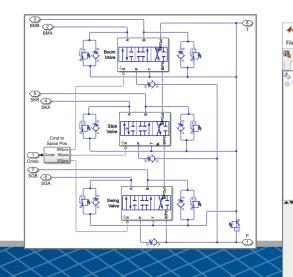
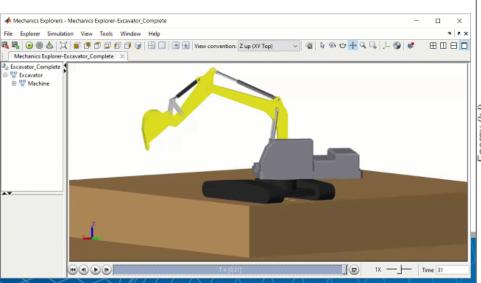
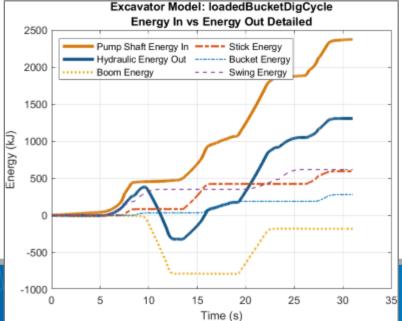


Virtuelle Maschinenentwicklung mit MATLAB und Simulink





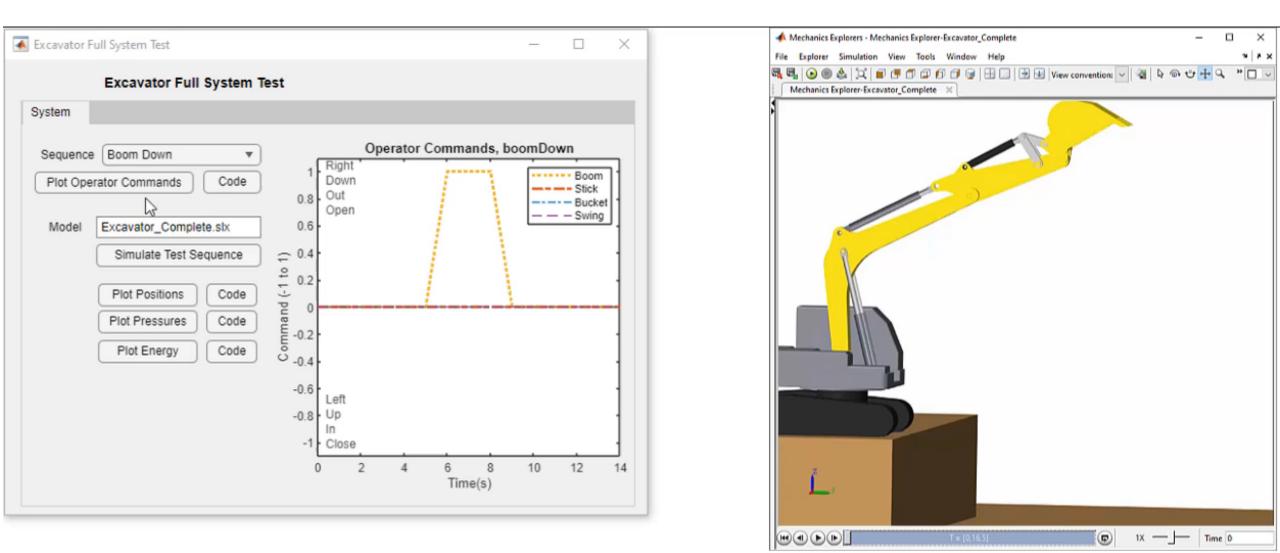


Eva Pelster, Application Engineering (<u>epelster@mathworks.com</u>) 04.05.2023

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Excavator Model Test by function or full cycle and review results





Aalto University Works with Industry Partners to Develop Energy-Efficient Designs for Construction Equipment

Challenge

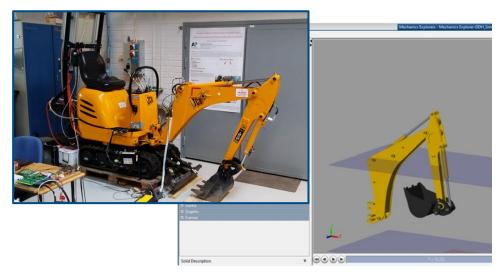
Work with manufacturers to develop more energy-efficient excavators, loaders, and other construction and off-road machinery

Solution

Use MATLAB, Simulink, and Simscape to model and simulate designs that incorporate hybrid technologies and decentralized hydraulic systems

Results

- Energy efficiency doubled
- Industry-academia collaboration established
- In-demand skills developed



The one-tonne micro excavator modeled by Aalto University and Tampere University researchers in the EL-Zon and EZE projects.

"With MATLAB, Simulink, and Simscape we were able to create and validate designs spanning multiple domains—mechanical, electrical, and hydraulic—that are now being used by our commercial partners to improve energy efficiency on their machines."

- Tatiana Minav, Aalto University and Tampere University



Modeling the Mechanical System \bigcirc (1)R Left Crank Right Crank Transform Transform Crank Model: rank 1 Right 🚹 Block Parameters: Crank Assembly Crank Pin Crank Assembly (mask) Consists of the backhoe crank assembly that connects the upper arm an the bucket. Crank 1 attaches to either side of the upper arm linkage, and Crank 2 connects Crank 1 and the Bucket. Attachment points are: AL: Arm attachment (Left). AR: Arm attachment (Right). B: Bucket attachment. P: Piston attachment. All attachment points are configured for Revolute joints. Click on Help to view a schematic of the crank assembly, its configurable dimension parameters and attachment points (in red). 2 UAL **Challenge:** Create a Crank 1 Crank 2 Other LC1 [m] (parameterized) mechanical model of 1.5 3 ٩R WC1 [m] UAR the backhoe 0.4 Crank Assembly TC1 [m] 0.2 **Solution:** Use components created DH1 [m] 1.1 in Simscape Multibody to rapidly RH1 [m] assemble the model in Simulink. OK Cancel Help

