Optimization of Process for Part Quality

Autodesk University – Las Vegas, December 2014

Gayle Rose, BD Corporate Computer Aided Engineering, Research Triangle Park, NC
Marcus Rademacher, BD Corporate Computer Aided Engineering, Research Triangle Park, NC
Antonio Mesquita, BD Medical - Process Automation and Development, Franklin Lakes, NJ

Class summary

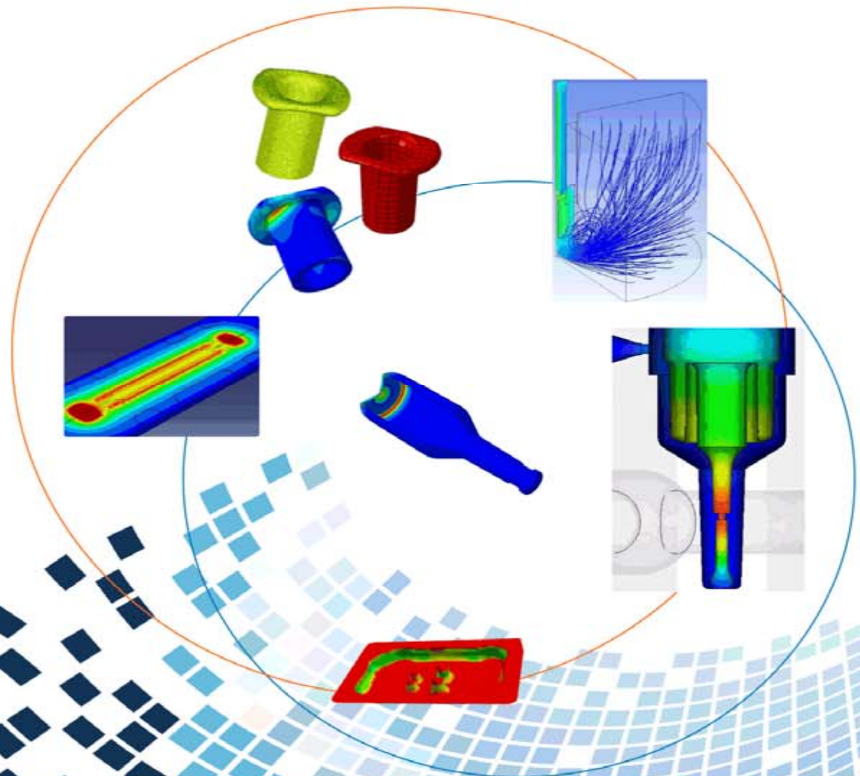
- There are several commercially available optimization software packages on the market. BD has successfully used HEEDS MDO (a multidisciplinary design optimization software package) with Abaqus FEA to drive part design. Now we take the next step: connecting HEEDS MDO with Simulation Moldflow Insight 2015 software to explore process space for optimization and part quality.

Key learning objectives

At the end of this class, you will be familiar with:

- Automation using Simulation Moldflow software's third-party optimization software toolkit
- The differences between optimization and Process Design of Experiments (DOE)
- Enabling efficiency when optimizing part quality and process robustness

Optimization of Process for Part Quality



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Outline

- BD Overview
- Simulation Based Optimization Overview
  - Optimization of Part Design
- Case Study – Plunger Rod
  - Process Design of Experiments (DOE)
  - Using Moldflow's Command Line Utilities
  - Process Optimization
  - Reviewing Results
- Conclusions

BD Overview

- BD is a leading global medical technology company that partners with customers and stakeholders to address many of the world's most pressing and evolving health needs.
- We are focused on improving drug delivery, enhancing the diagnosis of infectious diseases and cancers, supporting management of diabetes and advancing cellular research.

BD Medical

BD Diagnostics

BD Biosciences

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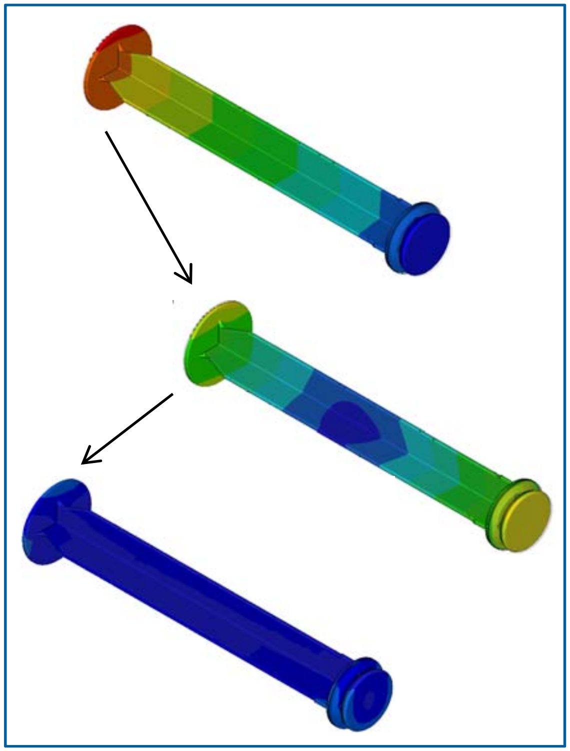
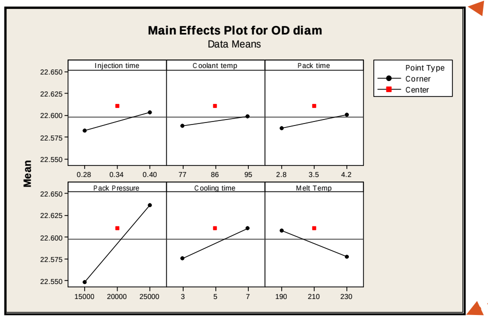
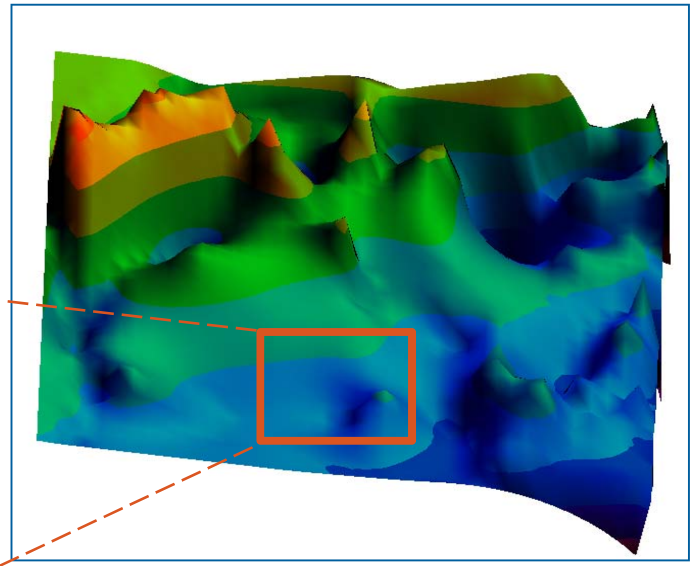
Simulation Based Optimization Overview



Discrete Simulations

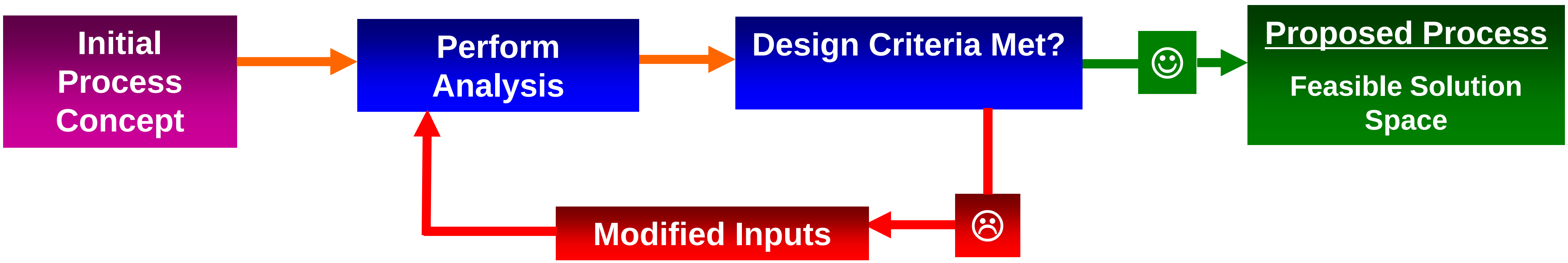


Virtual DOE



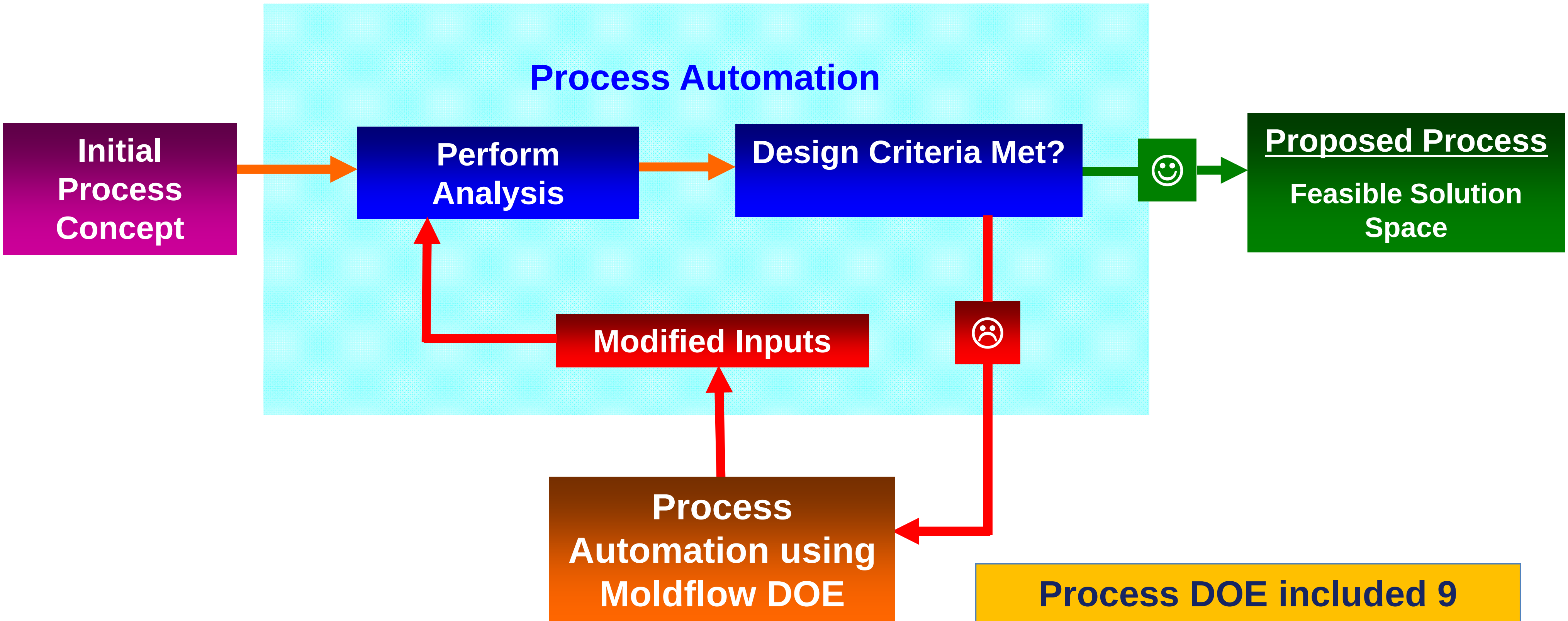
Optimization

Discrete Process



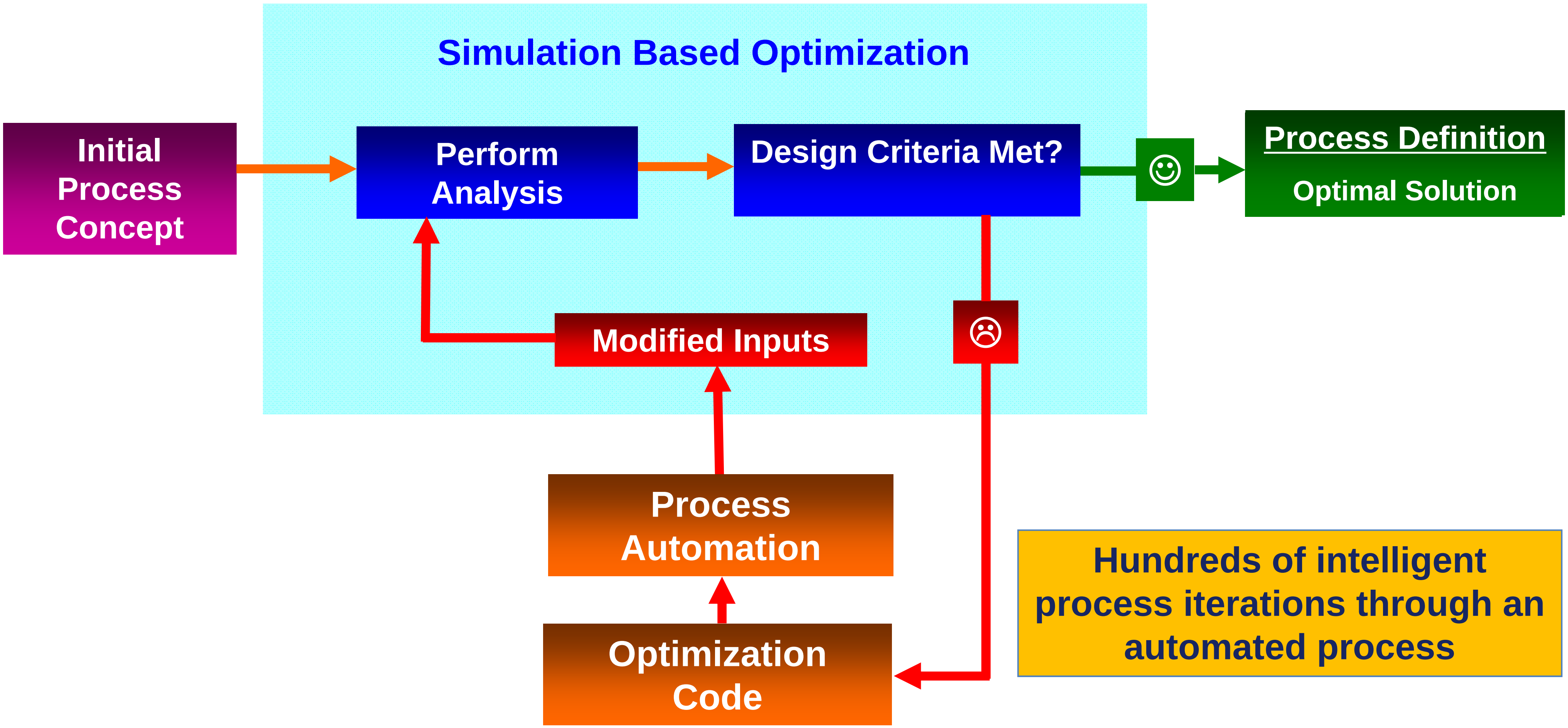
Normal approach would include 3-5 simulations

