TEG-054-Rev.1

First Technology Safety Systems

Design Freeze Status

FLEX-PLI-GTR Development Mechanical Design

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FTSS Europe

Updated according Design Freeze meeting
February 20th 2008, JARI, Tsukuba, Japan
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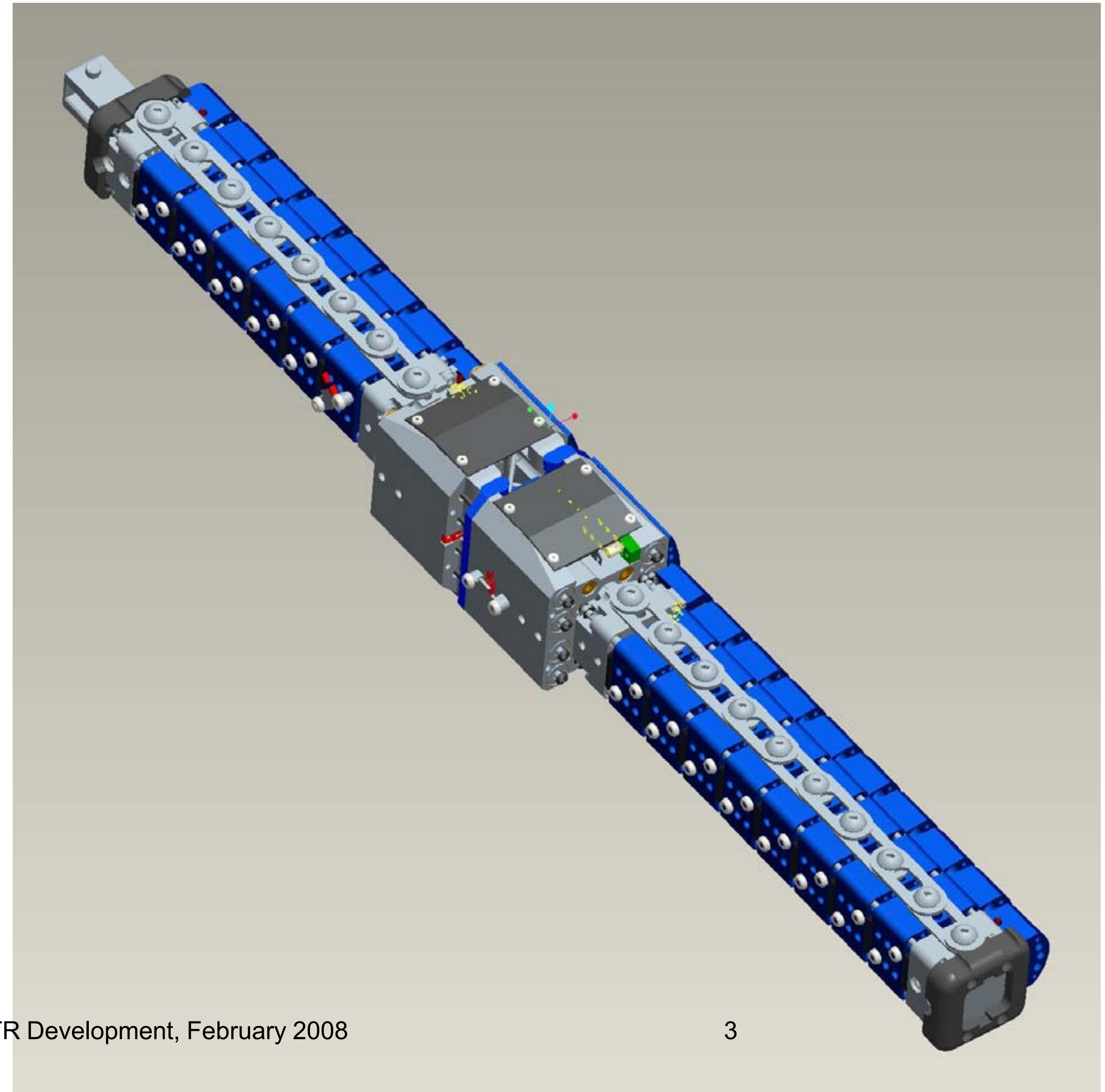
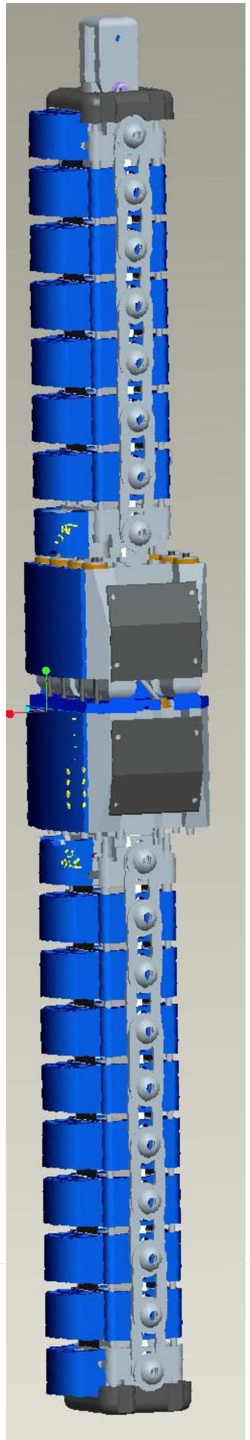
Content

- Mechanical design
- Problems addressed
- Packaging standard components

Introduction

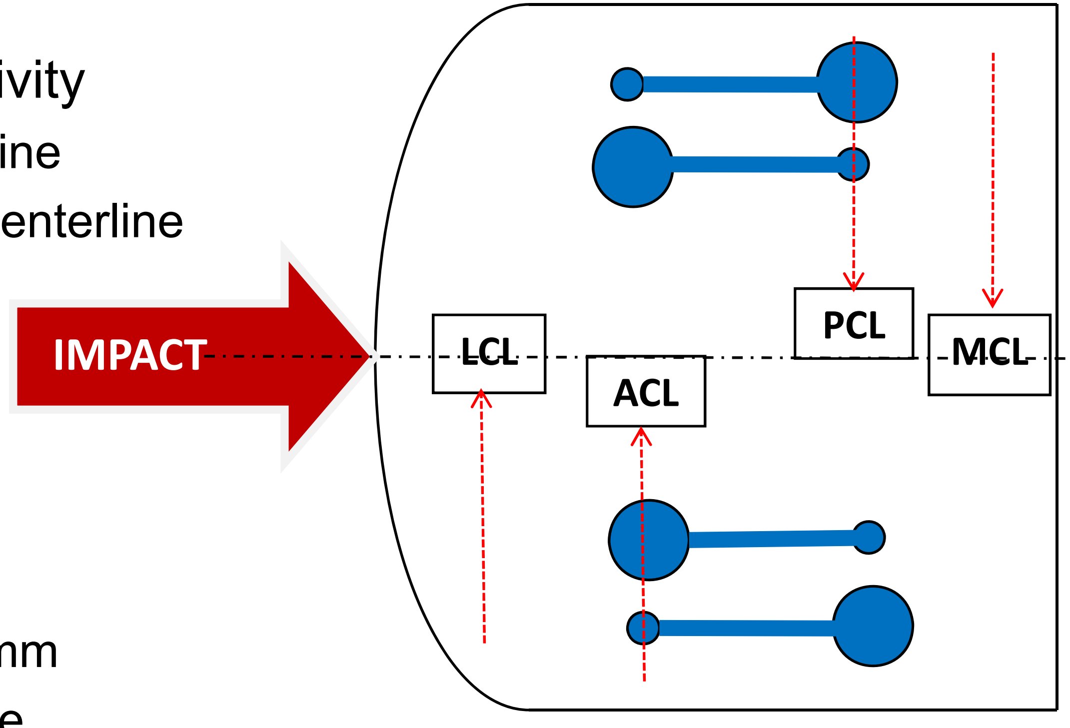




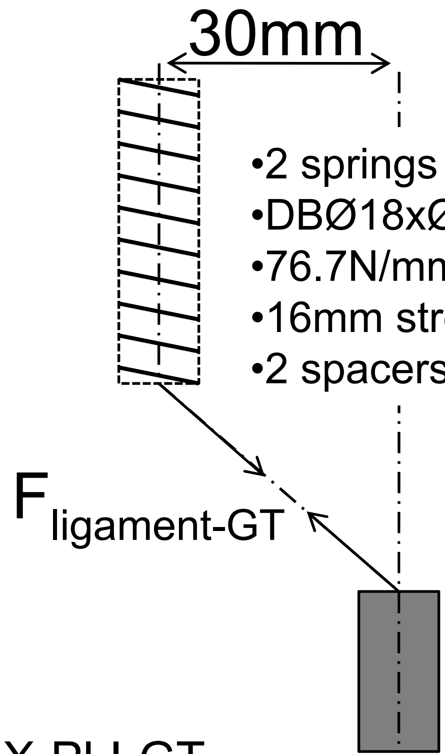
Channel	Purpose	Standard	Option	DAS
Femur moment 1, 2 and 3	Calibration	3	0	Standard option i-dummy
Tibia moment 1, 2, 3 and 4	Injury	4	0	
Tibia top acceln ax	Calibration	1	-1	
MCL elongation	Injury	1	0	
ACL elongation	Calibration	1	0	
PCL elongation	Calibration	1	0	
LCL elongation	Calibration	1	0	
Femur top acceln ax, ay, az	Motion	0	3	Lab
Femur bottom acceln ax, ay, az	Motion	0	3	Lab and optional i-dummy If feasibl
Tibia top acceln ax, ay, az	Motion	0	3	
Tibia angular rate ωx, ωy, ωz	Motion	0	3	
Femur angular rate ωx, ωy, ωz	Motion	0	3	
Tibia bottom acceln ax, ay, az	Motion	0	3	Lab
Segment acceln ax	Research	0	15	Lab
Total		**12**	**32**	

Conceptual Design

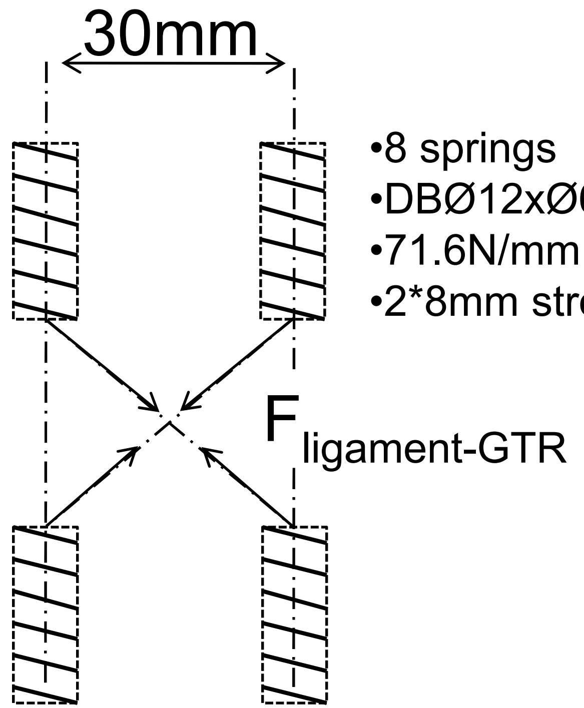
- To avoid A-symmetric sensitivity
  - Move MCL & LCL at centerline
  - Move ACL & PCL close to centerline
- To avoid knee twist
  - Use two sets of cruciate ligaments
  - To neutralize twist moment
- Cruciate ligaments 8 springs
  - DBØ12xØ6x40mm; 71.6N/mm
  - May need to go Ø3mm cable
  - Optimized space for DAS & connector
- Lateral ligaments 16 springs same
  - DBØ18xØ9x80mm; 76.7N/mm