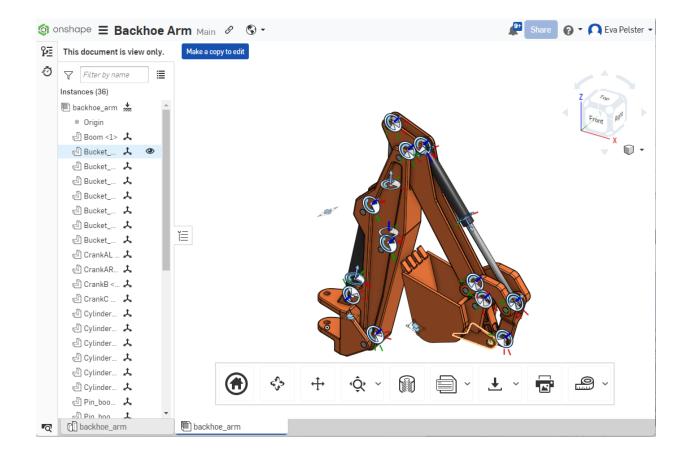
Apply

Х



Reusing CAD Data

- Import CAD assemblies
 - Part definitions
 - Converts mate definitions to joints
 - SOLIDWORKS, Inventor, Onshape, and PTC Creo® (Pro/ENGINEER®)
- Import CAD Parts
 - CATIA, NX, SolidEdge, and others
 - STEP files

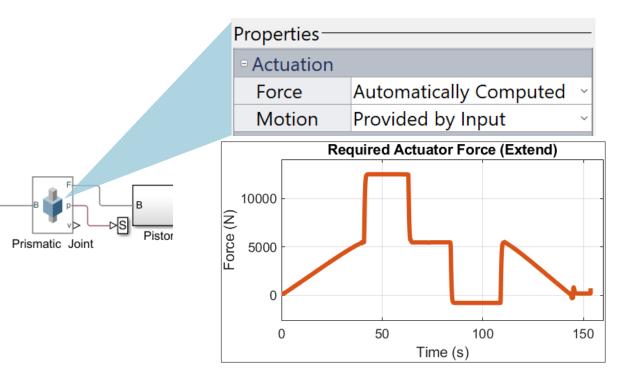


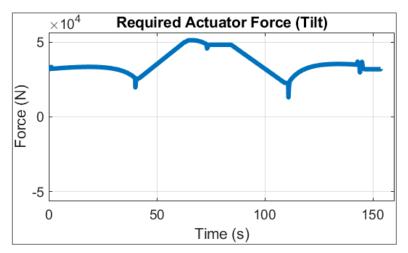


Determine Actuator Requirements

nder

- Define and run a set of tests
 - Maximum payload, speed
 - Worst case friction levels
 - Full range of movement
- Use dynamic simulations to calculate required torque and bearing forces
- If design changes, automatically rerun tests and re-evaluate results

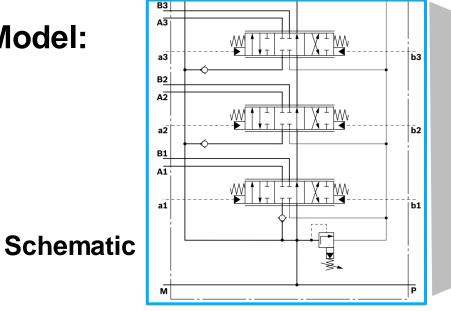






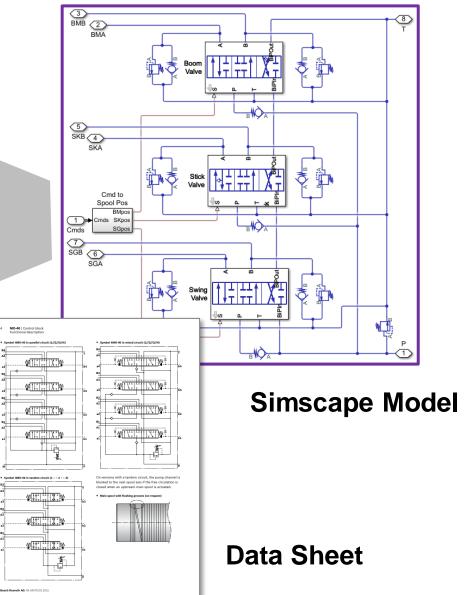
Modeling the Hydraulic Actuation System





Problem: Translate the hydraulic schematic into a models

Solution: Use Simscape Fluids blocks ans parameterize using data sheets



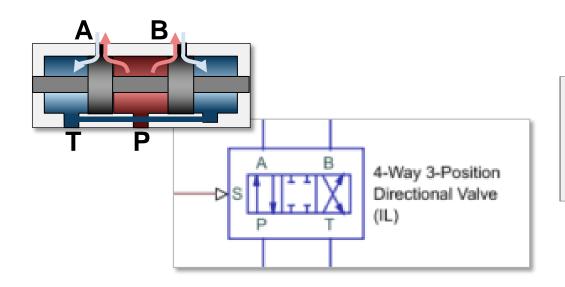


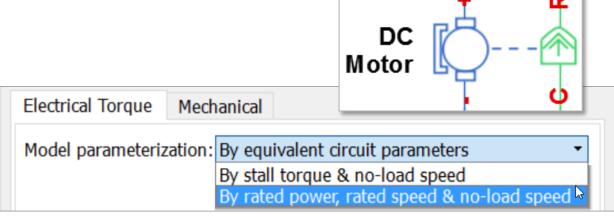
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Enhancing the Model with Simscape Add-on Libraries

- Advanced components and effects
 - Comprehensive components
 - Parameterization options
 - Physical effects (losses, thermal dependency)

				R –
Main	Meshing Losses	Viscous Losses	<u> </u>]
			ble for HIL simulation	
Theater		efficiency		₽