Virtual Design of Experiments (DOE)

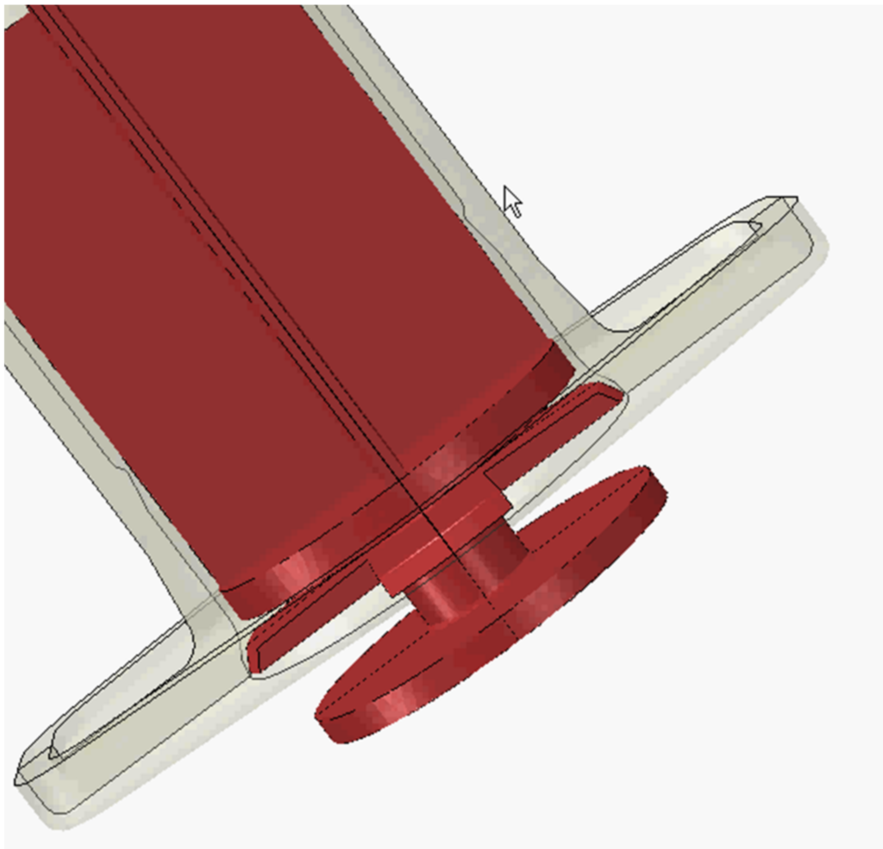


Process DOE included 9 simulations in a limited process window

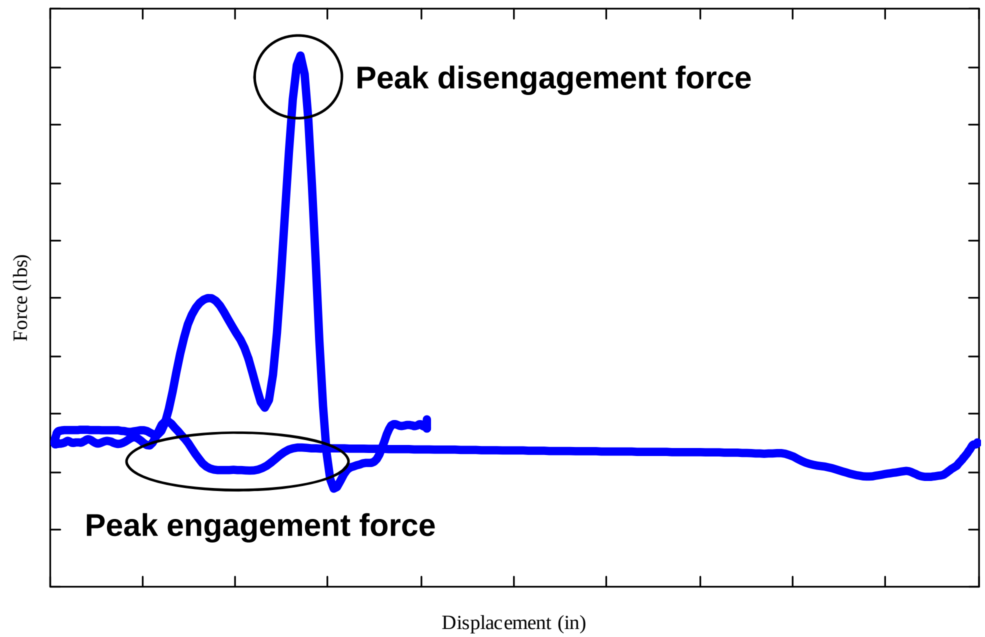
Simulation Based Process Optimization



Optimization of Part Design by BD



- Conflicting criteria: engagement force during assembly and disengagement force to prevent re-use
- A component design that offered very robust engagement behavior was developed using HEEDS
- BD products housing this mechanism have been successfully launched worldwide with significant user acceptance



Why has BD chosen HEEDS?

- **S**imultaneous **H**ybrid **E**xploration that is **R**obust **P**rogressive and **A**daptive (**SHERPA**) was used as the optimization algorithm
- SHERPA uses multiple optimization algorithms at the same time, leveraging the best aspects of each
- You don't have to know which algorithm will work best, because SHERPA will decide
- For BD product development, it has been shown to be effective and efficient

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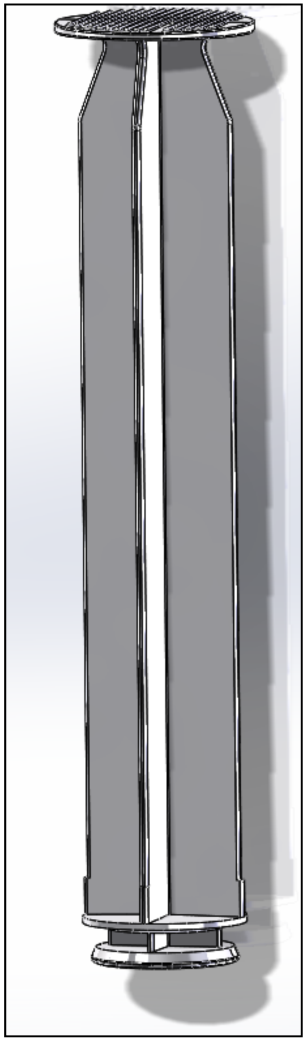
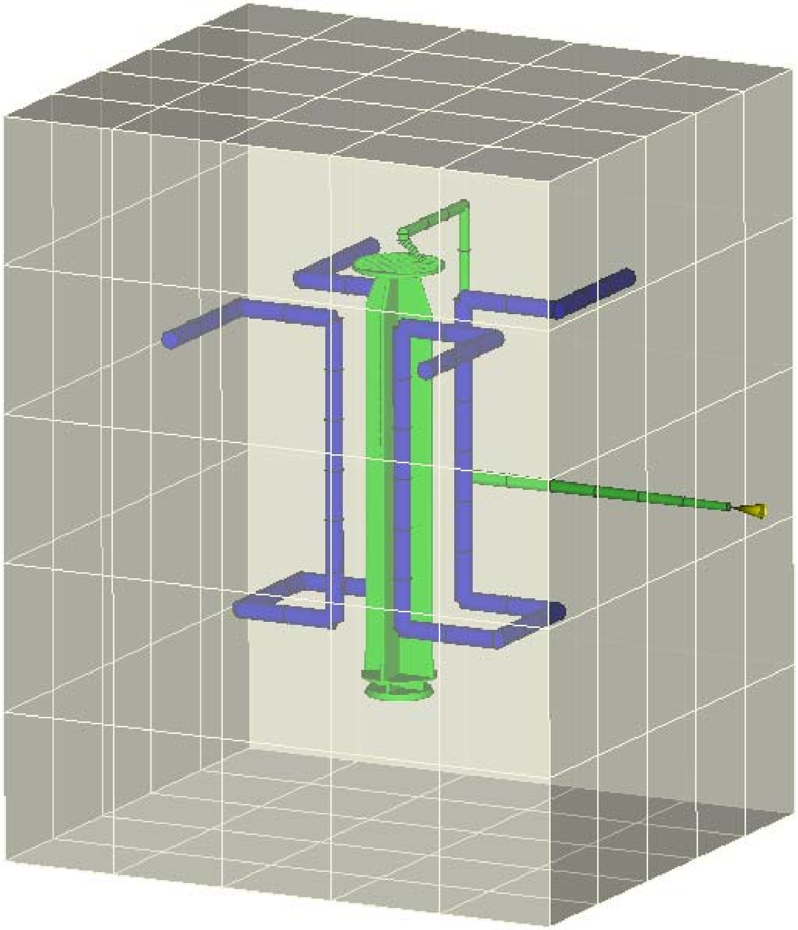
Case Study – Plunger Rod

- An experimental plunger rod mold was utilized to explore the effect of process on dimensional parameters
- Process development using the Moldflow Process DOE and a HEEDS optimization are compared



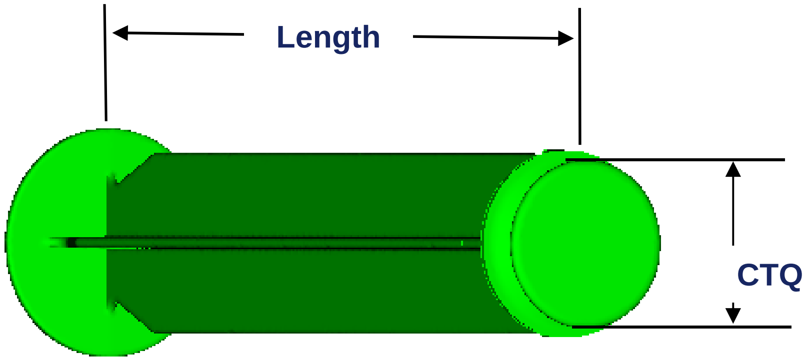
Moldflow model



Experimental and Moldflow Process DOE

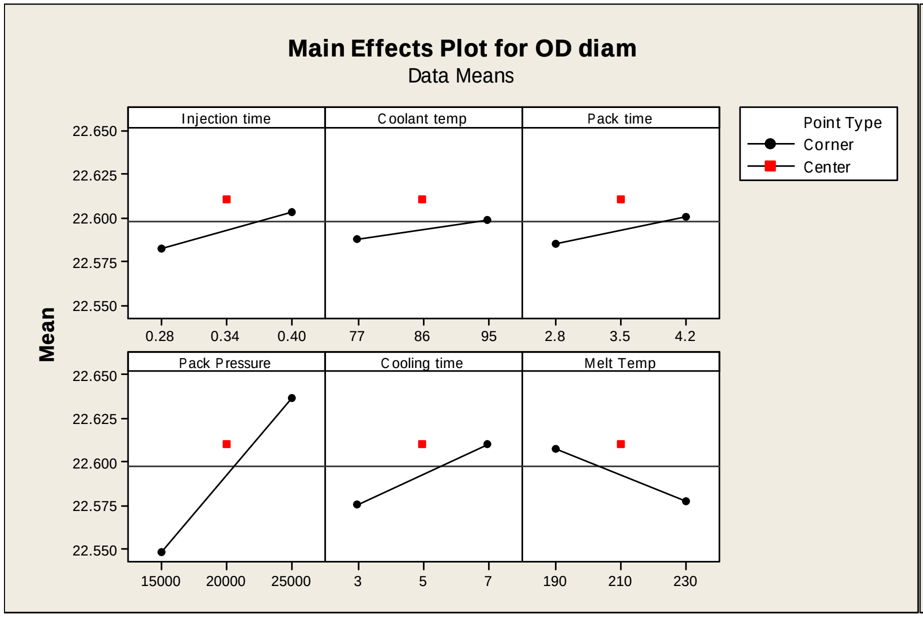
- Variables
  - Injection rate (injection time)
  - Cooling temperature
  - Pack time
  - Pack pressure
  - Cooling time
  - Melt temperature

