Imperial College
London

MORPHING SKINS: DEVELOPMENT OF NEW HYBRID MATERIALS

WHAT IS MORPHING?

- DICTIONARY DEFINITION: “morph-ing (n) : the smooth transition from one shape into another”
- WING APPLICATION: CHANGING SHAPE WITHOUT CONVENTIONAL CONTROL SURFACES AND/OR CONVENTIONAL ACTUATORS

WHY MORPH?

- FEWER COMPONENTS – INCREASE RELIABILITY
- FEWER EXPOSED EDGES – INCREASE STEALTH
- IMPROVED AERODYNAMICS – INCREASE RANGE

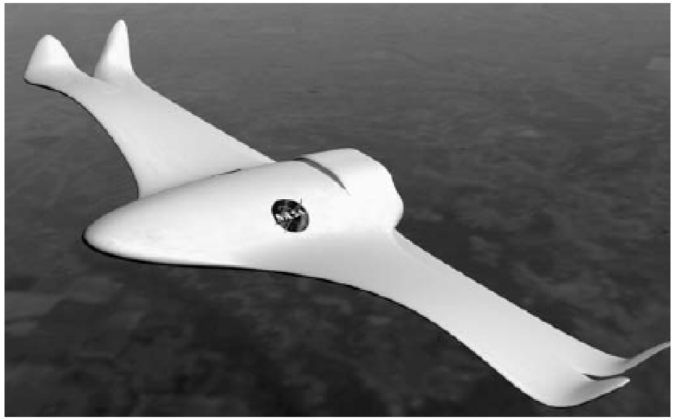


Figure 1: NASA’s morphing aircraft [1]

WHAT ARE THE REQUIREMENTS FOR A MORPHING SYSTEM?

- CAPABILITY TO OPERATE OVER WIDE RANGE OF CONDITIONS e.g. FLIGHT SPEED, AIR TEMP, WIND
- APPROPRIATE RESPONSE TIME: FLIGHT CONTROL 60-75degs/s, CAMBER CHANGE: ~5degs/s
- HIGH RELIABILITY WITH REPETITIVE ACTUATIONS
- LOW POWER CONSUMPTION DURING ACTUATION
- SKIN: HIGH RECOVERABLE STRAIN: 25% (COMPARE WITH 1% FOR NORMAL CARBON COMPOSITES)

MORPHING MATERIALS FOR WING APPLICATIONS: SOME CONCEPTS

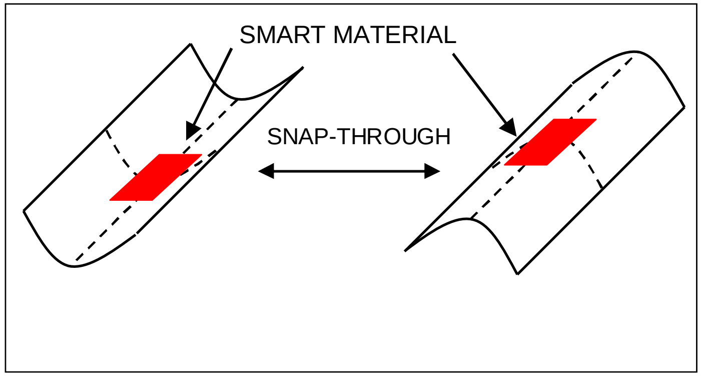


Figure 1: Multistable structures.
(Skin panels formed using
unsymmetrical laminate stack]

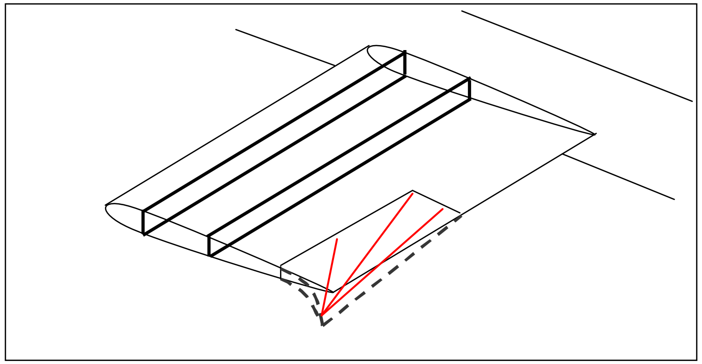


Figure 2: Shape memory wire.
(Flexible plate with
SMA (NiTi) elements embedded in the surface)

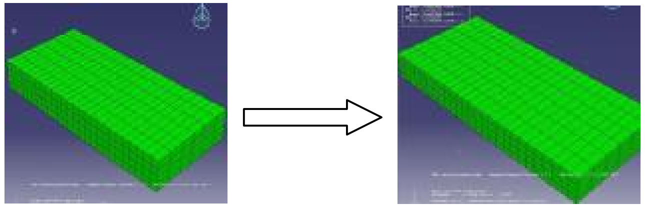
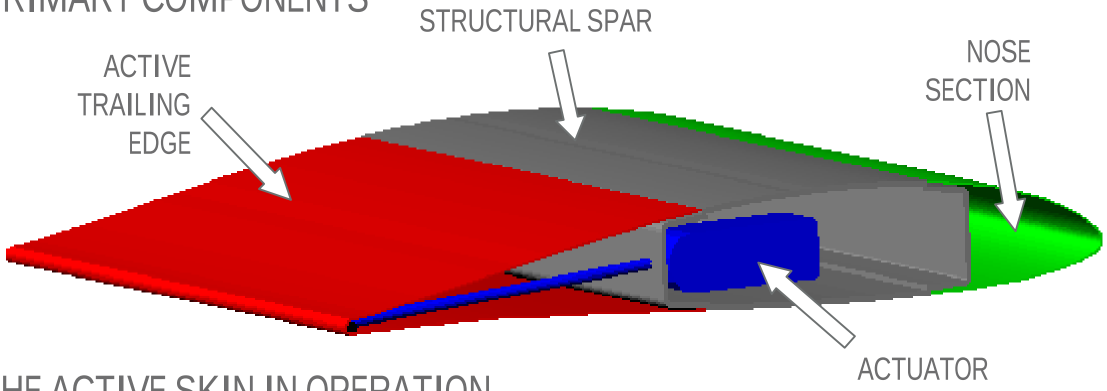


Figure 3: ElectoActive Elastomer (DEA)