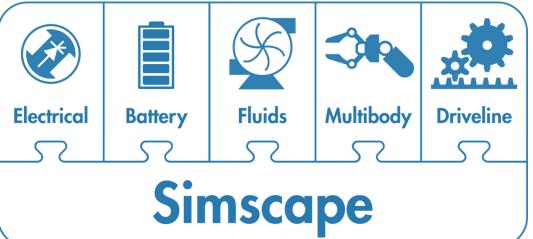


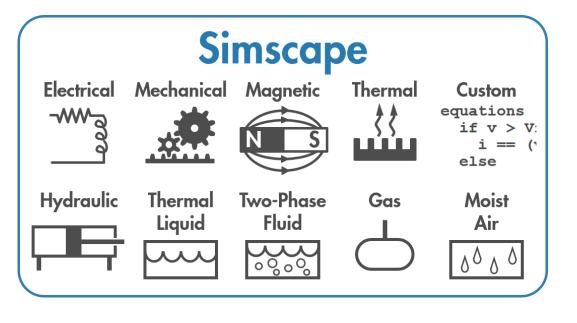




Simscape Add-on Libraries

- Simscape Battery
 - Battery packs, cooling, charge management
- Simscape Electrical
 - Electronics, mechatronics, and power systems
- Simscape Driveline
 - Gears, leadscrew, clutches, tires, engines
- Simscape Multibody
 - Multibody systems: joints, bodies, frames
- Simscape Fluids
 - Pumps, actuators, pipelines, valves, tanks



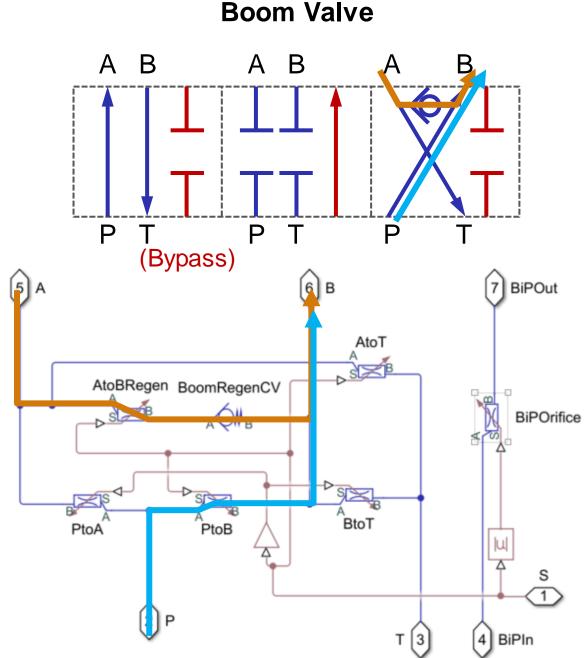




Add Regeneration Valves

- Regeneration valves
 - As cylinders move with gravity, oil from high pressure side is fed to low pressure side
 - Reduces load on pump and increases efficiency

Boom cylinder: regeneration when pump supplies rod end



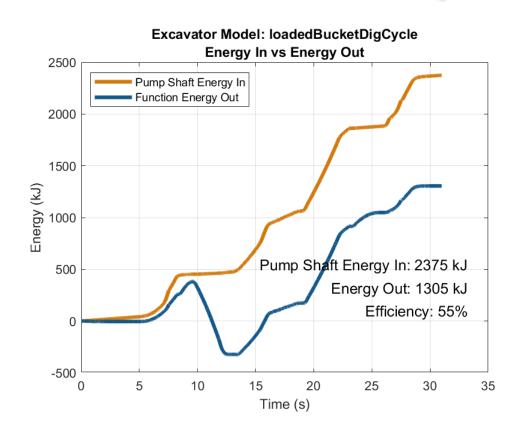


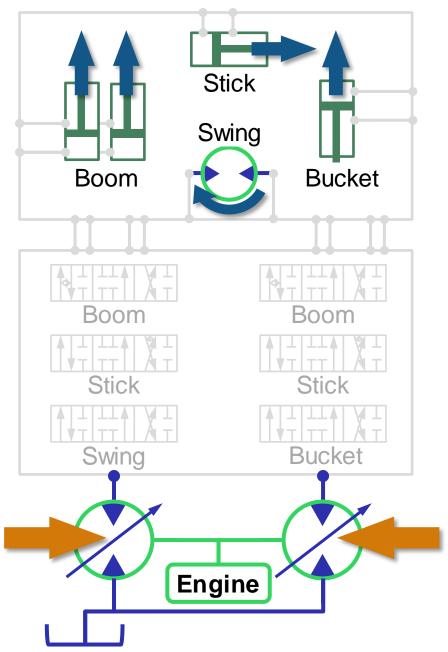
Assessing Overall Efficiency

- Simulation results used to calculate
 - Energy input to excavator



- Energy output by excavator

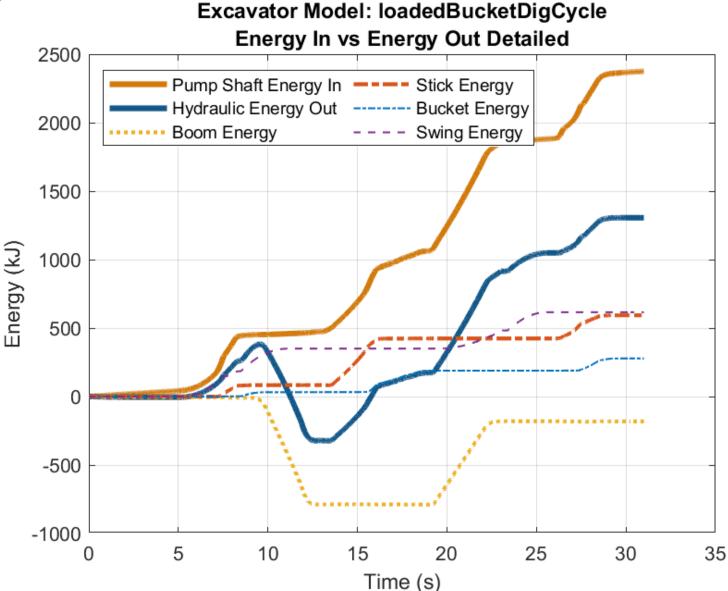






Assessing Overall Efficiency

- Periods of "negative" energy show where gravity helped lower the arm
 - Potential energy converted to energy we measured
- Efficiency would be lower if we did not use regenerative flow