- Responses
  - CTQ – tip OD
  - Cycle time
  - Total mass

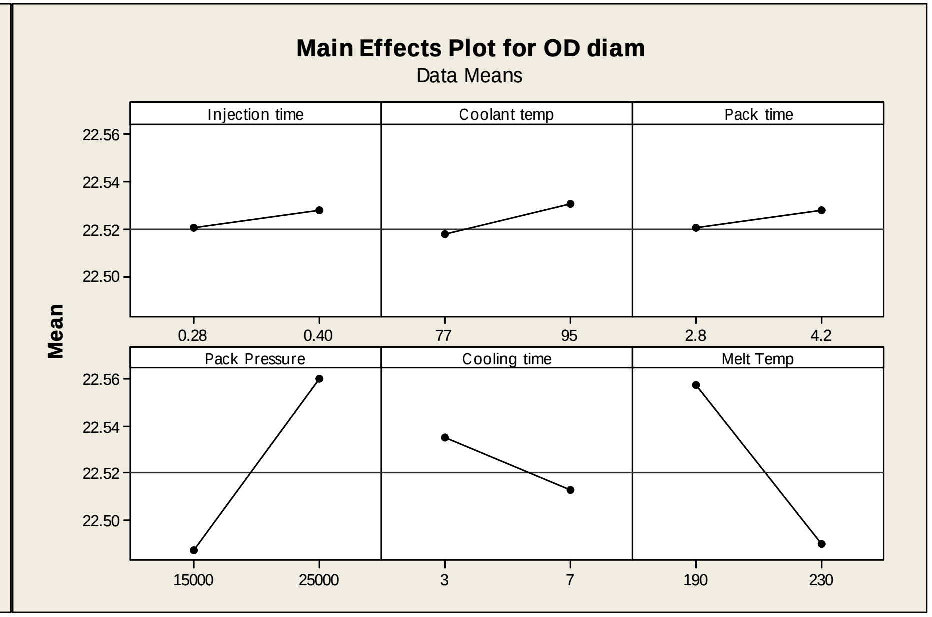


Moldflow DOE Main Effects

Experimental DOE

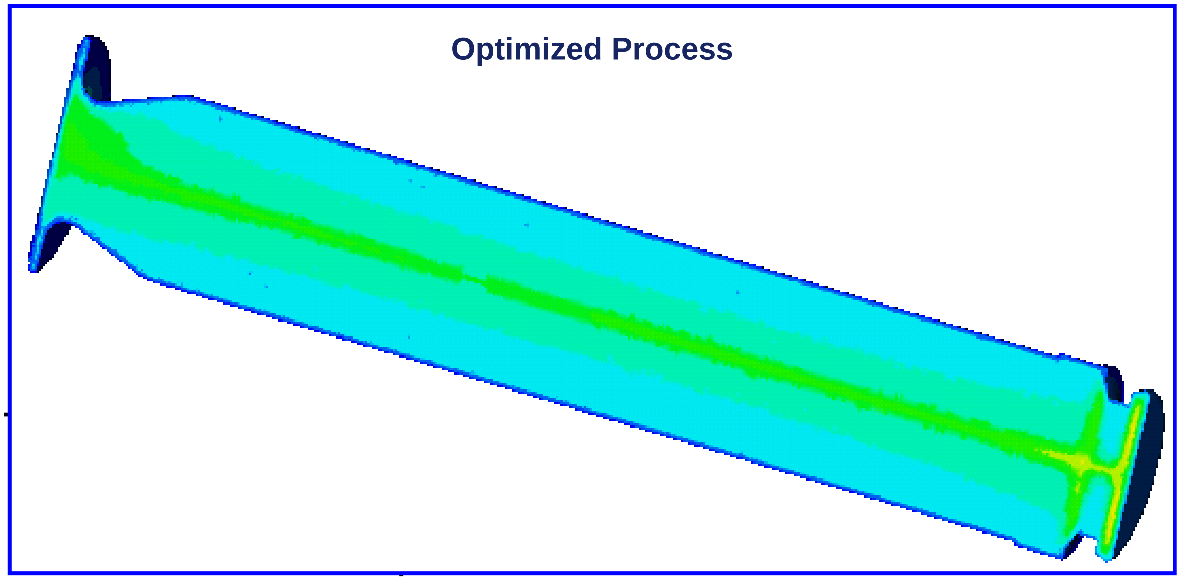


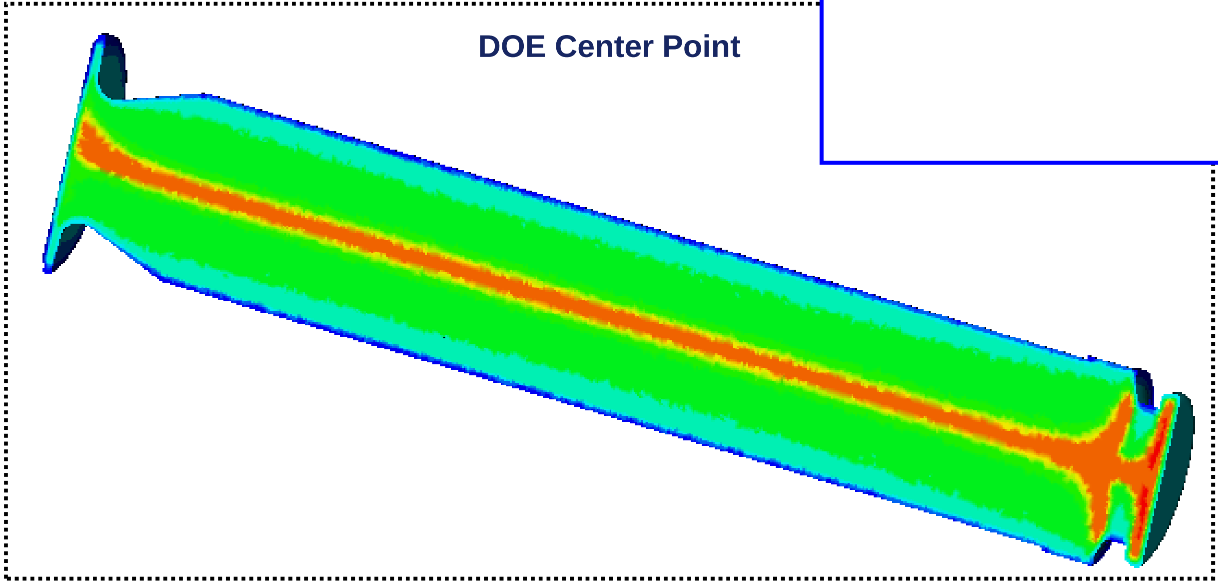
Moldflow Process DOE



- The Experimental DOE included high, low and center points
  – The center point was repeated twice for a total of 11 runs
- The Virtual DOE included 51 runs

Optimization Study Highlights





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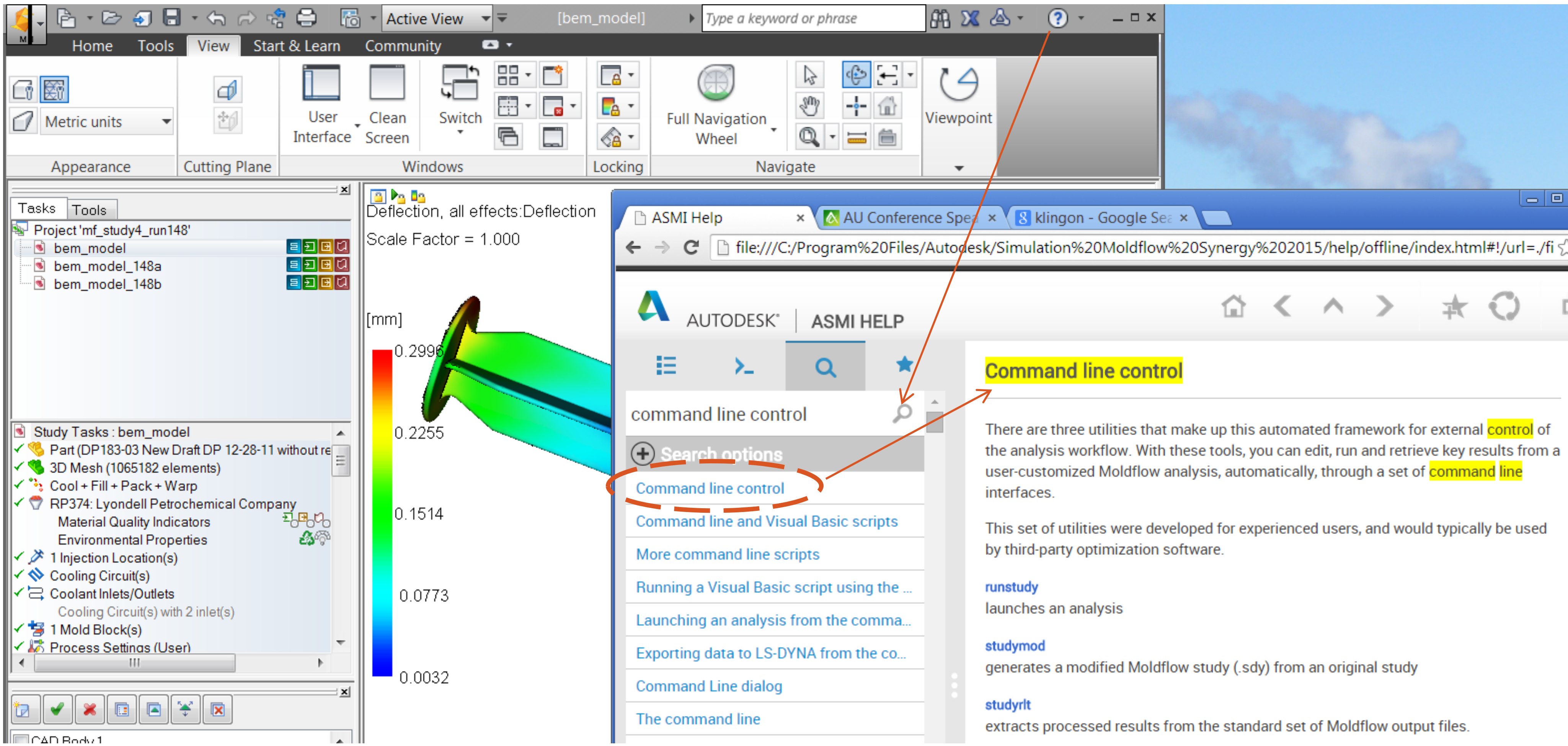
Using Moldflow's Command Line Utilities

- There are three Command Line Utilities needed to drive Moldflow: 'studymod', 'studyrun', and 'studyrlt'
- Implementation of the commands requires some programing skills
- For use with HEEDS, scripts and batch files needed to be developed
  - To get us started, we called in the professionals
- Once the extraction batch file was developed, we were able to add the necessary codes/IDs to expand our input and output lists
- Although functionality of the utilities is well documented in the On-line Help, implementation is not easy

Where to Find Help?



INPUT: Using ‘studymod’ with HEEDS tagging

```
<?xml version="1.0" encoding="utf-8"?>
<StudyMod title="Autodesk Studymod" ver="1.00">
  <UnitSystem>Metric</UnitSystem>
  <Property>
          <TSet>
                  <!--Coolant-->
                  <ID>40020</ID>
                  <SubID>0</SubID>
                  <!--Coolant inlet temperature-->
                  <TCode>
                          <ID>11106</ID>
                         <Value>29</Value>
         </TCode>  </TSet>
         <TSet>
      <!--Process controller-->
      <ID>30011</ID>
      <SubID>0</SubID>
      <!--Melt temperature-->
      <TCode>
        <ID>11002</ID>
        <Value>227</Value>
      </TCode>
      <!--Filling Control 10107 specifies the flow rate value, 10109 - the value 3 sa
      <TCode>
        <ID>10107</ID>
        <Value>39</Value>
      </TCode>
      <TCode>
        <ID>10109</ID>
        <Value>3</Value>
      </TCode>
```

HEEDS edits the inputs to study files via a predefined modification file

OUTPUT: Using ‘studyrlt’ to extract data

extractResults_bem.bat *

```
rem Fill time
studyrlt bem_model.sdy -result 1610 -max -cavity > FillTimeMax.txt

rem Volumetric shrinkage - max
studyrlt bem_model.sdy -result 1620 -max -cavity > ShrinkageMax.txt
studyrlt bem_model.sdy -result 1620 -max -layer headnodes >> ShrinkageMax.txt

rem Volumetric shrinkage - min
studyrlt bem_model.sdy -result 1620 -min -cavity > ShrinkageMin.txt

rem Frozen Volume
studyrlt bem_model.sdy -message 2 300380 0 1 > FrozenVolume.txt

rem Displacement Node 11314
studyrlt bem_model.sdy -result 6250 -node 11314 -component 1 > deflection.txt

rem Displacement Node 10894
studyrlt bem_model.sdy -result 6250 -node 10894 -component 1 >> deflection.txt

rem Displacement Node 10807
studyrlt bem_model.sdy -result 6250 -node 10807 -component 2 >> deflection.txt

rem Displacement Node 11245
studyrlt bem_model.sdy -result 6250 -node 11245 -component 2 >> deflection.txt

rem Displacement Node 27343
studyrlt bem_model.sdy -result 6250 -node 27343 -component 3 >> deflection.txt

rem Displacement Node 491204
studyrlt bem_model.sdy -result 6250 -node 491204 -component 3 >> deflection.txt
```

