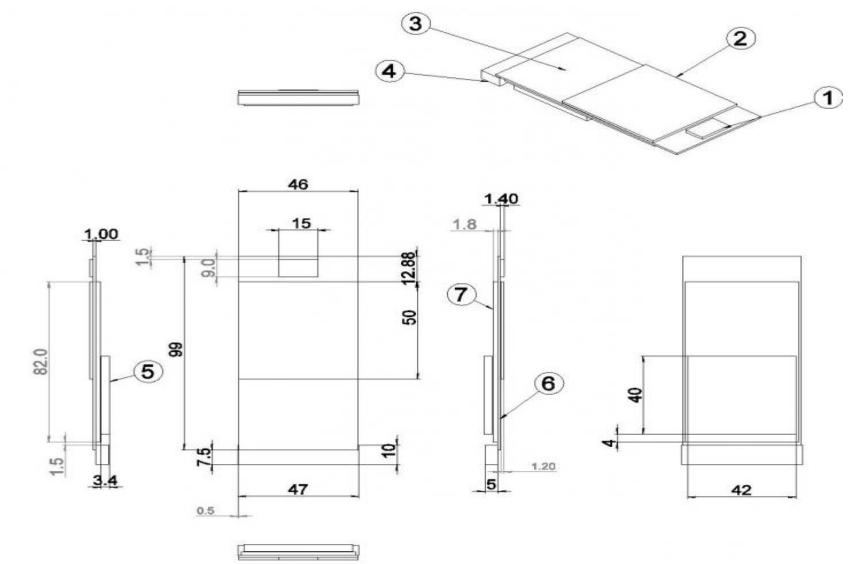
1. MDO of Mobile Phone: Antenna, SAR, HAC and Temperature

Chairman: Jari Jekkonen
Organization: Nokia Corporation
Country: Finland
Jyväskylä / CSC contact: Tero Tuovinen, M.I.T, Univ. Jyvaskyla, Finland
Keywords: Mobile phone, antenna, SAR, HAC, Temperature
Objectives: Maximise transmitted power of two GSM bands and at the same time minimise E-fields around ear piece for hearing aid compatibility. Also minimise SAR values to human head.

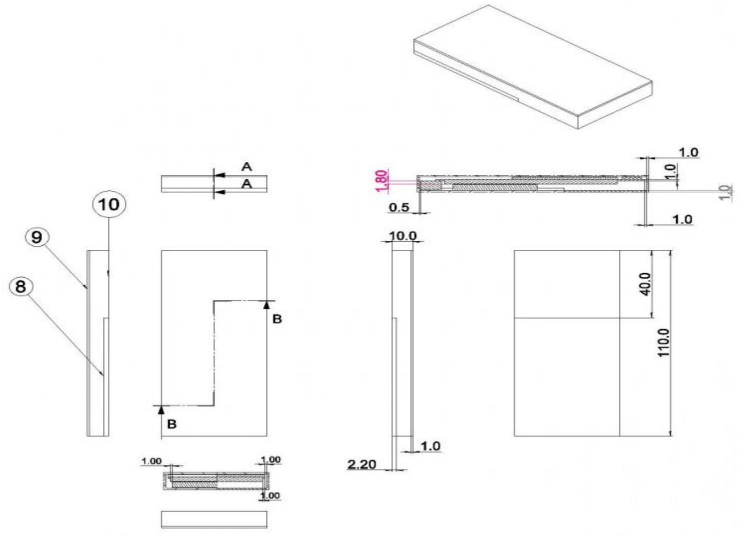
Requirements:
Realistic phone model (template given size and “must” use modules, as display, battery, antenna volume, etc.) with realistic materials.

Computational domain:
Simplified mobile phone
Sources
Boundaries
Parts to be included to the model
1. Ear piece - copper
2. Display module - stainless steel
3. Key pad - ABS/PC plastic
4. Antenna support - ABS/PC
5. Battery - aluminium
6. Printed wired board - copper
7. Shield can - stainless steel
8. Battery cover - ABS/PC
9. A-cover - ABS/PC
10. B-cover - ABS/PC

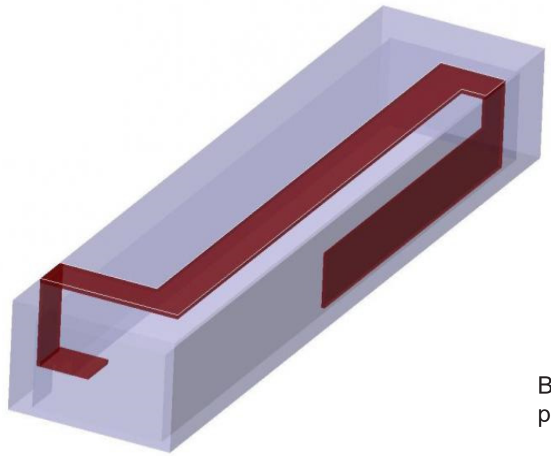
Illustration of the computational domain:



Dimensions for the PWB and other components of the phone



Dimensions for the phone



Example geometry for the antenna radiator

Modeling: physical properties:

* Antenna performance:
  o Antenna matching
  o Total Radiated Power (TRP)
* Hearing Aid Compatibility (HAC - Category M3)
  o E-fields above earpiece from specified height and area
* SAR (human head)
* Surface temperature of keypad

Boundary and/or initial conditions for computations:

* Case 1:
  o Antenna and HAC optimisation
* Case 2:
  o Antenna, HAC, SAR and Thermal optimisation

Optimization:

* Antenna bandwidth in 850/900MHz and 1800/1900MHz bands
* S11 of antenna feed
* Minimise E-field for HAC
* Minimise SAR values
* Minimise temperature on keypad

Design parameters:

* Antenna element dimensions
* Grounding points of mechanical structure
* Dimensions and groundings of thermal conductor

Objective function definition:

* S11−6dB with in each band, 824−960MHz and 1710−1990MHz

According to ANSI C63.19-2006 standard

* E−field2661Vm@f960MHz and E−field841Vm@f960MHz on the earpiece area
* H−field08Am@f960MHz and H−field025Am@f960MHz on the earpiece area

* SAR16Wkg in human head (CTIA standard head model/TBD)

Conformity level

* Temperature of keypad 55C
* Temperature difference on display between any two points 10C

Results:

Antenna performance:
Total radiated power (TRP) in dBm and antenna efficiency in percentage.
Antenna matching:
2d-plot; x-axis for frequencey from 800MHz to 2000MHz, y-axis for S11 from -30 to 0 dB.