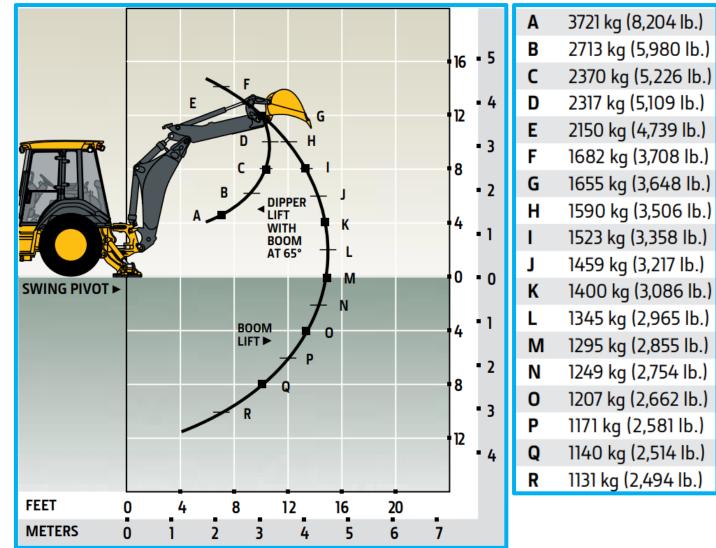




Explore Design Space: Load Chart

 Datasheets provide load charts to show lift capacity throughout excavator reach zone