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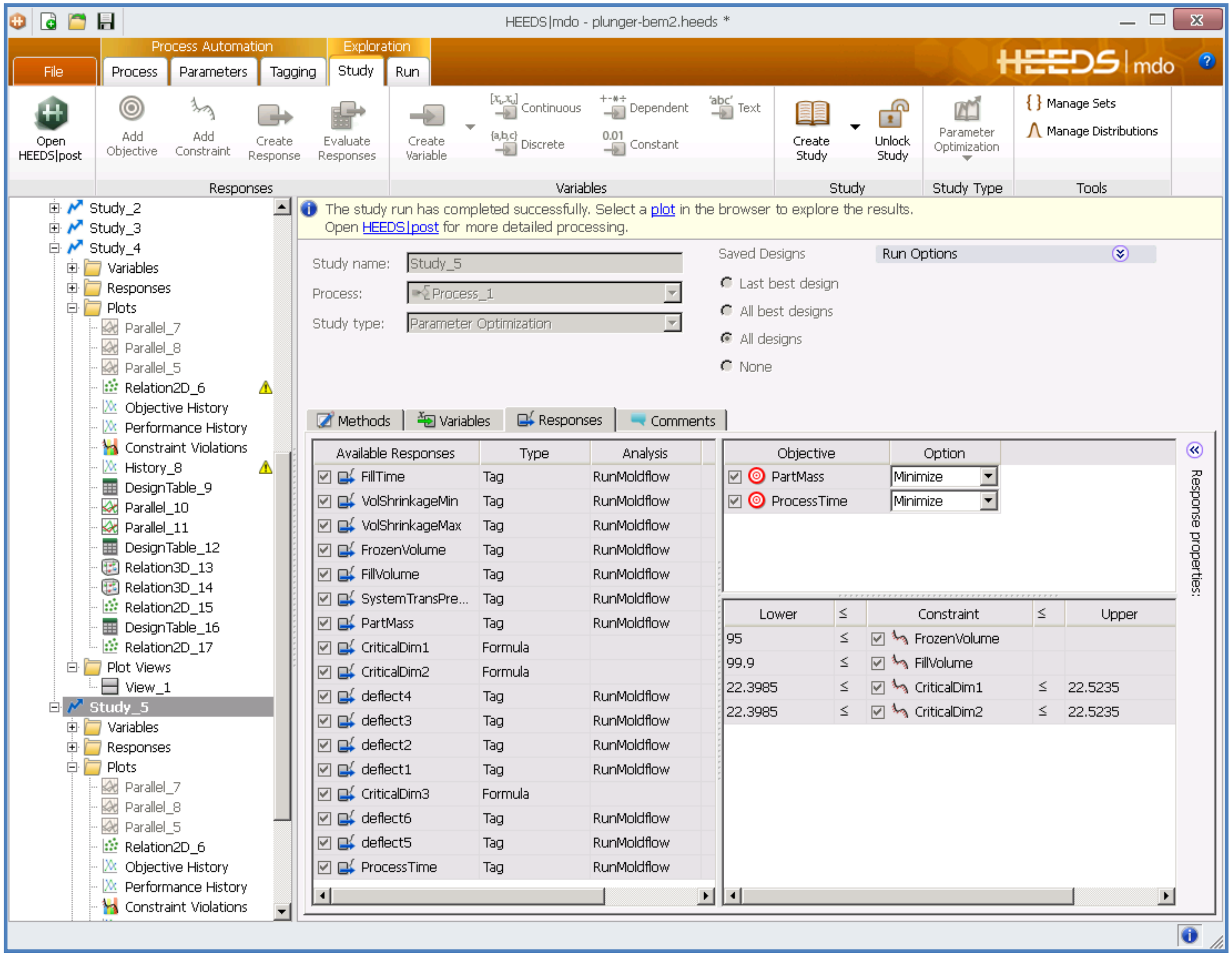
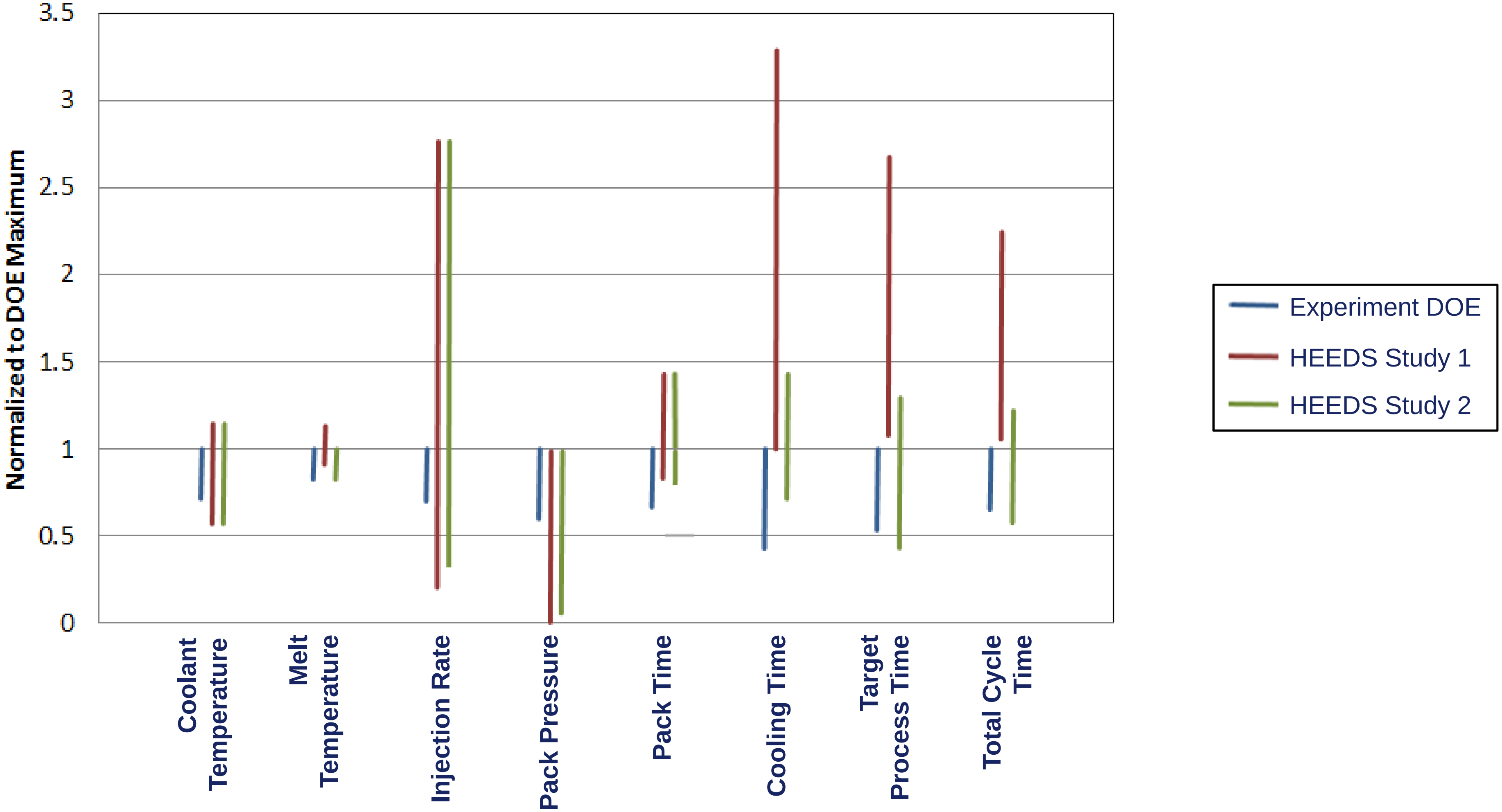
Process Optimization HEEDS GUI



Parameter Ranges – DOE versus Optimization



Optimization Study 1 Details

Variables

- Injection rate (injection time)
- Cooling temperature
- Melt temperature
- Pack time
- Pack pressure (staged cycle)
- Cooling time
- Transfer volume

Constraints

- Tip OD – half of the tolerance range
- 99% frozen volume
- 100% fill volume (no short shot)

Responses

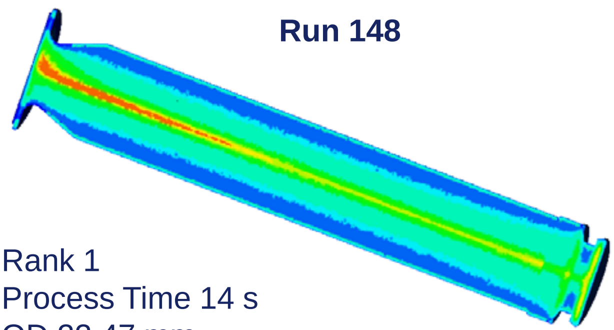
- Critical dimension
- Cycle time
- Total mass
- Fill volume
- Frozen volume

Objectives

1. **Minimize Cycle Time**
2. **Minimize Part Weight**

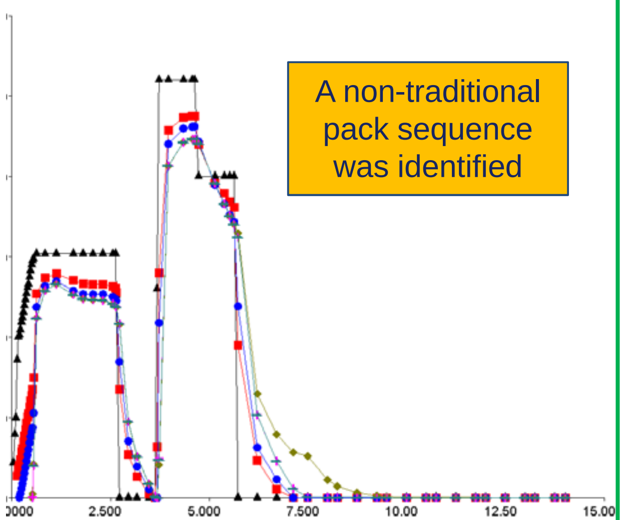
Study 1 Highlights

Run 148



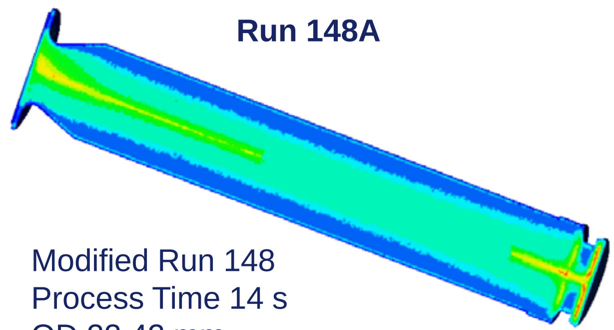
Rank 1
Process Time 14 s
OD 22.47 mm
Weight 10.92 g
Frz Volume 99.0%

Injection time 0.547s



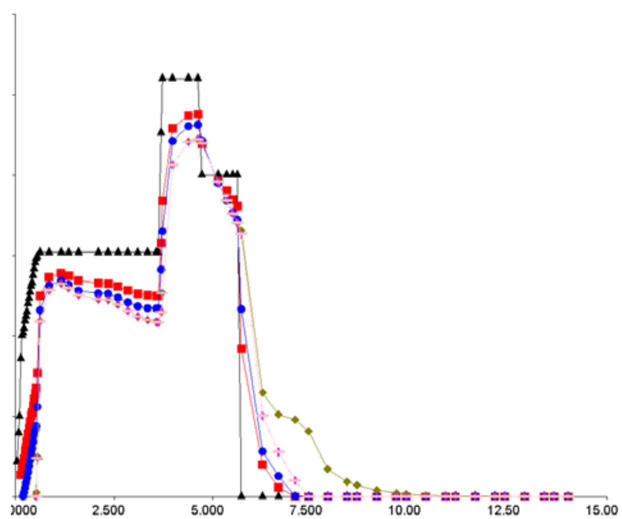
A non-traditional pack sequence was identified

Run 148A

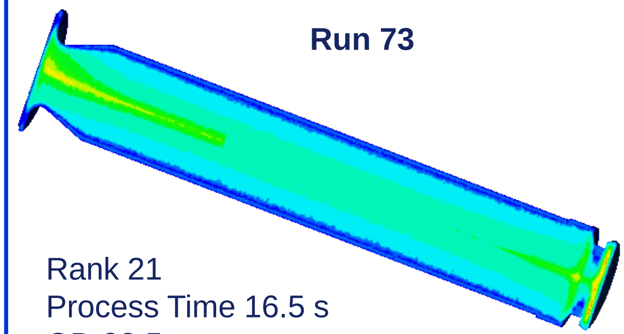


Modified Run 148
Process Time 14 s
OD 22.42 mm
Weight 11.01 g
Frz Volume 99.0%

Injection time 0.547 s

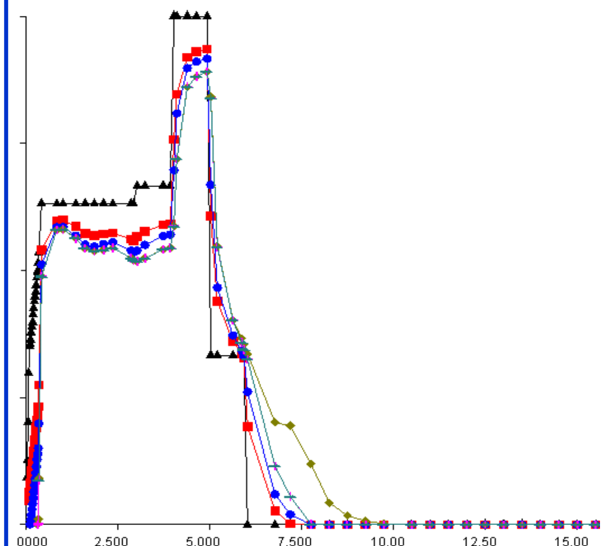


Run 73



Rank 21
Process Time 16.5 s
OD 22.5 mm
Weight 11.00 g
Frz Volume 100%

Injection time 0.363s



Optimization Study 2 Details

Variables

- Injection rate (injection time)
- Cooling temperature
- Melt temperature
- Pack time
- Pack pressure (controlled staged cycle)
- Cooling time
- Transfer volume

Constraints

- Tip OD – half of the tolerance range
- 95% frozen volume
- 100% fill volume (no short shot)

