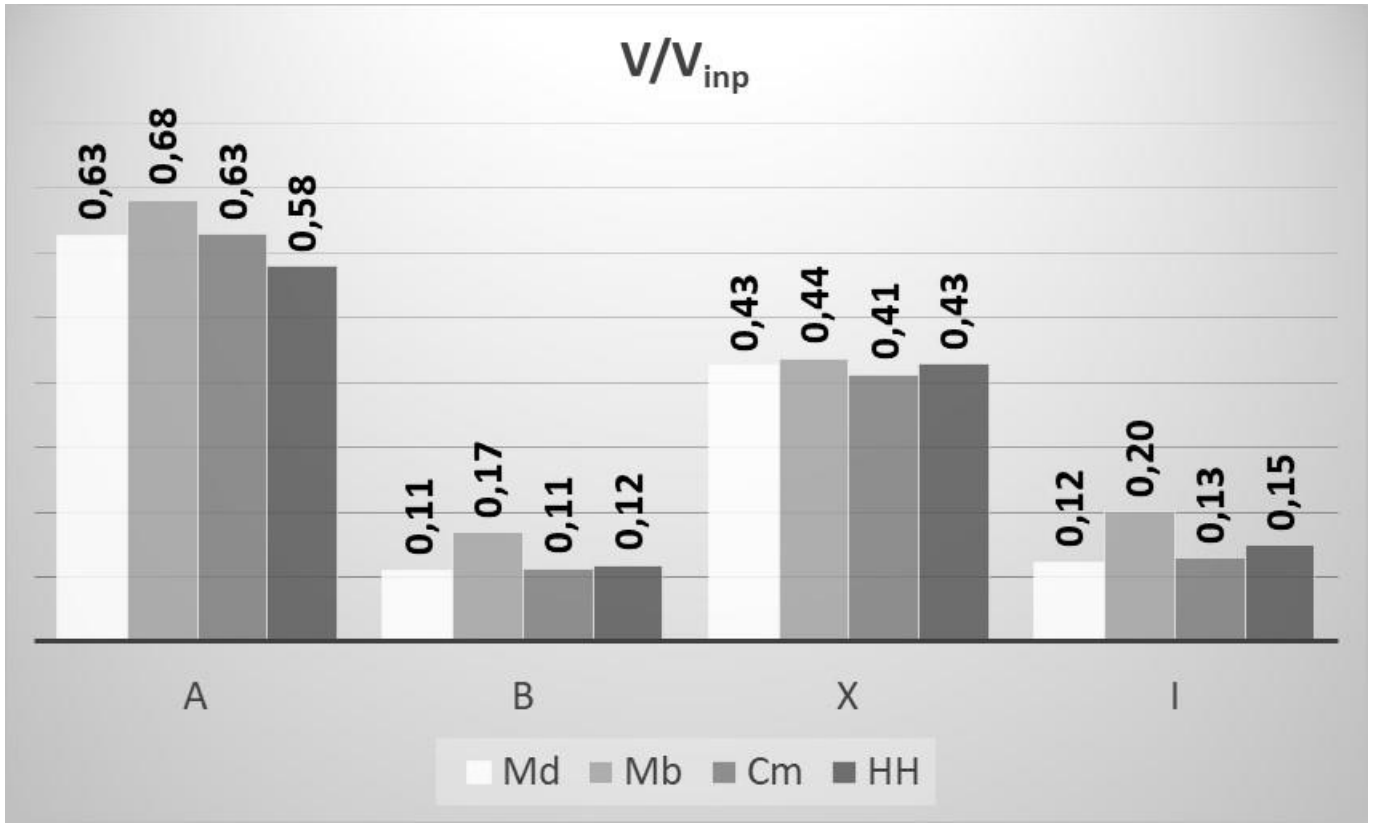
Commercial



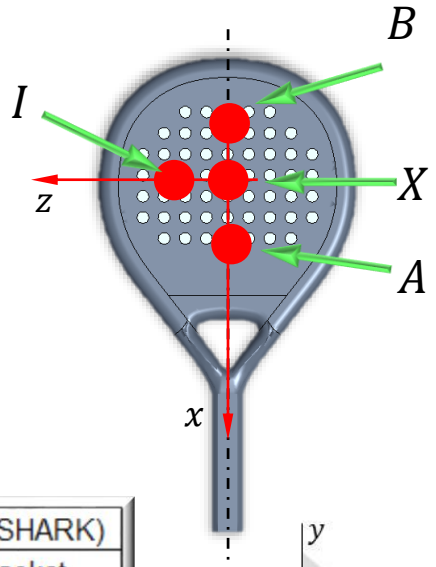
Huarte-Huera

POWER

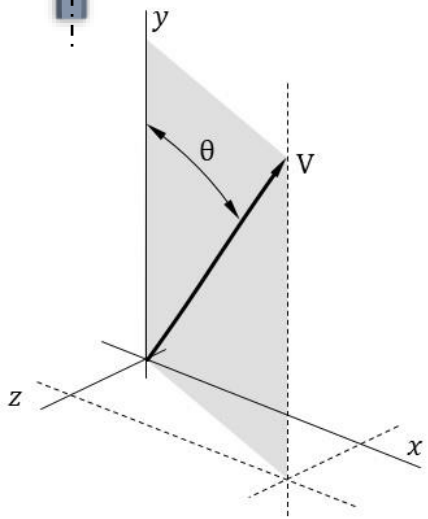
	A		B		X		I	
	V/Vinp	Δ%	V/Vinp	Δ%	V/Vinp	Δ%	V/Vinp	Δ%
Md	0,63		0,11		0,43		0,12	