Cruciate Ligament Springs



- 2 springs
- DBØ18xØ9x80mm
- 76.7N/mm rate
- 16mm stroke
- 2 spacers



- 8 springs
- DBØ12xØ6x40mm
- 71.6N/mm rate
- 2*8mm stroke

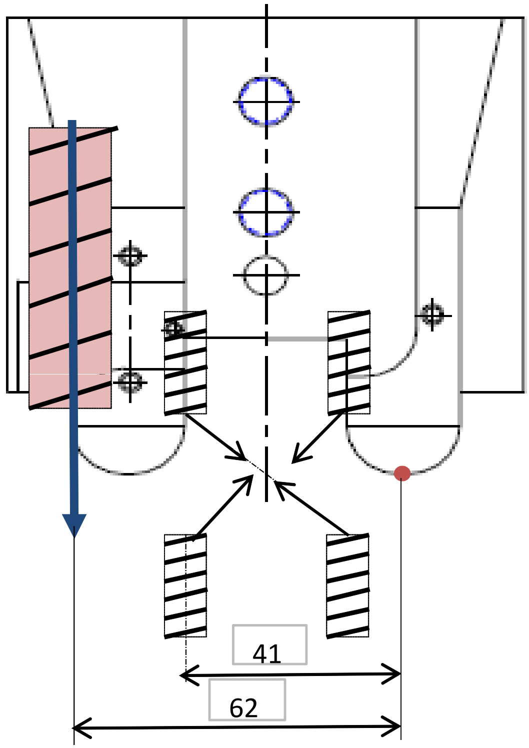
- FLEX-PLI-GT
- $F_{ligament\ GT}$ = 76.7*16 = 1227N
- Total $F_{ligament\ GT}$ = 2 * 1227 = 2454N

- FLEX-PLI-GTR
- $F_{ligament\text{-}GTR}$ = 71.6*8 = 573N
- Total $F_{ligament\text{-}GTR}$ = 4*71.6*8 = 2292N

- 8 Lateral ligaments DBØ18xØ9x80mm
- Cruciate ligaments contribute ~22% to bending moment
- Effect ~-1.3%

Knee Bending Moment Comparison

Knee Bending Moment Comparison GT-GTR	**GT**	**GTR**
Lateral ligament peak force FL	1227	1227
Cruciate ligament peak force FC	1227	573
Distance lateral ligament- Rotation point 72-10=62	62	62
Distance crucuate ligament- Rotation point 26+15=41	41	41
Lateral ligament Moment peak contribution ML [Nm]	304	304
Cruciate ligament Moment peak contribution MC [Nm]	71	66
Total moment before spring bottom out [Nm]	375	371
Difference GT-GTR [%]	**1.3**	



GT version
*ML=4*FL*62/1000*
*MC=2*FC*41/√2/1000*

GTR version
*ML=4*FL*62/1000*
*MC=4*FC*41/√2/1000*

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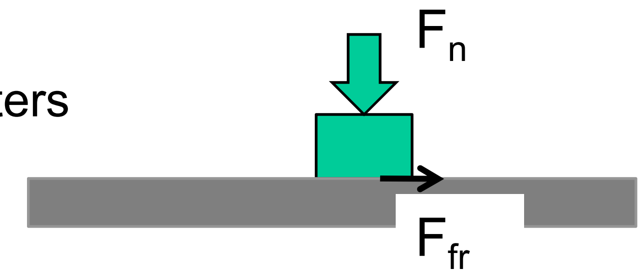
Ligament Wear

- Prevent wear of ligament cable plastic sleeves
  - Remove plastic sleeves from cables
  - Apply bronze guides cross ligaments
- The plastic tube is the source of the problem; it cannot sustain high surface strain
- Omitting plastic sleeve will avoid the damage
- Larger bending radius and reduced friction will protect the cable
- Ø3mm cable for cruciate ligaments agreed
  - May go to Ø4mm if problems arise
- Ø4mm 7*19 cable break strength 8.73kN
  - Alternative 7*7 cable break strength Ø4mm 9.52kN
  - Knee bending moment break strength 60mm * 9kN * 4 = 2160Nm
- Ø3mm 7*19 cable break strength 5.00kN

Friction Double Cruciate Ligaments

- A concern raised on change in friction of the double cruciate ligaments
- Friction is **undesired** unpredictable phenomena
  - Static and dynamic friction, slip-stick effect, effect of wear, state of lubrication, moisture
- GT version is unpredictable because of three material layers: steel-PVC tube-aluminium
- Friction force (F_{fr}) is dependent on two parameters
  - material pairing and friction coefficient (c)
  - force perpendicular to friction plane (F_n)



- In GTR version the total perpendicular force remains the same
- In GTR version friction coefficient will reduce
  - GT Plastic to steel ~ 0.2-0.5 friction coefficient
  - GTR Steel to bronze ~ 0.1 friction coefficient
- Cruciate ligaments only contribute ~ 20% to knee bending moment
  - Influence of friction is further reduced in GTR version
  - Knee bending characteristic dependent on spring tension and controlled by calibration

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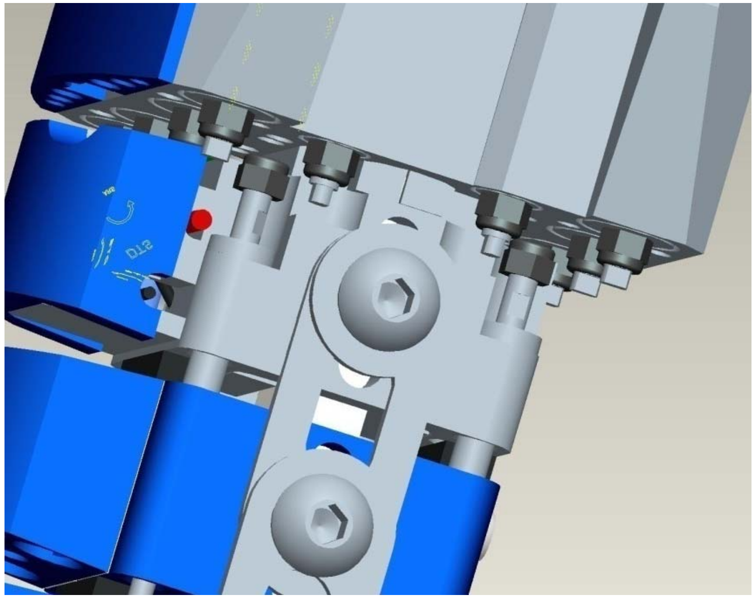
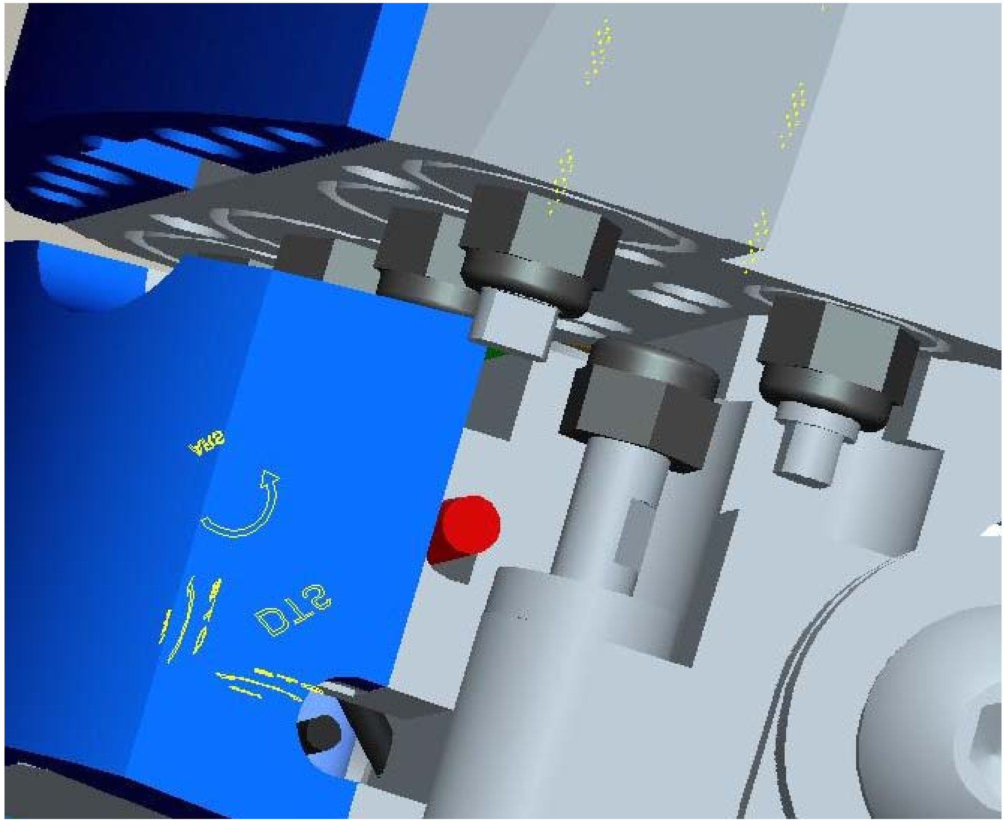
Ligament Spring Adjustment

- Problem of spring adjustment access
- Problem of spring adjustment loss (no retention of position)

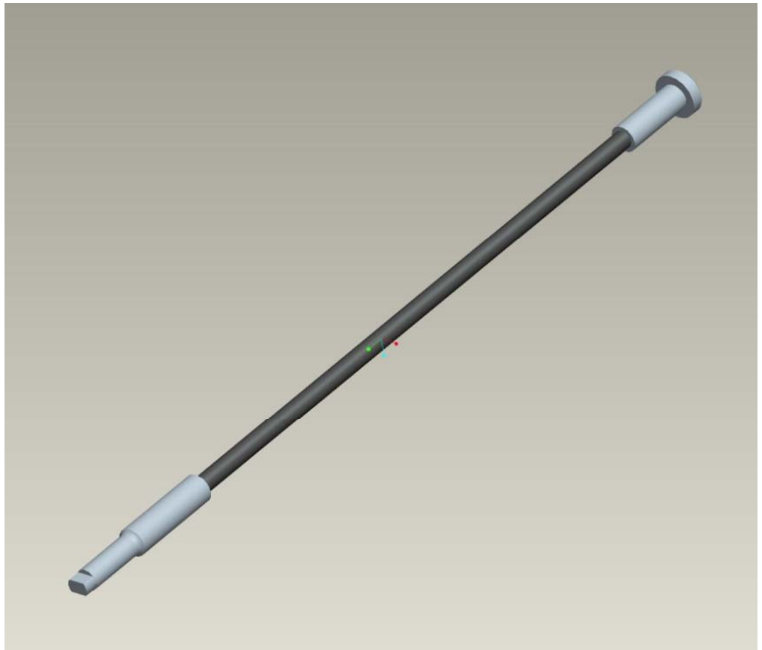
Ligament Spring Adjustment



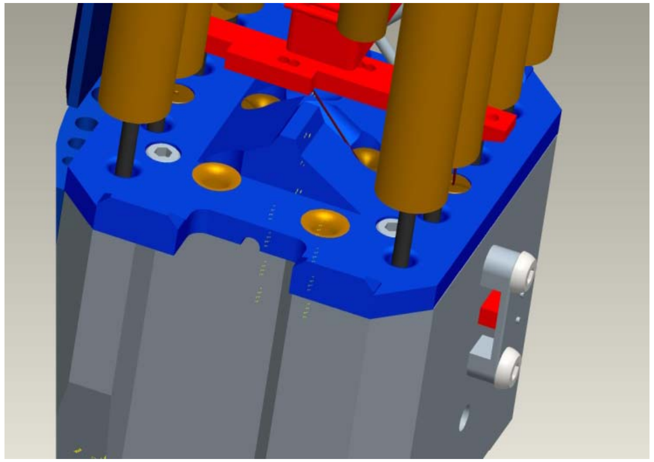


- Ligament springs made flush
- M5 Nyloc locking nuts
- Male thread on ligament wires
- Flats on end fittings for locking
- Improved access for ligament adjustment
- Less frequent adjustments required with locking nut