Responses

- Critical dimension
- Cycle time
- Total mass
- Fill volume
- Frozen volume

Objectives

1. **Minimize Cycle Time**
2. **Minimize Part Weight**

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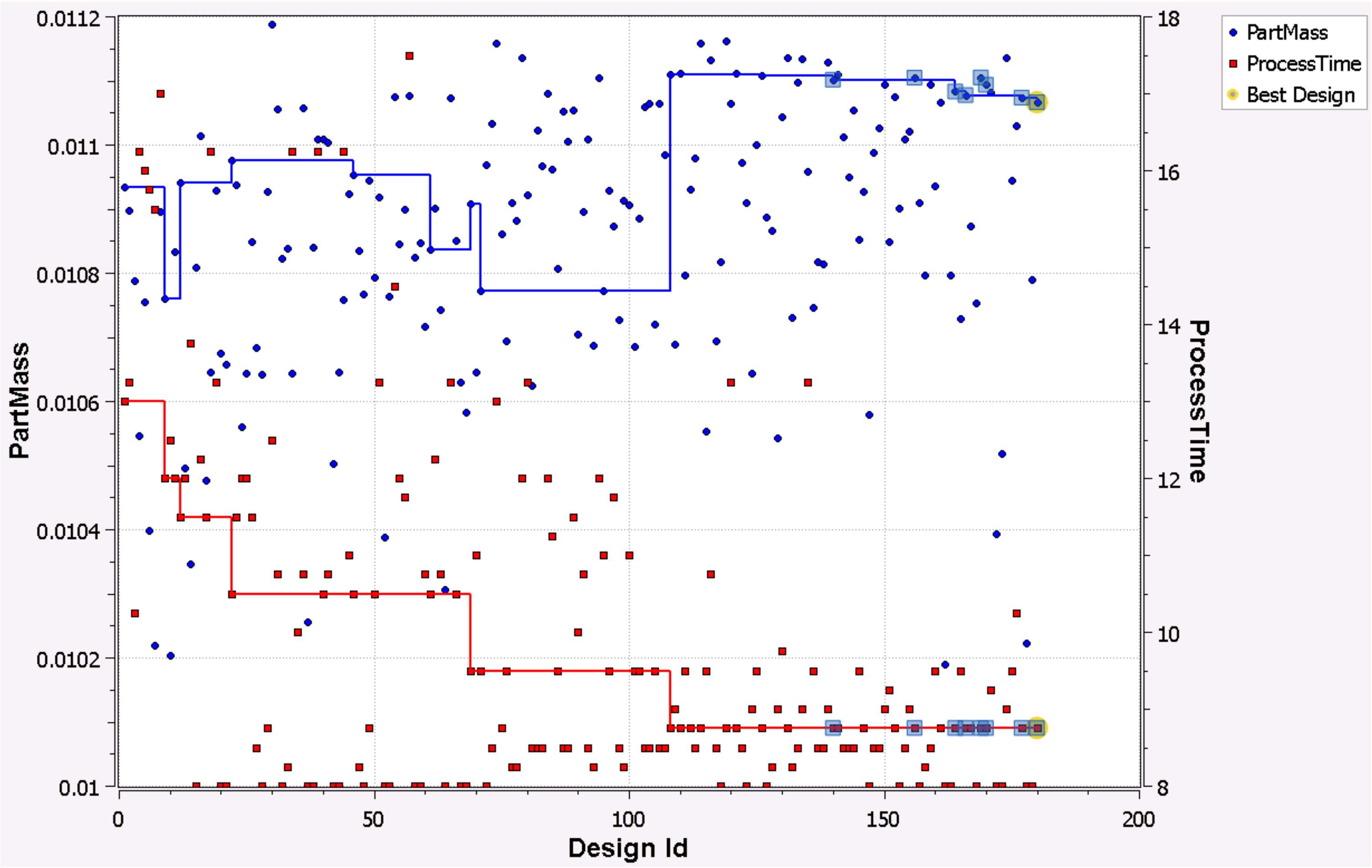
Optimization Conclusion



Improved process time over the DOE Center Point

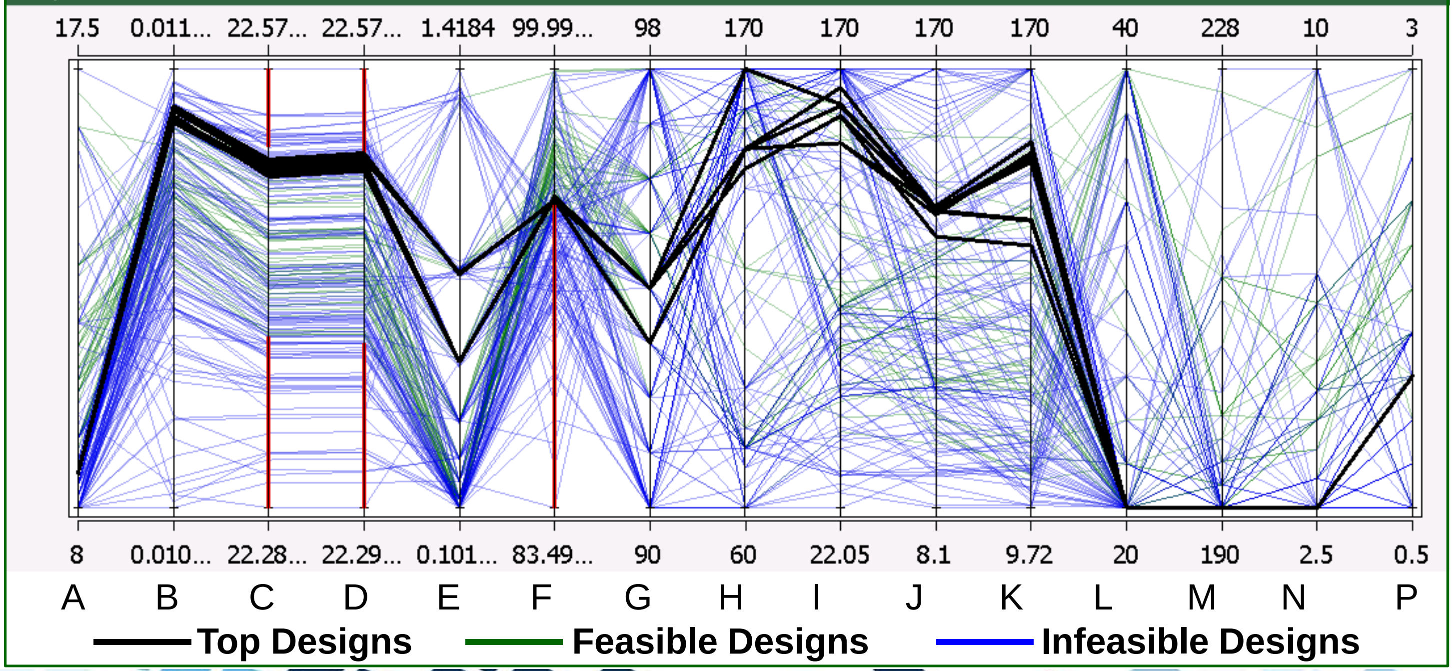
Top Feasible Cases from Study 2

A	Process Time
B	Part Mass
C	Critical Dimension 1
D	Critical Dimension 2
E	Fill Time
F	Frozen Volume
G	Transfer Volume
H	Pack Pressure 1
I	Pack Pressure 2
J	Pack Pressure 3
K	Pack Pressure 4
L	Cooling Temperature
M	Melt Temperature
N	Cooling Time
P	First Stage Time

Study_5: DesignTable_9

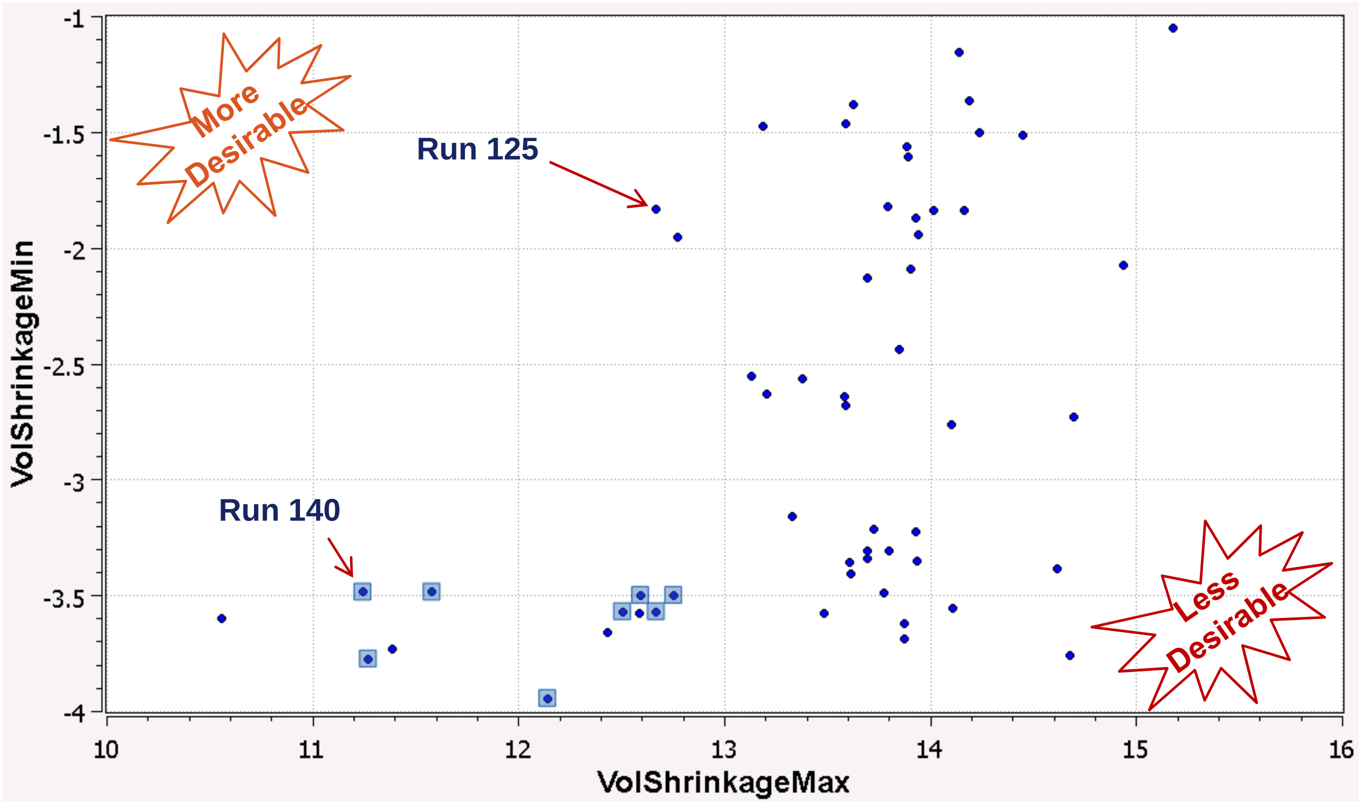
Design Id	Flag	Rank	performance	ProcessTime	PartMass	CriticalDim1	CriticalDim2	CriticalDim3	FillTime	VolShrinkageMin
180	FEASIBLE	1	-2.35829	8.75	0.011066	22.5065	22.5133	146.15	0.539886	-3.49875
177	FEASIBLE	2	-2.35895	8.75	0.0110732	22.5052	22.5123	146.169	0.539886	-3.49875
166	FEASIBLE	3	-2.35932	8.75	0.0110772	22.5086	22.5155	146.178	0.539439	-3.56929
164	FEASIBLE	4	-2.35982	8.75	0.0110827	22.5041	22.5119	146.206	0.539439	-3.56929
170	FEASIBLE	5	-2.36078	8.75	0.0110932	22.5107	22.5181	146.231	0.53782	-3.94384
140	FEASIBLE	6	-2.3615	8.75	0.0111011	22.5134	22.5215	146.258	0.805506	-3.48487
156	FEASIBLE	7	-2.36179	8.75	0.0111043	22.5113	22.5196	146.267	0.805506	-3.48487
169	FEASIBLE	8	-2.36182	8.75	0.0111046	22.5154	22.5235	146.266	0.800843	-3.77369
126	INFEASIBLE	9	-2.36217	8.75	0.0111077	22.5167	22.5248	146.272	0.803855	-3.72954
108	INFEASIBLE	10	-2.3622	8.75	0.0111087	22.5158	22.5239	146.282	0.803855	-3.91258

Study_5: Parallel_10



Top Feasible Cases – Evaluating Quality

- **Minimize** VolShrinkageMax – better part quality
- **Maximize** VolShrinkageMin – better ejection
- Comparing maximum to minimu values helps identify best solutions