Mb	0,68	8,74	0,17	52,22	0,44	2,57	0,20	64,09
Cm	0,63	0,27	0,11	1,43	0,41	-3,40	0,13	5,25
HH	0,58	-7,70	0,12	7,07	0,43	0,56	0,15	21,59



Reference Racquet: Marvel



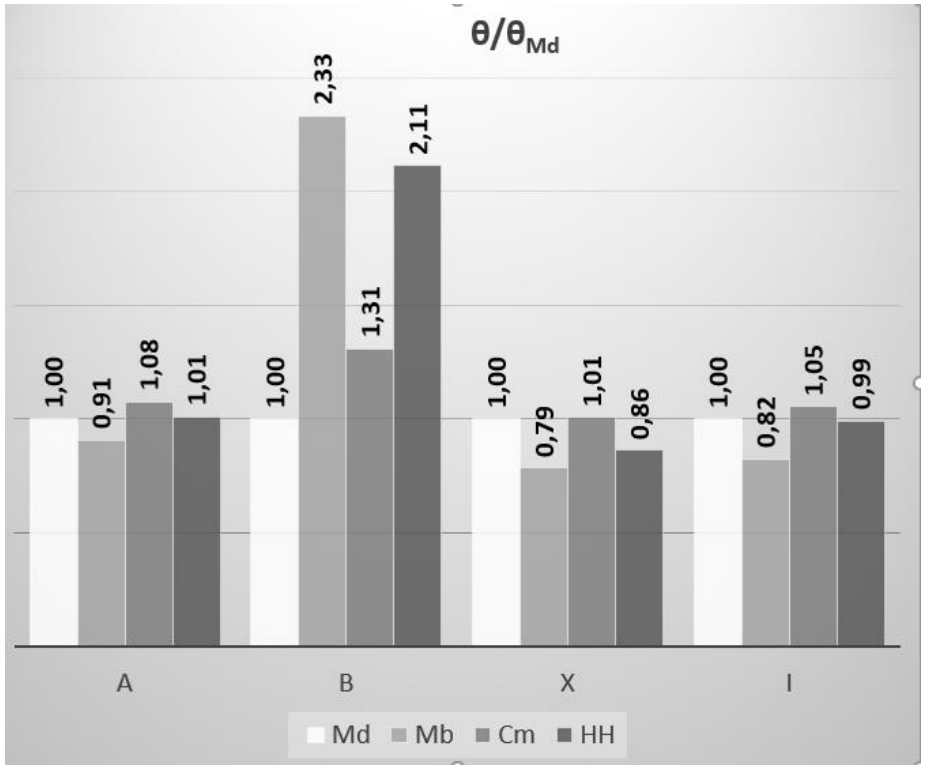
Md	Marvel (SHARK)
Mb	Rough racket
Cm	Commercial
HH	Huarte-Huera