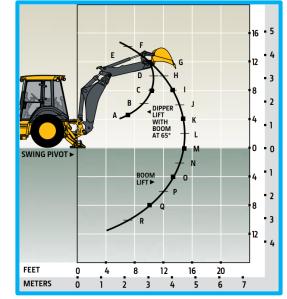
Long	for Dimensions and	Performance (continu	all 300 FP				3001			
LOAD	ter currensions and	Performance (contine			Heavy-duty				Heavy-duty	Maltine
Bucks	et Capacity		Heavy-duty 0.27 m ³	0.86 m ³	org (p 196 m²	Autourpear 0.96 m ²	Heavy-duty 0.77 m ³	Heavy-duty 0.86 m ¹	long lip 0.96 m ²	0.96 m ²
Webb			(1.00 cu. yd.) 206 mm (86 in 1	(12 cs.yd.) (20% mm (86 in)	1,25 cs. yd.) 284 mm 186 in 1	(1.25 cu. yd.) 2004 mm 185 in 1	(1.00 cu. yd.) 20% mm (86 in 1	(12 cs. yd.) 286 met (86 in 1	(125 cs. yd.) 284 mm (85 in 1	(L25 cu.) 2/84 mm
Weight	M.		363 kg (800 lb.)	390 kg (860 lb.)	405 kg (892 lb.)	794 kg (1,750 lb.)	363 kg (800 lb.)	390 kg (860 lb.)	405 kg (892 lb.)	794 kg 0
	out Force apacity, Full Height		413 KN (9,410 E.)	42.5 kN (9,564 lb.) 2998 kg (6,610 lb.)		367 kN (8,348 lb		42.3 kN (9,52 lb.) 2995 kg (6.602 lb.)		
8.1	feight to Bucket Hinge Pr	r, Maximum	351m0/ft.6is.1	351=01A.6in1	SImITA.6 in1	351m008.6m1	348m [[]ft Sin]	348 millft SinJ	348 millft. Sin1	348 mII
	Comp Cleanance, Bucket a Reach at Full Heipht, Buck		277 m (9 ft. 1 in.) 699 mm (275 in.)		271 m (8 ft. 11 in.) 20 mm (30 in.)	2.68 m [8 ft. 9 in 735 mm [290 in.]) 23% m (9 ft. 0 in.) 702 mm (277 in.)	2.28 m (9 ft. 1 in.) 667 mm (26.3 in.)	2.68 m(8 ft. 9 in.) 793 mm (3L2 in.)	2.68 m (i 705 mm)
	Digging Depth Below Grou	and, Bucket Level	41 mm (16 in.)	41mm(16in)	am (0.8 in.)	81mm (3.2 in.)	70 mm (2.8 in.)	71mm (2.8 in.)	Simm [2.0 in.]	III mm [4
V L	ength from Front Asle Ce	interline to Bucket Cutting	Edge 2.01 m (6 ft. 7 in.)	196 m (6 ft. 5 in.)	230 m (6 ft. 11 is.)	213 m (7 ft. 0 in.)	202 m (6 ft. 8 is.)	157 m (6 ft. 6 in.)	212 m (6 ft. 11 is.)	230 m 6
	Capacity with Quick raulic Capacity	k-Coupler Forks	1219-mm (48	a 1 Tinon	1524-mm (60 i	a I T/a aa	1219.mm (48.)	. 17)	1524-mm (60 i	- 17/
	Maximum Height		1737 kg (3.829		1616 kg (3,563 l		1219-mm (48) 1711 kg (3,772)		1524-mm (60 ii 1592 kg (3,510 i	
	Maximum Reach		2703 kg (5,959		2542 kg (5,605		2690 kg (5,931	b.)	2530 kg (5,578	
	At Ground Line		3449 kg (7,60)	3 Ib.)	3248 kg (7,160	b.)	3393 kg (7,480		3203 kg (7,061	
DI	Below Ground Line		156 mm (6.1 in	J 1	155 mm (6.1 in.)		185 mm (2.3 in	.)	185 mm (7.3 in.	
1164	U [] []		0	0		<u>></u>				÷ ,
	Capacities	end values in kg (R).				wailable.		HARREN OF T		ł ,
	Capacities capacities are over- With Standard Dige	end values in kg (lb.) perstick	With 1.06-m (3 ft. 6 Extendable Dippers	5 in.) tick, Retracted	With 1.06 Extendabl	m (3 ft. 6 in.) le Dipperstick,				20 - S
	Capacities capacities are over- With Standard Disc 310L EP	end values in kg (lb.) perstick 310L	With LD6-m (3 ft. 6 Extendable Dippers 310L EP	S in.) tick, Retracted 310L	With 1.06 Extendabl 310L EP	m (3 ft. 6 in.) le Dipperstick, 310	L			* ,
	Capacities capacities are over- With Standard Disc 310L EP 3721 kg (8,204 lb.)	end values in kg (lb.) perstick 110L 2593 kg (7,921 lb.)	With 1.06-m (3 ft. 6 Extendable Dippers 310L EP 4089 kg (9,015 lb.)	5 in.) tick, Retrocted 310L 3846 kg (8,478 lb	With 1.06 Extendabl 310L EP L) 2878 kg (6	m (3 ft. 6 in.) le Dipperstick, 310 (346 lb.)* 318	L D kg (7,011 lb.)'			<i>i</i> ,
Lift A B C	Capacities capacities are over- site. EP 3721 kg (8,204 lb.) 2370 kg (5,260 lb.) 2370 kg (5,226 lb.)	end values in kg (lb.) 310L 3593 kg (7.921 lb.) 2686 kg (5.922 lb.) 2686 kg (5.922 lb.)	With 1.06-m (3 ft. 6 Extendable Dippers 310L EP 4089 kg (9,015 lb.) 2466 kg (5,437 lb.) 2171 kg (4,786 lb.)	5 in.) stick, Retracted 310L 3846 kg (8,478 lb 2444 kg (5,388 lb 2165 kg (4,773 lb	With 1.06 Extendabi 310L EP L) 2878 kg (6 L) 2245 kg (4 L) 1790 kg (3	m (3 ft. 6 in.) le Dipperstick, 310 (346 lb.)* 318 (950 lb.) 209 (947 lb.) 169	L) kg (7,011 lb.)' 0 kg (4,607 lb.) 6 kg (3,740 lb.)			i,
A B C D	Capacities capacities are over- with Standard Direc 310L EP 3721 kg (6,204 lb.) 2370 kg (5,206 lb.) 2370 kg (5,206 lb.)	end values in kg (lb.) 310L 3933 kg (1,921 lb.) 2686 kg (5,922 lb.) 2363 kg (5,210 lb.) 2319 kg (5,114 lb.)	With LD6-m (3 ft. 6 Extendable Dippers 310L EP 4089 kg (9,015 lb.) 2466 kg (5,437 lb.) 2171 kg (4,786 lb.) 2124 kg (4,683 lb.)	5 in.) ttick, Retracted 310L 3846 kg (8,478 lb 2444 kg (5,388 lb 2165 kg (4,773 lb 2126 kg (4,688 lb	With 1.06 Extendabl 310L EP k) 2878 kg (6 k) 2245 kg (4 l) 1790 kg (3 c) 1607 kg (3	m (3 ft. 6 in.) ie Dipperstick, (346 lb.)' 318 (950 lb.) 205 (947 lb.) 169 (543 lb.) 153	L D kg (7,011 lb.)' O kg (4,607 lb.) 6 kg (3,740 lb.) 8 kg (3,380 lb.)			
