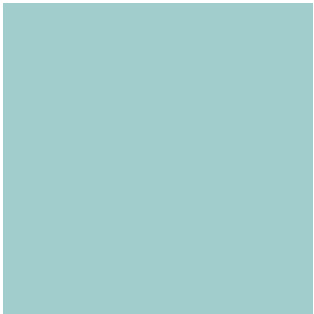




Conjugate Heat Transfer Simulations using the LS-DYNA ICFD Solver

DYNAmore Nordic

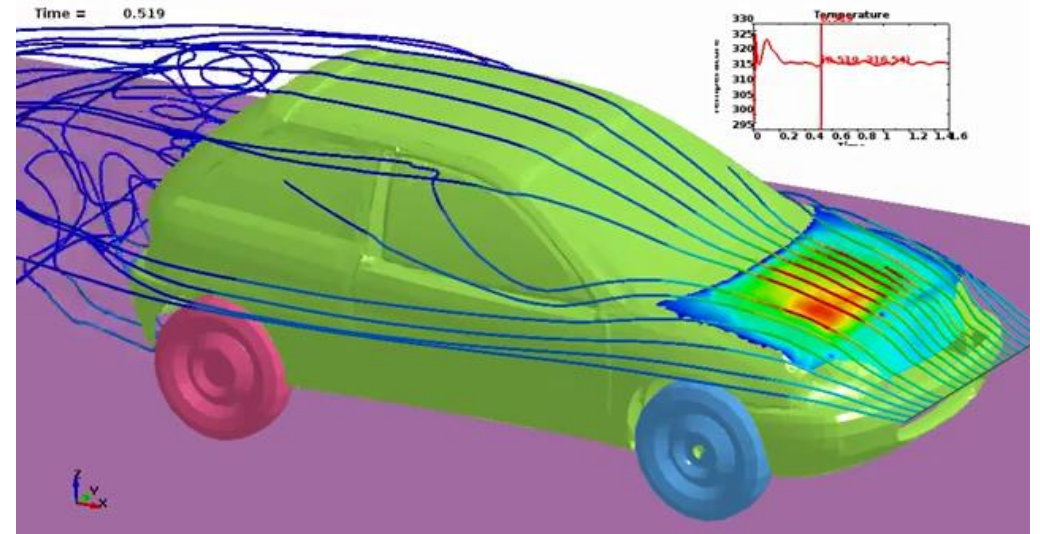
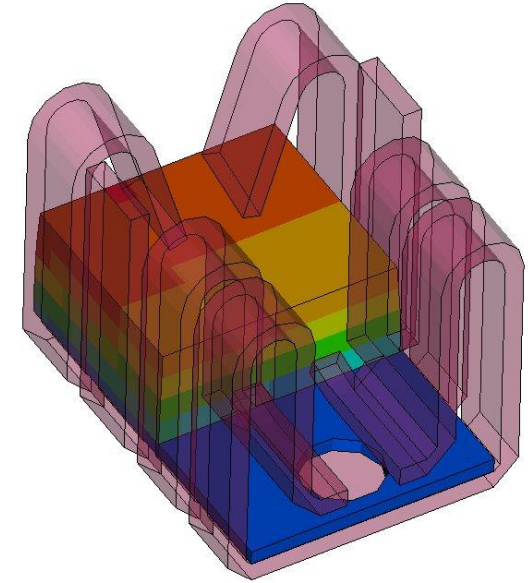
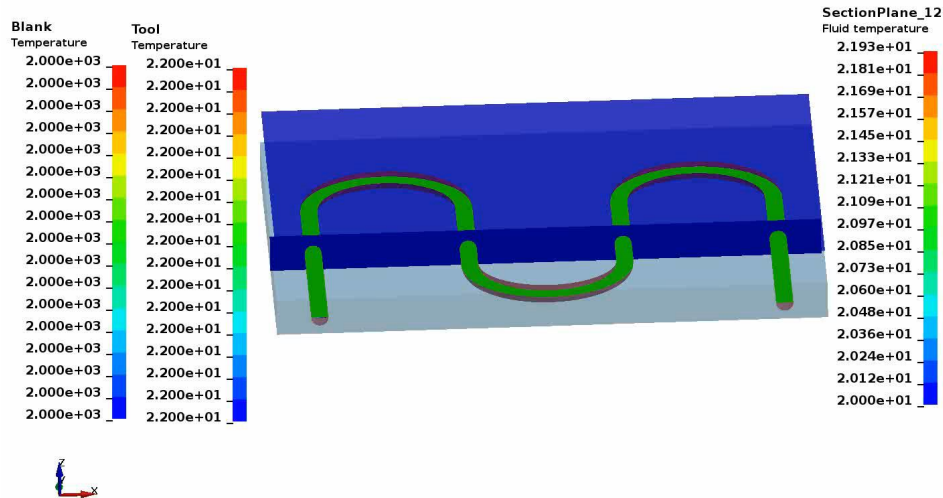
Outline

