

SOLIDWORKS®

SOLIDWORKS Simulation Professional

Dassault Systèmes SolidWorks Corporation
175 Wyman Street
Waltham, MA 02451 U.S.A.

© 1995-2019, Dassault Systemes SolidWorks Corporation, a Dassault Systemes SE company, 175 Wyman Street, Waltham, Mass. 02451 USA. All Rights Reserved.

The information and the software discussed in this document are subject to change without notice and are not commitments by Dassault Systemes SolidWorks Corporation (DS SolidWorks).

No material may be reproduced or transmitted in any form or by any means, electronically or manually, for any purpose without the express written permission of DS SolidWorks.

The software discussed in this document is furnished under a license and may be used or copied only in accordance with the terms of the license. All warranties given by DS SolidWorks as to the software and documentation are set forth in the license agreement, and nothing stated in, or implied by, this document or its contents shall be considered or deemed a modification or amendment of any terms, including warranties, in the license agreement.

Patent Notices

SOLIDWORKS® 3D mechanical CAD and/or Simulation software is protected by U.S. Patents 6,611,725; 6,844,877; 6,898,560; 6,906,712; 7,079,990; 7,477,262; 7,558,705; 7,571,079; 7,590,497; 7,643,027; 7,672,822; 7,688,318; 7,694,238; 7,853,940; 8,305,376; 8,581,902; 8,817,028; 8,910,078; 9,129,083; 9,153,072; 9,262,863; 9,465,894; 9,646,412; 9,870,436; 10,055,083; 10,073,600; 10,235,493 and foreign patents, (e.g., EP 1,116,190 B1 and JP 3,517,643).

eDrawings® software is protected by U.S. Patent 7,184,044; U.S. Patent 7,502,027; and Canadian Patent 2,318,706.

U.S. and foreign patents pending.

Trademarks and Product Names for SOLIDWORKS Products and Services

SOLIDWORKS, 3D ContentCentral, 3D PartStream.NET, eDrawings, and the eDrawings logo are registered trademarks and FeatureManager is a jointly owned registered trademark of DS SolidWorks.

CircuitWorks, FloXpress, PhotoView 360, and TolAnalyst are trademarks of DS SolidWorks.

FeatureWorks is a registered trademark of HCL Technologies Ltd.

SOLIDWORKS 2020, SOLIDWORKS Standard, SOLIDWORKS Professional, SOLIDWORKS Premium, SOLIDWORKS PDM Professional, SOLIDWORKS PDM Standard, SOLIDWORKS Simulation Standard, SOLIDWORKS Simulation Professional, SOLIDWORKS Simulation Premium, SOLIDWORKS Flow Simulation, SOLIDWORKS CAM, SOLIDWORKS Manage, eDrawings Viewer, eDrawings Professional, SOLIDWORKS Sustainability, SOLIDWORKS Plastics, SOLIDWORKS Electrical Schematic Standard, SOLIDWORKS Electrical Schematic Professional, SOLIDWORKS Electrical 3D, SOLIDWORKS Electrical Professional, CircuitWorks, SOLIDWORKS Composer, SOLIDWORKS Inspection, SOLIDWORKS MBD, SOLIDWORKS PCB powered by Altium, SOLIDWORKS PCB Connector powered by Altium, and SOLIDWORKS Visualize are product names of DS SolidWorks.

Other brand or product names are trademarks or registered trademarks of their respective holders.

COMMERCIAL COMPUTER SOFTWARE - PROPRIETARY

The Software is a "commercial item" as that term is defined at 48 C.F.R. 2.101 (OCT 1995), consisting of "commercial computer software" and "commercial software documentation" as such terms are used in 48 C.F.R. 12.212 (SEPT 1995) and is provided to the U.S. Government (a) for acquisition by or on behalf of civilian agencies, consistent with the policy set forth in 48 C.F.R. 12.212; or (b) for acquisition by or on behalf of units of the Department of Defense, consistent with the policies set forth in 48 C.F.R. 227.7202-1 (JUN 1995) and 227.7202-4 (JUN 1995).