Link: www.jyu.fi/aladdin/en/tools/design-optimization-benchmarks

2.1 Patria AST Test Case 1

Chairman: Petri Hepola
Organization: Patria Aerostructures Oy
Country: Finland
Jyväskylä / CSC contact: Tero Tuovinen
Keywords: TBD
Objectives: Optimization of a generic aircraft control surface

Requirements: TBD

Computational domain:
Control Surface Dimensions (figure 1):

Rectangular plan form with 3000mm x 1000mm dimensions

Triangular cross section with 1000mm chord and 200mm height

Fittings (figure 3)

Cross Section (figure 2):

Uniform cross section along the span
The maximum number of the internal spars is limited to 10 spc
Spar locations and tilting to be freely chosen
Skin and spar thicknesses to be freely chosen
Fittings not included in the optimization, supports can be assumed ideally rigid
The control surface structure is closed with inner and outer end ribs

Illustration of the computational domain:

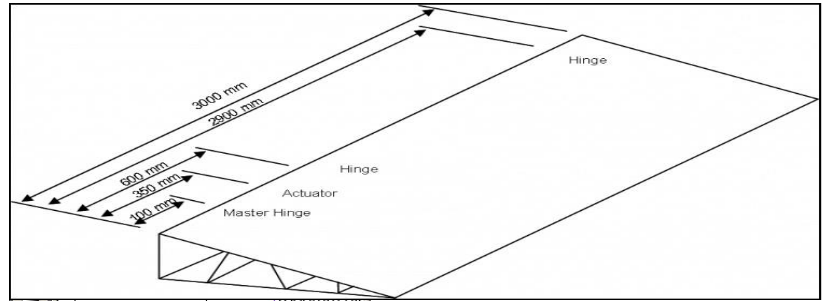


Figure 1. Control Surface Dimensions

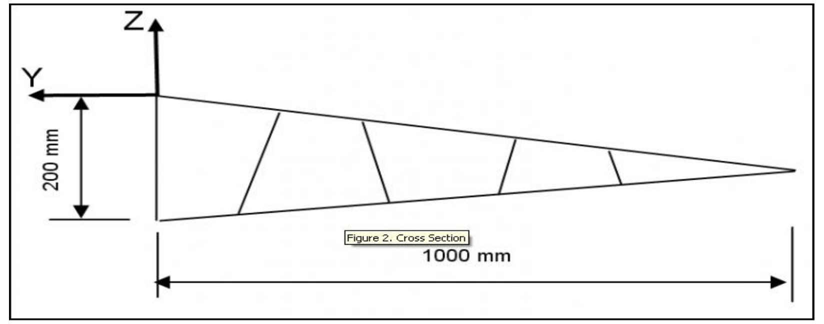


Figure 2. Cross Section

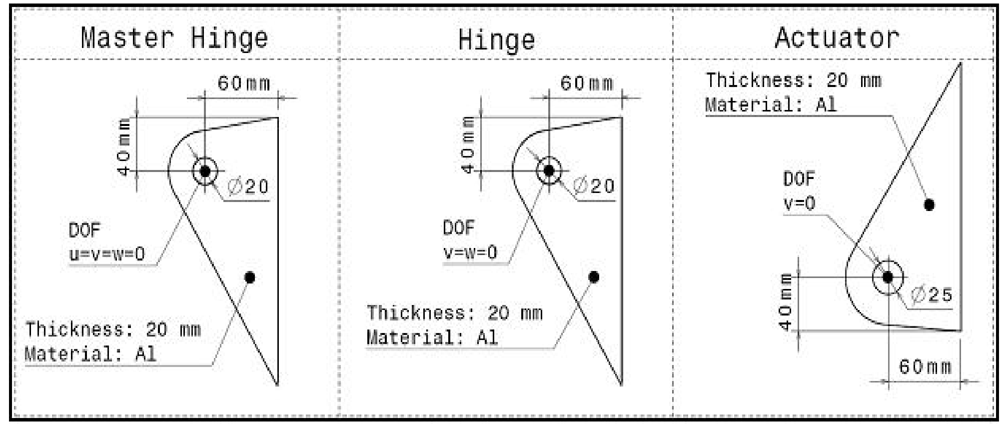


Figure 3. Fittings

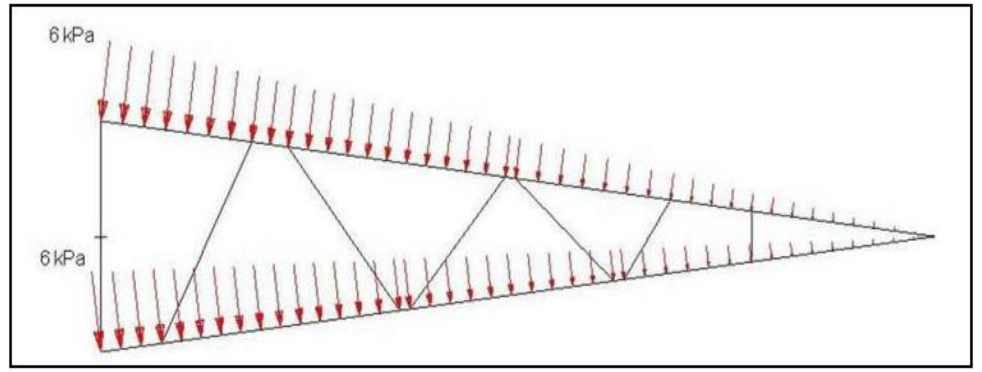


Figure 4. Aerodynamic loading

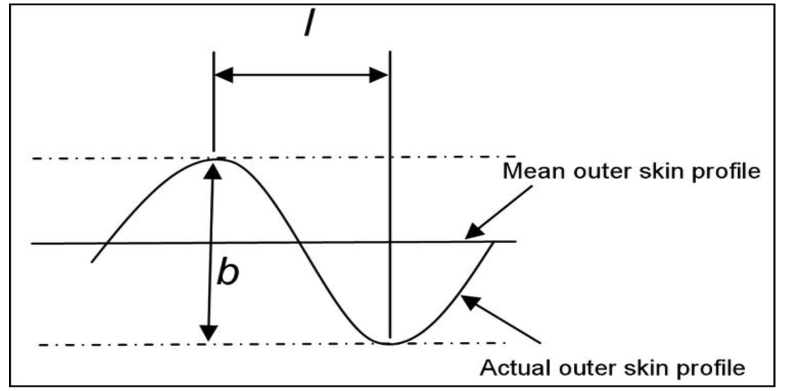


Figure 5. Surface waviness parameters

Modeling: physical properties:
Material Data for aluminium:

Density (kg/m^3)	2795
Elastic modulus	
E (GPa)	71
Poisson's ν	0.3

Loads:

The aerodynamic loading is assumed to follow triangular shape on both the upper and lower surfaces as shown in the figure 4.

Boundary and/or initial conditions for computations: TBD
Material Parameters: Solid
Optimization: Objective is to minimize the mass.

Design parameters:
$\mathbf{x} = [t_1\ t_2\ t_3\ \cdots\ t_n]^T$

Objective function definition:

Minimize	$F_{mass}(\mathbf{x})$			Objective is to minimize the mass
Subject to	$\delta_{\max}(\mathbf{x})$	$\leq$	10 mm	Constraint for maximum displacement
	n_{buck}	$\geq$	1.1	Constraint for minimum buckling factor
	$\sigma_{VonMises}$	$\leq$	260 MPa	Constraint for max Von Mises stress
	$\frac{b(\mathbf{x})}{l(\mathbf{x})}$	$\leq$	0.005	Constraint for surface waviness (see figure 5)
	$b(\mathbf{x})$	$\leq$	3 mm	Constraint for wave amplitude
	$\mathbf{x}$	=	$[t_1\ t_2\ t_3\ \cdots\ t_n]^T$	Thickness design variables (considered as continuous)

Note: Material thickness of each skin, spar and end rib has to remain constant along its surface area.

Results:
TBD

Link: www.jyu.fi/aladdin/en/tools/design-optimization-benchmarks

2.2 Patria AST Test Case 2

Chairman: Petri Hepola
Organization: Patria Aerostructures Oy
Country: Finland
Jyväskylä / CSC contact: Tero Tuovinen
Keywords: TBD
Objectives: Optimization of a generic aircraft control surface
Requirements: TBD

Computational domain:
Control Surface Dimensions (figure 1):

Rectangular plan form with 3000mm x 1000mm dimensions
Triangular cross section with 1000mm chord and 200mm height

Cross Section (figure 2):

Uniform cross section along the span
The maximum number of the internal spars is limited to 10 spc
Spar locations and tilting to be freely chosen
Skin and spar thicknesses to be freely chosen
Fittings not included in the optimization, supports can be assumed ideally rigid
The control surface structure is closed with inner and outer end ribs

Fittings (figure 3)

Illustration of the computational domain:

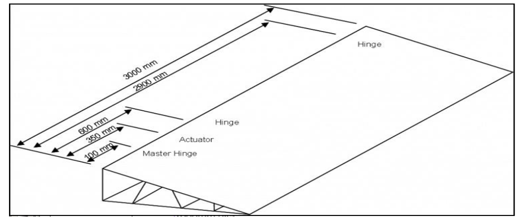


Figure 1. Control Surface Dimensions

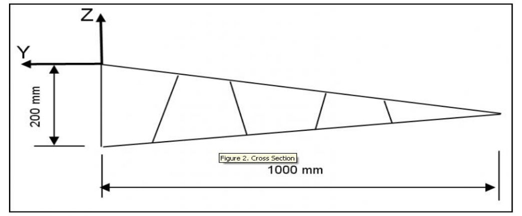


Figure 2. Cross Section

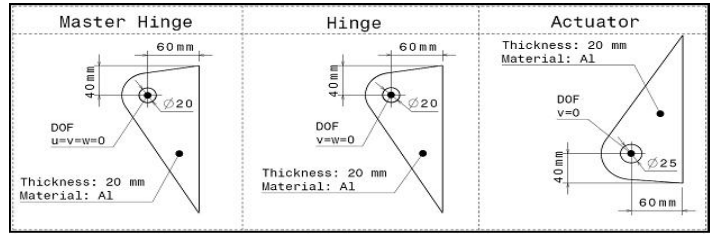


Figure 3. Fittings

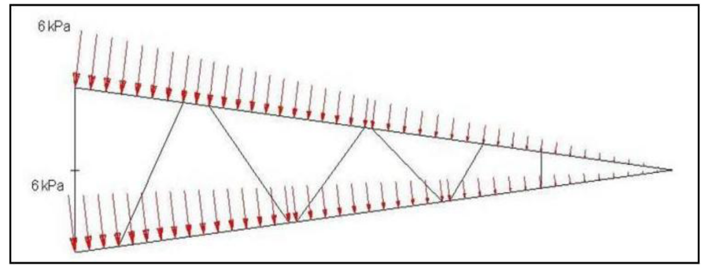


Figure 4. Aerodynamic loading

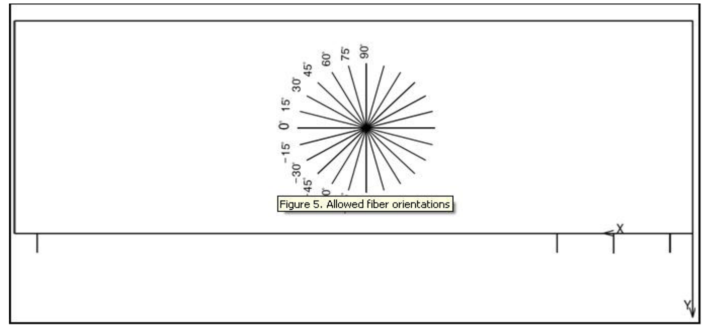


Figure 5. Allowed fiber orientations

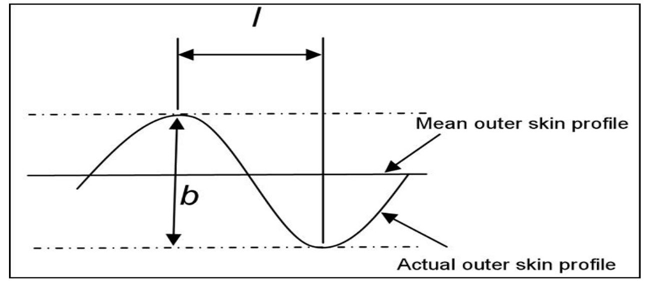


Figure 6. Surface waviness parameters

Modeling: physical properties:
Material Data for UD Tape:

Density (kg/m^3)	1600
Layer thickness (mm)	0.15
Elastic modulus	
E_1 (GPa)	125
E_2 (GPa)	4.5
G_12 (GPa)	4.5
Poisson's v	0.35
Allowable strengths	
σ_{1T} (MPa)	1300
σ_{1C} (MPa)	-800
σ_{2T} (MPa)	60
σ_{2C} (MPa)	-120
τ_{12} (MPa)	70

Material Data for aluminium:

Density (kg/m^3)	2795
Elastic modulus	
E (GPa)	71
Poisson's v	0.3

Loads:

The aerodynamic loading is assumed to follow triangular shape on both the upper and lower surfaces as shown in the figure 4.

The stacking sequence to be freely chosen
Allowed fiber orientations are shown in the figure 5

Boundary and/or initial conditions for computations: TBD
Material Parameters: Solid
Optimization: Objective is to minimize the mass.

Design parameters:
$\mathbf{x} = [t_1\ t_2\ t_3\ \cdots\ t_n]^T$

Objective function definition:

Minimize	$F_{mass}(\mathbf{x})$			Objective is to minimize the mass
Subject to	$\delta_{\max}(\mathbf{x})$	$\leq$	10 mm	Constraint for maximum displacement
	n_{buck}	$\geq$	1.1	Constraint for minimum buckling factor
	$(\frac{\sigma_1(\mathbf{x})}{X})^2 + (\frac{\sigma_2(\mathbf{x})}{Y})^2 + (\frac{\tau_{12}(\mathbf{x})}{S})^2 - (\frac{\sigma_1(\mathbf{x})\cdot\sigma_2(\mathbf{x})}{X^2})^2$	$\leq$	1	Constraint for failure criterion
			where	X is the fibre direction tensile or compressive allowable Y is the tensile or compressive allowable transverse to fibres S is the shear allowable n.b. For further details see Tsai-Hill criterion
	$\frac{b(\mathbf{x})}{l(\mathbf{x})}$	$\leq$	0.005	Constraint for surface waviness (see figure 6)
	$b(\mathbf{x})$	$\leq$	3 mm	Constraint for wave amplitude
	$\mathbf{x}$	$=$	$[t_1\ t_2\ t_3\ \cdots\ t_n]^T$	Thickness design variables (considered as continuous)

Note: Material thickness of each skin, spar and end rib has to remain constant along its surface area.

Results:
TBD

Link: www.jyu.fi/aladdin/en/tools/design-optimization-benchmarks

2.3 Patria AST Test Case 3

Chairman: Petri Hepola
Organization: Patria Aerostructures Oy
Country: Finland
Jyväskylä / CSC contact: Tero Tuovinen
Keywords: TBD
Objectives: Optimization of a generic aircraft control surface
Requirements: TBD

Computational domain:
Control Surface Dimensions (figure 1):

Rectangular plan form with 3000mm x 1000mm dimensions
Triangular cross section with 1000mm chord and 200mm height

Cross Section (figure 2):

Uniform cross section along the span
The maximum number of the internal spars is limited to 10 spc
Spar locations and tilting to be freely chosen
Skin and spar thicknesses to be freely chosen
Fittings not included in the optimization, supports can be assumed ideally rigid
The control surface structure is closed with inner and outer end ribs

Fittings (figure 3)

Illustration of the computational domain:

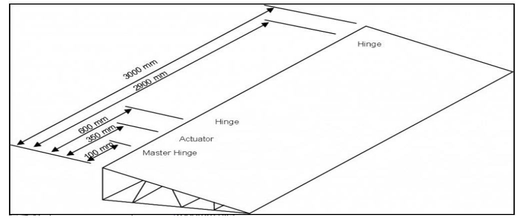


Figure 1. Control Surface Dimensions

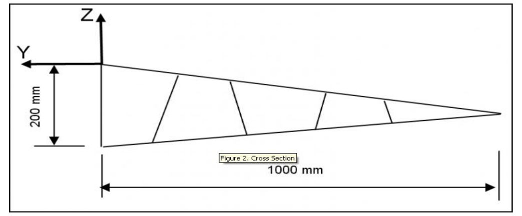


Figure 2. Cross Section

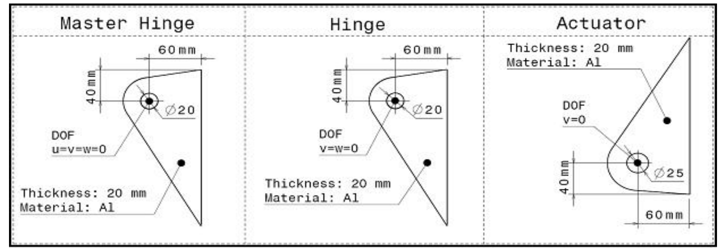


Figure 3. Fittings

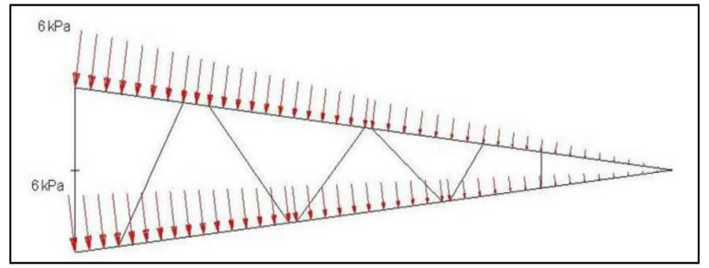


Figure 4. Aerodynamic loading

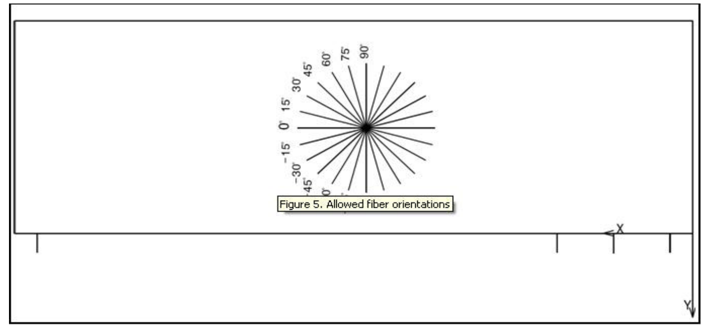


Figure 5. Allowed fiber orientations

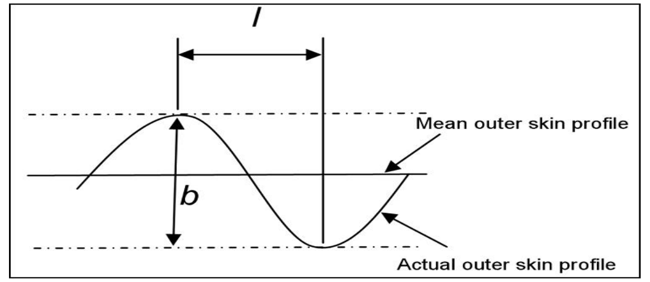


Figure 6. Surface waviness parameters

Modeling: physical properties:
Material Data for UD Tape:

Density (kg/m^3)	1600
Layer thickness (mm)	0.15
Elastic modulus	
E_1 (GPa)	125
E_2 (GPa)	4.5
$G_1 2$ (GPa)	4.5
Poisson's v	0.35
Allowable strengths	
σ_{1T} (MPa)	1300
σ_{1C} (MPa)	-800
σ_{2T} (MPa)	60
σ_{2C} (MPa)	-120
τ_{12} (MPa)	70

Material Data for aluminium:

Density (kg/m^3)	2795
Elastic modulus	
E (GPa)	71
Poisson's v	0.3

Loads:

The aerodynamic loading is assumed to follow triangular shape on both the upper and lower surfaces as shown in the figure 4.

The stacking sequence to be freely chosen
Allowed fiber orientations are shown in the figure 5

Boundary and/or initial conditions for computations: TBD
Material Parameters: Solid
Optimization: Objective is to minimize the mass.

Design parameters:
$\mathbf{x} = [t_1\ t_2\ t_3\ \cdots\ t_n]^T$

Objective function definition:

Minimize	$F_{mass}(\mathbf{x})$			Objective is to minimize the mass
Subject to	$\delta_{\max}(\mathbf{x})$	$\leq$	10 mm	Constraint for maximum displacement
	n_{buck}	$\geq$	1.1	Constraint for minimum buckling factor
	$(\frac{\sigma_1(\mathbf{x})}{X})^2 + (\frac{\sigma_2(\mathbf{x})}{Y})^2 + (\frac{\tau_{12}(\mathbf{x})}{S})^2 - (\frac{\sigma_1(\mathbf{x})\cdot\sigma_2(\mathbf{x})}{X^2})^2$	$\leq$	1	Constraint for failure criterion
			where	X is the fibre direction tensile or compressive allowable
				Y is the tensile or compressive allowable transverse to fibres
				S is the shear allowable
				n.b. For further details see Tsai-Hill criterion
	$\frac{b(\mathbf{x})}{l(\mathbf{x})}$	$\leq$	0.005	Constraint for surface waviness (see figure 6)
	$b(\mathbf{x})$	$\leq$	3 mm	Constraint for wave amplitude
	$\mathbf{x}$	=	$[t_1\ t_2\ t_3\ \cdots\ t_n]^T$	Thickness design variables (considered as discrete)
				$x_i = [0\ 0.15\ 0.30\ \cdots\ 15.00]\ mm$

Note: Composite laminate of each skin, spar and end rib is allowed to vary freely along its surface area.

Results:

TBD

Link: www.jyu.fi/aladdin/en/tools/design-optimization-benchmarks

3. Shock control bump optimization on a transonic laminar flow airfoil

Chairman: Ning Qin
Organization: University of Sheffield
Country: UK
Jyväskylä / CSC contact: Tero Tuovinen
Keywords: Shock control bump, transonic flow, natural laminar flow airfoil
Objectives:
Drag reduction for transonic wings is crucial for the aeronautical industry, for control of aviation emission and operational efficiency.
Shock control bumps were found to be effective in reducing the wave drag and the total drag if installed on transonic airfoils or wings. However, their effectiveness relies on the position, height, and size of the bumps. In this test case, we will look into the optimal design parameters for a given laminar flow airfoil, i.e. RAE5243 airfoil, at the design Mach number and Reynolds number. It will be divided into two cases: (1) fully turbulent flow; (2) fixed transition at 45%c. The optimization will be constrained by the given lift condition.

Requirements:
Navier-Stokes flow solver with turbulence modelling
Optimization method with lift constraint

Computational domain:
Figures 1 and 2 below show the airfoil, the bump and its parameterisation. The computational domain is suggested to be 20 chord length away from the airfoil in all directions.