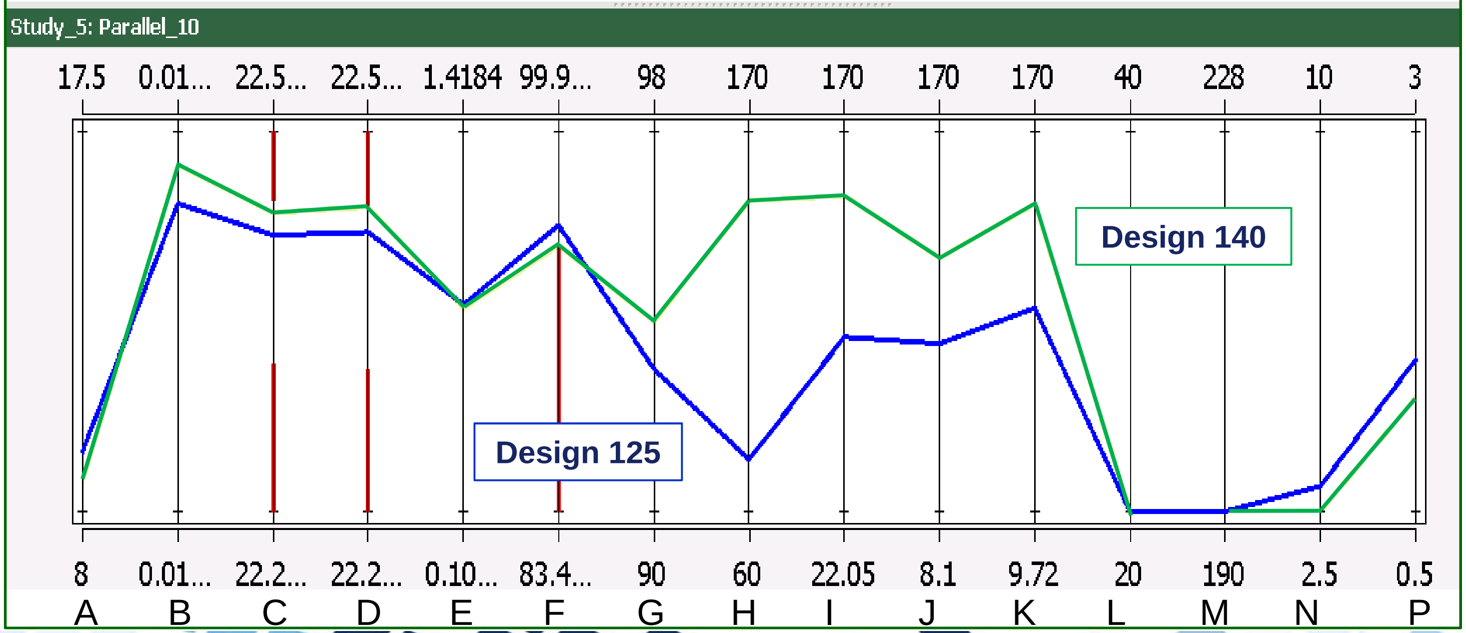


Two Cases from Study 2

A	Process Time
B	Part Mass
C	Critical Dimension 1
D	Critical Dimension 2
E	Fill Time
F	Frozen Volume
G	Transfer Volume
H	Pack Pressure 1
I	Pack Pressure 2
J	Pack Pressure 3
K	Pack Pressure 4
L	Cooling Temperature
M	Melt Temperature
N	Cooling Time
P	First Stage Time

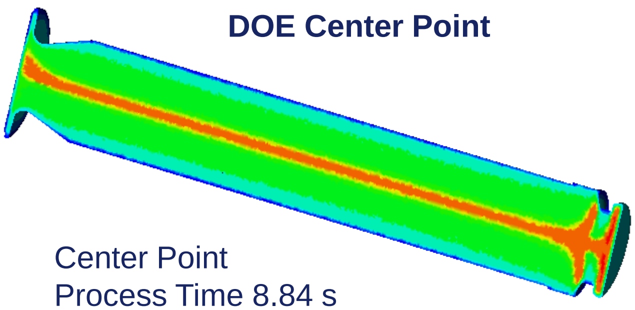
Study_5: DesignTable_9

Design Id	Flag	Rank	performance	ProcessTime	PartMass	CriticalDim1	CriticalDim2	CriticalDim3	FillTime	VolShr
180	FEASIBLE	1	-2.35829	8.75	0.011066	22.5065	22.5133	146.15	0.539886	-3.49
177	FEASIBLE	2	-2.35895	8.75	0.0110732	22.5052	22.5123	146.169	0.539886	-3.49
166	FEASIBLE	3	-2.35932	8.75	0.0110772	22.5086	22.5155	146.178	0.539439	-3.56
164	FEASIBLE	4	-2.35982	8.75	0.0110827	22.5041	22.5119	146.206	0.539439	-3.56
170	FEASIBLE	5	-2.36078	8.75	0.0110932	22.5107	22.5181	146.231	0.53782	-3.94
140	FEASIBLE	6	-2.3615	8.75	0.0111011	22.5134	22.5215	146.258	0.805506	-3.48
156	FEASIBLE	7	-2.36179	8.75	0.0111043	22.5113	22.5196	146.267	0.805506	-3.48
169	FEASIBLE	8	-2.36182	8.75	0.0111046	22.5154	22.5235	146.266	0.800843	-3.77
125	FEASIBLE	28	-2.4676	9.5	0.0109996	22.4963	22.5025	146.049	0.818803	-1.833

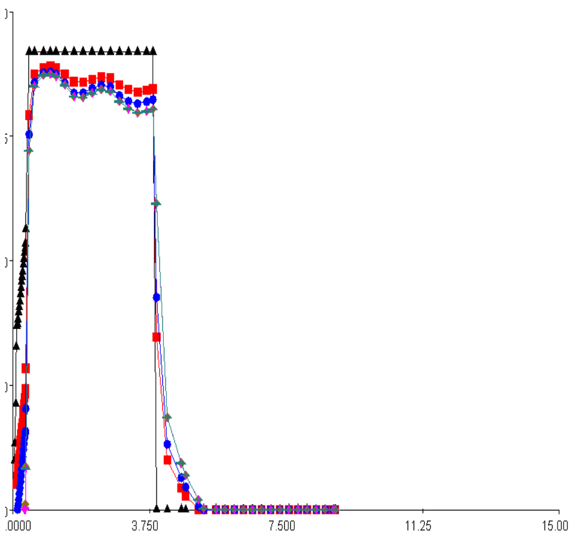


Study 2 Highlights and Improvements

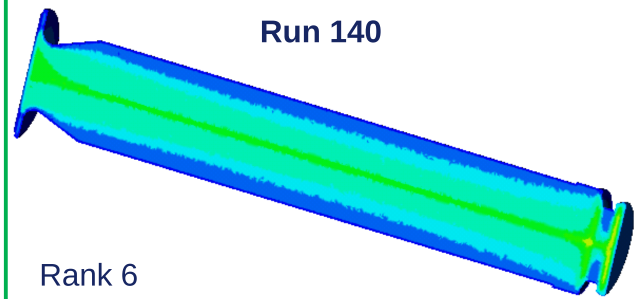
DOE Center Point



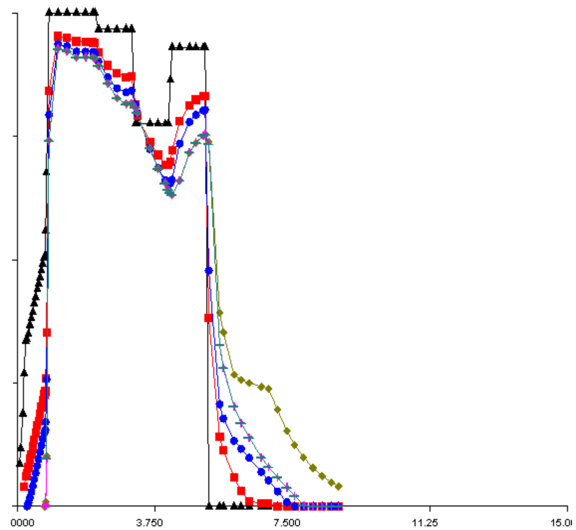
Center Point
Process Time 8.84 s
OD 22.33 mm
Weight 10.69 g
Frz Volume 88.9%   Injection time 0.34s



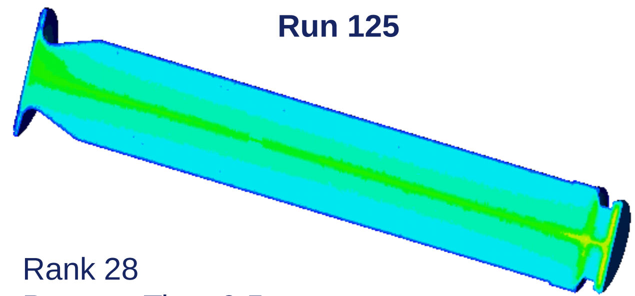
Run 140



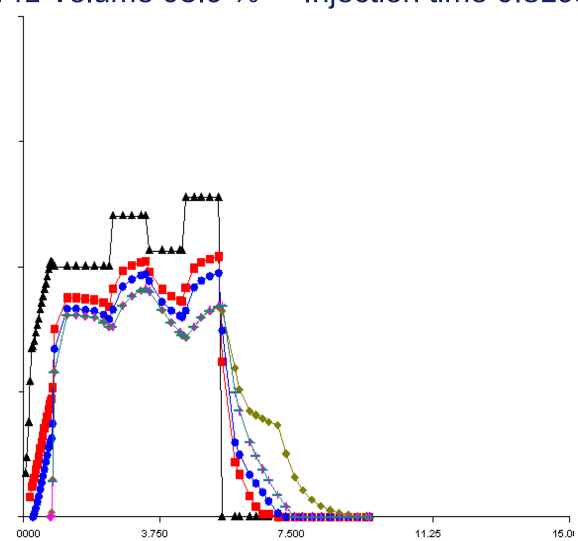
Rank 6
Process Time 8.75 s
OD 22.52 mm
Weight 11.10 g
Frz Volume 95.0 %   Injection time 0.806s



Run 125



Rank 28
Process Time 9.5 s
OD 22.50 mm
Weight 11.00 g
Frz Volume 95.9 %   Injection time 0.819s



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Conclusions

- Optimization with a third party software package is made possible via the Moldflow Command Line Utilities
  - User needs some level of programing or scripting capability for success
- Optimization using HEEDS allows the full exploration of a process space to maximize the objectives
  - SHERPA makes decisions for optimization algorithm for efficiency
  - Responses and the interactions are fully explored
  - More input and output options are available
  - Enables decisions with a wide range of feasible solutions
- Optimization resulted in a better process
  - Shorter overall cycle time
  - Increased potential to achieve critical dimension range
  - Better part quality
- We plan to leverage this new optimization method on actual BD processes

Questions?

Thank you for your time.

Automation Overview and Update

Autodesk Simulation Moldflow Insight

Dr. Franco Costa

Senior Research Leader, DLS Simulation (Moldflow)

Class summary

Autodesk provides a number of automation tools to assist with the integration of the Autodesk Moldflow Insight product into 3rd party Optimization packages.

This Presentation provided a basic description of these tools and utilities.

Key learning objectives

At the end of this class, you will be able to:

- Understand how the tools provided can assist integration into 3rd party optimization tools

- Understand the capabilities of the studymod utility
- Understand the capabilities of the runstudy utility
- Understand the capabilities of the studyrlt utility

- Understand how recent changes to the synergy API can assist

Automation Tools in Moldflow Insight

Command Line Tools

- Studymod
- Runstudy
- StudyRlt

- Windows and Linux

Synergy API

- All pre-process functionality
- All results viewing, manipulation & export
- Create custom results

- Windows Only

Studymod

- A tool used to generate a study with modified geometry, boundary conditions and process parameters from an existing Autodesk Moldflow Insight study *(.sdy)* file.
- Command Line Tool
  - Easy integration in external tools
  - Available on Windows and Linux
  - XML based format
  - Allows multiple changes

Studymod

- To modify an existing study

  studymod <original.sdy> <modified.sdy> <mychanges.xml>

- Formats are described in the Help “Command Line Control”

- Changes planned for the 2016 Release.
  - The ability to change the tcode description
  - Better Error Checking
  - Greatly Improved Documentation and Examples

Note: Some knowledge of Autodesk Moldflow Insight study *(.sdy)* file is required.

Studymod

There are four basic sections in the modifier file:

Section	XML tag	Description
Boundary condition	<BoundaryCondition> </BoundaryCondition>	For changes to the analysis boundary conditions. • · injection locations, • · coolant inlets, • · warpage constraints.
Mesh	<Mesh></Mesh>	For including mesh data to replace the original mesh data.
Properties	<Property></Property>	For changes specific to analysis properties.
Material	<Material></Material>	For changing the material used in the study.

Runstudy

- A tool to launch the simulation defined in an Autodesk Moldflow Insight study *(.sdy)* file.
- Command Line Tool
  - Easy integration in external tools
  - Available on Windows and Linux
- To launch an Autodesk Moldflow Insight study *(.sdy)* file.

runstudy [-project project_file] [-temp temp_dir] [-keeptmp] <Study.sdy>

StudyrIt

- A tool to extract result and study data from Autodesk Moldflow result files.
- Extracts Study/Result data for direct use or for further processing
- Command Line Tool
  - Easy integration in external tools
  - Available on Windows and Linux

StudyrIt

- To extract a numerical value for a result set

```
studyrlt <study> -result <result ID>
        -min|-max|-average|-stddev|-count|-node <node number>|-element <element number>
        [-layer <layer name>|-cavity|-gate|-runner|-sprue]
        [-component <number> [-anchor <node1> <node2> <node3>]
        [-unit SI|Metric|English]
```

- To extract a numerical value from the screen output

```
studyrlt  <study> -message <sequence>  <message ID> <occurrence> <item>
        [-unit SI|Metric|English]
```

Studyrlt

- To extract the summary Information to a text file

  studyrlt <study> -exportoutput [<sequence>] [-output <filename>] [-unit SI|Metric|English]