In the event that you receive a request from any agency of the U.S. Government to provide Software with rights beyond those set forth above, you will notify DS SolidWorks of the scope of the request and DS SolidWorks will have five (5) business days to, in its sole discretion, accept or reject such request. Contractor/Manufacturer: Dassault Systemes SolidWorks Corporation, 175 Wyman Street, Waltham, Massachusetts 02451 USA.

Copyright Notices for SOLIDWORKS Standard, Premium, Professional, and Education Products

Portions of this software © 1986-2018 Siemens Product Lifecycle Management Software Inc. All rights reserved.

This work contains the following software owned by Siemens Industry Software Limited:

D-Cubed® 2D DCM © 2019. Siemens Industry Software Limited. All Rights Reserved.

D-Cubed® 3D DCM © 2019. Siemens Industry Software Limited. All Rights Reserved.

D-Cubed® PGM © 2019. Siemens Industry Software Limited. All Rights Reserved.

D-Cubed® CDM © 2019. Siemens Industry Software Limited. All Rights Reserved.

D-Cubed® AEM © 2019. Siemens Industry Software Limited. All Rights Reserved.

Portions of this software © 1998-2019 HCL Technologies Ltd.

Portions of this software incorporate PhysX™ by NVIDIA 2006-2010.

Portions of this software © 2001-2019 Luxology, LLC. All rights reserved, patents pending.

Portions of this software © 2007-2019 DriveWorks Ltd. © 2012, Microsoft Corporation. All rights reserved.

Includes Adobe® PDF Library technology.

Copyright 1984-2016 Adobe Systems Inc. and its licensors. All rights reserved. Protected by U.S. Patents 6,563,502; 6,639,593; 6,754,382; Patents Pending.

Adobe, the Adobe logo, Acrobat, the Adobe PDF logo, Distiller and Reader are registered trademarks or trademarks of Adobe Systems Inc. in the U.S. and other countries.

For more DS SolidWorks copyright information, see Help > About SOLIDWORKS.

Copyright Notices for SOLIDWORKS Simulation Products

Portions of this software © 2008 Solversoft Corporation.

PCGLSS © 1992-2017 Computational Applications and System Integration, Inc. All rights reserved.

Copyright Notices for SOLIDWORKS PDM Professional Product

Outside In® Viewer Technology, © 1992-2012 Oracle © 2012, Microsoft Corporation. All rights reserved.

Copyright Notices for eDrawings Products

Portions of this software © 2000-2014 Tech Soft 3D.

Portions of this software © 1995-1998 Jean-Loup Gailly and Mark Adler.

Portions of this software © 1998-2001 3Dconnexion.

Portions of this software © 1998-2017 Open Design Alliance. All rights reserved.

The eDrawings® for Windows® software is based in part on the work of the Independent JPEG Group.

Portions of eDrawings® for iPad® copyright © 1996-1999 Silicon Graphics Systems, Inc.

Portions of eDrawings® for iPad® copyright © 2003 – 2005 Apple Computer Inc.

Copyright Notices for SOLIDWORKS PCB Products

Portions of this software © 2017-2018 Altium Limited.

Copyright Notices for SOLIDWORKS Visualize Products

NVIDIA GameWorks™ Technology provided under license from NVIDIA Corporation. Copyright

© 2002-2015 NVIDIA Corporation. All rights reserved.

Contents

Introduction

| | |
|---|---|
| About This Course | 2 |
| Prerequisites | 2 |
| Course Design Philosophy | 2 |
| Using this Book | 2 |
| Laboratory Exercises | 2 |
| About the Training Files | 3 |
| Windows | 3 |
| User Interface Appearance | 3 |
| Conventions Used in this Book | 3 |
| Use of Color | 4 |
| More SOLIDWORKS Training Resources | 4 |
| Local User Groups | 4 |
| What is SOLIDWORKS Simulation? | 5 |
| Limitations of SOLIDWORKS Simulation Professional | 6 |

Lesson 1:

Frequency Analysis of Parts

| | |
|--|----|
| Objectives | 7 |
| Modal Analysis Basics | 8 |
| Required Material Properties | 10 |
| Frequencies and Mode Shapes | 10 |
| Fundamental Frequency | 10 |
| Case Study: The Tuning Fork | 11 |
| Project Description | 11 |
| Stages in the Process | 11 |

| | |
|---|----|
| Frequency Analysis With Supports | 12 |
| Procedure | 12 |
| Results | 13 |
| Postprocessing Frequency Results | 15 |
| Frequency Analysis Without Supports | 17 |
| Rigid Body Modes | 18 |
| Fundamental Frequency | 18 |
| Effect of Restraints | 18 |
| Frequency Analysis with Load | 18 |
| Effects of Prestress | 19 |
| Summary | 20 |
| Questions | 20 |
| Exercise 1: Frequency Analysis of a Car Suspension Bulkhead | 21 |
| Exercise 2: Frequency Analysis of a Blower Fan | 24 |
| Part 1: Analysis Without Load | 24 |
| Part 2: Analysis With Load | 25 |
| Design Study (optional) | 27 |
| Summary | 28 |
| Exercise 3: Frequency Analysis of an Impeller | 29 |
| Summary | 30 |
| Lesson 2: | |
| Frequency Analysis of Assemblies | |
| Objectives | 31 |
| Case Study: The Engine Mount | 32 |
| Project Description | 32 |
| Stages in the Process | 32 |
| All Bonded Contact Conditions | 32 |
| Procedure | 33 |
| Remote Mass | 33 |
| Mass Properties | 34 |
| Connecting the Assembly Parts | 35 |
| Bonded and Allow Penetration Contacts | 37 |
| Discussion | 40 |
| Summary | 40 |
| Questions | 41 |
| Exercise 4: Frequency Analysis of a Particle Separator | 42 |
| Lesson 3: | |
| Buckling Analysis | |
| Objectives | 45 |
| Buckling Analysis | 46 |
| Linear vs. Nonlinear Buckling Analysis | 46 |
| Buckling Factor of Safety (BFS) | 47 |
| Buckling Analysis Considerations | 47 |
| Case Study: Particle Separator | 48 |

| | | |
|--------------------------|---|----|
| | Project Description | 48 |
| | Stages in the Process. | 48 |
| | Conclusion | 50 |
| | Calculating Buckling Loads | 50 |
| | Results Discussion | 51 |
| | Will the structure Buckle or Yield First? | 52 |
| | Summary. | 52 |
| | Questions | 52 |
| | Exercise 5: Buckling Analysis of a Stool | 53 |
| | Exercise 6: Cabinet. | 59 |
| Lesson 4: | | |
| Load Cases | | |
| | Objectives | 65 |
| | Load Cases | 66 |
| | Case Study: Scaffolding | 66 |
| | Project Description | 66 |
| | Stages in the Process. | 67 |
| | Initial Load Case. | 74 |
| | Summary. | 77 |
| Lesson 5: | | |
| Submodeling | | |
| | Objectives | 79 |
| | Submodeling. | 80 |
| | Parent Study | 80 |
| | Case Study: Scaffolding | 81 |
| | Project Description | 81 |
| | Stages in the Process. | 82 |
| | Part 1: Parent Study | 82 |
| | Parent Load Cases in Submodeling Study | 83 |
| | Part 2: Child Study | 84 |
| | Selecting Components for Submodeling | 85 |
| | Submodel Fixtures | 86 |
| | Summary. | 89 |
| | Questions. | 89 |
| Lesson 6: | | |
| Topology Analysis | | |
| | Objectives | 91 |
| | Topology Analysis | 92 |
| | Case Study: Rear Bike Shock Link. | 92 |
| | Project Description | 92 |
| | Stages in the Process. | 93 |
| | Goals and Constraints. | 94 |
| | Best Stiffness to Weight ratio | 94 |
| | Minimize Maximum Displacement | 95 |
| | Minimize Mass | 95 |