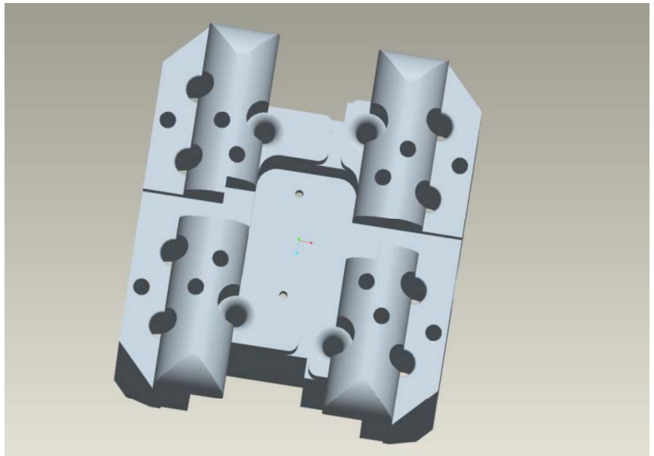
Proposed Cables



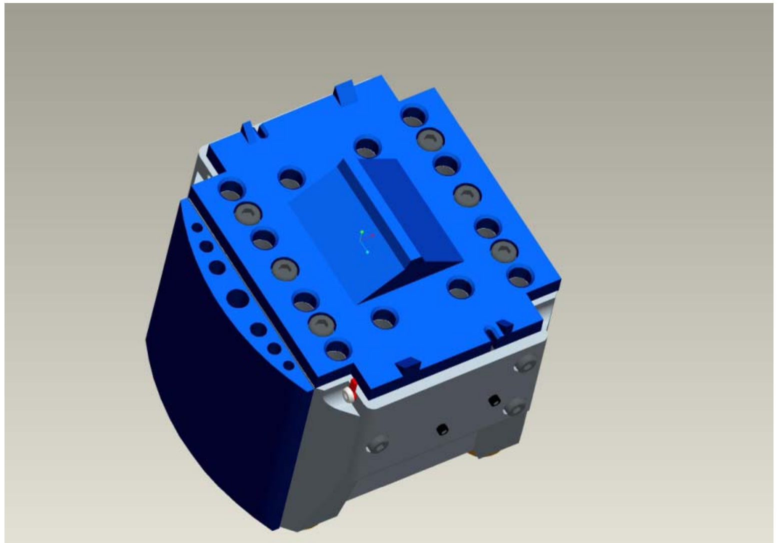
•New cable end fitting design
•Metric threads and fasteners

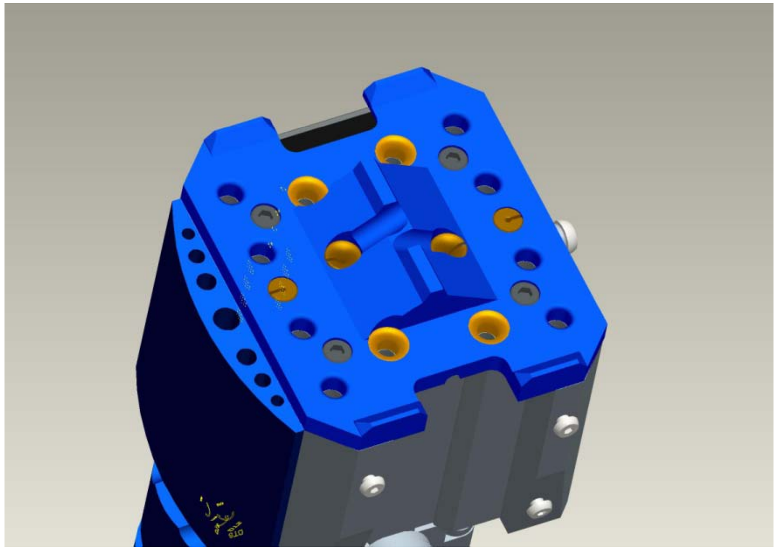


Bronze bushing
Rounded corners



Knee interface





GT retained
with six M5 screws

GTR Retained with
four M5 screws
Bronze wire guides

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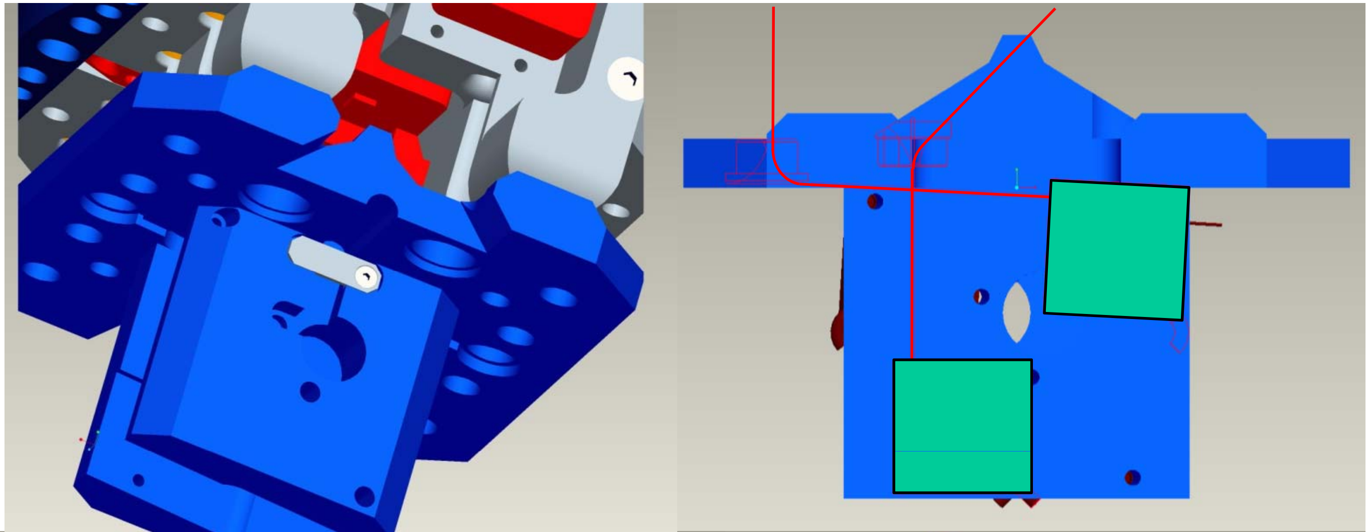
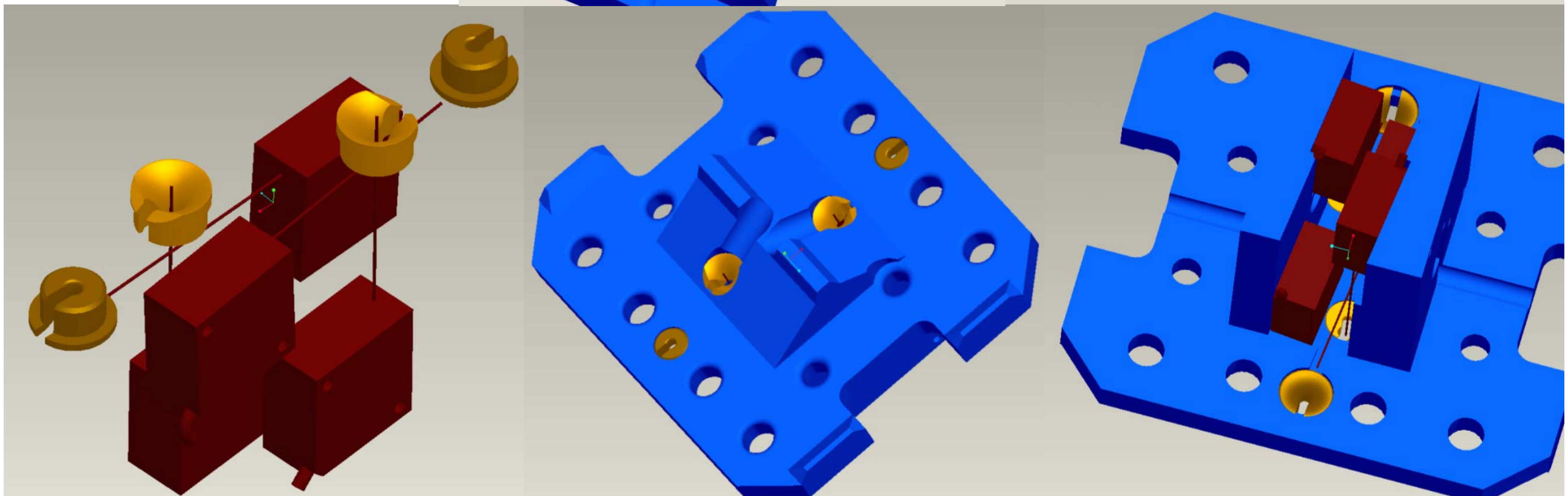
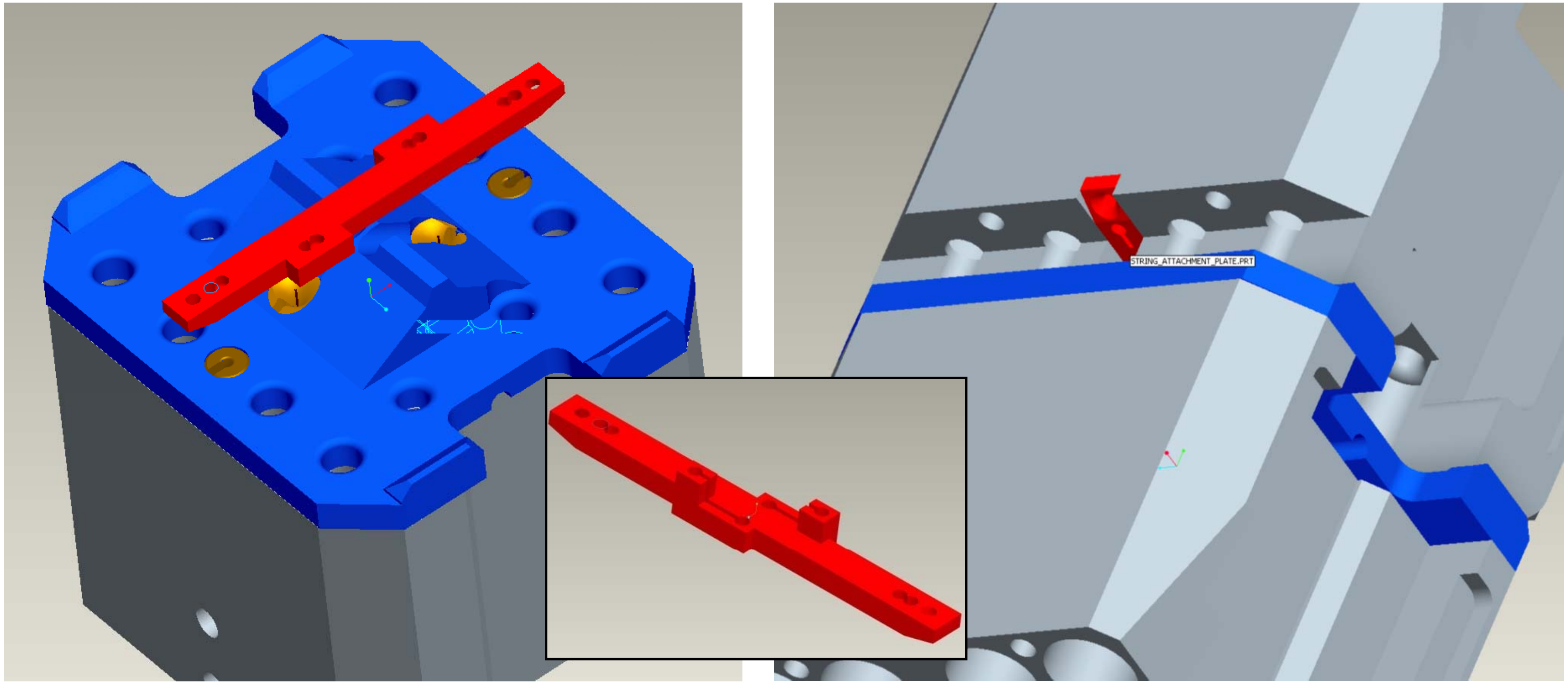
Packaging Ligament Elongations
Sensors at Centre Line