- Motivation
- Intro to the ICFD solver in LS-DYNA
- LS-DYNA Conjugate Heat Transfer (CHT) capabilities
- Important keywords
- Simulation example
- Remarks
- Summary

Why simulations of Conjugate Heat Transfer (CHT)?

- Problems involving simultaneous heat transfer in solids and fluids appear in
 - Manufacturing processes, e.g. tool cooling
 - Thermal management of electronic components
 - Engine cooling
 - Natural convection

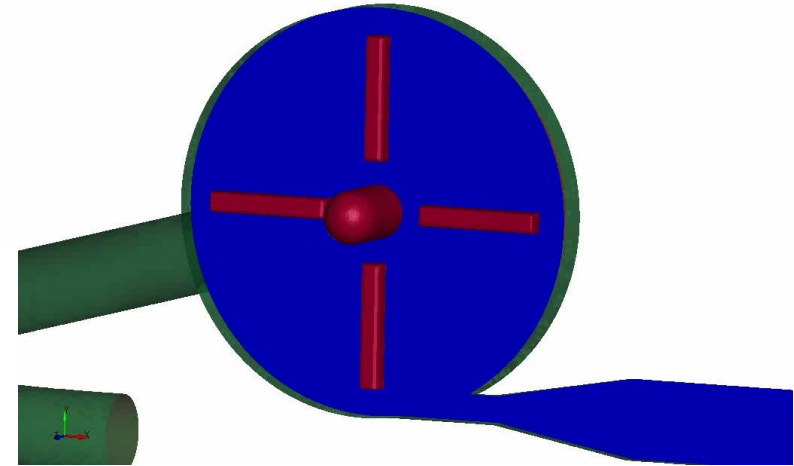
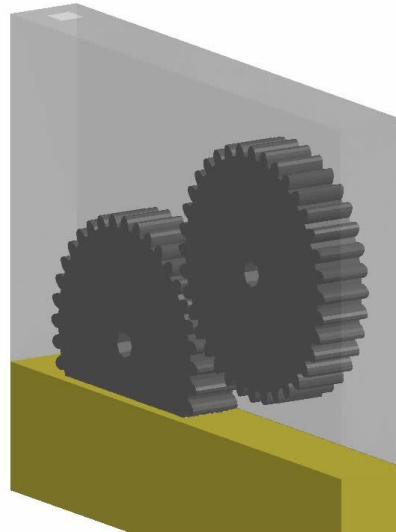
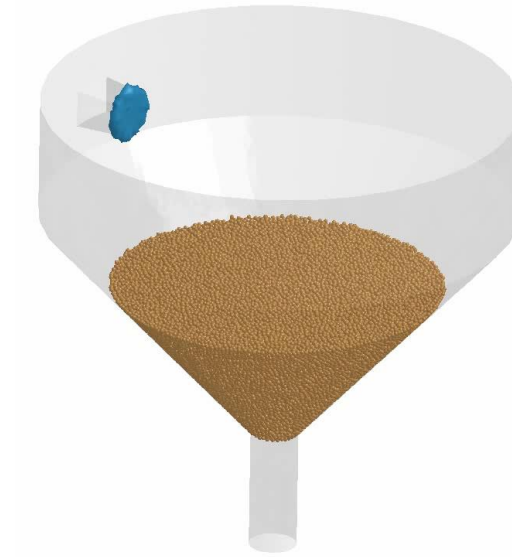
LS-DYNA keyword deck by LS-PrePost
Time = 0