CONTROL

Reference Racquet: Marvel

	A		B		X		I	
	θ/θ_{Md}	Δ%	θ/θ_{Md}	Δ%	θ/θ_{Md}	Δ%	θ/θ_{Md}	Δ%
Md	1,00		1,00		1,00		1,00	
Mb	0,91	-9,24	2,33	133,33	0,79	-21,39	0,82	-17,65
Cm	1,08	7,62	1,31	30,96	1,01	0,68	1,05	5,44
HH	1,01	1,00	2,11	111,44	0,86	-13,84	0,99	-0,71



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Mb	Rough racket
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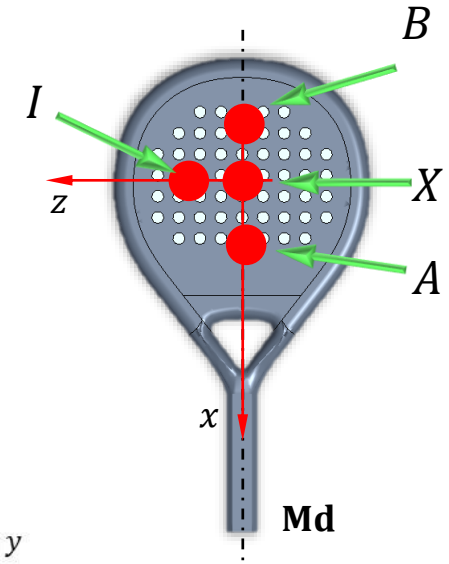
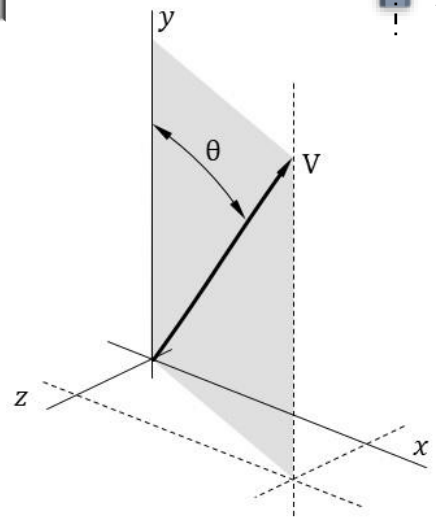
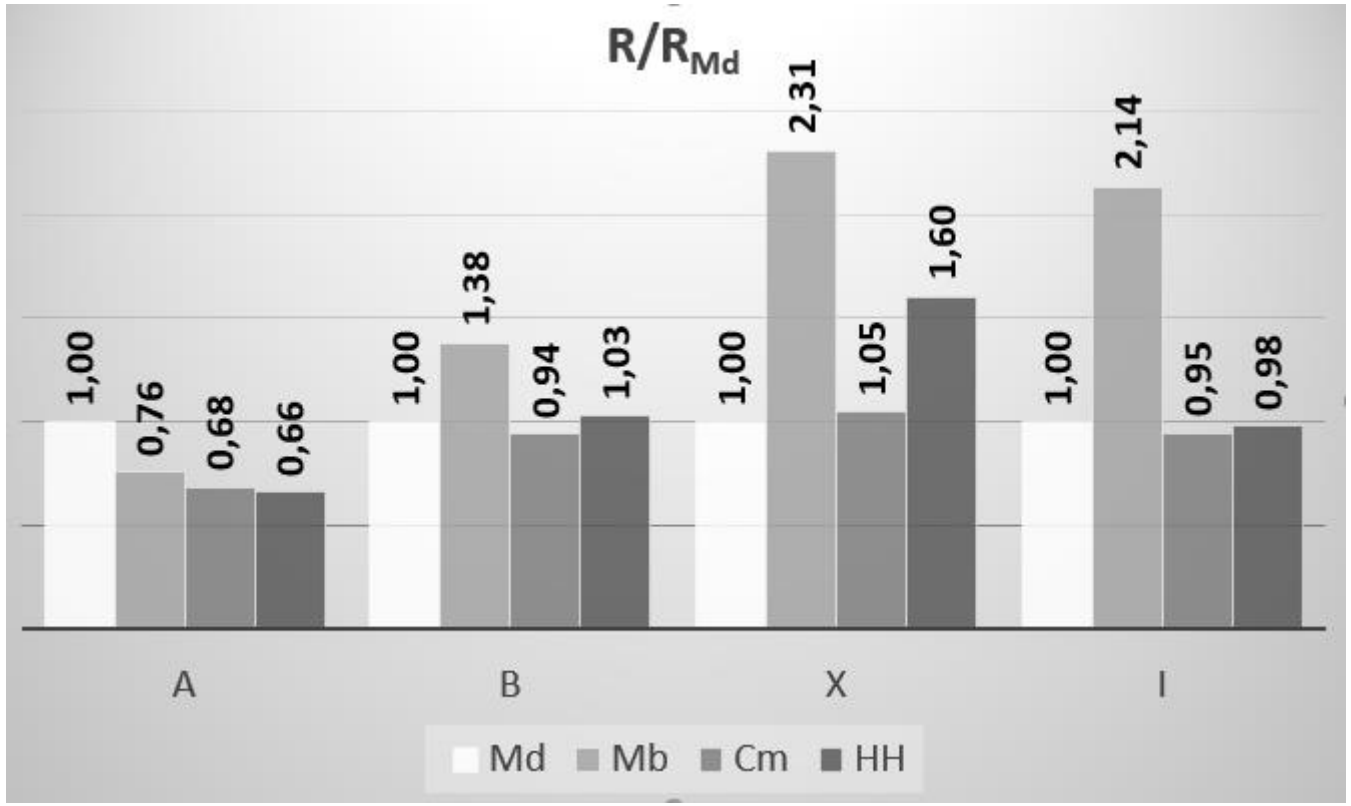