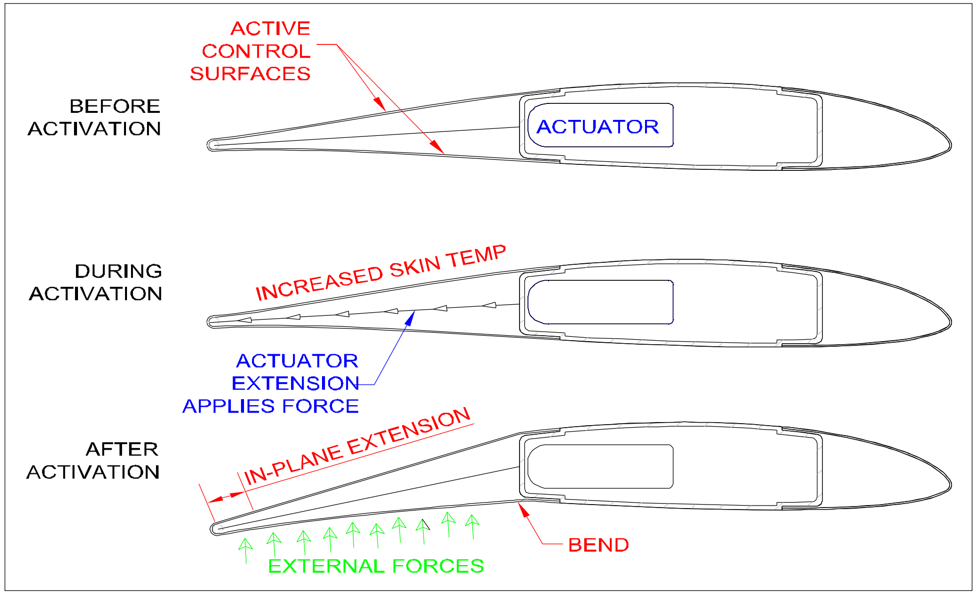
Imperial College
London

SHAPE MEMORY POLYMER CONCEPT: STRUCTURAL LAYOUT AND OPERATION

PRIMARY COMPONENTS

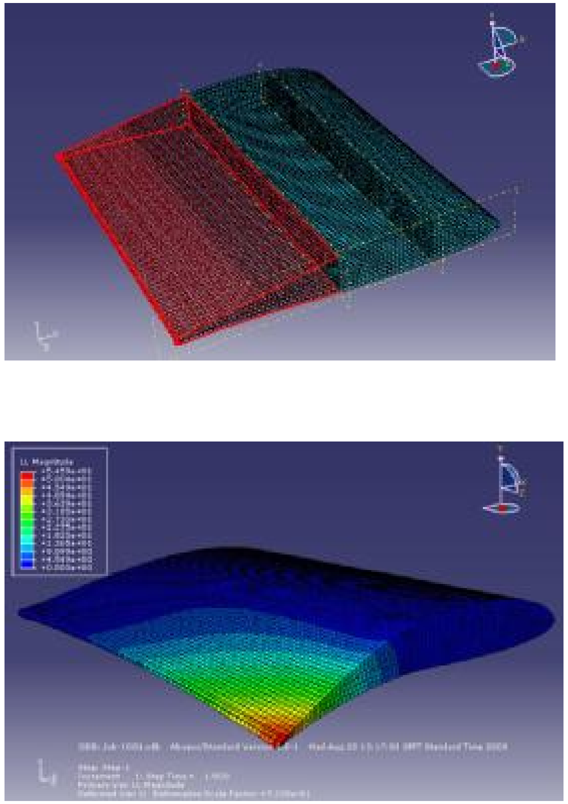


THE ACTIVE SKIN IN OPERATION



FE MODEL AND DEFLECTED SHAPE

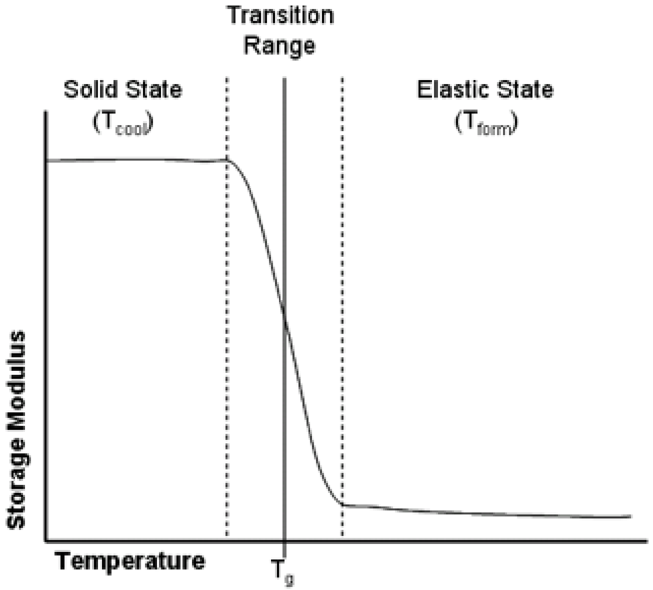
(ABAQUS CAE)



THE MORPHING SKIN: CARBON+SHAPE MEMORY POLYMER MATRIX

FIBRE

- Standard Modulus Carbon
- Fabric Type, Fibre Length and Orientation – IN PROGRESS!



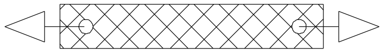
MATRIX

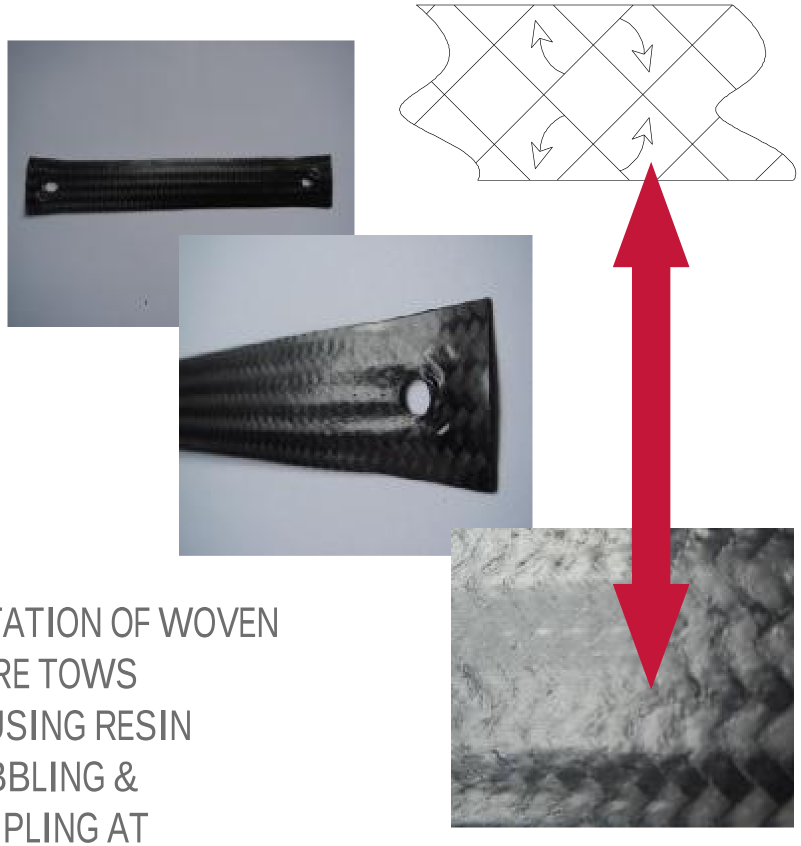
Veriflex E2 - CRG Industries
- Commercially available
- Cost: $45/kg – 5x standard epoxy, represents a 40% increase in material costs for laminated plate
- Ability to change from a rigid polymer to rubbery elastomer
- Over 100% elongation in elastic state
- Transition temperature of approximately 103 °C
- Alternatives: Diaplex® 5510 Mitsubishi Heavy Industries, Tembo ® CTD Inc.