Solver introduction

■ Features of the ICFD solver in LS-DYNA

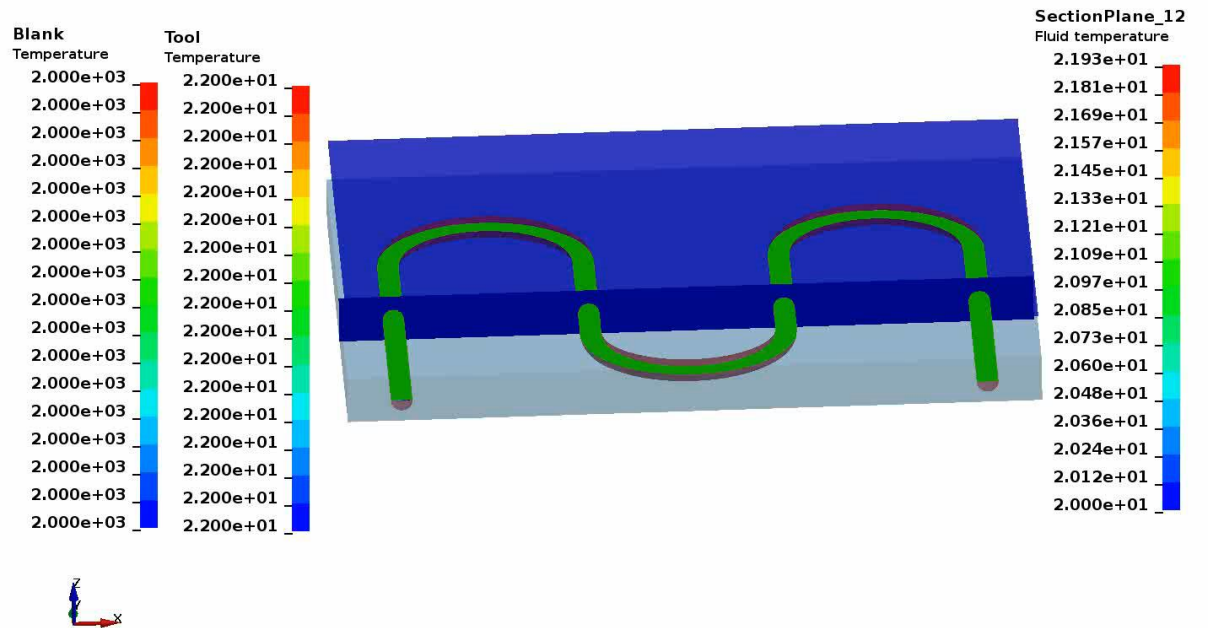
- Implicit solver for incompressible fluids
- Ideally suited for coupled simulations
 - Fluid Structure Interaction (FSI)
 - Conjugate Heat Transfer (CHT)
 - CFD particle coupling (DES)
 - Free surface flows (level set)
 - Sliding meshes
- Uses the Finite Element Method (FEM)
- 2D and 3D calculations
- Automatic volume mesh generation
- Non-Newtonian fluids
- Turbulence models
- Porous media
- Steady state solver (from R10)



CHT capabilities

- Thermal coupling between solid thermal solver and ICFD fluid solver
- Natural convection
- Solid capabilities
 - Thermal contacts
 - Radiation losses
- Analytical expressions for convective and radiative heat loss to the environment
 - BOUNDARY_CONVECTION
 - BOUNDARY_RADIATION

LS-DYNA keyword deck by LS-PrePost
Time = 0



Important keywords

- *ICFD_MAT
 - Second card defines thermal fluid parameters.