DURABILITY

	A		B		X		I	
	R/R_{Md}	Δ%	R/R_{Md}	Δ%	R/R_{Md}	Δ%	R/R_{Md}	Δ%
Md	1,00		1,00		1,00			
Mb	0,76	-24,28	1,38	38,02	2,31	130,68	2,14	113,51
Cm	0,68	-31,52	0,94	-5,73	1,05	4,55	0,95	-5,41
HH	0,66	-34,06	1,03	2,60	1,60	60,23	0,98	-2,16



Reference Racquet: Marvel

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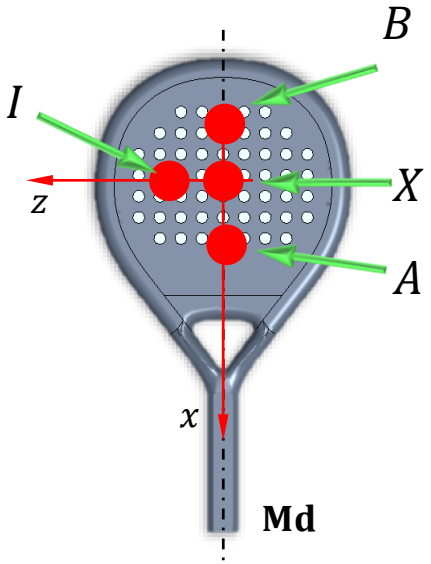