TENSILE TESTS AT T>Tg : VERIFLEXE2 + CARBON CLOTH

SIMPLE COUPON TEST
TO SIMULATE TENSION
IN UPPER ACTIVE
CONTROL SURFACE
DURING FLAP-DOWN

RIDGING AND
NECKING AT
BEARING POINT
AT HIGH STRAIN
(8%)





ROTATION OF WOVEN
FIBRE TOWS
CAUSING RESIN
BUBBLING &
DIMPLING AT
INTERSECTIONS

EXPERIMENTAL RESULTS:

Actuation force required

CASE (A) 2 x CC (2x2 Twill) @+/-45 + VeriflexE2: 82N

CASE (B) pure VeriflexE2: 8N

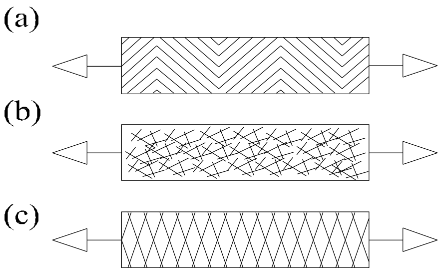
TARGET

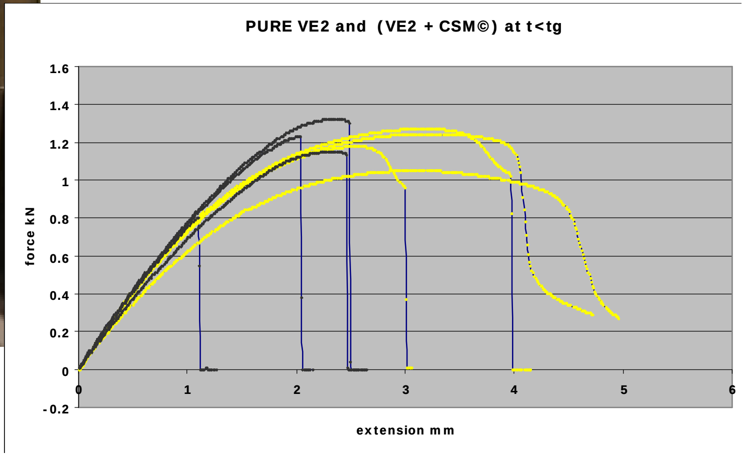
To reduce the actuation force in Case (A) so that it is closer to that of (B),

without adversely affecting structural performance

OTHER FIBRE CONFIGURATIONS

Laminates in consideration:
(a) continuous fibres aligned in zigzag
(b) short fibres in random mat
(c) woven cloth with shallow angles (+/-75º)

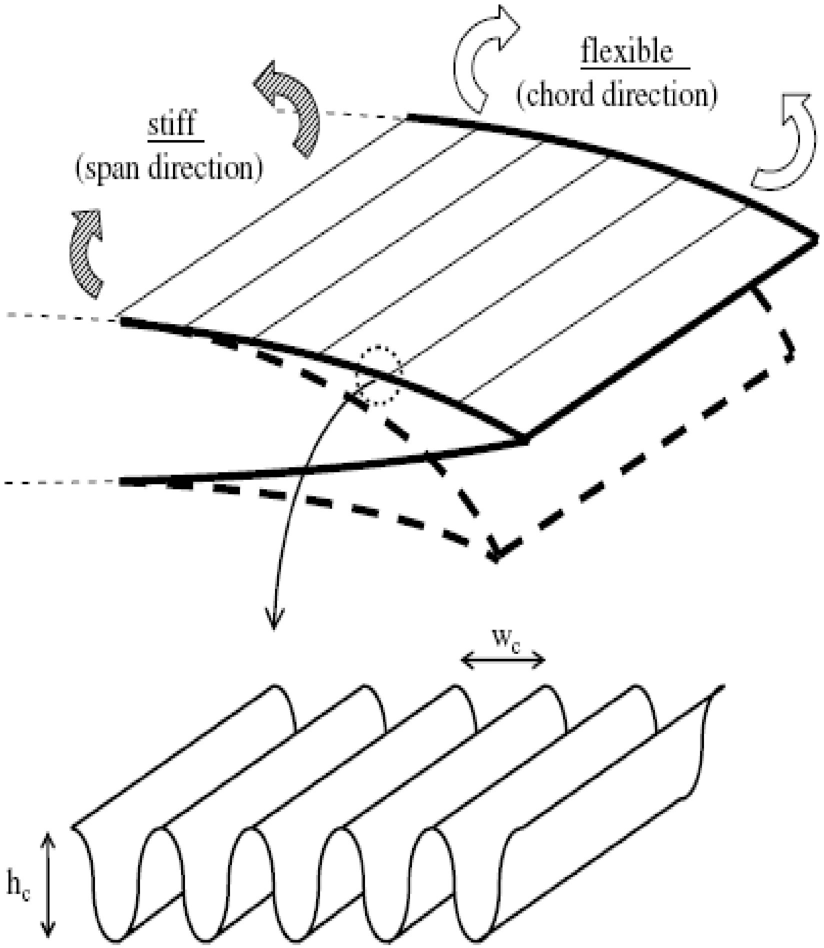




ALTERNATIVE SKIN CONCEPT – CORRUGATED PANEL

- Yokozeki *et al* (2005) proposed idea of using corrugated composites as a possible candidate for flexible wing structures.

- This type of structure provides stiffness in spanwise direction and flexibility in chordwise direction.



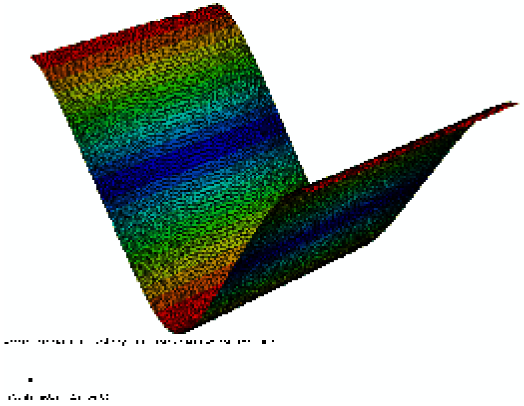
OPTIMISATION OF GEOMETRY & LAMINATE FOR CORRUGATED PLATE

Yokozeki *et al.* (2005) built a corrugated panel from T300-1K/RS11 carbon fibre plain woven fabric prepreg system.