- To extract a result to an XML file

  studyrlt <study> -xml <result ID>

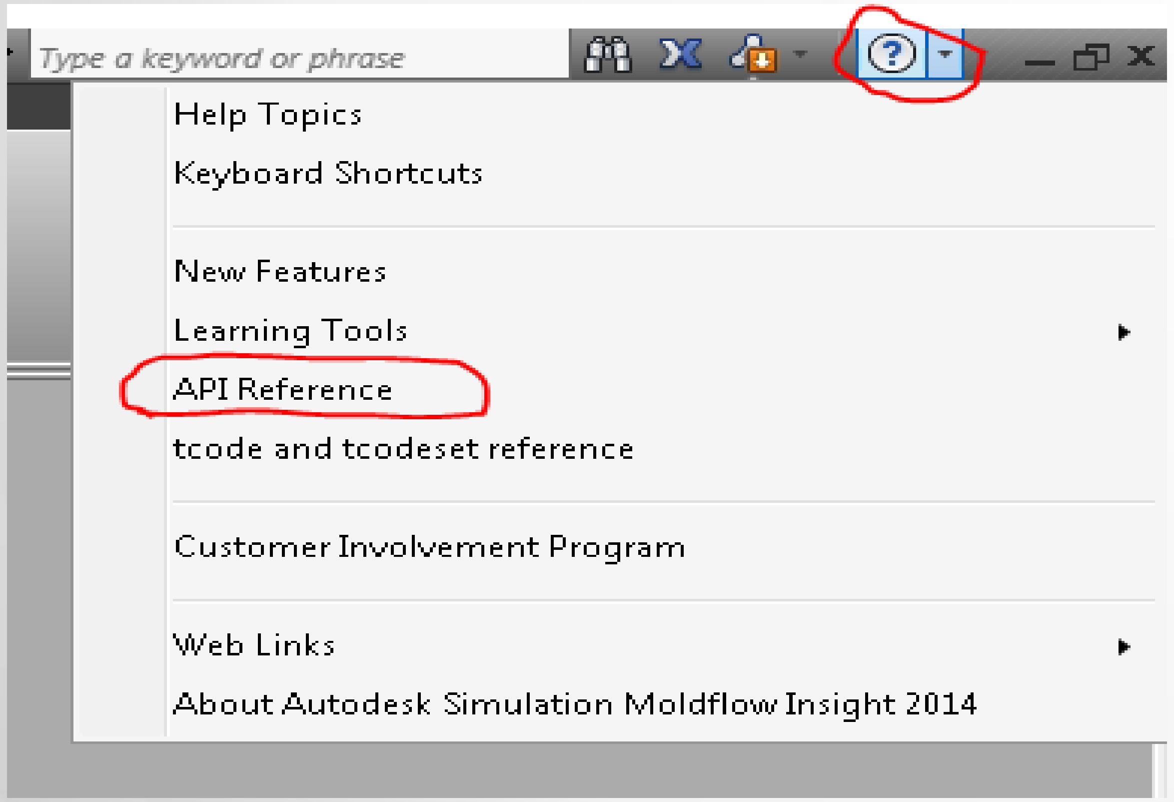
- To export the study file (.sdy) in Patran format

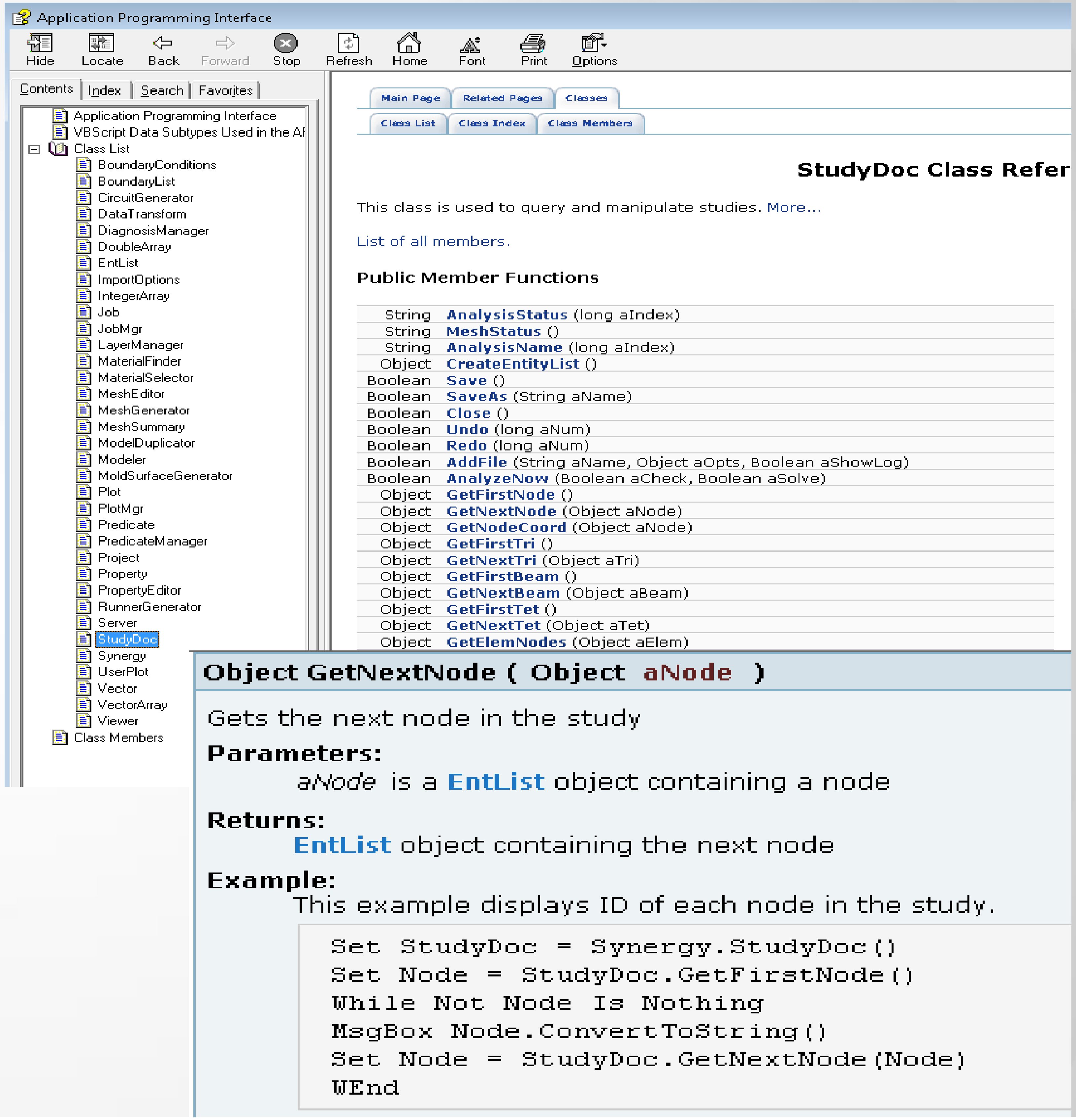
  studyrlt <study> -exportpatran

Note: Some knowledge of Autodesk Moldflow Insight study *(.sdy)* file is required.

The Synergy API

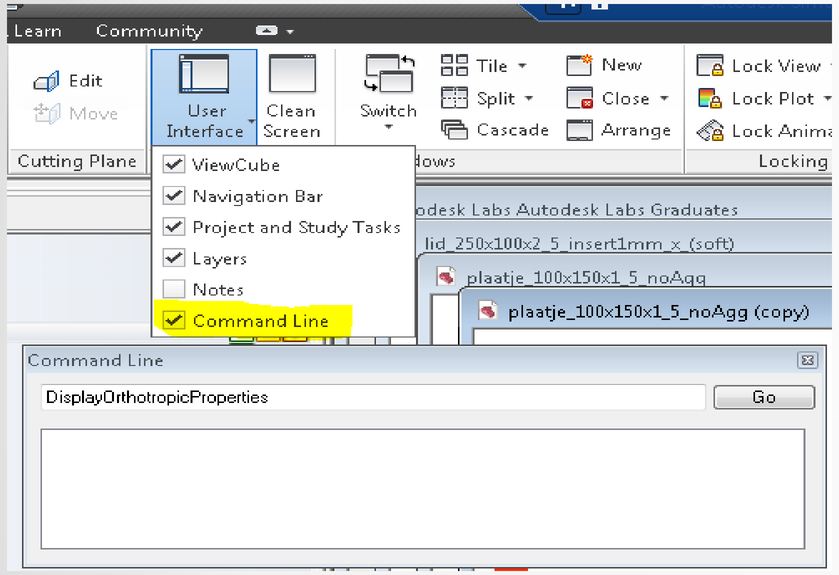
- COM objects
- VBS, Python, Perl, C++
- Documented in-product
- Record Macros to learn

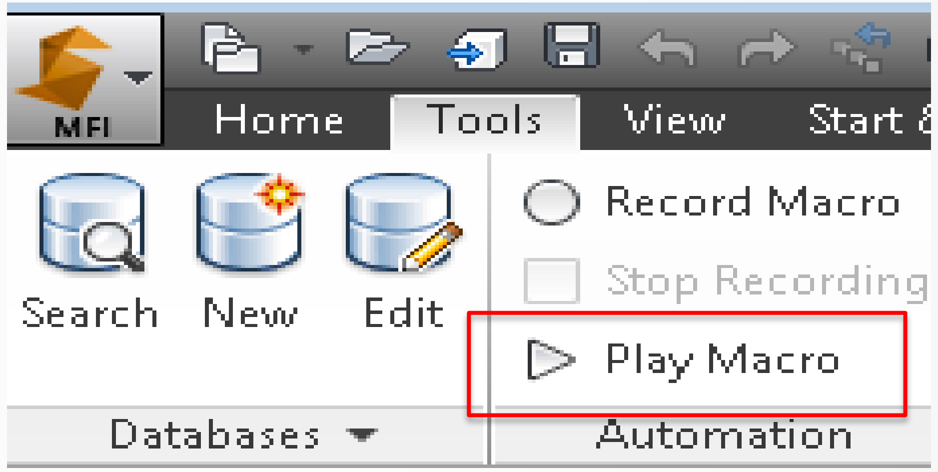




Invoking the Moldflow API

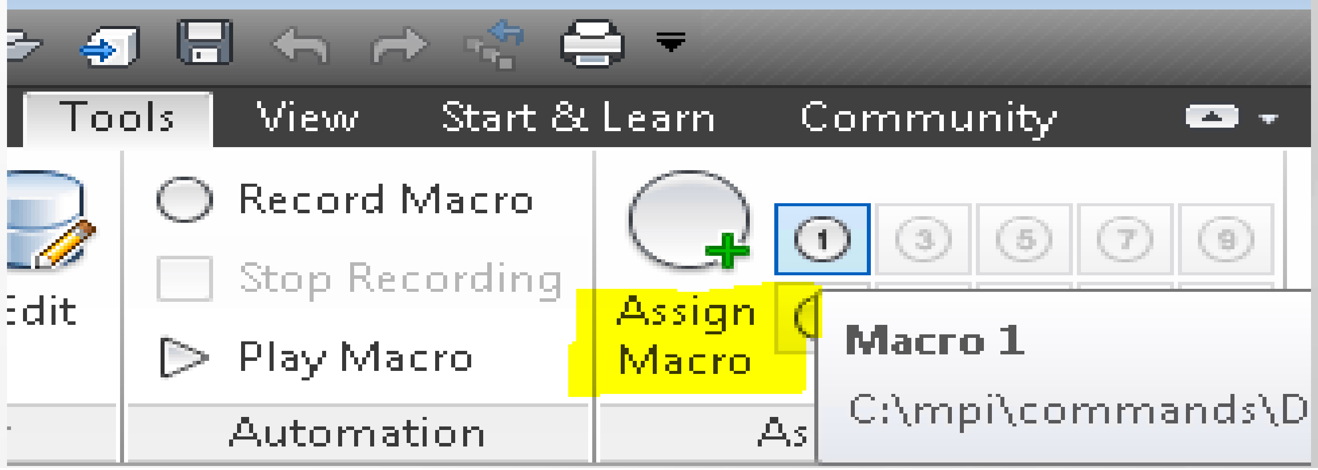
- VBS scripts can be launched from inside Moldflow Synergy
  - Command line or Play Macro