Lift A B C	Capacities capacities are over- with Standard Dice 3021 kg (8,204 lb.) 2773 kg (5,980 lb.) 2370 kg (5,226 lb.) 2370 kg (5,206 lb.) 2370 kg (4,739 lb.)	end values in kg (lb.) 300L 3933 kg (7.921 lb.) 2686 kg (5.922 lb.) 2366 kg (5.922 lb.) 2319 kg (5.10 lb.) 2319 kg (5.10 lb.) 2317 kg (4.666 lb.)	With L06-m (3 ft. 4 Extendable Dippers 310L EP 4089 kg (9,015 lb.) 2466 kg (5,437 lb.) 2171 kg (4,786 lb.) 2124 kg (4,683 lb.) 1950 kg (4,299 lb.)	5 in.) 310L 3846 kg (8,478 lb 2444 kg (5,388 lb 2165 kg (4,773 lb 2126 kg (4,688 lb 1920 kg (4,232 lb	With 1.06 Extendabl 310L EP L) 2878 kg (6 L) 2245 kg (4 L) 1790 kg (3 L) 1607 kg (3 L) 1528 kg (3	m (3 ft. 6 in.) ie Dipperstick, 310 (346 lb.)' 318 (950 lb.) 205 (947 lb.) 169 (543 lb.) 153 (369 lb.) 146	L 0 kg (7,011 lb.)* 0 kg (4,607 lb.) 6 kg (3,740 lb.) 8 kg (3,380 lb.) 5 kg (3,229 lb.)			ł.,
Lift A B C D E F	Capacities capacities are over- soc. IP 3721kg (8,204 lb.) 2713 kg (5,980 lb.) 2370 kg (5,226 lb.) 2370 kg (5,226 lb.) 2370 kg (5,239 lb.) 1682 kg (3,708 lb.)	end values in kg (lb.) postick 100L 2693 kg (7.921 lb.) 2686 kg (5.922 lb.) 2686 kg (5.922 lb.) 2694 kg (5.114 lb.) 2107 kg (4.666 lb.) 1600 kg (3.704 lb.)	With L06-m (3 ft. d Extendable Dippers 310L EP 4089 kg (9,015 lb.) 2466 kg (5,437 lb.) 2171 kg (4,786 lb.) 2124 kg (4,663 lb.) 1950 kg (4,299 lb.) 1489 kg (1,283 lb.)	5 in.) stick, Retracted 300L 3846 kg (8,478 lb 2444 kg (5,388 lb 2455 kg (4,773 lb 2125 kg (4,668 lb 1920 kg (4,232 lb 1488 kg (3,290 lb	With 1.06 Extendabi 310L EP L) 2878 kg (6 L) 2245 kg (4 L) 1790 kg (3 L) 1607 kg (3 L) 1528 kg (3 L) 1475 kg (3	m (3 ft. 6 in.) ie Dipperstick, 310 (346 lb.) ¹ 318 (950 lb.) 209 (947 lb.) 169 (543 lb.) 153 (369 lb.) 146 (251 lb.) 145	L D kg (7,011 lb.) ¹ O kg (4,607 lb.) 6 kg (3,740 lb.) 3 kg (3,380 lb.) 5 kg (3,229 lb.) 7 kg (3,212 lb.)			ł ,
A B C D	Capacities capacities are over- with Standard Dice 3021 kg (8,204 lb.) 2773 kg (5,980 lb.) 2370 kg (5,226 lb.) 2370 kg (5,206 lb.) 2370 kg (4,739 lb.)	end values in kg (lb.) spestick 100. 1993 kg (1921 b.) 2666 kg (5,922 b.) 219 kg (5,101 b.) 217 kg (4,666 b.) 160 kg (1204 b.) 167 kg (2,631 b.) 167 kg (2,631 b.)	With L06-m (3 ft. 4 Extendable Dippers 310L EP 4089 kg (9,015 lb.) 2466 kg (5,437 lb.) 2171 kg (4,786 lb.) 2124 kg (4,683 lb.) 1950 kg (4,299 lb.)	5 in.) tick, Retracted 300L 3846 kg (8,478 lb 2444 kg (5,388 lb 2465 kg (4,773 lb 2126 kg (4,688 lb 1920 kg (4,232 lb 1488 kg (3,289 lb 1469 kg (3,239 lb 1412 kg (3,112 lb.)	With 1.06 Extendabi 310L EP k) 2878 kg (6 k) 2245 kg (4 l) 7590 kg (3 k) 1607 kg (3 k) 1627 kg (3 k) 1528 kg (3 k) 1528 kg (3 k) 1522 kg (2 1080 kg (2 1080 kg (2 1080 kg (2) kg	-m (3 ft. 6 in.) ie Dipperstick, 310 (346 lb.)" 318 (950 lb.) 205 (947 lb.) 169 (543 lb.) 153 (369 lb.) 146 251 lb.) 145 (915 lb.) 130	L 0 kg (7,011 lb.)* 0 kg (4,607 lb.) 6 kg (3,740 lb.) 8 kg (3,380 lb.) 5 kg (3,229 lb.)			* ,
Lift A B C D E F G	Capacities are over- With Standord Dire and, EP 3721 kg (8,204 lb.) 2733 kg (5,900 lb.) 2370 kg (5,226 lb.) 2370 kg (5,226 lb.) 2370 kg (5,226 lb.) 2150 kg (3,644 lb.) 1550 kg (3,644 lb.) 1550 kg (3,564 lb.)	end values in kg (b), secritick 1901, 1903 kg (1921 b), 2903 kg (1921 b), 2003 kg (1922 b), 2019 kg (1914 b), 2019 kg (1914 b), 2019 kg (1914 b), 1017 kg (1960 b), 1020 kg (1916 b), 1021 kg (1931 b), 1021 kg (1931 b), 1021 kg (1931 b), 1021 kg (1936 kg (1936 b), 1021 kg (1936 b), 1021 kg (1936 b), 1021 kg (1936 b), 1021 kg (1937 kg (1936 b), 1021 kg (1937 kg (1936 b), 1021 kg (1937	With L06-m (3 ft. d Extendeble Dippers 310L EP 4089 kg (9,015 lb.) 2466 kg (5,437 lb.) 2171 kg (4,786 lb.) 2124 kg (4,683 lb.) 1950 kg (4,299 lb.) 1469 kg (3,234 lb.) 1409 kg (3,206 lb.) 1409 kg (2,969 lb.)	5 in.) tick, Retracted 300L 3046 kg (8,478 lb 2465 kg (4,773 lb 2165 kg (4,273 lb 1205 kg (4,232 lb 1488 kg (3,239 lb 1469 kg (3,239 lb 1412 kg (3,112 lb.) 1349 kg (2,975 lb	With 1.06 Extendabi 310L EP k) 2898 kg (6 c) 2245 kg (4 c) 790 kg (3 c) 1607 kg (3 c) 1607 kg (3 c) 1528 kg (3 c) 1528 kg (3 c) 1522 kg (2 c) 1620 kg (2 c) 1620 kg (2 c) 883 kg (1)	-m (3 ft. 6 in.) ie Dipperstick, 310 (346 lb.)' 318 (950 lb.) 205 (947 lb.) 169 (543 lb.) 153 (369 lb.) 146 251 lb.) 146 251 lb.) 130 (380 lb.) 104 (380 lb.) 104 (346 lb.) -	L) kg (7,011 lb.) ¹ O kg (4,607 lb.) 6 kg (3,740 lb.) 3 kg (3,380 lb.) 5 kg (3,229 lb.) 7 kg (3,212 lb.) 3 kg (2,873 lb.) 6 kg (2,307 lb.)			÷.,