Space Age Control
150 series
19*19*10mm
49G acceleration
38mm stroke
2xLH & 2xRH pull
Bronze wire guides





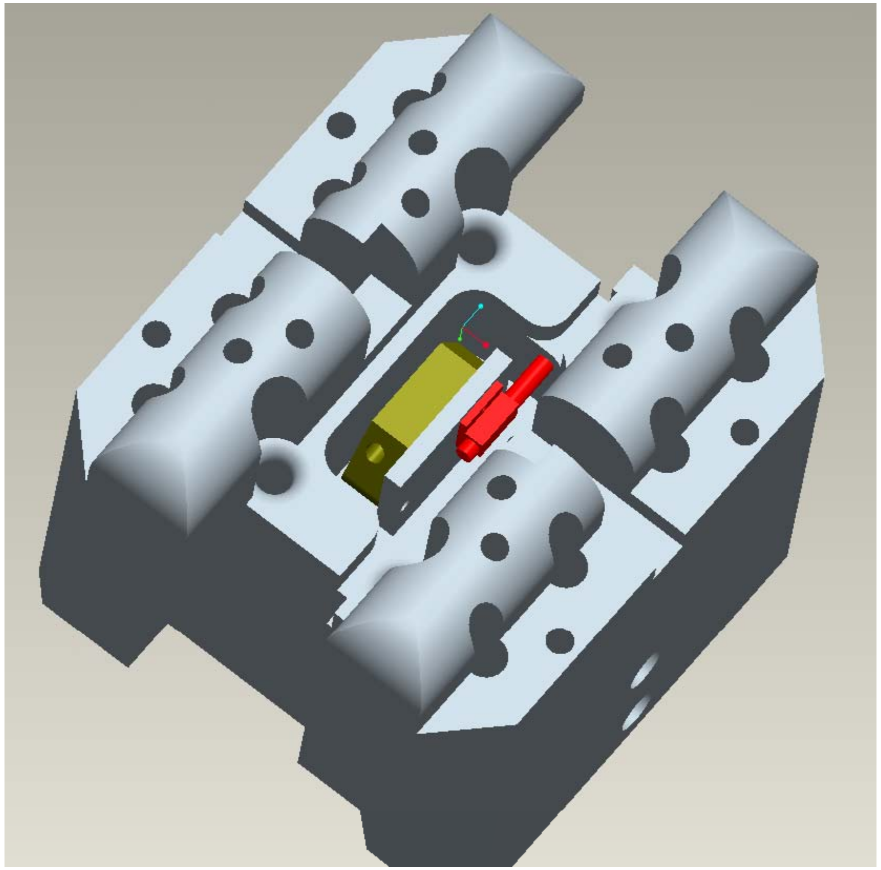
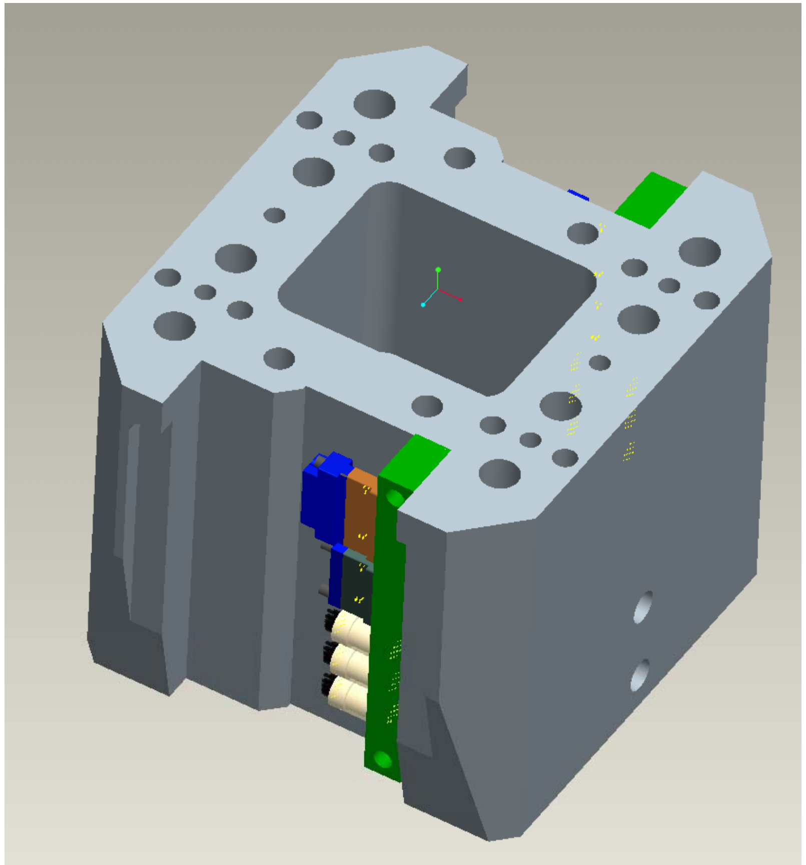
Potentiometer String Assembly



•Assembly of potentiometer string fittings is always difficult due the tension on the string and small fitting size

•This method enables mounting string fittings without tension

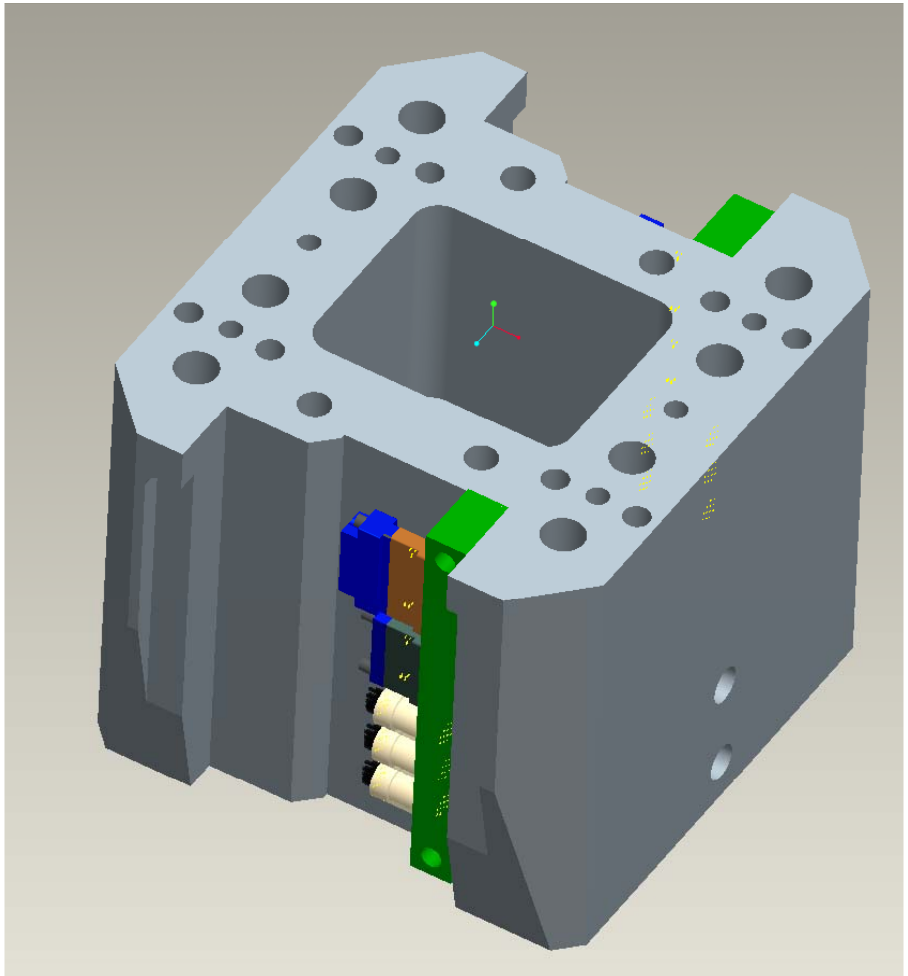
Packaging Space

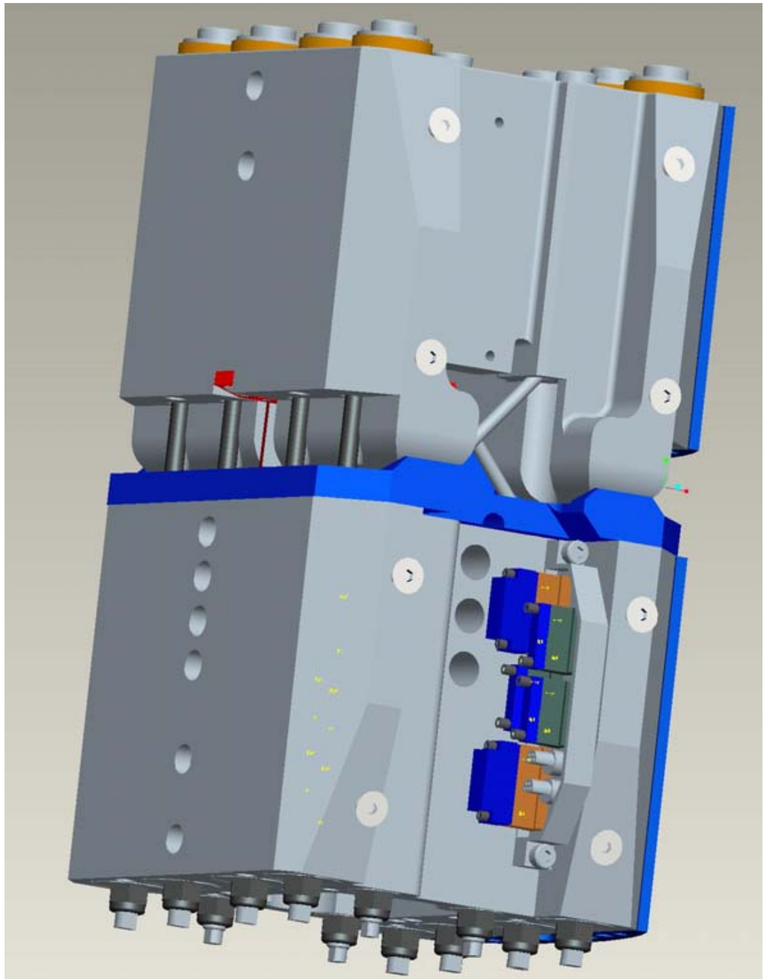



Side cavities: DAS, wiring, connectors

Central cavity: Auxiliary components: battery, terminator, etc.