MID	FLG	RHO	VIS	ST	STSFLCID		
HC	TC	BETA	PRT	HCSFLCID	TCSFLCID		

- **HC:** Heat capacity.
- **TC:** Thermal conductivity.
- **BETA:** Thermal expansion coefficient used in the Boussinesq approximation for buoyancy.
 - Drives natural convection.
- **PRT:** Turbulent Prandtl number. Only used if K-Epsilon turbulence model is selected.
- **HCSFLCID:** Load curve ID for scale factor applied on HC function of time.
If a *DEFINE_FUNCTION is used: f(x, y, z, vx, vy, vz, temp, pres, time).
- **TCSFLCID:** Load curve ID for scale factor applied on TC function of time.
If a *DEFINE_FUNCTION is used: f(x, y, z, vx, vy, vz, temp, pres, time).

Important keywords

■ *ICFD_BOUNDARY_FSI

- This keyword defines which fluid surfaces will be considered in contact with the solid surfaces for fluid-structure interaction (FSI) analysis.

PID							

■ *ICFD_BOUNDARY_CONJ_HEAT

- Specify which boundary of the fluid domain will exchange heat with the solid.

PID	CTYPE	VAL	SFLCID				

- PID: PID of the fluid surface in contact with the solid.
- CTYPE: Contact type
 - EQ.0: Constraint approach
 - EQ.1: Mortar contact
- VAL: Optional Temperature drop if CTYPE = 0 or Interface Heat Transfer Coefficient if CTYPE = 1 (high value by default to ensure perfect contact).
- SFLCID: Load curve ID used to describe scale factor on VAL value versus time, see *DEFINE_CURVE, *DEFINE_CURVE_FUNCTION, or *DEFINE_FUNCTION.
- Remark: CTYPE, VAL and SFLCID new from R12.

Important keywords

- *ICFD_BOUNDARY_PRESCRIBED_TEMP
 - Impose a fluid temperature on the boundary.

PID	LCID	SF	DEATH	BIRTH			

- *ICFD_CONTROL_CONJ
 - This keyword allows to pick between the different coupling methods for conjugate heat transfer applications.

CTYPE							TSF

- CTYPE
 - EQ.0:Robust and accurate monolithic coupling where the temperature field are solved simultaneously between the fluid and the structure. Default.
 - EQ.1:Weak thermal coupling. The fluid passes the heat flux to the solid at the fluid-structure interface and the solid returns the temperature which is applied as a Dirichlet condition.
- TSF
 - Thermal Speedup Factor. This factor multiplies all thermal parameters present in the heat equation with units of time in the denominator (e.g., thermal conductivity, convection heat transfer coefficients). It is used to artificially time scale the thermal problem. A negative value will refer to a time dependent load curve.
 - New from R12.

Important keywords

- *ICFD_INITIAL

- Purpose: Simple initialization of velocity and temperature within a volume.

PID	Vx	Vy	Vz	T	P		

- Vx: x coordinate for the velocity.
 - Vy: y coordinate for the velocity.
 - Vz: z coordinate for the velocity.
 - T: Initial temperature.
 - P: Initial Pressure.

Important keywords

- *ICFD_BOUNDARY_CONVECTION_TEMP

- Impose a heat transfer coefficient on the boundary expressed as $h = \frac{q}{T_s - T_b}$

PID	HLCID	HSF	TBLCID	TBSF			
		1.0		1.0			

- HLCID: Load curve ID to describe the heat transfer coefficient value versus time.
- HSF: Load curve scale factor applied on the heat transfer coefficient value.
- TBLCID: Load curve ID to describe the environment (i.e bulk) temperature value versus time.
- Load curve scale factor applied on the environment value.
- New from R12.

- *ICFD_BOUNDARY_FLUX_TEMP

- Impose a heat flux on the boundary

PID	LCID	SF	DEATH	BIRTH			

- LCID: Load curve ID to describe the temperature flux value versus time.
- SF: Load curve scale factor.