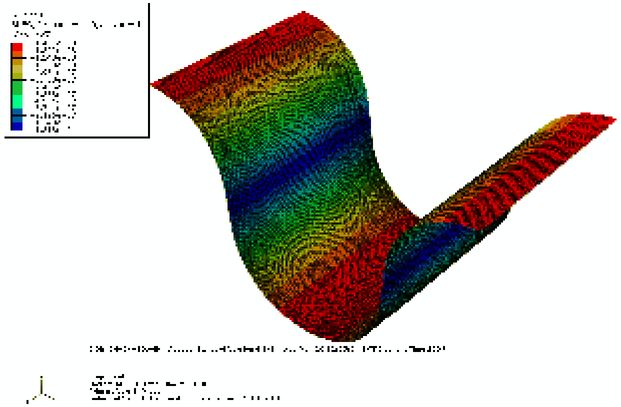
The epoxy prepreg solution provides too much stiffness
Hence we are investigating whether we can improve flexibility through changes in:

A) matrix
B) the cross-section profile and its geometry

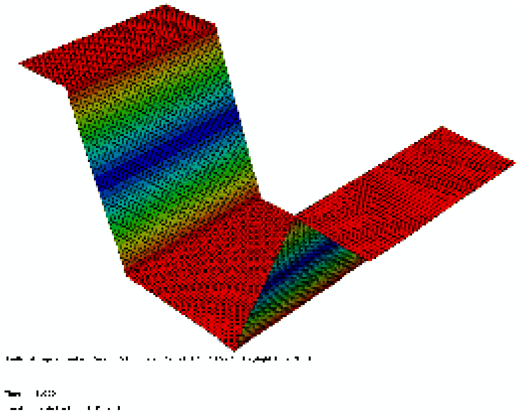
SINUSOIDAL



U-SHAPE



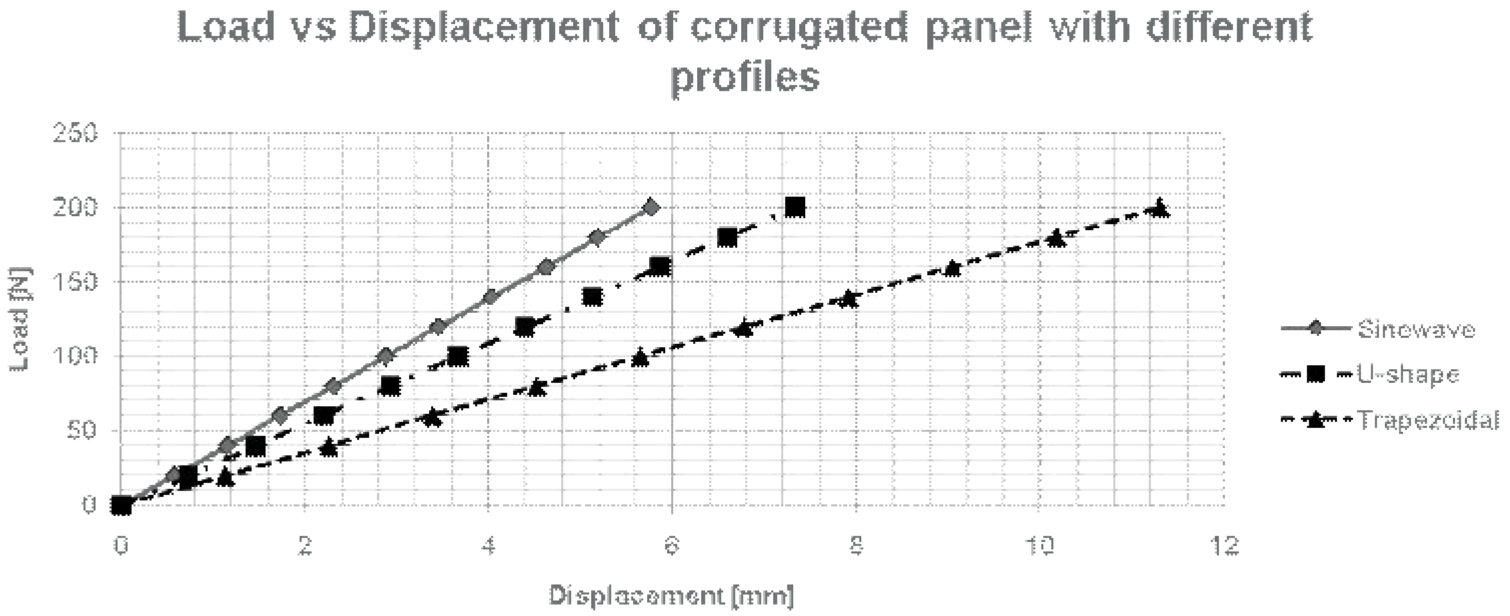
TRAPEZOIDAL



COMPARISON OF CORRUGATION GEOMETRY

The maximum Mises stress for each design is similar. However, the distribution of stress is different.

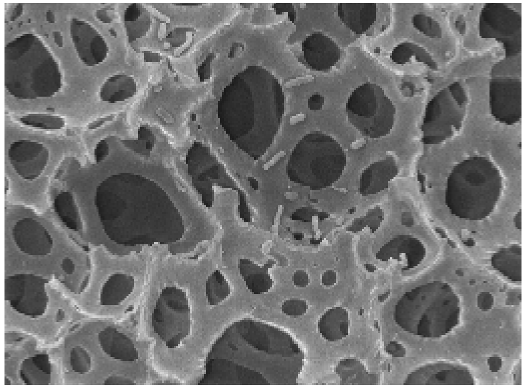
It has been found that the stiffness of sinusoidal design is maximum and the minimum is trapezoidal design (see the graph below).