Integration of connector blocks and wiring





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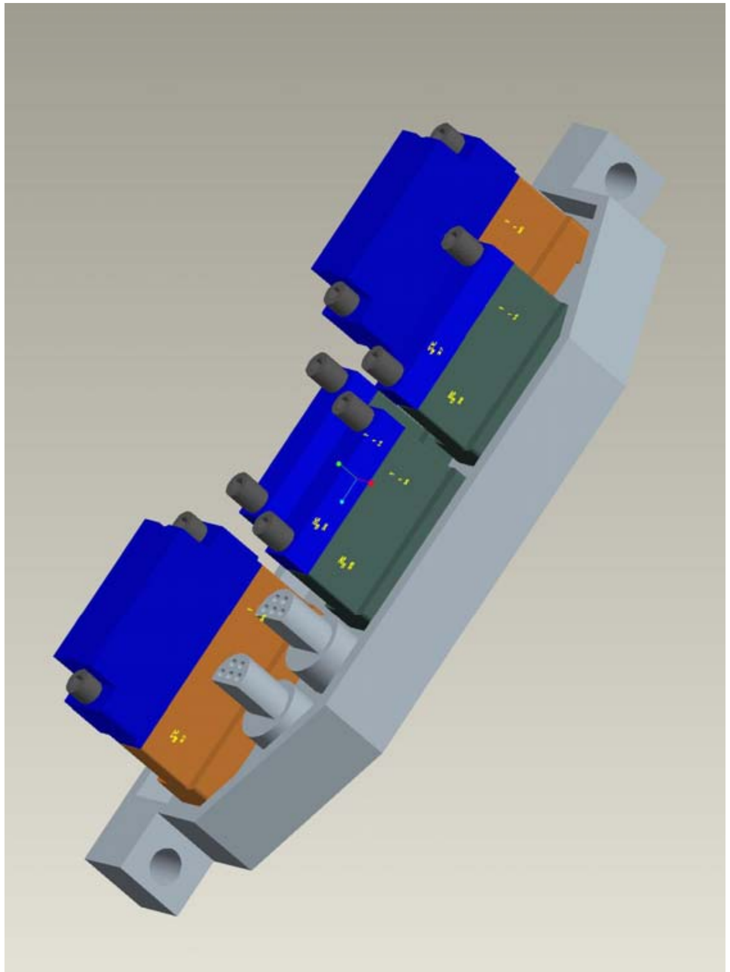
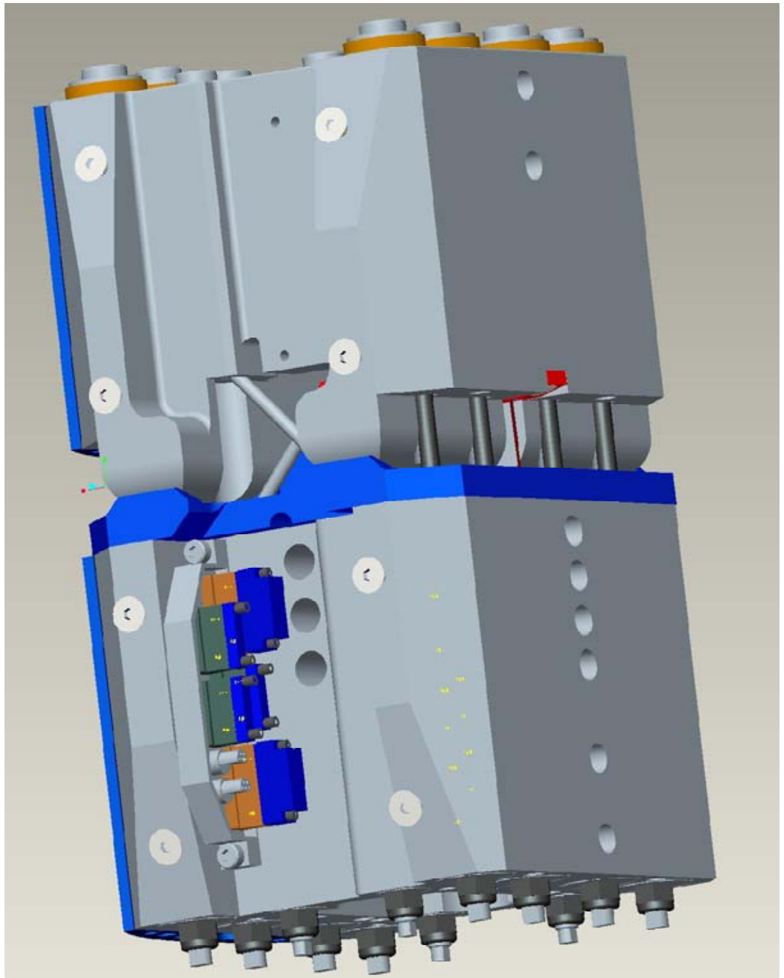
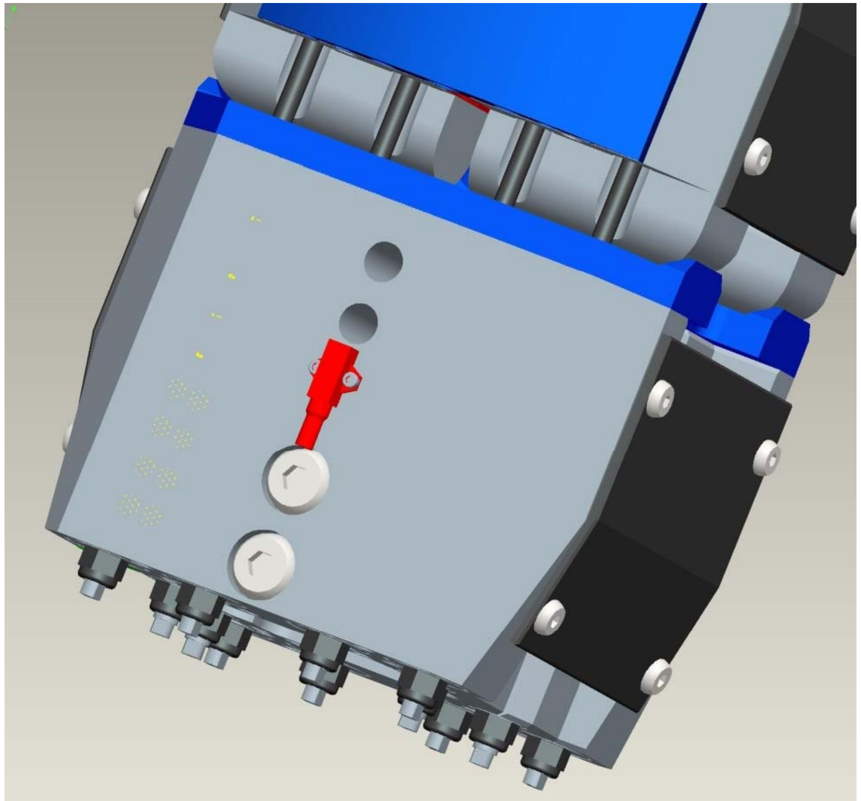
Integration Connector Blocks

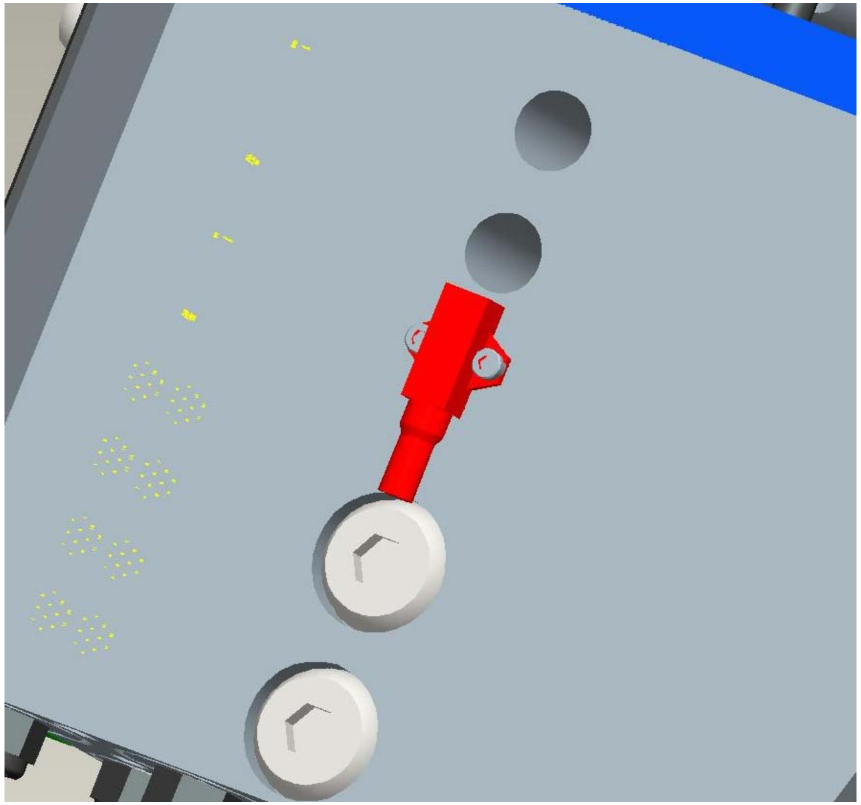
TEG-054





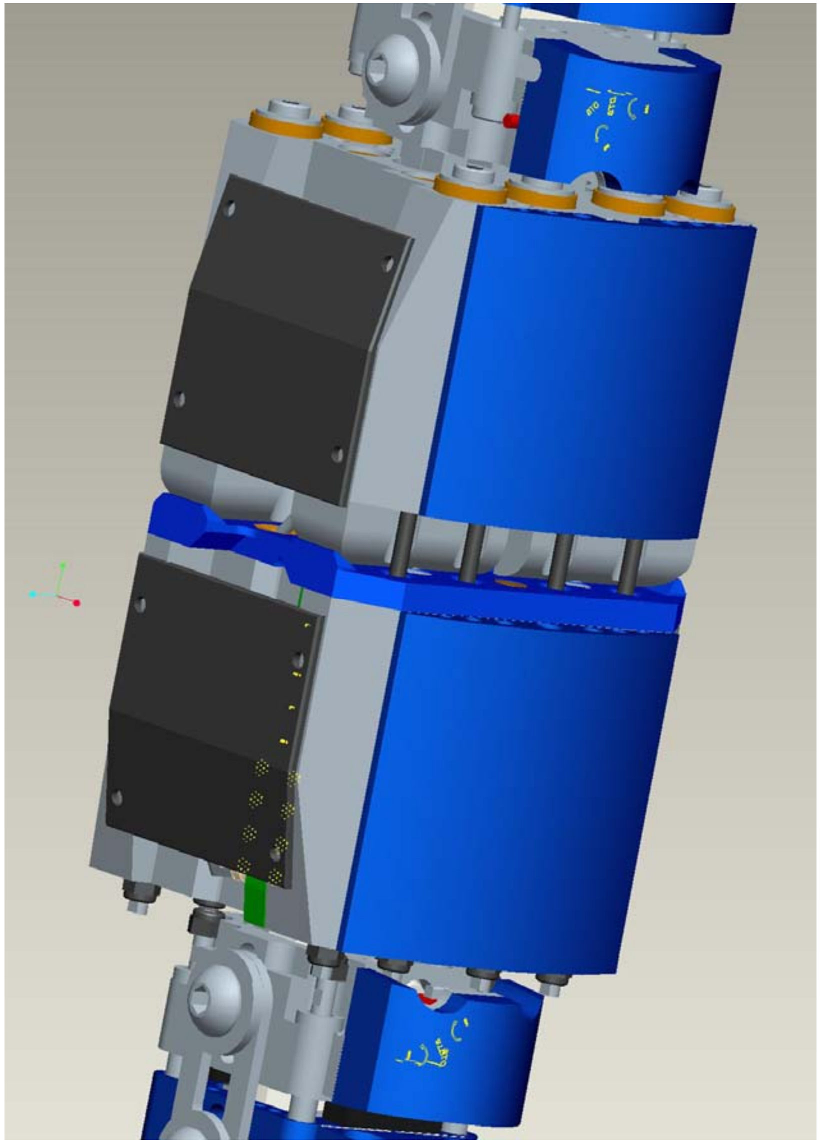
Single axis accelerometer x-direction for certification