Illustration of the computational domain:

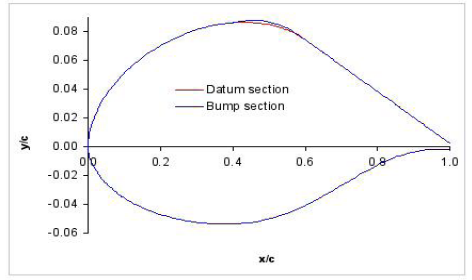


Figure 1. RAE5243 with shock control bump

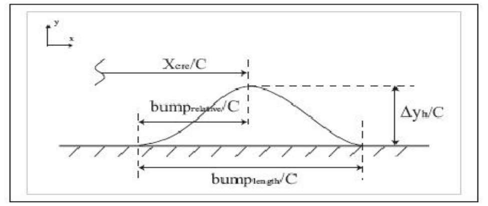


Figure 2. Bump design parameters

Modeling: physical properties:
Air as perfect gas
Laminar or turbulent flow (fixed transition)

Table 1. Test cases

Aerofoil	M_∞	$\mathrm{Re}_{c,\infty}$	C_l	Flow condition
RAE5243	0.68	19×10^6	0.82	Fully turbulent
RAE5243	0.68	19×10^6	0.82	45% transition

Boundary and/or initial conditions for computations:
Steady state solution
No-slip boundary condition at wall and far field boundary condition
Fully turbulent or fixed transition

Material Parameters:
Fluid
Optimization:
Minimum total drag Min C_d for given C_l

Design parameters:
Bump height, position, length and crest position

Bounds of design parameters:
Bump crest position
$0 < X_{cre}/C < 1$

Bump starting point to crest
$0 < X_{bumprelative}/C < X_{bumplength}/C$

Bump total length
$0 < X_{bumplength}/C < 0.4$

Bump height
$0 < \Delta Y_h/C < 0.05$

Objective function definition:
Total drag of the airfoil $C_d = C_{d,pressure} + C_{d,friction}$

Results:
Results for datum airfoil:
Lift curve, drag polar and flowfield at the given C_l

Results for optimized airfoil:
Bump shape and position parameters
Lift, drag (both components) and pitching moment at the design condition
Lift curve and drag polar for a range of lift around the design point

Data to be stored requested from Analysis
Flow field data

Link: www.jyu.fi/aladdin/en/tools/design-optimization-benchmarks

4. Optimization of beam profile in fluid-structure interaction

Chairman: Peter Råback
Organization: CSC - IT Center for Science
Country: Finland
Jyväskylä / CSC contact: Tero Tuovinen
Keywords: Fluid-structure interaction, Elastic beam, Optimization
Introduction: The test case combines fluid-structure interaction with optimization in a simple but effective way. The cost function is well defined, has a definate global minimum and its evaluation requires the solution of a strongly coupled fluid-structure interaction problem. The individual problems are easily solved while the coupled problem sets requirements to the efficient coupling of the different subproblems.
The one biggest challenge of the case is to find a surface presentation that allows sufficient freedom in design and also enables the use of efficient optimization techniques. The test case may be used to provide a reference solution for the verification of software components for multiphysical optimization problems. Even though the case itself is not realistic it may help in the development and testing of tools needed for industrial fluid-structure interaction problems.

Objectives:
The aim is to optimize the geometry of an elastic beam so that it bends as little as possible under the pressure and traction forces resulting from viscous incompressible flow. The profile of the beam has an effect both on the flow and the structural stiffness of the beam, respectively.

The case includes three different variations. The first case is fully linear and involves only one-directional coupling between the models. The linearity is achieved by neglecting the inertial forces in the Navier-Stokes equation, and by setting the beam to be so stiff that its bending is so small that its influence on the flow does not need to be taken into account. This also means that there is no geometric nonlinearities in the problem. The second variation increases the Reynolds number but the coupling is still one-directional. The third variation includes geometric nonlinearities in the elasticity equation, and nonlinearity resulting from the fluid-structure coupling. The optimum profile of the linear problem will not depend on any of the material parameters while in the nonlinear case the optimum profile will be parameter dependent.

Requirements: Incompressible Navier-Stokes solver for laminar flow
Elasticity solver for large displacement
Method to extent elastic deformarmation of the to the geometry of the fluid mesh
Capability to solve fluid-structure-interaction problems

Computational domain: Rectangular domain of size 102
Standing beam (height = 1, total area = 0.3), the tip of the beam located at x=25

Illustration of the computational domain:

A possible initial geometry for the case

Modeling: physical properties:

>

Property	Case A	Case B	Case C
Density of fluid	$0\ kg/m^3$	$10\ kg/m^3$	$10\ kg/m^3$
Viscosity of fluid	$1\ m/s^2$	$1\ m/s^2$	$1\ m/s^2$
Young's modulus of structure	$1e9\ Pa$	$1e9\ Pa$	$2e4\ Pa$
Poisson ratio of structure	0.3	0.3	0.3

Boundary and/or initial conditions for computations:
Boundary conditions:

- Left-hand side boundary: inlet with mean velocity 1 and a parabolic inlet flow profile, $v_x = \frac{3}{2}y(2-y)$
- Right-hand side boundary: outlet which vanishing traction component
- FSI-boundary: force equality
- Other boundaries: no-slip boundaries

Material Parameters:
Solid
Fluid
Optimization:
The goal is to optimize the shape of the left-hand side wall of the beam so that its height and area stay fixed. The width at the bottom may freely vary as long as the other constraints are met.
Design parameters:
The standing beam: height = 1, total area = 0.3. The left and right walls may be assumed to be smooth.

Objective function definition:
f=max(|u|)

Results:
The different solutions may be compared to each other using 0D, 1D and 2D data.. Below the different data for comparison is defined.

Scalar values:

- Maximum displacement on the beam at optimum
- Maximum displacement on the beam at rectangular shape
- Displacement reduction factor
- Area of the optimized beam
- Parametrization of the left wall pro file

Ideally the results are saved in a format which enables that the results are studied with the same software. For line plotting the natural format is a table where the columns represent different fields and the rows different nodes.

- The shape of the left side wall as a [y;x] table
- The displacement on the left side wall as [y;ux] table
- The pressure on the left side wall as [y;p] table

Contour plots:

Ideally the results are saved in a format which enables that the results are compared within the same visualization software. For 2D the contour plots this format could be the VTK format (or its newer XML generalizations) that enable visualization with all VTK derived software such as Paraview.

- Contour plot of absolute velocity
- Contour plot of pressure
- Contour plot of displacement

Additional information:

The results may also discuss the different numerical methods and optimization algorithms used. For successful comparison this information is however, not required.