MORPHING FOAM: CONSTRUCTION USING EMULSION TEMPLATING

Existing applications of emulsion templates

Flow-through micro bioreactors

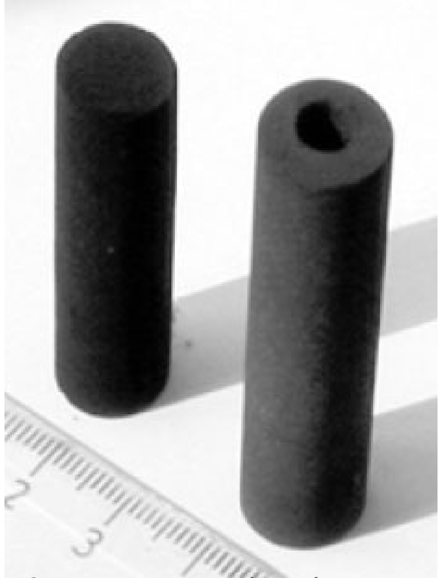


Ref.: G. Akay et al. *Biotech. Bioeng.* **90** (2005) 180

Scaffolds for TE

Ref.: A. Barbetta et al. *AFM* **15** (2005) 118

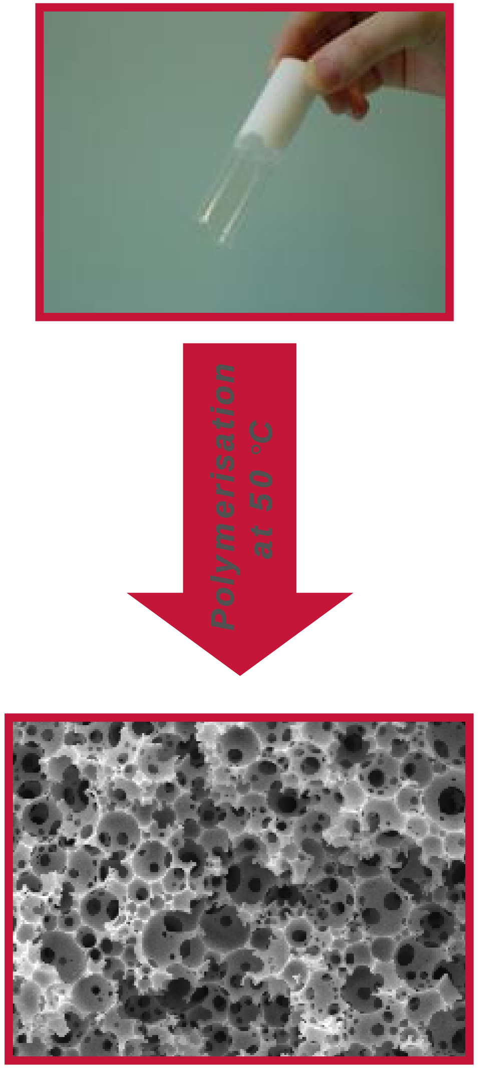
Adsorbents & Catalysis



Ref.: D. Wang et al. Polym. Intern. **54** (2005) 297

Introduction of new property: Morphing

THE EMULSION TEMPLATE METHOD OF CORE MANUFACTURE



High Internal Phase Emulsion (HIPE)

- Continuous phase: max. 26% of total volume of emulsion
  - monomers, surfactant and initiator
- Internal phase: min. 74% of total volume of emulsion
- HIPE properties:
  - Either oil (o) or water (w) phase for o/w and w/o emulsions
  - Deformed droplets
  - Highly viscous

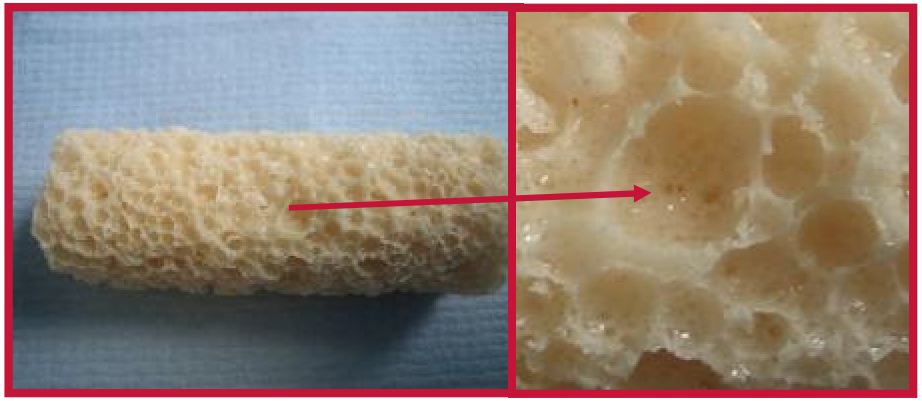
Polymerised HIPE (polyHIPE)

- Highly porous and interconnected polymer foam
- Low foam density
- Porosities of up to 95%

Shiga, T., *Adv. Polymer Sci.* 134, pp. 131-163 (1997).

THERMO-ACTIVE VERIFLEX-E2 FOAM

First Veriflex E2 based polyHIPE



After drying at 50^{o}C under vacuum

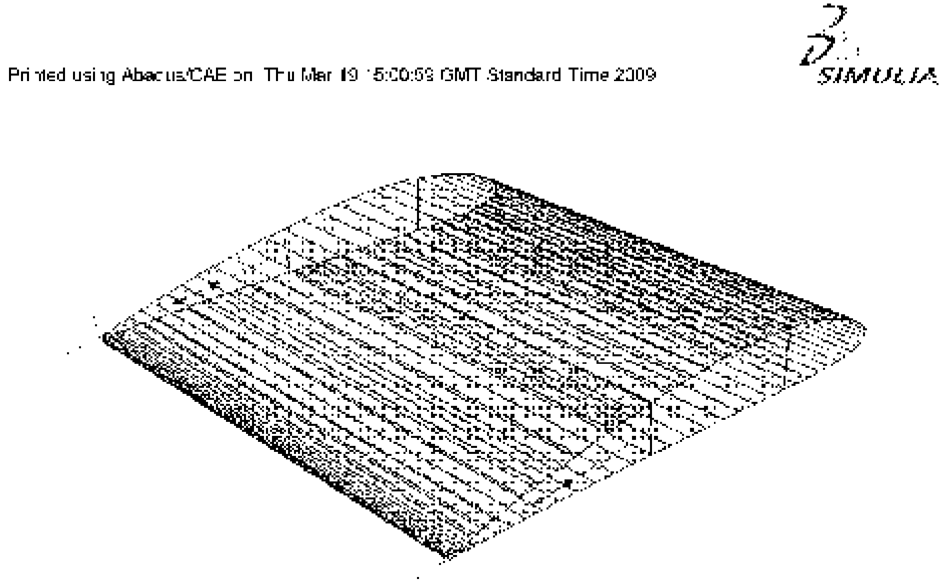
- Interconnected polymer foam
- Pores > 2 mm
- Pore throats of about 0.5 mm
- very brittle

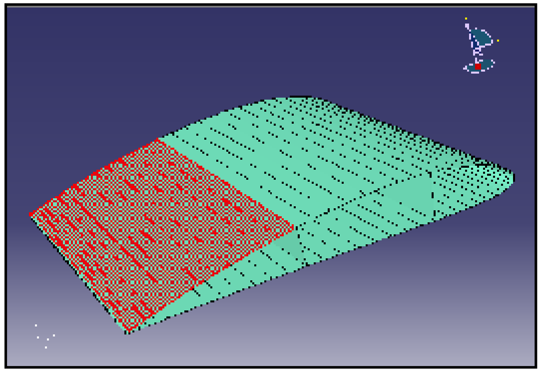
BUT difficulties regarding purification and drying due to:

- low T_g (about 50^{o}C)
- poor mechanical properties (very brittle)

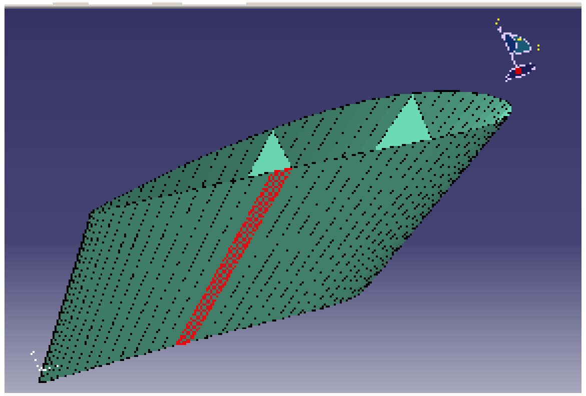
ACTUATION – PRELMINARY WORKINGS

Development of FE model to predict required actuation force
Plots showing actuators modelled as connector beams, and region of activated surface panel