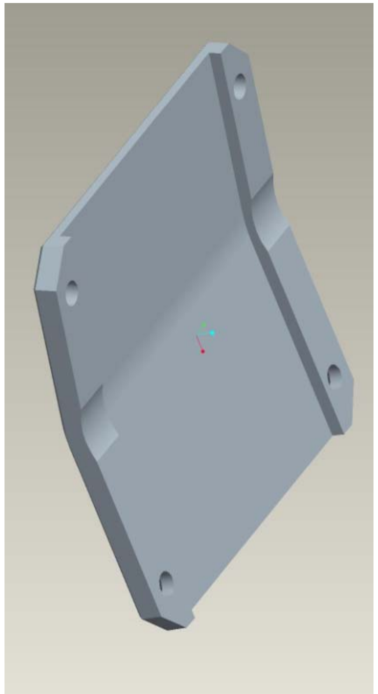


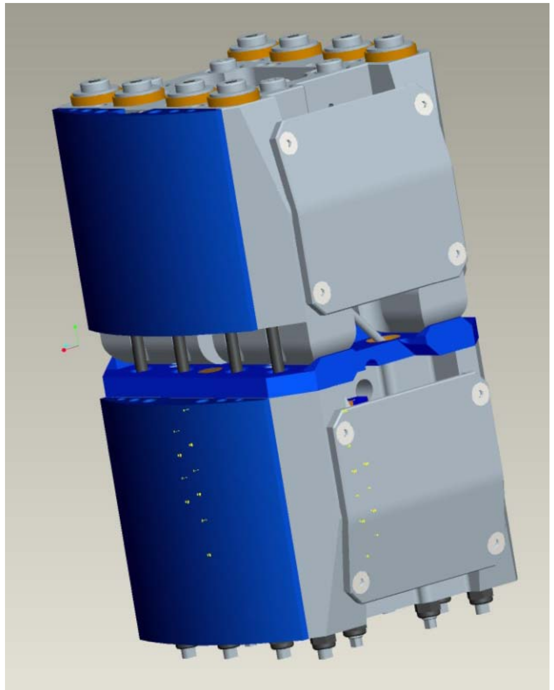
- Mounted behind Nylon Impact Cover
- Threaded metal inserts to enable thread repair
- Kyowa ASE, Measurement specialties M62, Endevco 7264

Protective Covers on Side Cavities

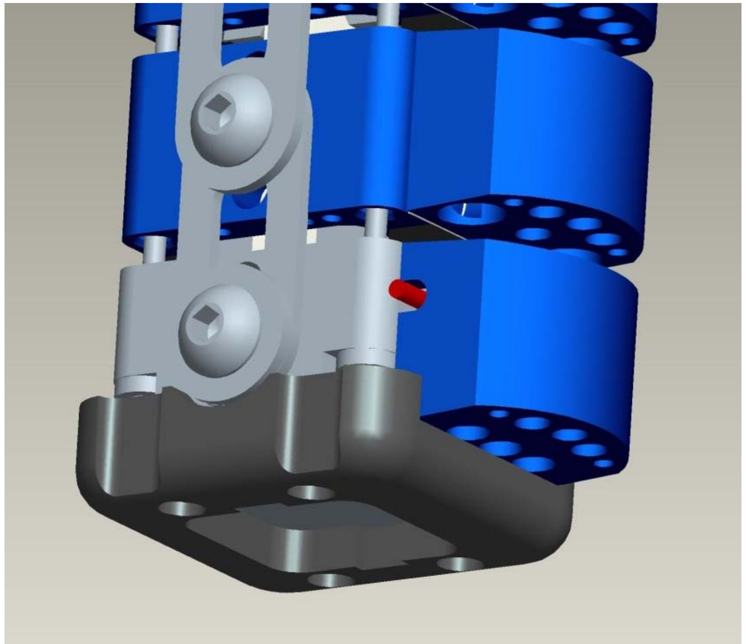


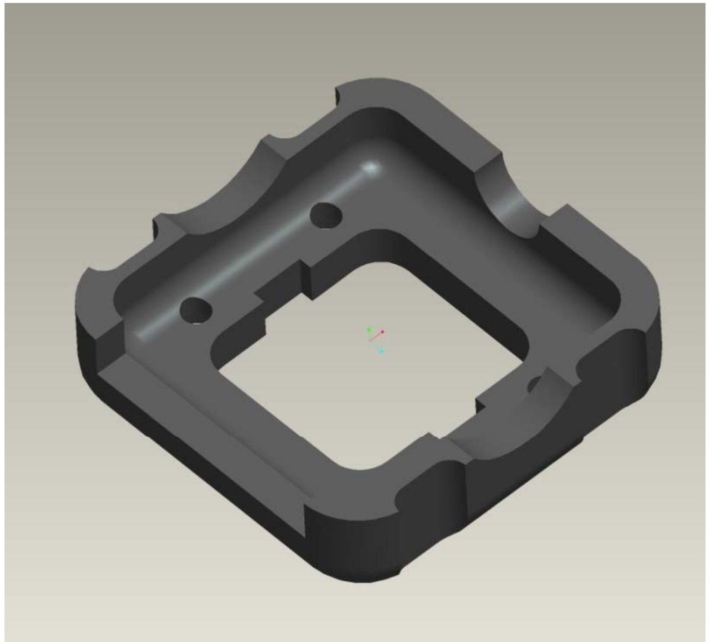
- Side cavity covers are 2mm thick and bent for strength





Protective rubber bumpers to distal and proximal ends

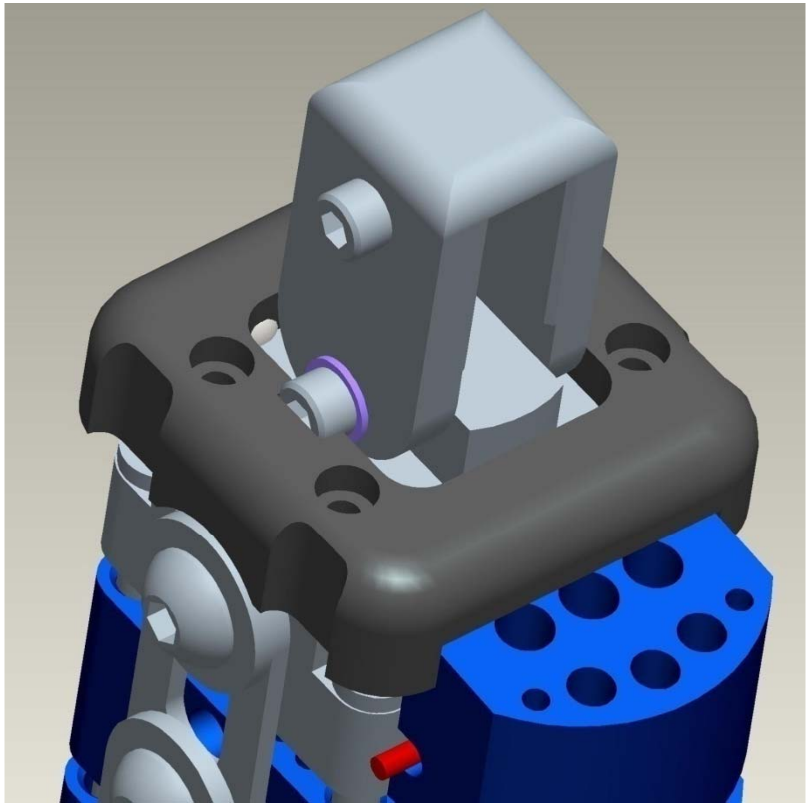




- Rubber bumper mass 0.04kg each
- Mounted with Nylon screw for mass reduction
- Provision of threads for catch ropes
  - Catch ropes and bumper may be used simultaneously
  - But may need special fixture

Top of femur launching Bracket

- Lower pivot is clamped
- Function 1: protection of bracket under secondary impact
- Function 2: angle adjustment to achieve stable suspension on ejection platform
- Bumper on distal femur
  - Cut outs for cables



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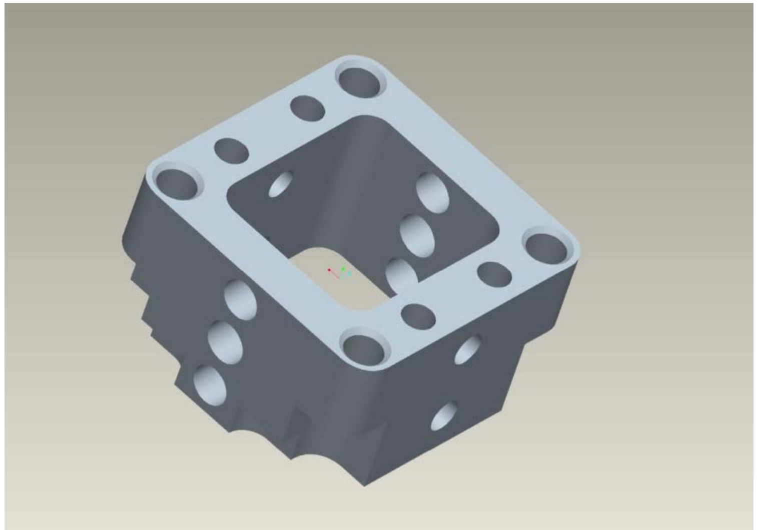
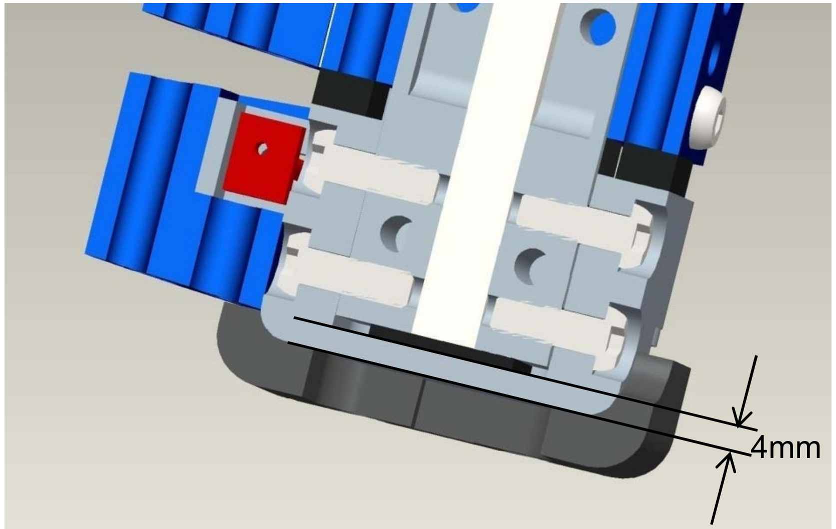
Segment C1A_AL
Bottom tibia segment C3_AL

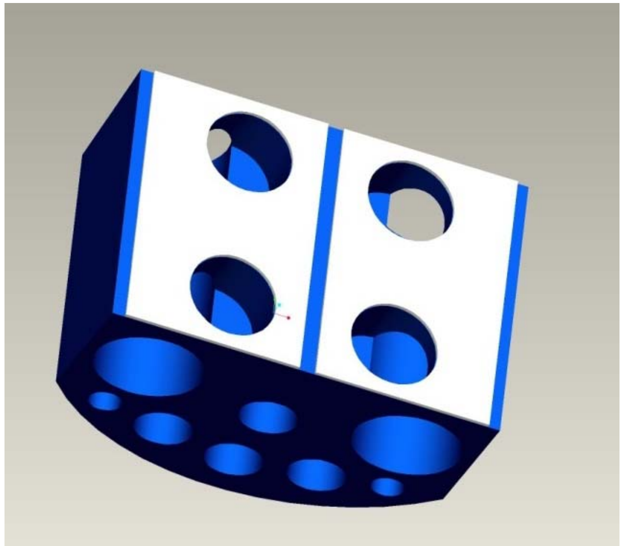


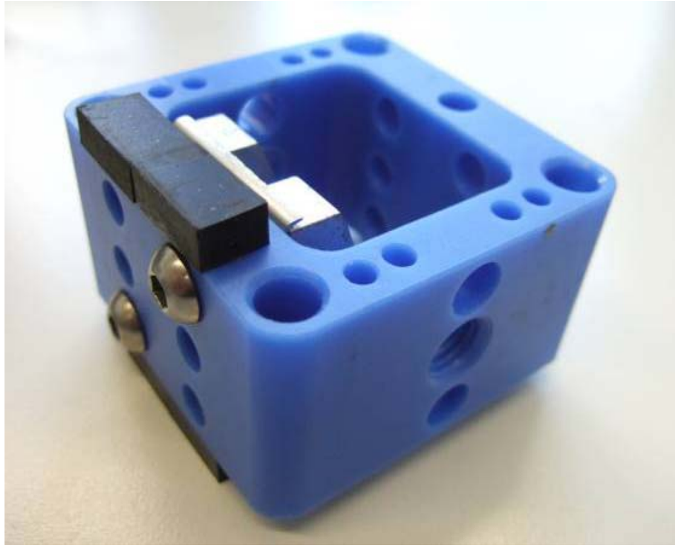


- Increase strength of C1A_AL:
  - Counter bores removed
  - Additional mass +10gr
- Increase strength of bottom tibia segment C3_AL
  - Increase bottom to 4mm thickness
  - Additional mass +18gr
- Shorten the bone by 2mm