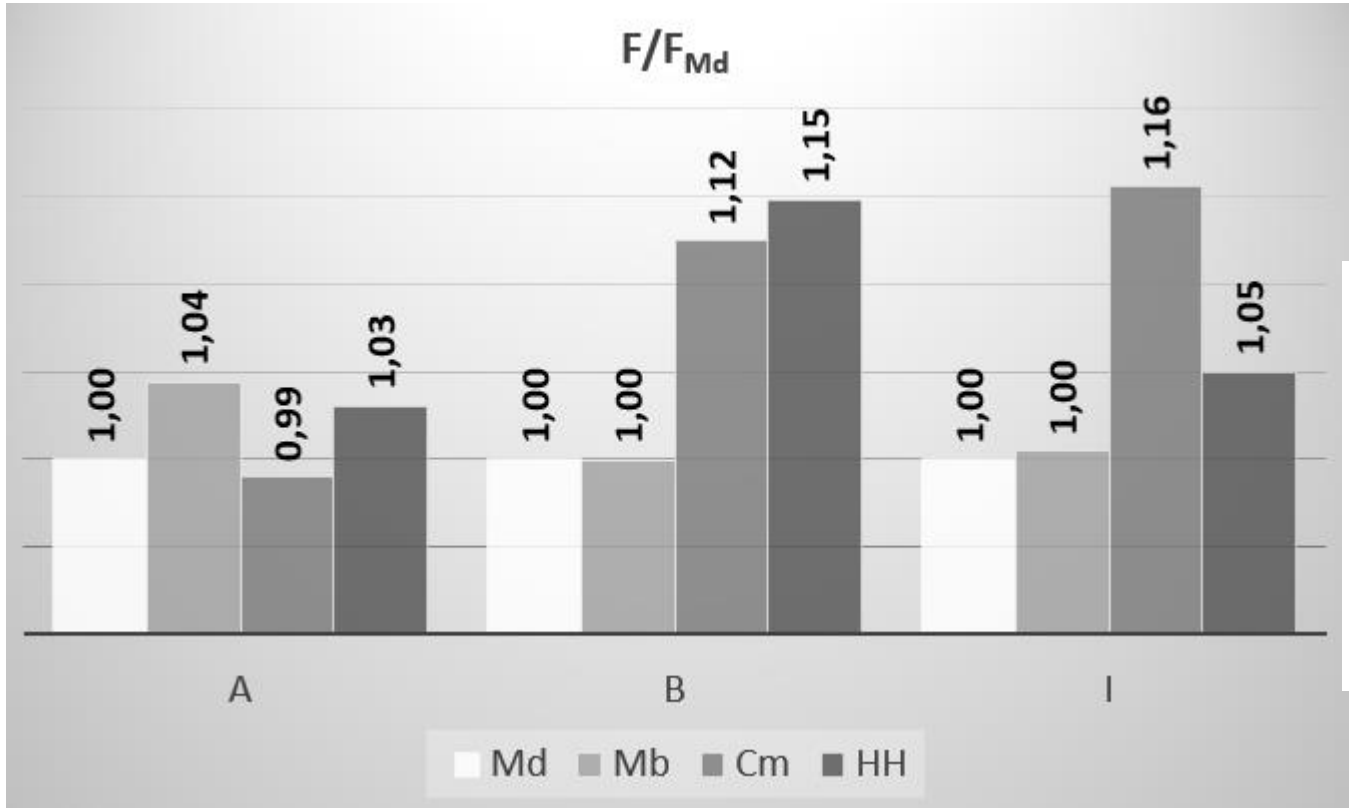
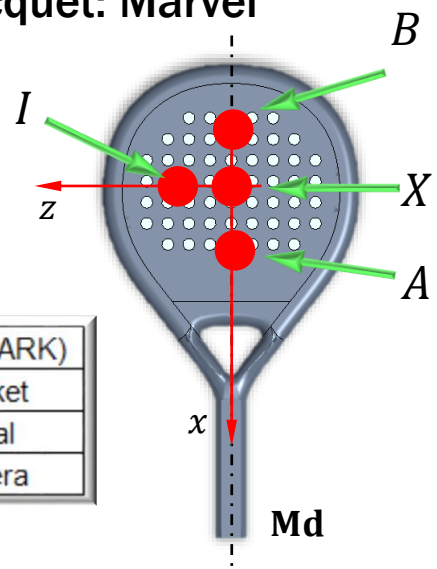


COMFORT- FORCES

	A		B		X		I	
	F/F_{Md}	Δ%	F/F_{Md}	Δ%	F/F_{Md}	Δ%	F/F_{Md}	Δ%
Md	1,00		1,00		1,00		1,00	
Mb	1,04	4,42	1,00	-0,04	0,91	-8,69	1,00	0,47
Cm	0,99	-1,02	1,12	12,49	1,11	10,57	1,16	15,54
HH	1,03	3,05	1,15	14,80	0,99	-1,19	1,05	5,00