Important keywords

- *ICFD_CONTROL_TURBULENCE

TMOD	SUBMOD	WLAW	KS	CS		TWLAW	TYPLUS

- TWLAW: Thermal law of the wall flag
 - EQ.0: No thermal law of the wall activated.
 - EQ.1: Thermal law of the wall.
 - New from R12.
- TYPLUS: Thermal Y+ value.
- Additional cards for turbulence models available.

Important keywords

- *CONTACT_XXX_THERMAL_XXX
 - Thermal Card 1.

K	FRAD	H0	LMIN	LMAX	FTOSLV	BC_FLG	ALGO

- K: Thermal conductivity of fluid between the contact surfaces.
- FRAD: Radiation factor between the contact surfaces.
- H0: Heat transfer conductance for closed gaps.
- LMIN: Minimum gap.
- LMAX: No thermal contact if the gap is greater than this value.
- FTOSLV: Fraction of sliding friction energy partitioned to the slave surface.
- BC_FLG: Thermal boundary condition flag
 - EQ.0: Thermal boundary conditions are on when parts are in contact.
 - EQ.1: Thermal boundary conditions are off when parts are in contact.
- ALGO: Contact algorithm type
 - EQ.0: Two-way contact, both surfaces change temperature due to contact.
 - EQ.1: One-way contact, master surface does not change temperature due to contact.

Important keywords

- *CONTROL_SOLUTION

- To specify the analysis solution procedure if thermal only or combined thermal analysis is performed.

SOLN	NLQ	ISNAN	LCINT	LCACC	NCDCF	NOCOPY	

- SOLN

- EQ.0: Structural analysis only
 - EQ.1: Thermal analysis only
 - EQ.2: Combined structural, multiphysics, and thermal analysis

Important keywords

■ *CONTROL_THERMAL_SOLVER

ATYPE	PTYPE	SOLVER		GPT	EQHEAT	FWORK	SBC
MSGLVL	MAXITR	ABSTOL	RELTOL	OMEGA			TSF

■ ATYPE: Thermal analysis type

- EQ.0: Steady state analysis
- EQ.1: Transient analysis

■ PTYPE: Thermal problem type

- EQ.0: Linear problem
- EQ.1: Nonlinear problem with material properties evaluated at gauss point temperature
- EQ.2: Nonlinear problem with material properties evaluated at element average temperature

■ TSF: Thermal Speedup Factor. Used to artificially time scale the problem.