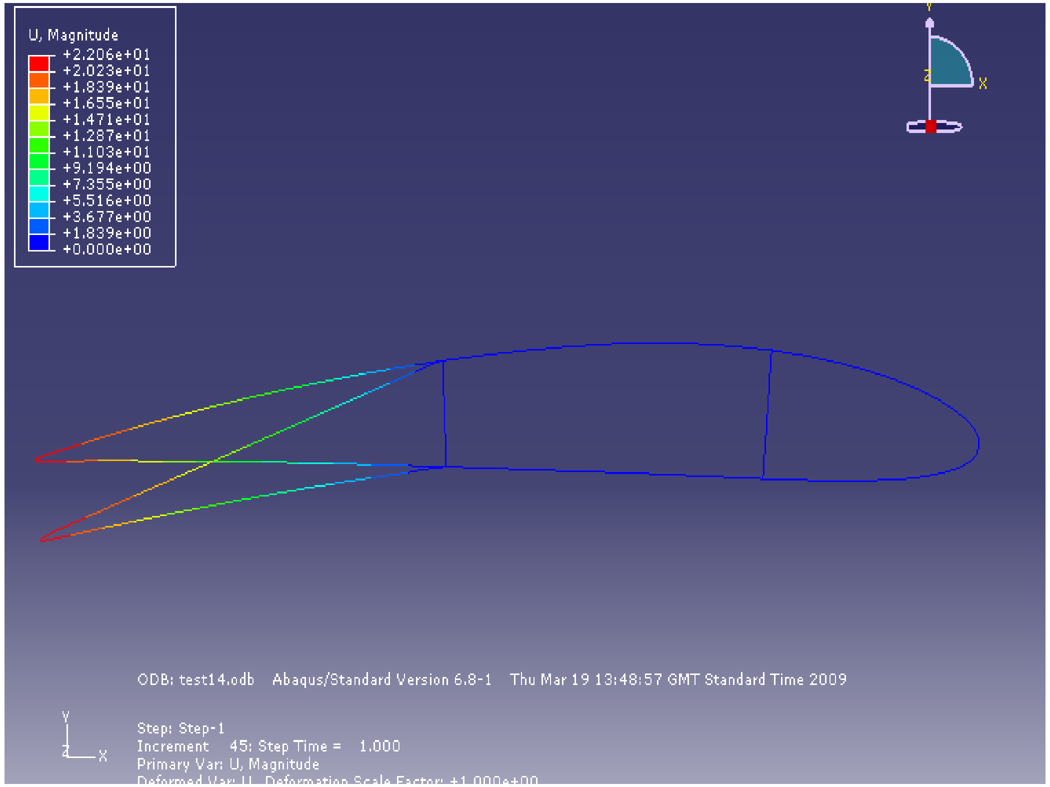




ADDITIONAL CONTROL SURFACE REGION



Model showing region of additional activation at fwd end of lower control surface, and new deflected shape (results as per ref 11. in table above



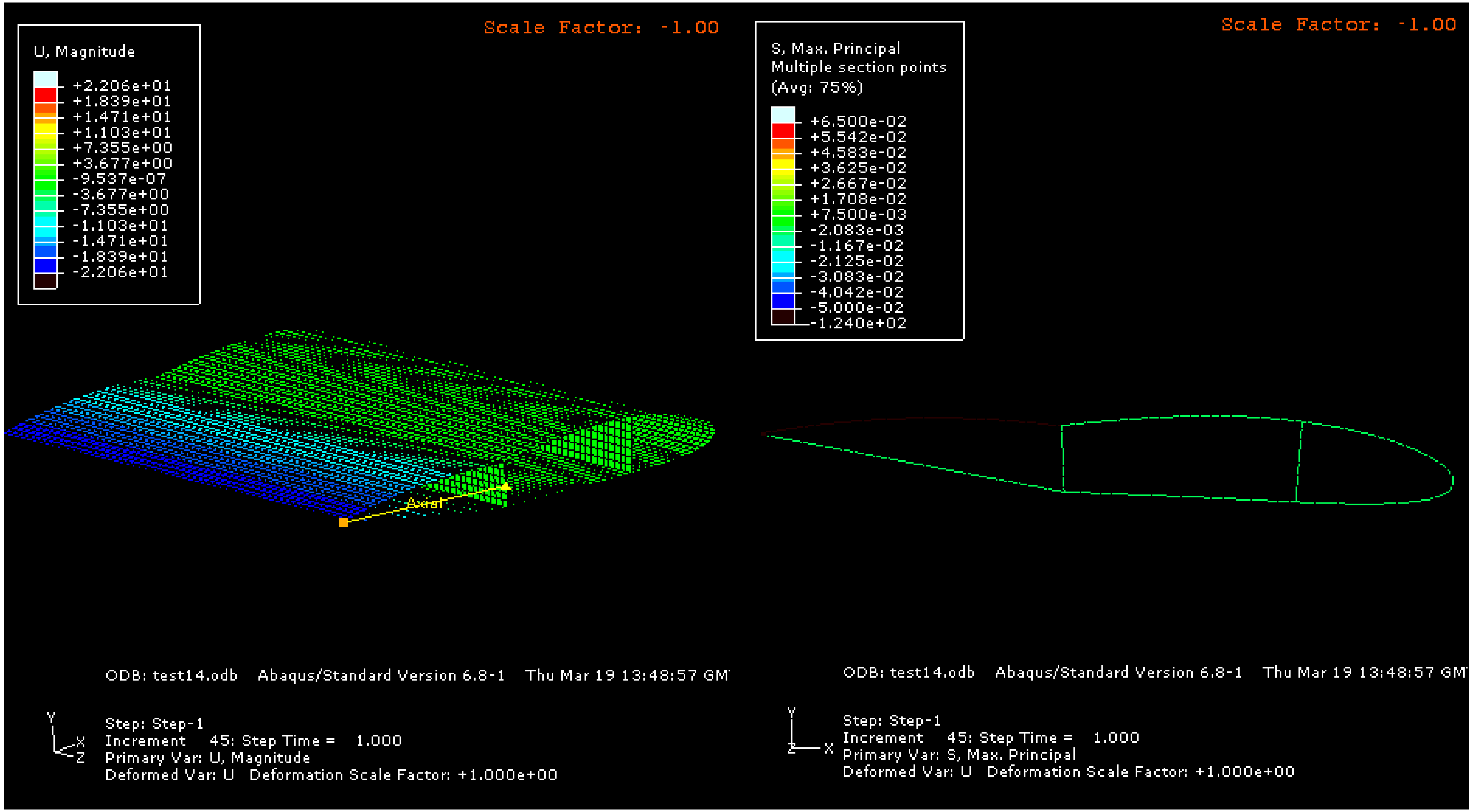
```
ODB: test14.odb    Abaqus/Standard Version 6.8-1    Thu Mar 19 13:48:57 GMT Standard Time 2009

Step: Step-1
Increment    45: Step Time =    1.000
Primary Var: U, Magnitude
Deformed Var: U  Deformation Scale Factor: +1.000e+00
```

Adding this region of activated panel can increase the trailing edge deflection by a factor of 5, for a given applied activation force

ACTUATION FORCE PREDICTION – PRELIMINARY STUDIES

CONCEPT ANIMATION (ABAQUS CAE)