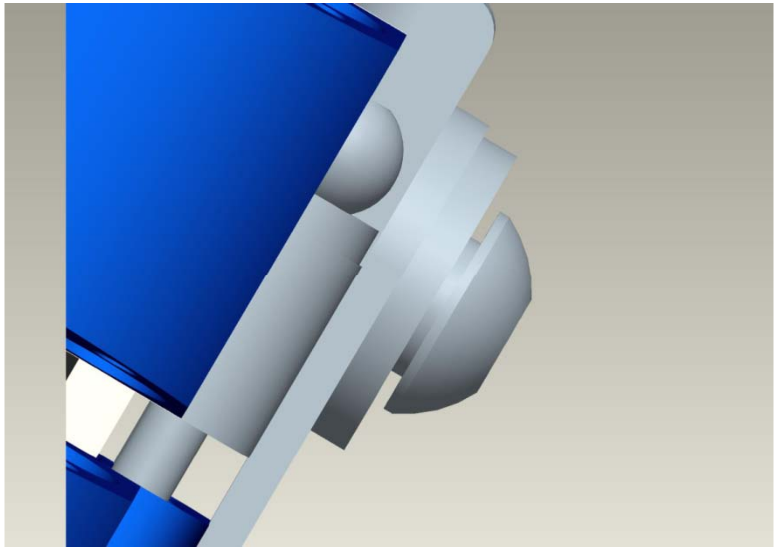
Proposed impact cover designs

- FLEX-PLI-GT mounting maintained with double sided tape
- Button head screws maintained
  - To allow dislocation to protect against overload
  - Hole centers reduced in to avoid thin section at edge
  - Minimum section 1.7mm

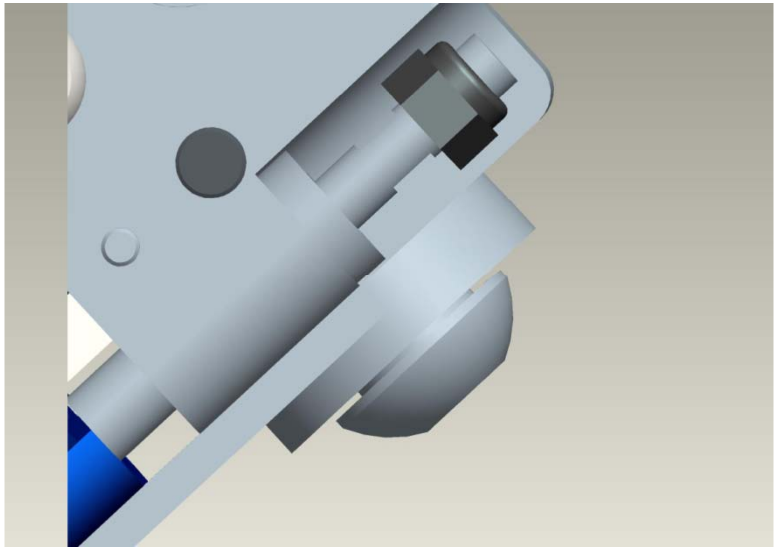




Screw clearance

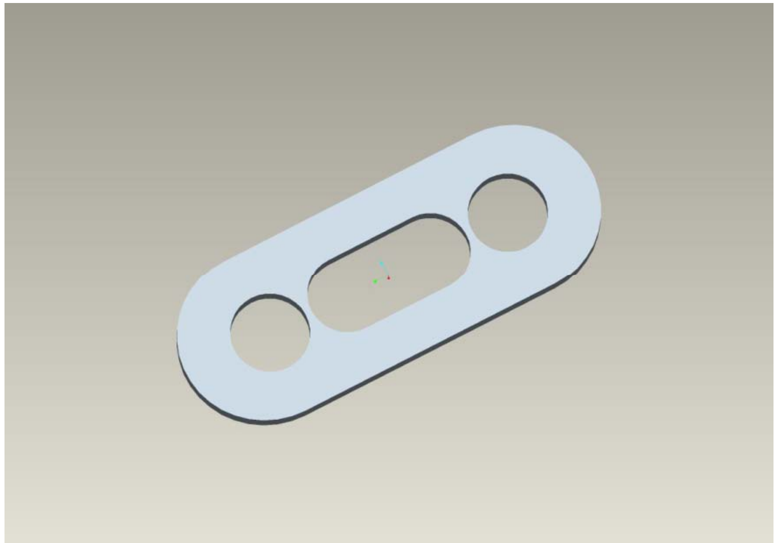


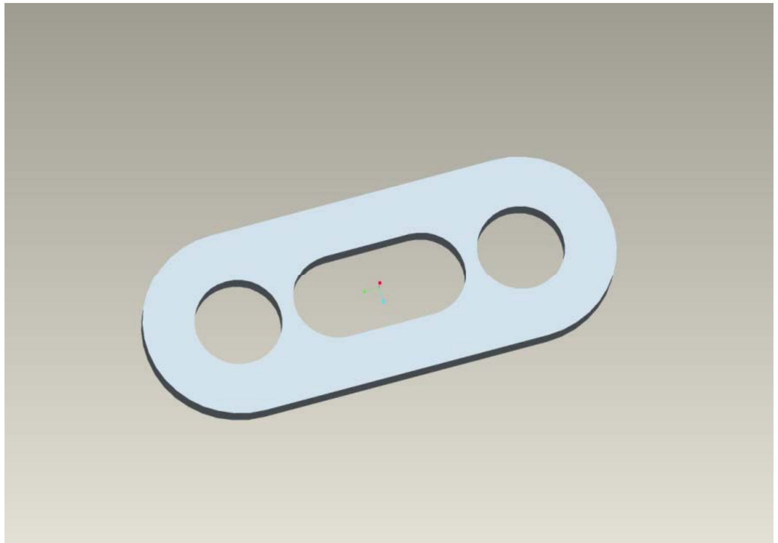
1mm clearance on screw
current design



Propose 0.5 mm?

Segment links

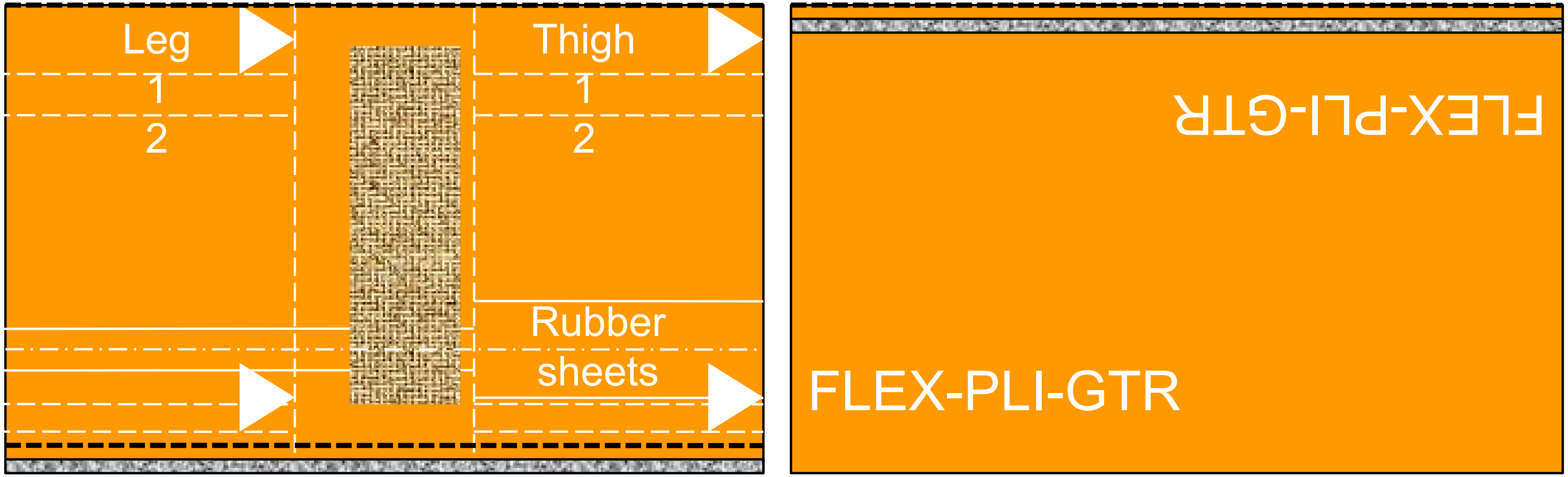




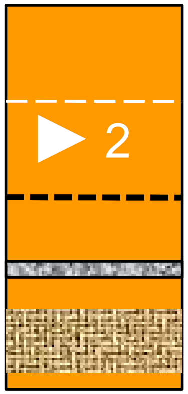
Material between holes 1mm

Material between holes 2mm

Rubber and Neoprene sheets



Outer Neoprene Sheet with alignment marks to aid assembly



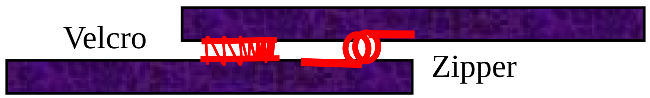
Neoprene Type, Color and Thickness

Alignment marks and text

Zipper

Velcro hooks and loops

Schoeller Keprotec lining inside



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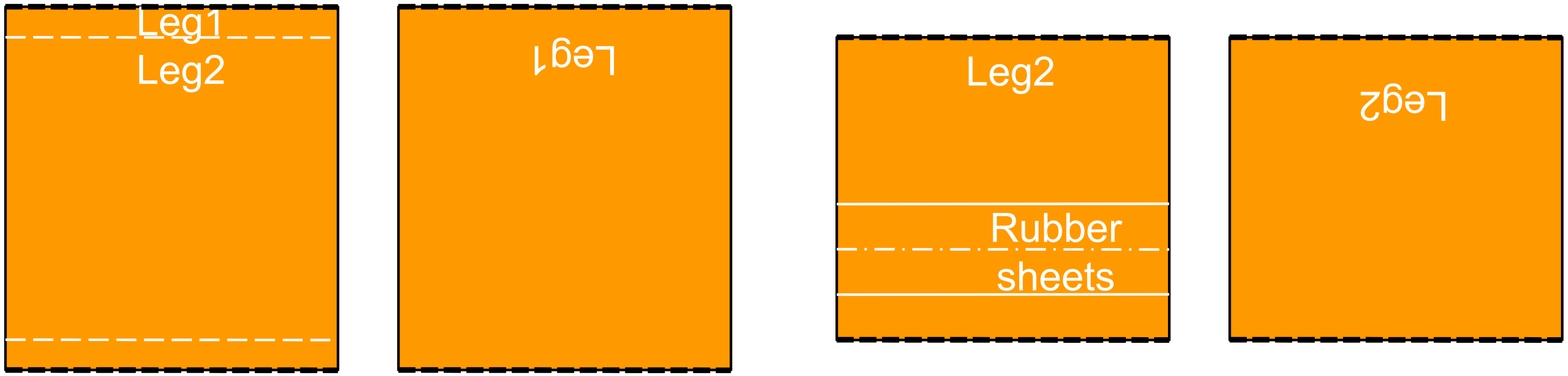
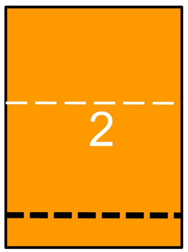
Rubber and Neoprene sheets