| | |
|--|-----|
| Manufacturing Controls | 96 |
| Add Preserved Region | 96 |
| Specified Thickness Control. | 96 |
| Specify De-mold Direction. | 96 |
| Specify Symmetry Planes. | 97 |
| Mesh Effects | 98 |
| Load Cases in Topology Studies. | 100 |
| Export Smoothed Mesh | 102 |
| Summary. | 103 |
| Exercise 7: Topology Analysis of a Stool | 104 |
| Lesson 7: | |
| Thermal Analysis | |
| Objectives | 107 |
| Thermal Analysis Basics. | 108 |
| Mechanisms of Heat Transfer. | 109 |
| Conduction | 109 |
| Convection | 110 |
| Radiation. | 111 |
| Material Properties for Thermal Analysis | 113 |
| Case Study: Microchip Assembly. | 114 |
| Project Description | 114 |
| Stages in the Process. | 114 |
| Steady-State Thermal Analysis. | 115 |
| Procedure | 115 |
| Interfacial Conductance | 116 |
| Insulation | 119 |
| Initial Temperature | 119 |
| Thermal Results | 119 |
| Heat Flux. | 120 |
| Heat Flux Results | 121 |
| Heat Power | 122 |
| Transient Thermal Analysis | 122 |
| Importing Convective Effect from SOLIDWORKS Flow Simulation | 124 |
| Transient Data Sensors | 125 |
| Results Comparison | 126 |
| Transient Analysis with Time Varying Load. | 127 |
| Time Curves | 128 |
| Temperature Curves | 128 |
| Transient Thermal Analysis using a Thermostat. | 129 |
| Symmetry Boundary Condition in Thermal Analysis | 132 |
| Summary. | 132 |
| Questions | 132 |
| Exercise 8: Thermal Analysis of a Cup | 133 |
| Summary. | 135 |

Lesson 8:**Thermal Analysis with Radiation**

| | |
|---|-----|
| Objectives | 137 |
| Case Study: Spot Light Assembly | 138 |
| Project Description | 138 |
| Stages in the Process. | 139 |
| Steady State Analysis | 139 |
| Review of Analysis Parameters | 144 |
| Heat Flux Singularities | 146 |
| Summary. | 147 |

Lesson 9:**Advanced Thermal Stress2D Simplification**

| | |
|---|-----|
| Objectives | 149 |
| Thermal Stress Analysis | 150 |
| Case Study: Metal Expansion Joint | 150 |
| Project Description | 150 |
| Stages in the Process. | 151 |
| Thermal Analysis | 151 |
| 2D Simplification | 151 |
| Prescribed Temperature Condition | 156 |
| Meshing Considerations in Thermal Analysis | 156 |
| Thermal Stress Analysis | 159 |
| Importing Temperatures and Pressures from SOLIDWORKS Flow Simulation | 160 |
| Reference Temperature at Zero Strains | 160 |
| 3D Model | 165 |
| Summary. | 167 |
| Questions | 168 |
| Exercise 9: Thermal Stress Analysis of a Microchip Testing Assembly | 169 |
| Thermal Stress Study | 172 |
| Change in Thermal Boundary Conditions | 173 |
| Summary. | 175 |
| Exercise 10: Thermal Stress Analysis of a Gas Tank. | 176 |
| Exercise 11: Thermal Stress Analysis of a Thermoelectric Cooler | 181 |
| Problem Description | 181 |
| Materials | 182 |
| Loading Conditions. | 183 |
| Goal. | 183 |