Reference Racquet: Marvel



Md	Marvel (SHARK)
Mb	Rough racket
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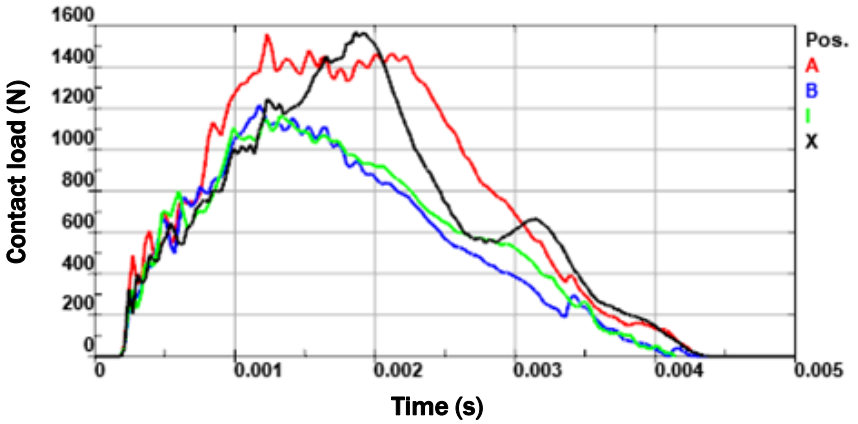
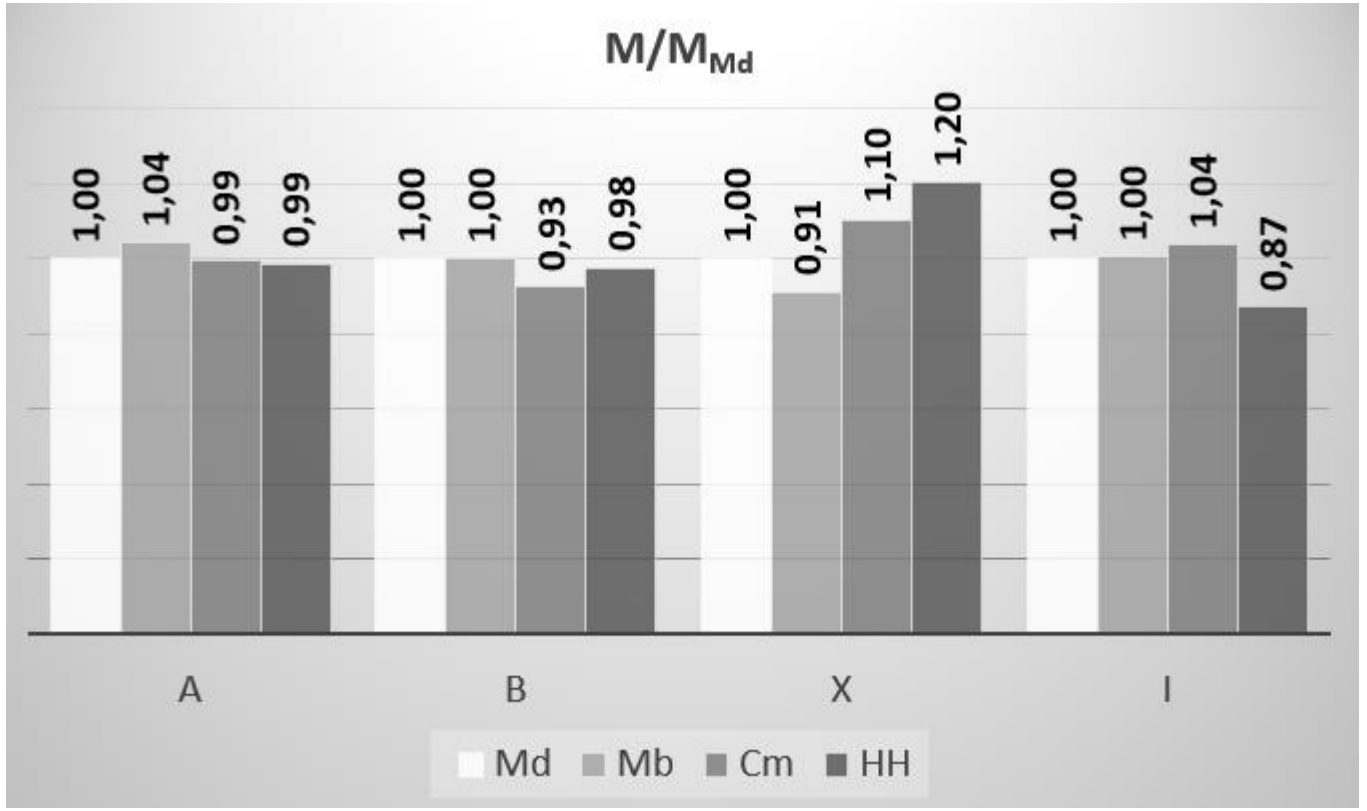
HH	Huarte-Huera