ODB: test14.odb   Abaqus/Standard Version 6.8-1   Thu Mar 19 13:48:57 GM

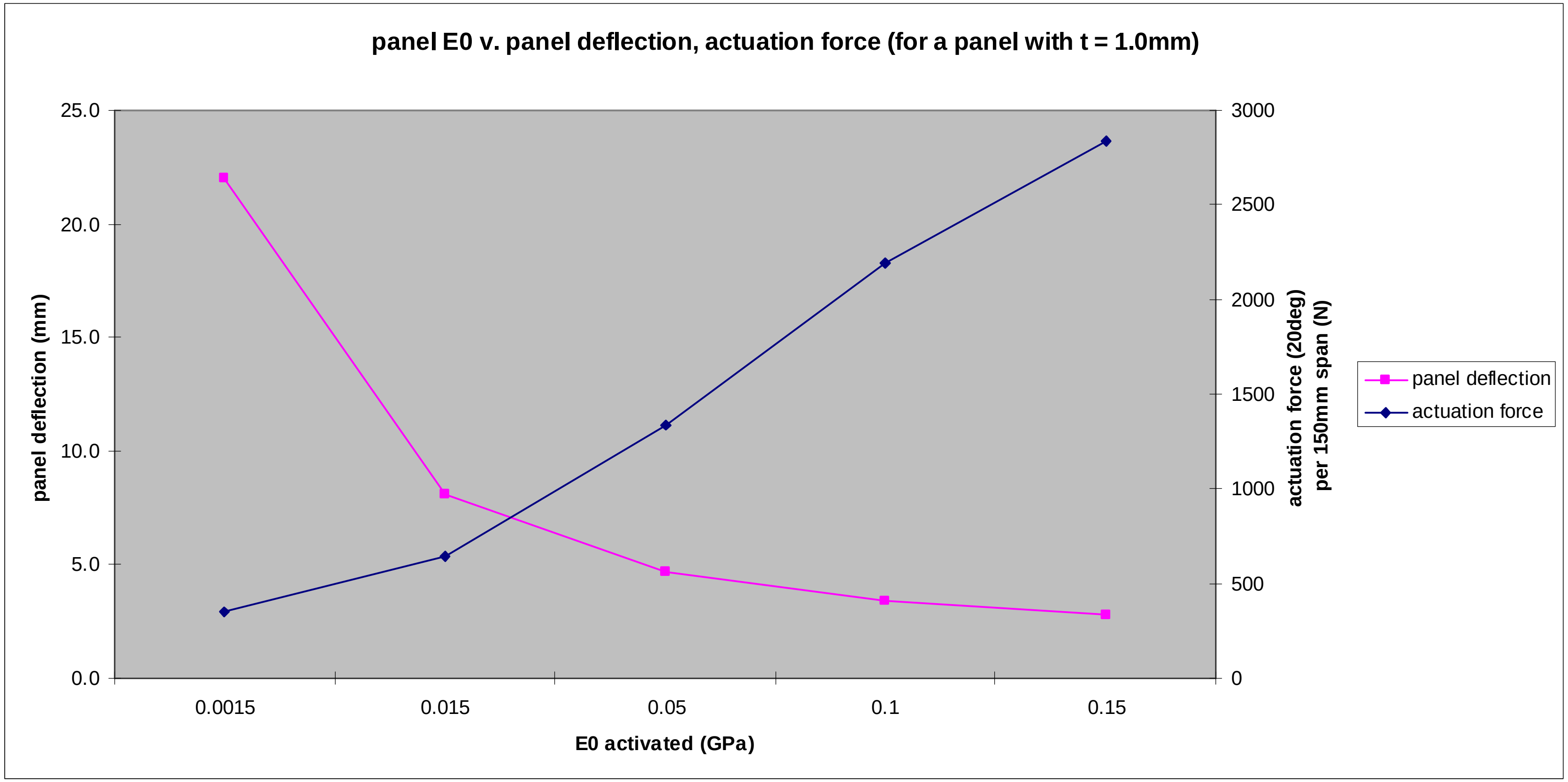
Step: Step-1
Increment   45: Step Time =   1.000
Primary Var: U, Magnitude
Deformed Var: U   Deformation Scale Factor: +1.000e+00

ODB: test14.odb   Abaqus/Standard Version 6.8-1   Thu Mar 19 13:48:57 GM

Step: Step-1
Increment   45: Step Time =   1.000
Primary Var: S, Max. Principal
Deformed Var: U   Deformation Scale Factor: +1.000e+00

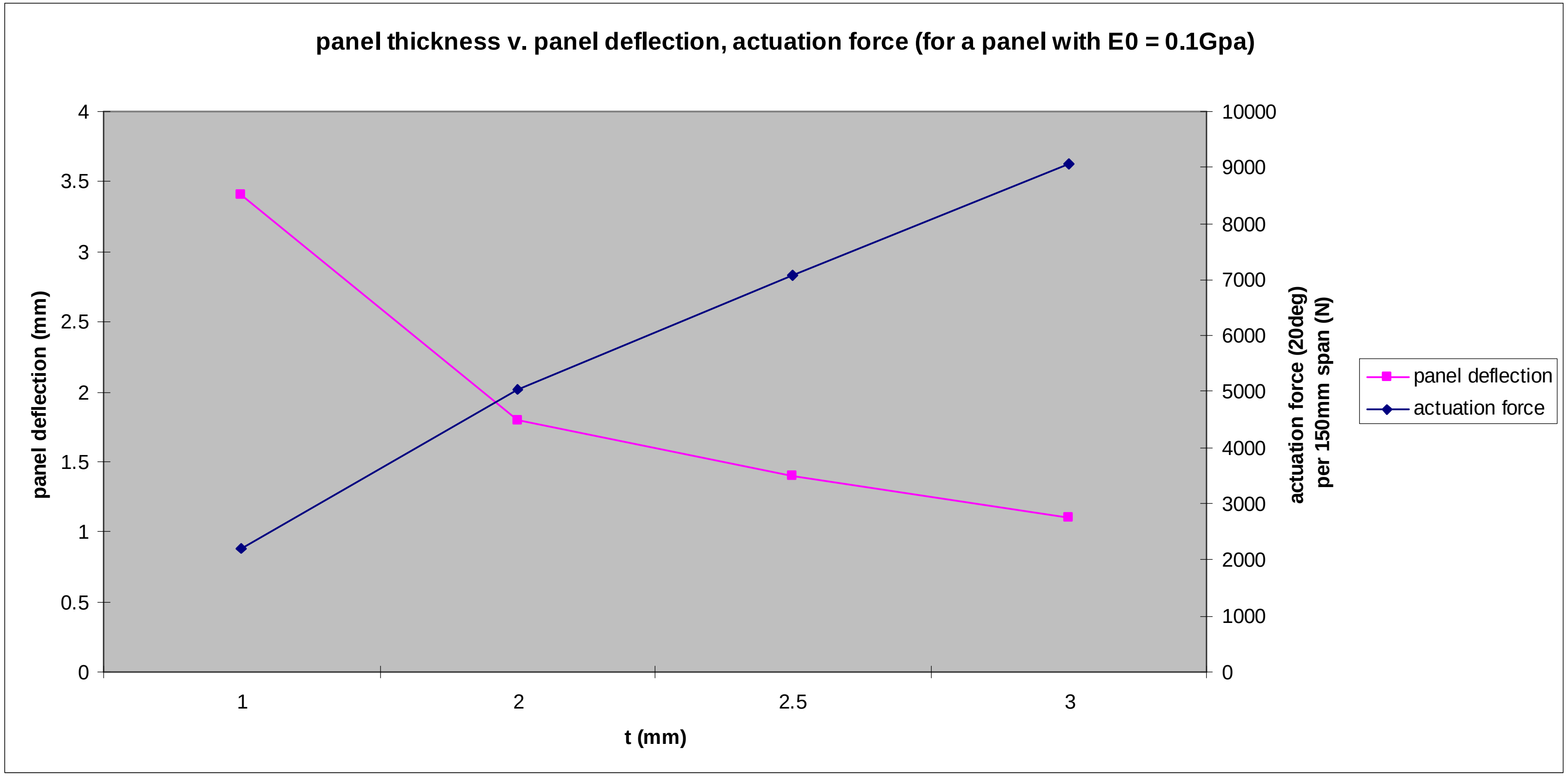
ACTUATION FORCE PREDICTION – PRELIMINARY STUDIES