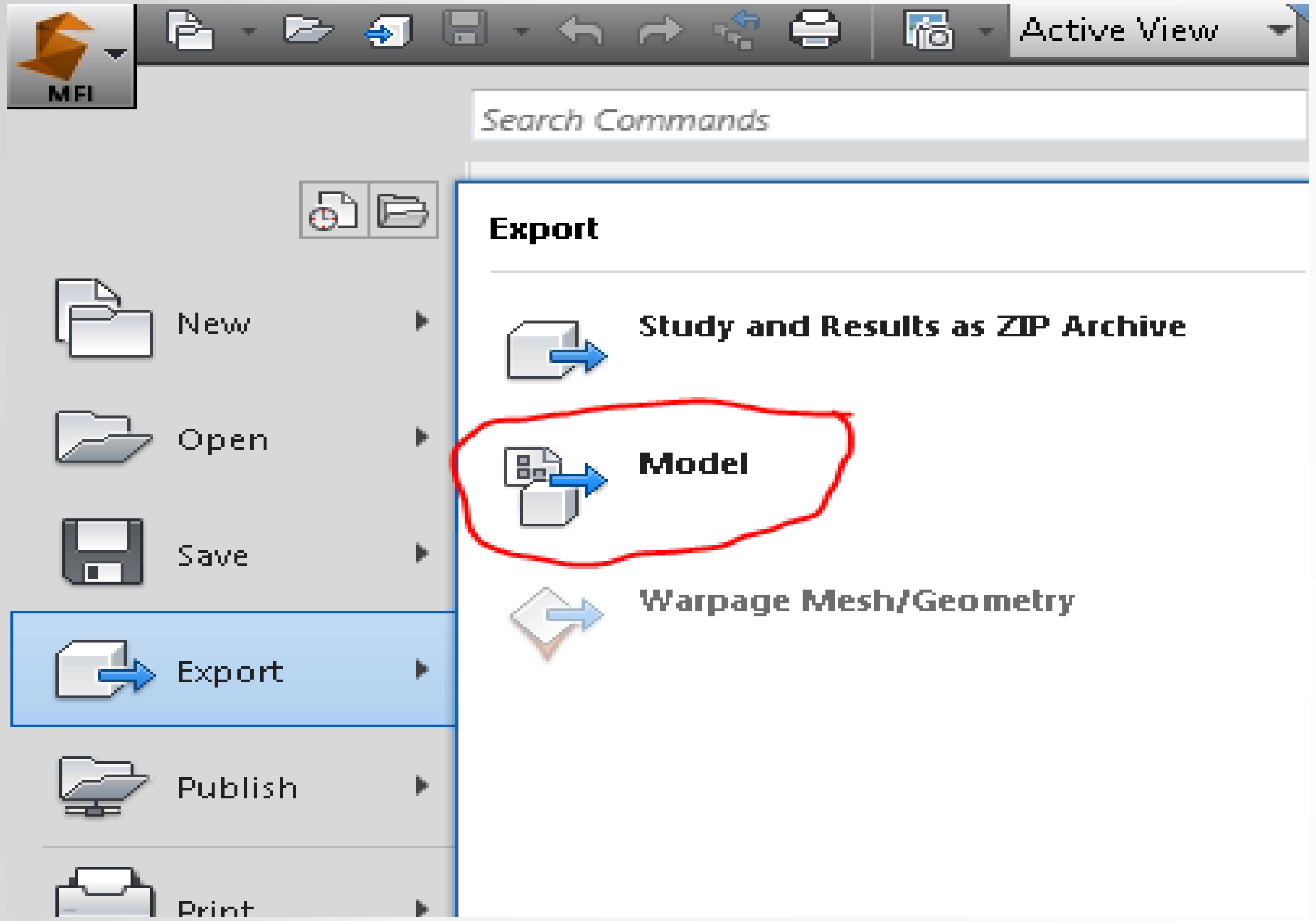


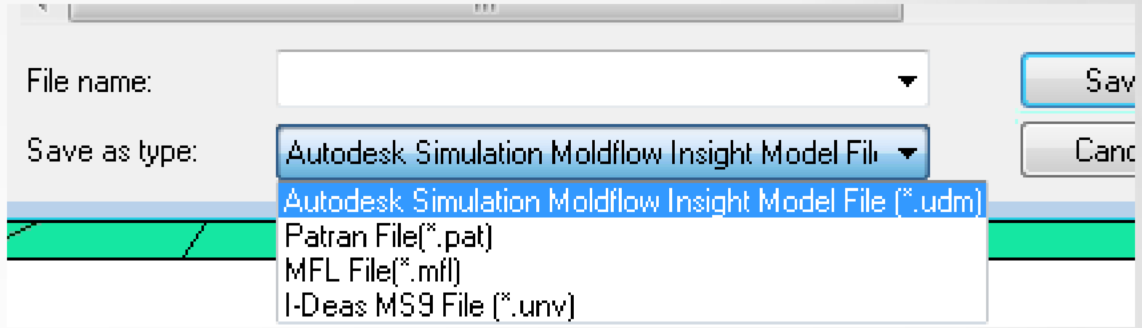
Can automate analysis setup and launch through API

- All scripts & programs can be:
  - Mapped to a button
  - Launched externally
    - Can start Synergy



Extracting Mesh Data - Manually



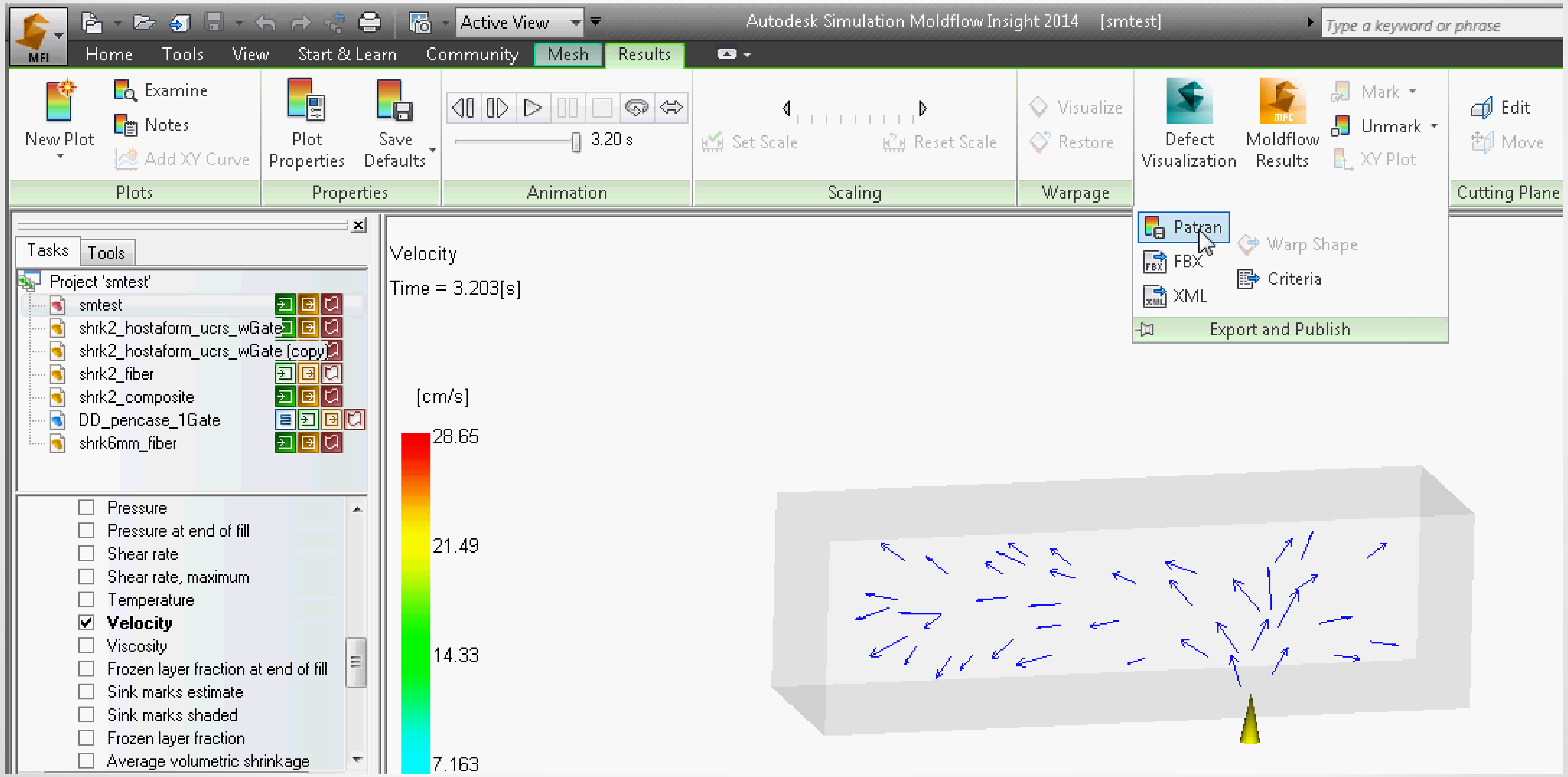


- Patran or UNV formats are solely mesh files
- UDM also includes attributes

SetOrthotropicProperties.vbs includes an example of reading the udm mesh information back into a script. In Moldflow 2016 Beta, or http://autodesk.typepad.com/beyondmoldflowinsight/2014/10/script-update-for-moldflow-2015-sp12-available.html

Extracting Result Data - Manually

- Select a result and export to a Patran file



Use API to write text files for mesh and results

- Get the same outcome as manually writing the files

Boolean ExportModel (String aFile)

Exports current study into a file

Parameters:
aFile name of file

Returns:
True if successful; False otherwise

Note: The format of the exported file is automatically determined from the file extension

Example:
This example exports the current model into an mfl file.

```
Set Project = Synergy.Project()
Project.ExportModel "C:\My MPI 4.0 Pr
```

Boolean SaveResultDataInPatran (long aDataID, String aFileName, String aUnitSysName)

Save result data in Patran file with given unit

Parameters:
aDataID result data ID
aFileName Patran file name
aUnitSysName Unit name, Metric or English

Returns:
True if successful

Example:
This example save result 1180 into "d:\temp\pressure"

```
Set PlotMgr=Synergy.PlotManager()
PlotMgr.SaveResultDataInPatran 1180, "d:\temp\pressure", "Metric"
```

Velocity has result ID 1750

API access to result data

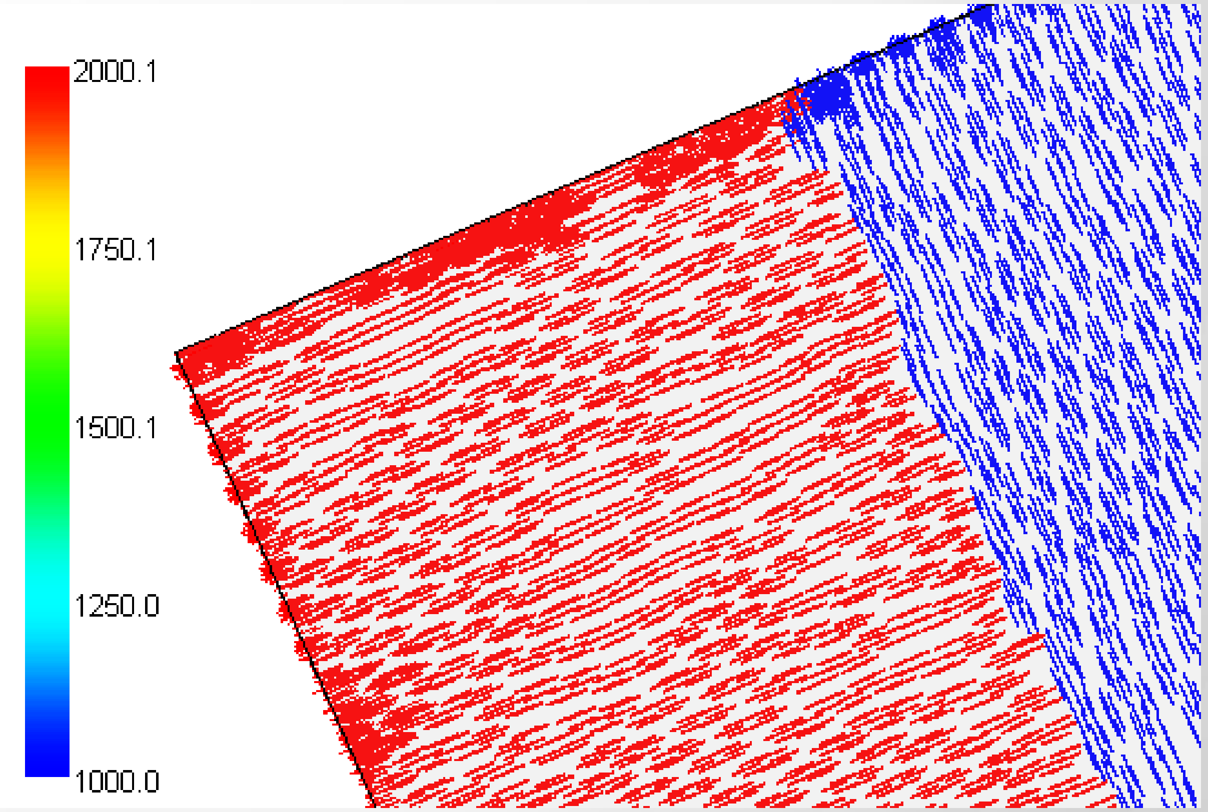
```
' Read the Last Gas Core Result
Set PlotMgr = Synergy.PlotManager
Set IndpValues = Synergy.CreateDoubleArray()
PlotMgr.GetIndpValues(1992, IndpValues)
Set Indp = Synergy.CreateDoubleArray()
Indp.AddDouble IndpValues.Val( IndpValues.Size - 1 )
Set Entity = Synergy.CreateIntegerArray()
Set NodeResult = Synergy.CreateDoubleArray()
PlotMgr.GetScalarData 1992, Indp, Entity, NodeResult
Dim vbArrNode, vbArrNodeResult
vbArrNode = Entity.ToVBSArray()
vbArrNodeResult = NodeResult.ToVBSArray()
```

- Independent Variable is time (intermediate results)
- Entities is the list of node numbers in the result set
- For Velocity use "GetVectorData 1750, …"
- Synergy arrays are VERY slow ! So convert to VBS arrays

Creating a custom result

- Scalar and Vector results can be created (not tensor)
- This example shows the creation of a vector result which will be displayed at the center of each element named in the *InsertElemArr* list
  - Color and length can be used to convey value

```
' Set up the custom plot showing Principal directions
Set PlotManager = Synergy.PlotManager()
Set FPUserPlot = PlotManager.CreateUserPlot()
FPUserPlot.SetName "Part Insert First Principal Modulus"
FPUserPlot.SetDataType "ELDT"
FPUserPlot.SetVectorData InsertElemArr, FirstPrinXArr, FirstPrinYArr, FirstPrinZArr
Set FirstPrinPlot = FPUserPlot.Build()
FirstPrinPlot.SetPlotMethod 16  ' vector as segment
FirstPrinPlot.Regenerate
```



Running an API instance per Synergy

- In the 2016 release one API instance per synergy is allowed
  - In the 2015 release only one API instance per machine was allowed.

- 2015 Script Syntax

```
'@  Myscript
'@
Option Explicit
SetLocale("en-us")
Dim Synergy
Set Synergy = CreateObject("synergy.Synergy")
'  Add my content here
```

Running an API instance per Synergy

- 2016

```
'%RunPerInstance
'@  Myscript
'@
Option Explicit
SetLocale("en-us")
Dim SynergyGetter, Synergy
On Error Resume Next
Set SynergyGetter = GetObject(CreateObject("WScript.Shell").ExpandEnvironmentStrings("%SAInstance%"))
On Error GoTo 0
If (Not IsEmpty(SynergyGetter)) Then
  Set Synergy = SynergyGetter.GetSASynergy
Else
  Set Synergy = CreateObject("synergy.Synergy")
End If
'  Add my content here
```

Launching a Synergy API script from the command line

- In the 2016 release synergy can be run from the command line and accept a script to run

```
synergy.exe  -script  myscript.vbs
```

- No longer limited to the functionality of studymod, runstudy and studyrlt

- Note: Synergy is not available on Linux
- Note: Two synergies cannot access the same project at the same time

Session Feedback

- Via the Survey Stations, email or mobile device
- AU 2015 passes given out each day!
- Best to do it right after the session
- Instructors see results in real-time

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