Important keywords

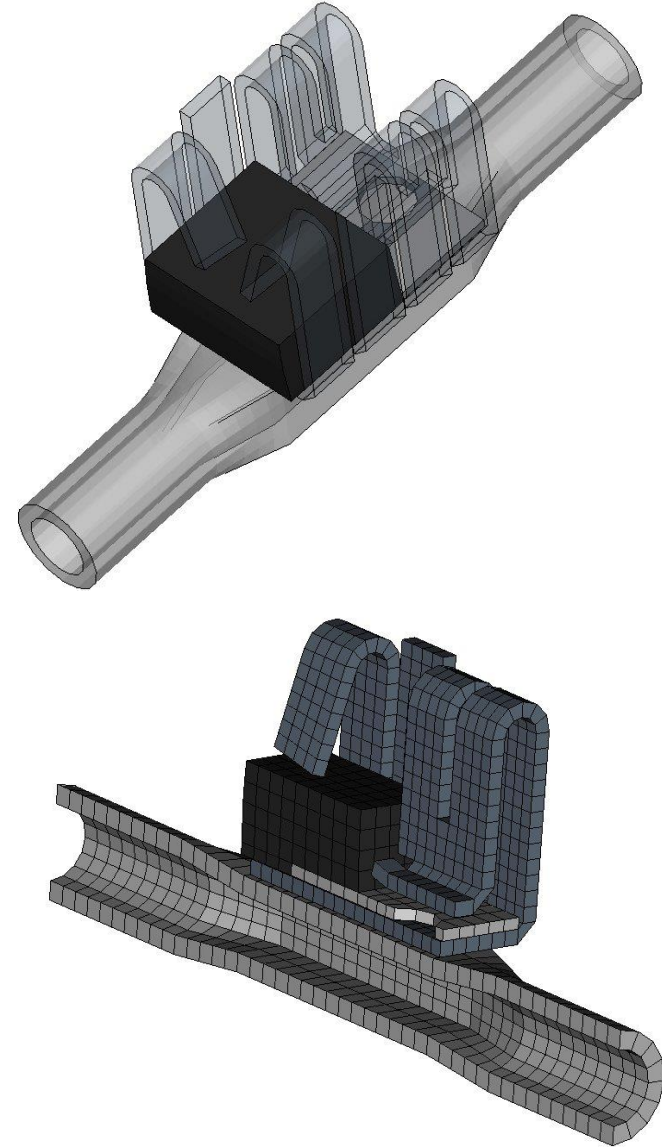
- *CONTROL_THERMAL_TIMESTEP

TS	TIP	ITS	TMIN	TMAX	DTEMP	TSCP	LCTS

- TS Time step control
 - EQ.0: Fixed time step.
 - EQ.1: Variable time step.
- TIP Time integration parameter
 - EQ.0.5: Crank-Nicolson scheme.
 - EQ.1.0: Fully implicit.
- ITS Initial thermal time step

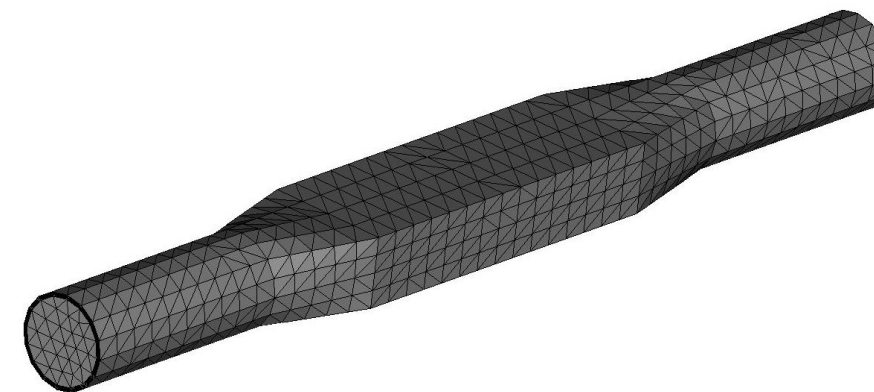
Simulation example

- Small illustration example:
Thermal management of electronic components
 - Transistor with fluid cooling
 - Heat transfer in rigid structure
 - Fluid flow and heat transfer
 - Coarse mesh
- Transistor with volumetric heat source
- Aluminum mount
- Aluminum pipe
- Solid parts connected with
*CONTACT_TIED_SURFACE_TO_SURFACE_THERMAL

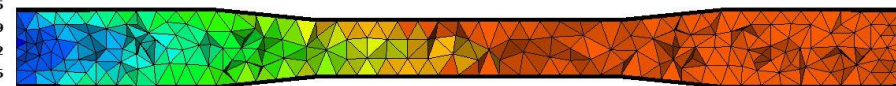
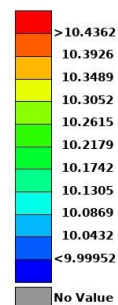