A B C D E F G H I J	Capacities capacities are over- 3721 kg (5296 b). 2731 kg (5296 b). 2731 kg (5296 b). 2372 kg (5296 b). 2372 kg (5296 b). 2372 kg (5296 b). 1562 kg (1209 b). 1562 kg (1209 b). 1562 kg (1206 b). 1523 kg (1217 b).	end values in kg (b). 100. 1993 kg (1521 b.). 2063 kg (1522 b.). 2063 kg (1520 b.). 2173 kg (4666 b.). 1600 kg (1204 b.). 1673 kg (4663 b.). 1693 kg (1513 b.). 1524 kg (1253 b.). 1526 kg (1255 b.)	With 1.06-m (3 ft. 4 Extendable Dippers 310L EP 4089 kg (9,015 lb.) 2466 kg (5,437 lb.) 2171 kg (4,2786 lb.) 2171 kg (4,2786 lb.) 2124 kg (4,683 lb.) 1950 kg (4,299 lb.) 1467 kg (3,234 lb.) 1467 kg (3,234 lb.) 1347 kg (2,969 lb.) 1346 kg (2,836 lb.)	5 in.) tick, Retracted 300L 3866 kg (8,478 lb 2464 kg (8,478 lb 2166 kg (4,773 lb 2126 kg (4,573 lb 2126 kg (4,522 lb 1468 kg (3,200 lb 1469 kg (3,229 lb 1412 kg (3,127 lb) 1429 kg (2,975 lb 1289 kg (2,941 lb) 289 kg (2,941 lb)	With 1.06 Extended 310L CP 2878 kg (6) 2245 kg (4) 1790 kg (3) 1607 kg (3) 1607 kg (3) 1628 kg (3) 1475 kg (3) 1475 kg (3) 1880 kg (1) 1057 kg (2	m (3 ft. 6 in.) ie Dipperstick, 310 (346 lb.) ¹¹ 318 (950 lb.) 205 (947 lb.) 169 (543 lb.) 153 (369 lb.) 146 (251 lb.) 146 (380 lb.) 104 446 lb.) = (331 lb.) 990	L D kg (2011 lb.) ¹ O kg (2,607 lb.) 6 kg (3,740 lb.) 3 kg (3,340 lb.) 5 kg (3,229 lb.) 7 kg (3,212 lb.) 8 kg (2,873 lb.) 6 kg (2,307 lb.) kg (2,188 lb.)			
Lift A B C D E F G	Capacities Capacities are over- With Standord Dire 301, EV 3721 kg (520 kb.) 273 kg (520 kj.) 2170 kg (520 kj.) 2170 kg (520 kj.) 2162 kg (1270 kj.) 1652 kg (126 kj.) 1552 kg (1276 kj.) 1553 kg (1276 kj.) 1555 kg (end values in kg (ik.) sertick 100. 1933 kg (2221 k.) 2966 kg (5222 k.) 219 kg (520 k.) 107 kg (4666 kg) 107 kg (4666 kg) 107 kg (1453 k.) 1953 kg (1453 k.) 1953 kg (1253 k.) 1954 kg (1253 k.) 1954 kg (1251 k.)	With 106-m (3 ft. d Extendable Dippers 300L (P 4089 lig (9,015 lb.) 2466 lig (5,437 lb.) 2171 lig (4,268 lb.) 212k lig (4,688 lb.) 1950 lig (4,299 lb.) 1489 lig (3,234 lb.) 1409 lig (3,026 lb.) 124k g (4,268 lb.) 124k g (4,268 lb.) 1200 lig (2,236 lb.) 1286 lig (2,266 lb.) 1286 lig (2,236 lb.) 1286 lig (2,231 lb.) 1286 lig (2,231 lb.) 1286 lig (2,231 lb.) 1286 lig (2,231 lb.)	5 in.) 300L 300L 300L 2444 kg (5,388 li 2464 kg (5,388 li 2465 kg (4,73 li 2165 kg (4,688 li 1920 kg (4,232 lib 1488 kg (1,200 li 1469 kg (3,239 lib 1412 kg (3,112 li.) 1349 kg (2,955 lib 1229 kg (2,2716 lib.)	With 1.06 Extendebi 310L CP () 2878 kg (6 () 2245 kg (4 () 1790 kg (3 () 1607 kg (3 () 1627 kg (3 () 1627 kg (2 1080 kg (2 () 883 kg (1) () 1087 kg (2 () 1080 kg (2) () 1080 kg (2 () 1080 kg (2) () 108	m (3 ft. 6 in.) is Dipperstick, 3100 (346 lb.) 318 (950 lb.) 205 (947 lb.) 169 (543 lb.) 153 (369 lb.) 146 (915 lb.) 104 (380 lb.) 104 (346 lb.) - (331 lb.) 990 (381 lb.) 104	L D kg (2011 kb.) ¹ O kg (2,607 kb.) D kg (3,740 kb.) D kg (3,280 kb.) D kg (3,280 kb.) D kg (2,273 kb.) D kg (2,293 kb.) D kg (2,299 kb.) D kg (2,299 kb.) D kg (2,299 kb.)		urpperstock	
A B C D E F G H I J	Capacities capacities are over- 3721 kg (5296 b). 2731 kg (5296 b). 2731 kg (5296 b). 2372 kg (5296 b). 2372 kg (5296 b). 2372 kg (5296 b). 1562 kg (1209 b). 1562 kg (1209 b). 1562 kg (1206 b). 1523 kg (1217 b).	end values in kg (b). Sectick 100. 1993 kg (7211 b.) 2063 kg (522 b.) 2193 kg (520 b.) 2193 kg (520 b.) 1993 kg (1204 b.) 2073 kg (4666 b.) 657 kg (1653 b.) 1993 kg (1531 b.) 1954 kg (1232 b.) 1462 kg (1232 b.) 1462 kg (1297 b.) 1474 kg (2970 b.)	With 1.06-m (3 ft. 4 Extendable Dippers 310L EP 4089 kg (9,015 lb.) 2466 kg (5,437 lb.) 2171 kg (4,2786 lb.) 2171 kg (4,2786 lb.) 2124 kg (4,683 lb.) 1950 kg (4,299 lb.) 1467 kg (3,234 lb.) 1467 kg (3,234 lb.) 1347 kg (2,969 lb.) 1346 kg (2,836 lb.)	5 in.) tick, Retracted 300L 3866 kg (8,478 lb 2464 kg (8,478 lb 2166 kg (4,773 lb 2126 kg (4,573 lb 2126 kg (4,522 lb 1468 kg (3,200 lb 1469 kg (3,229 lb 1412 kg (3,127 lb) 1429 kg (2,975 lb 1289 kg (2,941 lb) 289 kg (2,941 lb)	With 1.06 Extended 300L EP 2898 kg (6) 2295 kg (4) 1790 kg (3) 1607 kg (3) 1528 kg (3) 1528 kg (3) 1528 kg (3) 1322 kg (2 1080 kg (2) 1057 kg (2) 1090 kg (2) 1090 kg (2) 1090 kg (2)	m (3 ft. 6 in.) in Dipperstick, 3100 (346 lb.) 318 (950 lb.) 205 (947 lb.) 169 (543 lb.) 153 (369 lb.) 146 (316 lb.) 104 (380 lb.) 104 (380 lb.) 104 (381 lb.) 104 (381 lb.) 104 (359 lb.) 104	L D kg (2011 lb.) ¹ O kg (2,607 lb.) 6 kg (3,740 lb.) 3 kg (3,340 lb.) 5 kg (3,229 lb.) 7 kg (3,212 lb.) 8 kg (2,873 lb.) 6 kg (2,307 lb.) kg (2,188 lb.)			