Contact Load

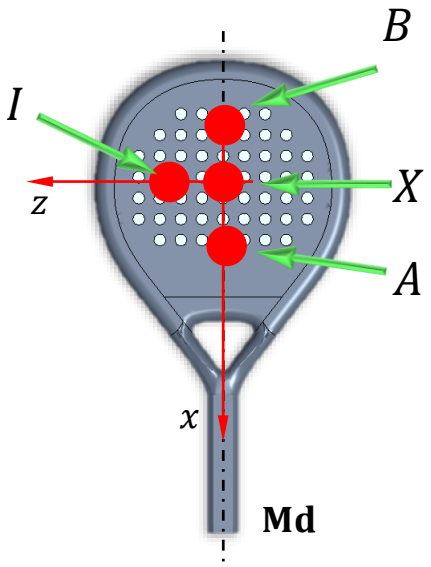


COMFORT- MOMENT

	A		B		X		I	
	M/M_{Md}	Δ%	M/M_{Md}	Δ%	M/M_{Md}	Δ%	M/M_{Md}	Δ%
Md	1		1		1		1	
Mb	1,02	2,37	0,97	-3,39	1,09	8,53	1,05	5,44
Cm	0,99	-0,53	0,93	-7,50	1,10	10,39	1,04	3,74
HH	0,99	-1,24	0,98	-2,25	1,20	20,35	0,87	-12,65

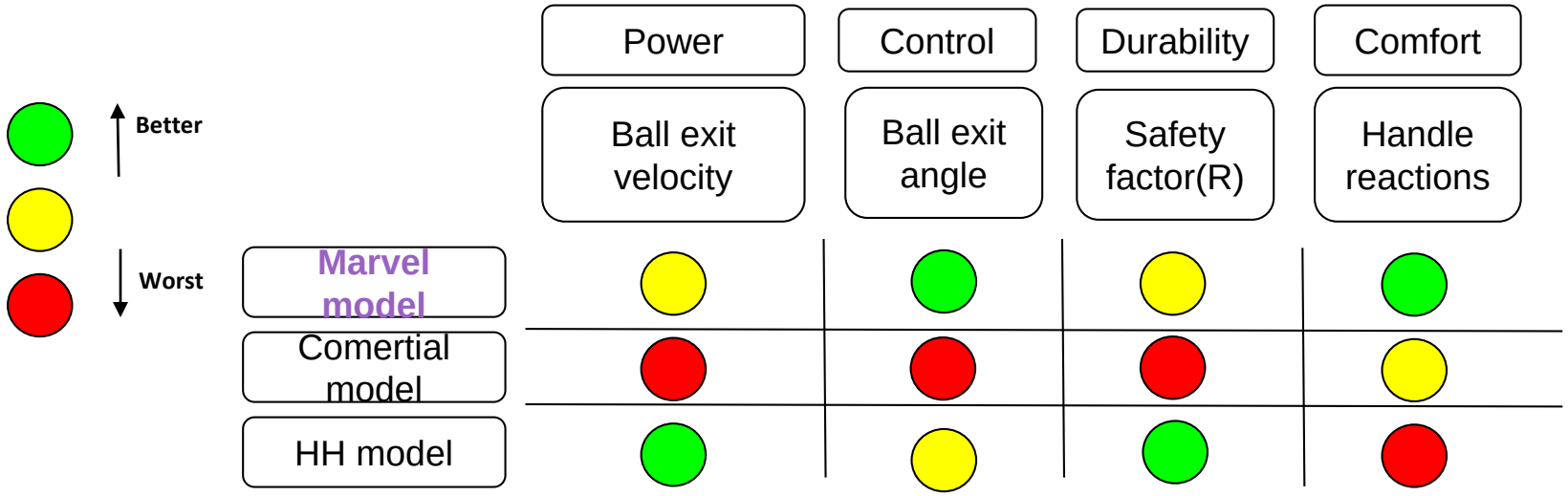


Reference Racquet: Marvel



Md	Marvel (SHARK)
Mb	Rough racket
Cm	Commercial
HH	Huarte-Huera

- ❑ Ball model validated by regulations.
- ❑ Racquet-ball model.
- ❑ Definition of engineering parameters that make it possible to quantify the player's sensations.