Inner Neoprene Sheets (only Leg shown, Thigh similar)

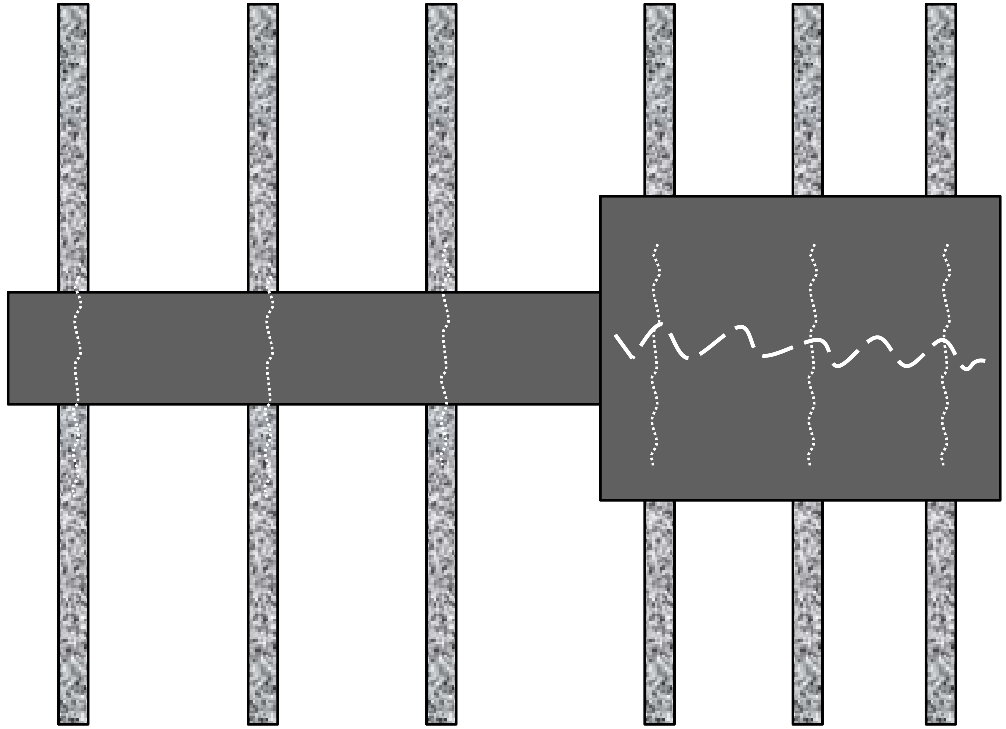


Neoprene Type, Color and Thickness

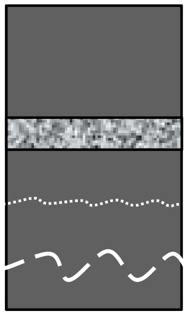
Alignment marks and text

Zipper

Rubber and Neoprene sheets



Rubber Sheets



Rubber sheet Type, Hardness and Thickness
Velcro hooks and loops tape
Velcro to rubber sheet adhesive
Adhesive between rubber sheets

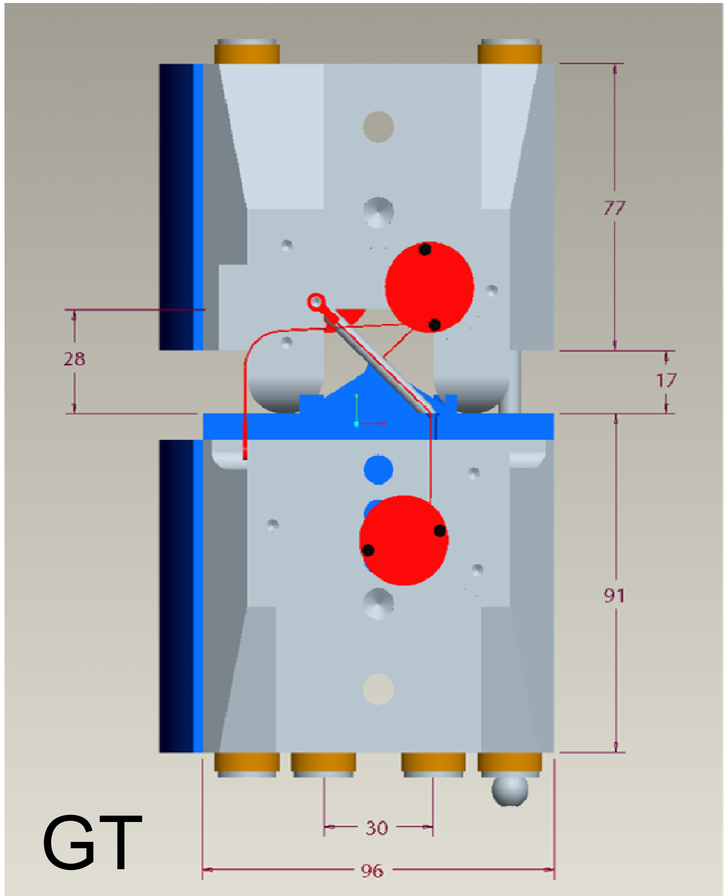
Glass Fiber Bone Specifications

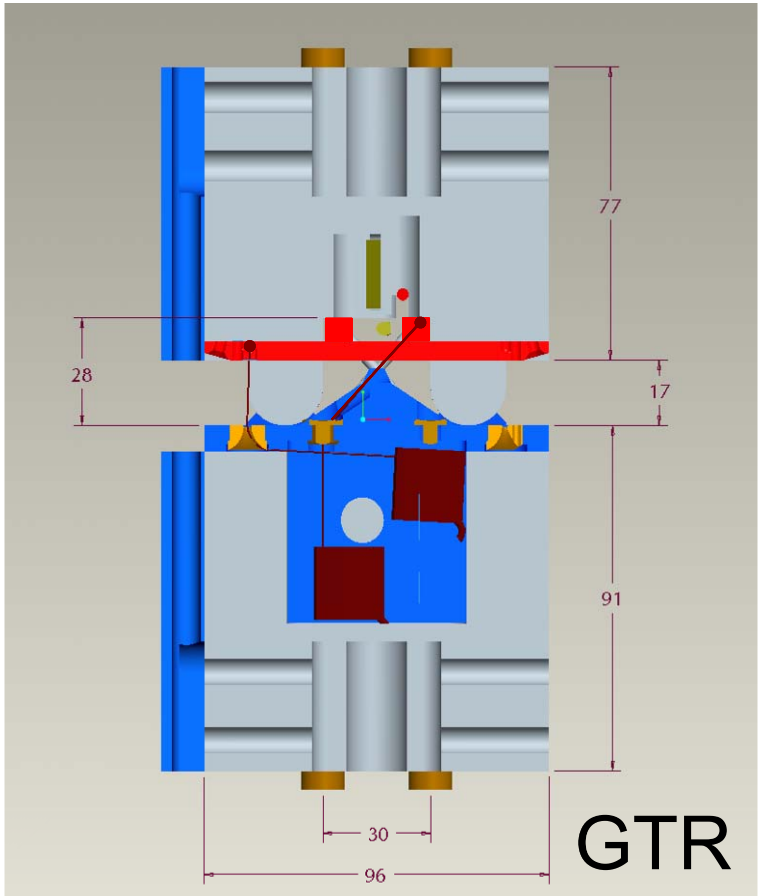
- Glass Fiber Reinforced Plastic
- Supplier PL Alloy Japan
- Material specs JARI SPEC F45
- Bone painted to retain glass fibers
  - JARI please provide specs

Comparison GT - GTR

- The project aims at keeping the dynamic response of the GTR as close as possible to current GT version
- GTR aimed to maintain GT Mass and Mass distribution
  - FLEX-GT mass breakdown study was performed
- GTR aimed at maintaining GT dynamic response
  - FTSS will perform material characterization tests
  - GTR materials will be as close as possible
  - Bone material and dimensions will remain the same
- Changes in the knee will not affect bending moment
  - Lateral Ligaments and springs and spacing in y- direction (impact) remain the same
  - Cruciate ligaments total force may slightly change, spacing in y-direction and pull direction remain the same
  - Elongation sensors MCL, PCL, ACL, LCL remain in line with ligaments, position projected to mid knee position

Comparison GT - GTR





- GT and GTR cruiciate ligament and spring location remain the same
  - All dimensions and interactive geometry remain the same
- Accommodation connectors and DAS -> larger space in the side -> mass compensated

CAD Mass Estimate GT-GTR-Options

	Femur Assy	Knee Assy	Tibia Assy	sub Total	Suit	Total	[%]	[gram]
GT Assy without wires	2432	4176	2608	9216	3723	**12939**	**±2**	**±259**
GTR Assy without DAS	2432	4126	2626	9184	3723	**12907**	**-0.25**	**-32**
GTR Assy with DTS Das 12 channels	2432	4146	2626	9204	3723	**12927**	**-0.09**	**-12**
GTR Assy with Messring Das 12 channels	2432	4250	2626	9308	3723	**13031**	**0.71**	**92**
GTR Assy with Messring Das, Distal &Prox accls and knee accls	2478	4250	2718	9446	3723	**13169**	**1.78**	**230**
GTR Assy Messring DAS with all accls incl all segment accls	2523	4250	2778	9551	3723	**13274**	**2.59**	**335**

Target tolerance ±2% total mass, ±259gram
There is a small reduction adjustment included for CAD screw for actual mass

No wire mass is included in these figures

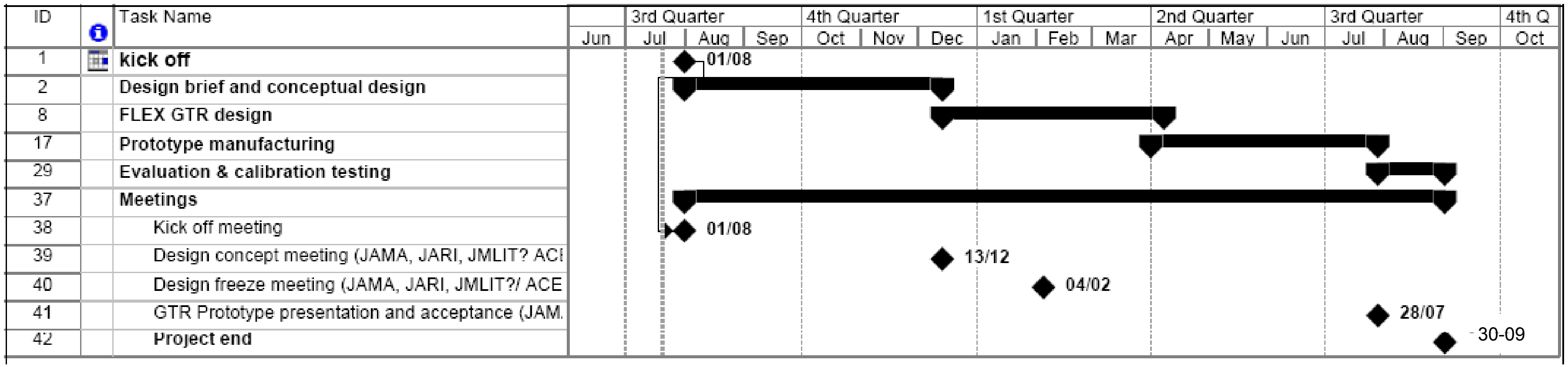
Suit mass aim to maintain existing mass of 3723g

Further Activities

- Completion Calibration design
- Development of User Manual, including procedures, training..
- Material sourcing and tests
  - Characterize dynamic response of current and new source materials
    - Neoprene, Synthetic rubber 30 Shore A, 45 Shore A

Schedule, future activities, etc.

- 6th FLEX-PLI-TEG meeting, March 31st Germany
- Manufacturing Drawing release 15th April
- Prototype Manufacturing 15th April – 28th July
- Prototype assembly, Testing and Calibration 29th July- September
- GTR prototype Delivery End September 2008



Design frozen