Link: www.jyu.fi/aladdin/en/tools/design-optimization-benchmarks

5. A numerical set-up for benchmarking and optimization of fluid-structure interaction

Chairman: Stefan Turek, Mudassar Razzaq
Organization: TU Dortmund
Country: Germany
Jyväskylä / CSC contact: Tero Tuovinen
Keywords: Discretization techniques, robustness of solver, lift/drag optimization, FSI
Objectives: Objective of this benchmarking scenario is to test and compare different numerical approaches for fluid-structure interaction and code implementations qualitatively and particularly quantitatively with respect to efficiency and accuracy of the computation and to extend these validated configurations to optimization problems such that minimum drag/lift of the elastic object, minimal pressure loss or minimal nonstationary oscillations through boundary control of the inflow, change of geometry or optimal control of volume forces can be reached.

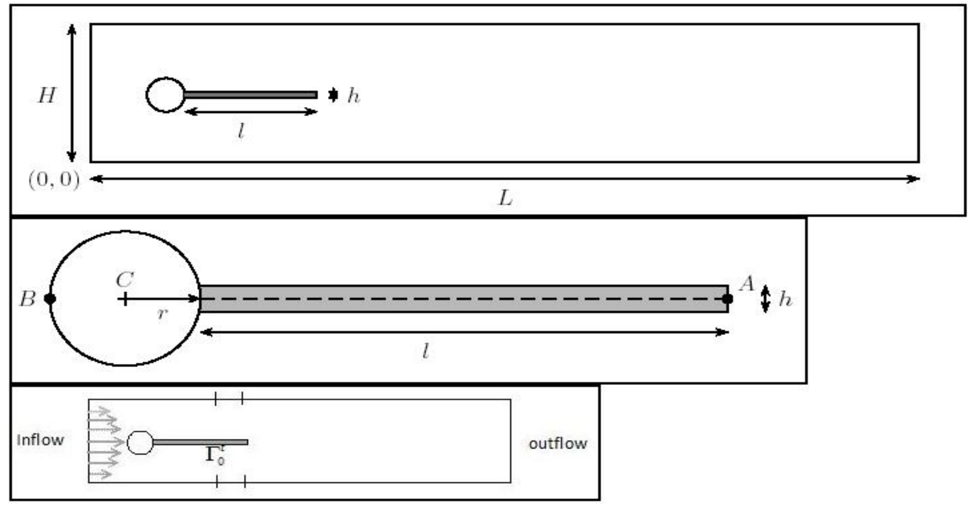
Requirements: meshing, FSI solver and optimizer software, 2D, laminar regime
Computational domain: The domain is shown here in Figure 1. Details can be found in the attached papers.
Geometry parameters:

Table 1. Overview of the geometry parameters.

geometry parameters		value [m]
channel length	L	2.5
channel width	H	0.41
cylinder center position	C	(0.2, 0.2)
cylinder radius	r	0.05
elastic structure length	l	0.35
elastic structure thickness	h	0.02
reference point (at $t = 0$)	A	(0.6, 0.2)
reference point	B	(0.15, 0.2)

- The setting is intentionally non-symmetric to prevent the dependence of the onset of any possible oscillation on the precision of the computation.
- By omitting the elastic bar attached with the cylinder one can exactly recover the setup of the well known flow around cylinder benchmark configuration which can be used for validating the CFD part.
- The control points are **A(t)**, fixed with the structure with **A(0)=(0602)**, and **B=(01502)**.

Illustration of the computational domain:



Modeling: physical properties:
- incompressible Newtonian fluid (Navier-Stokes)
- elastic compressible solid (St. Venant-Kirchhoff material)
- see attached papers for more details

Table 2. Material combination.

parameter	FSI1	FSI2	FSI3
$\beta = \frac{\rho^s}{\rho^f}\ [10^3 \frac{kg}{m^3}]$	1	1	1
ν^s	0.4	0.4	0.4
$Ae = \frac{E^s}{\rho^f \bar{U}^2}$	3.5×10^4	1.4×10^3	1.4×10^3
$Re = \frac{\bar{U}d}{\nu^f}$	20	100	200
$\bar{U}\ [\frac{m}{s}]$	0.2	1	2

Boundary and/or initial conditions for computations:
Boundary conditions:

A parabolic velocity profile is prescribed at the left channel inflow

$$v^f(0,y) = 1.5\bar{U}\frac{y(H-y)}{(\frac{H}{2})^2} = 1.5\bar{U}\frac{4.0}{0.1681}y(0.41-y)$$

such that the mean inflow velocity is **U** and the maximum of the inflow velocity is **1.5U**.
- The outflow condition can be chosen by the user, for example stress free or do nothing conditions.
- The no-slip condition is prescribed for the fluid on the other boundary parts i.e. top and bottom wall, circle and fluid structure interface Γ_t^0

Initial conditions:
Suggested starting procedure for the non-steady tests is to use a smooth increase of the velocity profile in time

Optimization:
Lift reduction under variation of geometrical design variables and boundary control.

Design parameters:
- Boundary control

Objective function definition:
1. $minimize(lift^2 + \alpha(V^2))$ (definition of lift see attached papers) w.r.t V_1 velocity from top and V_2 velocity from bottom (parabolic), where V is from $x \in (0.45, 0.6)$ and $\alpha = 1, 10e-2, 10e-4, 10e-6$ for tests.

Results:
Quantities of interest

- Table, three mesh levels
- The position of the end of the structure, displacement in x y directons, drag and lift, **V1** and **V2** additionally Number of equations, number of iterations, and CPU time.
- Forces exerted by the fluid on the whole body (lift and drag forces acting on the cylinder and the structure together
- Frequency and maximum amplitude (for nonstationary tests)

Stationary without and with optimization:

- Produce FSI1, CFD1, CSM1 (see attached pdf file)
- FSI1 and FSI1 example1 (see table of example 1 in ppt file attached)
- Minimum lift values in case of optimization

Nonstationary without optimization

- Check your code on FSI2 and FSI3

Suggestions

- Validate your FSI code without optimization
- FSI1 + Ex1 send us results untill summer
- Preliminary test for other examples untill fall
  pressure loss minimize: **minimize**(**P** in−**P** out) w.r.t elastic deformation of the wall or geometrical and material properties of the beam

Link: www.jyu.fi/aladdin/en/tools/design-optimization-benchmarks

Inverse or optimization problems for multiple (ellipse) ellipsoid configurations

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Keywords: inverse problems, shape recovery, CFD, electromagnetics, acoustics
Introduction: This academic test case was developed in order to study algorithmic convergence by splitting the inverse problem (recovery of target pressure on the surface) into smaller subproblems. It also provides a way to study the behaviour of algorithms with meshes of different quality. Finally, it can be expanded into a simple test platform for multiphysics optimization (computational fluid dynamics, computational electromagnetism, and aeroacoustics), both in 2D and 3D.