**Lesson 10:
Fatigue Analysis**

| | |
|---|-----|
| Objective..... | 185 |
| Fatigue | 186 |
| Stages of Failure due to Fatigue | 186 |
| High vs. Low Cycle Fatigue | 187 |
| Stress-life (S-N) Based Fatigue | 187 |
| Fatigue Loading | 187 |
| Case Study: Pressure Vessel | 189 |
| Project Description | 189 |
| Stages in the Process..... | 189 |
| Thermal Study..... | 191 |
| Thermal Stress Study | 191 |
| Static Pressure Study | 193 |
| Fatigue Terminology..... | 195 |
| S-N Curve | 195 |
| Fatigue Study | 198 |
| Derive from Material Elastic Modulus..... | 201 |
| Constant Amplitude Events Interaction | 201 |
| Alternating Stress Computation | 201 |
| Mean Stress Correction..... | 202 |
| Fatigue Strength Reduction Factor..... | 204 |
| Damage Factor Plot | 204 |
| Damage Result Discussion | 206 |
| Fatigue Study with Dead Load | 207 |
| Dead Loads in Fatigue Analysis..... | 207 |
| Bolts in Fatigue Analysis | 208 |
| Find Cycle Peaks | 209 |
| Summary..... | 211 |
| Questions | 211 |
| Exercise 12: Fatigue Analysis of a Basketball Rim | 212 |
| Exercise 13: Fatigue of Trailer Hitch | 218 |

Lesson 11:**Variable Amplitude Fatigue**

| | |
|---|-----|
| Objectives | 221 |
| Case Study: Suspension | 222 |
| Project Description | 222 |
| Stages in the Process. | 223 |
| Discussion. | 224 |
| Fatigue Study | 225 |
| Variable Amplitude Fatigue Event | 225 |
| Rainflow Cycle Counting Method | 225 |
| Variable Loading Curve | 226 |
| Bins for Rainflow Counting | 231 |
| Noise in Random Loading History | 231 |
| Fatigue Strength Reduction Factor | 231 |
| Rainflow Matrix Chart | 234 |
| Results. | 234 |
| Fatigue Literature | 235 |
| Summary. | 235 |
| Questions | 235 |

Lesson 12:**Drop Test Analysis**

| | |
|--|-----|
| Objectives | 237 |
| Drop Test Analysis | 238 |
| Case Study: Camera | 238 |
| Project Description | 238 |
| Stages in the Process. | 238 |
| Rigid Floor Drop Test. | 239 |
| Drop Test Parameters | 240 |
| Dynamic Analysis. | 241 |
| Damping | 242 |
| Solution Time | 243 |
| Graphing Results. | 244 |
| Linear vs. Nonlinear Solution. | 246 |
| Elastic Floor, Elasto-Plastic Material | 248 |
| Elasto-Plastic Material Model | 250 |
| Elasto-Plastic Model Parameters | 251 |
| Processing Elasto-Plastic Results | 252 |
| Discussion. | 253 |
| Drop Test with Contact (optional) | 253 |
| Summary. | 255 |
| Exercise 14: Drop Test of a Clip | 256 |

Lesson 13: Optimization Analysis

| | |
|--|-----|
| Objectives | 259 |
| Optimization Analysis. | 260 |
| Case Study: Press Frame. | 260 |
| Project Description | 260 |
| Design Requirements | 261 |
| Stages in the Process. | 261 |
| Static and Frequency Analyses | 261 |
| Optimization Analysis. | 263 |
| Design Study. | 263 |
| Optimization Goal. | 264 |
| Design Variable Summary | 266 |
| Define Constraints | 266 |
| Constraint Tolerance. | 269 |
| Constraint Definition Procedure | 269 |
| Postprocessing Optimization Results | 270 |
| Local Trend Graphs | 274 |
| Summary. | 274 |
| Exercise 15: Optimization Analysis of a Cantilever Bracket | 277 |
| Exercise 16: Optimization of Heat Sink | 281 |

Lesson 14: Pressure Vessel Analysis

| | |
|--|-----|
| Objectives | 283 |
| Case Study: Pressure Vessel | 284 |
| Project Description | 284 |
| Stages in the Process. | 284 |
| Stress Intensity | 286 |
| Membrane and Bending Stresses (stress linearization) | 286 |
| Basic Stress Intensity Limits. | 286 |
| Pressure Vessel Analysis. | 286 |
| Load Case Combinations | 288 |
| General Primary Membrane Stress Intensity | 289 |
| Manhole Nozzle Flange and Cover | 290 |
| Stress Linearization. | 291 |
| Summary. | 294 |