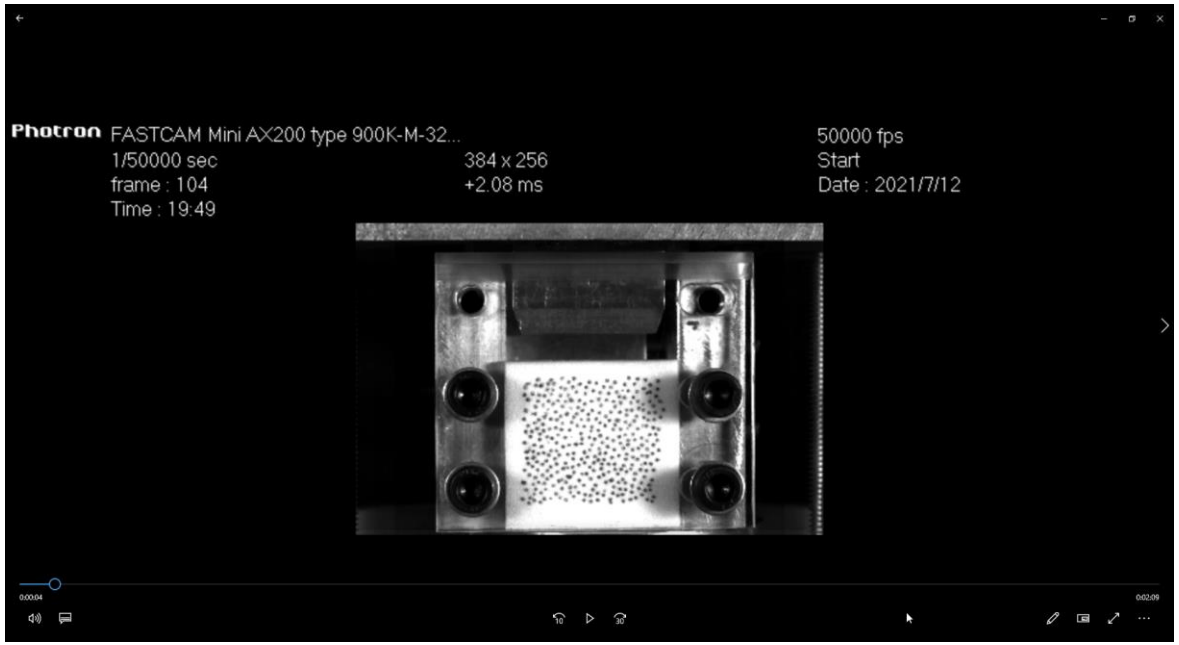


❑ Introduction to viscoelastic foam behavior

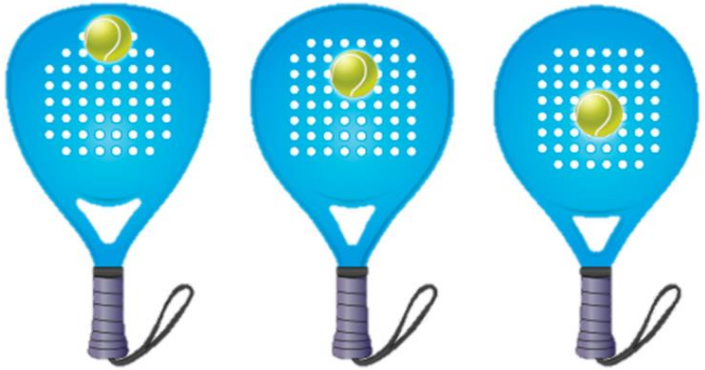
	$\dot{\varepsilon}\ (s^{-1})$	$Ex\ (MPa)$	
		Average	Deviation
Quasi-static Tests (1)	22.10^{-3}	0,111	0,003
	132.10^{-3}	0,1107	0,0004
Low velocity impact test (2)	79	0,417	0,008
	105	1,59	0,02

(1) Universal test machine Servosis ME-405/10. Load cell $1\ kN$

(2) Drop test machine Instron CEAST 9350. Load cell $2{,}25\ kN$



❑ Racket geometry change



Diamond Teardrop Round

❑ Modification of reinforcing materials.

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NUMERICAL MODEL FOR THE PARAMETRIC ANALYSIS OF THE IMPACT BALL-PADDLE RACQUET.

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Thank you very much for your attention