Objectives:
Aerodynamic reconstruction problem
Recovery of the original position of two ellipses (2D) or ellipsoids (3D) using potential, Euler, or turbulent Navier-Stokes flows.

CEM radar wave problem
RCS optimization using perfectly conducting or coated material (under development).

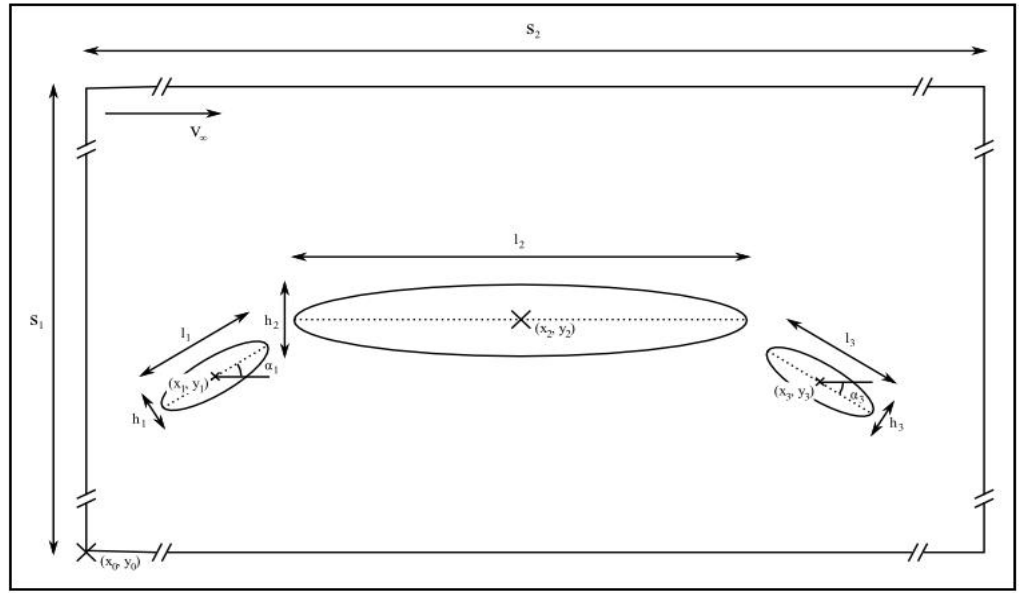
CAA wave problem
Noise prediction and reduction (under development).

Requirements: Navier-Stokes solver, acoustics solver, Maxwell solver

Computational domain: See the figure for the 2D case.

$s_1 = s_3$	=	160	height (and width) of the bounding box
s_2	=	320	length of the bounding box
(x_0, y_0, z_0)	=	$(-80, -80, -80)$	front lower left corner of the bounding box
l_1	=	2.0	length of the ellipse/ellipsoid 1
h_1, w_1	=	0.5	height (and width) of the ellipse/ellipsoid 1
z_1	=	0	position on the z-axis of the ellipsoid 1
l_2	=	10.0	length of the ellipse/ellipsoid 2
h_2, w_2	=	1.0	height (and width) of the ellipse/ellipsoid 2
(x_2, y_2, z_2)	=	$(0, 0, 0)$	position of the ellipse/ellipsoid 2
l_3	=	3.5	length of the ellipse/ellipsoid 3
h_3, w_3	=	0.5	height (and width) of the ellipse/ellipsoid 3
z_3	=	0	position on the z-axis of the ellipsoid 3

Illustration of the computational domain:



Modeling: physical properties:
Aerodynamic reconstruction problem

- Incompressible fluid (Navier-Stokes turbulent flow).
- Kinematic viscosity **V = 1/100**.

Boundary and/or initial conditions for computations:
Aerodynamic reconstruction problem

Upstream entrance: **u = 1.0**, angle of attack **a = 3.0º**
Downstream exit: free boundary conditions
Ellipse/ellipsoid surface: no-slip condition

Material Parameters:
Solid
Fluid

Optimization:
Aerodynamic reconstruction problem

Reconstruction of the target pressure on the surfaces of the ellipses. The target vector is
$x^* = \{x_1, y_1, \alpha_1, y_3, y_3, \alpha_3\} = \{-14.0, -1.0, -3.0°, 15.0, -1.0, 3.0°\}$.

Design parameters:
Aerodynamic reconstruction problem

-20.0	$\leq$	x_1	$\leq$	-13.0	position of the ellipse 1
-3.0	$\leq$	y_1	$\leq$	0.0	
$-10.0°$	$\leq$	α_1	$\leq$	$0.0°$	clockwise angle of the ellipse 1
14.5	$\leq$	x_3	$\leq$	20.0	position of the ellipse 3
-3.0	$\leq$	y_3	$\leq$	0.0	
$0.0°$	$\leq$	α_3	$\leq$	$10.0°$	clockwise angle of the ellipse 3

Objective function definition:
Aerodynamic reconstruction problem

The objective function $f = f_1 + f_2 + f_3$ is the L^2 error norm of the surface pressure,

$$
\begin{aligned}
f_1 &= \int_{\Gamma_1} |p_1 - p_1^*|^2 \\
f_2 &= \int_{\Gamma_2} |p_2 - p_2^*|^2 \\
f_3 &= \int_{\Gamma_3} |p_3 - p_3^*|^2
\end{aligned}
$$

where p_i is the current pressure and p_i^* the target pressure on the surface of the ellipse i, respectively ($i = \{1, 2, 3\}$).

Results:
Aerodynamic reconstruction problem

- Pressure contours of the best solution
- Final mesh
- Averaged convergence curves of the tested algorithms
- For the tested algorithms the following values are required
    - mean final value
    - standard deviation
    - minimum value
    - maximum value
    - average number of fitness calculations required

Link: www.jyu.fi/aladdin/en/tools/design-optimization-benchmarks