Simulation example

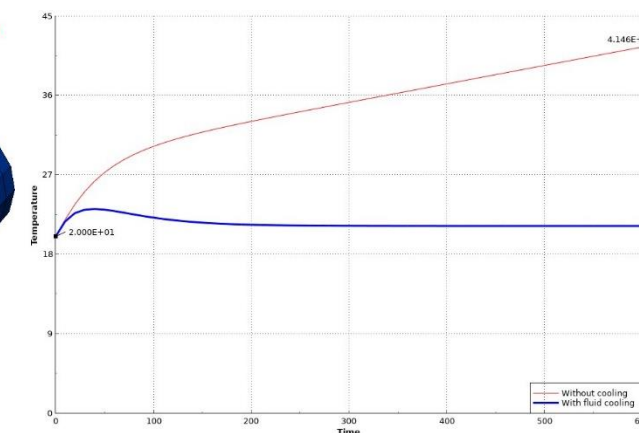
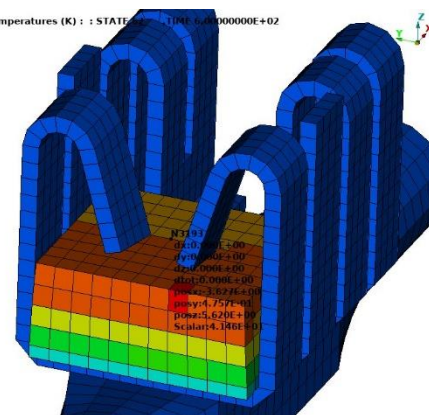
- Fluid flow
 - Water with prescribed inlet velocity and temperature
 - Zero pressure outlet
- Fluid structure coupling at pipe wall
- Possible output
 - Temperature of cooling fluid
 - Steady state temperature in a point of interest
- Simulation time for this example:
8 min on 2 cores



1:d3plot : LS-DYNA keyword deck by LS-PrePost : Scalar: Fluid temperature (K) : : STATE 56 ,TIME 5.4950000E+02



0:d3plot : Scalar: Temperatures (K) : : STATE 56 ,TIME 5.4950000E+02

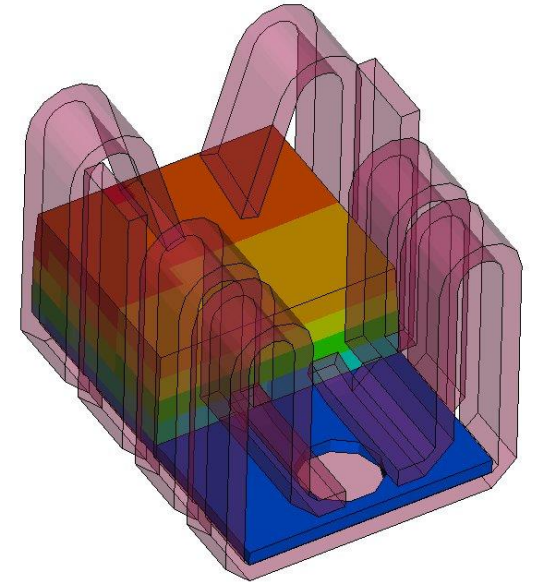


Remarks

- Possible to choose weak or strong coupling between fluid and solid thermal solvers
 - CTYPE on *ICFD_CONTROL_CONJ
- Thermal contact modeling
 - *CONTACT_XXX_THERMAL_XXX between solid parts
- The thermal time scale is often longer than the time scale for the deformation
 - Thermal Speedup Factor
 - Available in solid thermal solver for a long time.
 - Now also available for the ICFD solver. TSF on *ICFD_CONTROL_CONJ
 - Possible to freeze fluid flow simulation when it has stabilized and solve only for heat transfer.
 - Set TDEATH on *ICFD_CONTROL_TIME
- BOUNDARY_CONVECTION and BOUNDARY_RADIATION
- Recent developments for thermal capabilities in the ICFD solver
 - R12 recommended
 - Double precision required

Summary

- CHT simulations in LS-DYNA:
Coupling the ICFD solver with the structural thermal solver
 - Solid capabilities
 - Thermal contacts
 - Radiation losses
 - Analytical expressions for convective and radiative heat loss to the environment
 - BOUNDARY_CONVECTION
 - BOUNDARY_RADIATION
 - Natural convection
- Tool cooling example on Dynaexamples
 - https://www.dynaexamples.com/icfd/beta_examples/cooling



Thank you!



Your LS-DYNA distributor and
more