Relationship between activated panel stiffness, panel deflection under aero loads and required actuation force

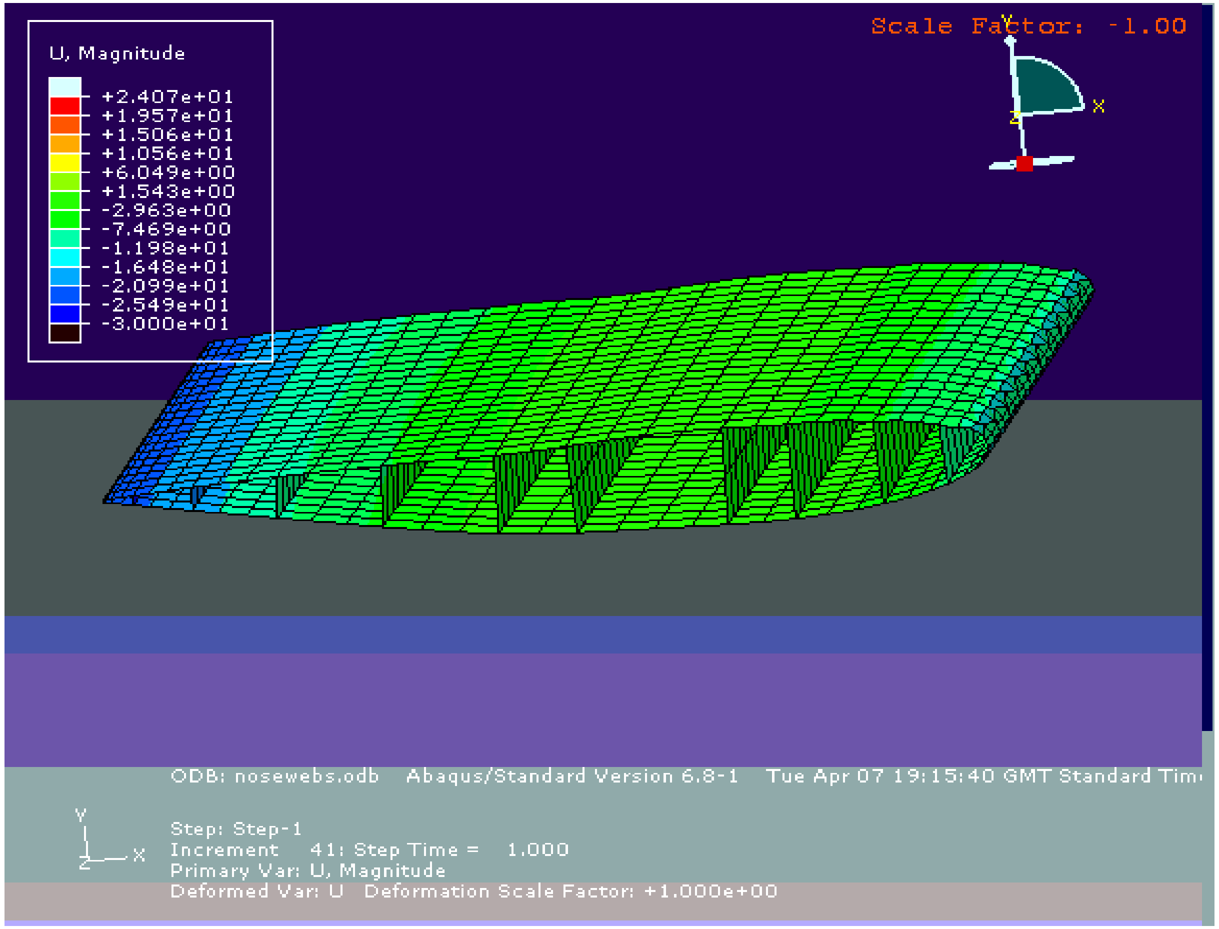


ACTUATION FORCE PREDICTION – PRELIMINARY STUDIES

Relationship between panel thickness, panel deflection under aero loads and required actuation force



ADDED WEBS: ANIMATION OF CAMBER CHANGE (ABAQUS CAE)



```
ODB: nosewebs.odb    Abaqus/Standard Version 6.8-1    Tue Apr 07 19:15:40 GMT Standard Tim

Step: Step-1
Increment     41: Step Time =    1.000
Primary Var: U, Magnitude
Deformed Var: U   Deformation Scale Factor: +1.000e+00
```

CONCLUSIONS FROM WORK COMPLETED...AND UPCOMING WORK

- FIBRE REINFORCED SHAPE MEMORY POLYMERS OFFER INTERESTING POSSIBILITIES FOR ELIMINATING CONVENTIONAL HINGES AND EXPOSED EDGES ON WINGS, AND MIGHT BE APPLICABLE TO ENTIRE CONTROL SURFACES.

- FOR USE ON ENTIRE CONTROL SURFACES WE MUST OPTIMISE PANEL SIZE, SKIN STIFFNESS AND ACTUATION FORCE.

- CORRUGATED SKINS MIGHT BE APPLICABLE FOR CONTROL SURFACES TOO

-THE MORE INTERESTING GOAL IS TO CREATE AN INTEGRAL WING SKIN/STRUCTURE THAT SELF ACTUATES, THUS PROVIDING US WITH MORE OF THE ORIGINAL BENEFITS OF MORPHING:

FEWER COMPONENTS – INCREASE RELIABILITY
FEWER EXPOSED EDGES – INCREASE STEALTH
IMPROVED AERODYNAMICS – INCREASE RANGE

-AN ACTIVE FOAM CORE, IN COMBINATION WITH ACTIVE SKINS, MIGHT HELP US MOVE CLOSER