A B C D E F G H I J K L M N	Capacities Capacities are over- With Standard Dice 390. ct ⁹ 3721 kg (8,204 h.). 273 kg (8,204 h.). 273 kg (8,204 h.). 273 kg (8,206 h.). 255 kg (8,204 h.). 1950 kg (3,206 h.). 1956 kg (2,206 h.). 1956 kg (2,206 h.). 1956 kg (2,206 h.). 1956 kg (2,206 h.). 1956 kg (2,205 h.). 1956 kg (2,255 h.). 1956 kg (2	end values in tog (b.) serstick 100. 10393 tog (1921 b.) 3696 tog (1921 b.) 2696 tog (1922 b.) 2030 tog (1920 b.) 2030 tog (1920 b.) 2030 tog (1931 b.) 567 tog (1933 b.) 562 tog (1933 b.) 562 tog (1933 b.) 462 tog (1923 b.) 1447 tog (1930 b.) 1447 tog	With LOG-m B ft. Extendeble Dippers 3100. EP 4089 kg (9015 kL) 2466 kg (5,437 kL) 2171 kg (1,276 kL) 2124 kg (4,683 kL) 1409 kg (1,280 kL) 1409 kg (1,206 kL) 1204 kg (2,266 kL) 1204 kg (2,266 kL) 1204 kg (2,260 kL) 1204 kg (2,260 kL) 1204 kg (2,271 kL) 1129 kg (2,249 kL) 1128 kg (2,249 kL)	5 in.) abids, Retrocted 300. 2065 kg (4,670 lb 2065 kg (4,670 lb 2065 kg (4,677 lb 2065 kg (4,677 lb 1020 kg (4,220 lb 1468 kg (3,220 lb 1468 kg (3,220 lb 1468 kg (3,220 lb 1469 kg (3,237 lb 128 kg (2,207 lb 128 kg (2,207 lb 119 kg (2,600 lb 113 lkg (2,493 lb.) 1036 kg (2,395 lb 1036 kg (2,395 lb 1036 kg (2,395 lb	With 1.06 Extended 3000 LP 1, 2245 kg (4 1, 1290 kg (1 1, 12245 kg (4 1, 1290 kg (1 1, 1528 kg (2 1, 1528 kg (2 1, 1528 kg (2 1, 1000 kg (2) k	m (3 ft. 6 in.) in (3 ft. 6 in.) in (2 ft. 6 i	L lig (2011 lb.) ² O lig (4,607 lb.) o lig (3,800 lb.) lig (3,300 lb.) lig (3,300 lb.) lig (3,229 lb.) 7 lig (3,229 lb.) lig (2,293 lb.) 6 lig (2,307 lb.) lig (2,299 lb.) 7 lig (2,299 lb.) lig (2,299 lb.) lig (2,299 lb.) lig (2,299 lb.)			
A B C D E F G H I J K L M	Capacities Capacities are over- with Stondard Dire 300, EF 301, EF 302, EF 302, EF 302, EF 303, EF 304, EF 304, EF 305, EF 305	end values in kg (b). serstick 100. 1993 kg (1921 b.) 2666 kg (1922 b.) 2063 kg (1922 b.) 2063 kg (1920 b.) 2073 kg (1966 b.) 1074 kg (1966 b.) 506 kg (1076 b.) 507 kg (1985 b.) 2073 kg (1985 b.) 2093 kg (1985 b.) 2003 kg (1985 b.) 2	With LOS-m B R. Extendeble Dippers JOL EP 4099 lag (9015 las) 4099 lag (9015 las) 2046 lag (5437 las) 2024 lag (4,683 las) 2030 lag (2,234 las) 1409 lag (2,266 las) 2206 lag (2,265 las) 2206 lag (2,265 las) 1229 lag (2,489 las) 1024 lag (2,499 las) 1024 lag (2,206 las) 1024 lag (2,207 las) 1044 lag (2,207 las)	5 m.) 300L 300L 2016 kg (8,478 lb 2016 kg (8,478 lb 2016 kg (4,688 lb 1920 kg (4,688 lb 1920 kg (4,628 lb 1920 kg (4,628 lb 1920 kg (4,229 lb 1920 kg (2,294 lb 1929 kg (2,944 lb 1929 kg (2,944 lb 1929 kg (2,944 lb 1929 kg (2,944 lb 1939 kg (2,949 lb) 1931 kg (2,499 lb) 1066 kg (2,396 lb 1936 kg (2,	With Lo6 Extended JOLL PP (1) 2878 kg (6) (2) 2245 kg (4) (1) 700 kg (1) (1) 1607 kg (2) (1) 1607 kg (2) (1) 1627 kg (2) (1) 1624 kg (2) (1) 1	m (3 ft. 6 in.) ib Opportation, 3100 3146 (b.)" 318 3950 (b.) 205 3047 (b.) 205 3047 (b.) 205 3047 (b.) 205 3047 (b.) 205 3047 (b.) 205 3047 (b.) 104 3046 (b.) - 3048 (b.) 404 3048 (b.) 40	L D kg (2011 lb.) ¹ O kg (2,011 lb.) ls (3,340 lb.) ls (3,340 lb.) ls (3,340 lb.) ls (3,340 lb.) ls (3,222 lb.) ls (3,222 lb.) ls (2,293 lb.) ls (2,299 lb.) ls (2,299 lb.) ls (2,299 lb.) ls (3,229 lb.) ls (3			
A B C D E F G H I J K L M N O P	Capacities capacities are over- sol. Cr 300. Cr 301 (g (5204 h.). 2713 kg (5204 h.). 2713 kg (5204 h.). 2713 kg (5204 h.). 2713 kg (5209 h.). 1623 kg (1209 h.). 1623 kg (1209 h.). 1623 kg (1206 h.). 1623 kg (1206 h.). 1624 kg (1206 h.). 1624 kg (1206 h.). 1026 kg (1206 h.).	end values in tog (b.) 100. 101. 1039 kg (1921 b.) 1069 kg (1922 b.) 1069 kg (1922 b.) 1069 kg (1920 b.) 1079 kg (1966 b.) 1079 kg (1966 b.) 1060 kg (1920 b.) 1079 kg (1920 b.) 1079 kg (1920 b.) 1079 kg (1950 b.) 1070 kg (1950 b	With 106-m B 14: Extendebb (Dipers) 100 LP 4099 lg (2015 lb.) 4099 lg (2015 lb.) 2466 lg (5437 lb.) 2171 lg (4266 lb.) 128 lg (4688 lb.) 1950 lg (4296 lb.) 1960 lg (2365 lb.) 1467 lg (2364 lb.) 1467 lg (2364 lb.) 1247 lg (2469 lb.) 1290 lg (2,218 lb.) 1024 lg (2,496 lb.) 1024 lg (2,496 lb.) 1024 lg (2,496 lb.) 1024 lg (2,496 lb.) 1024 lg (2,218 lb.) 1024 lg (2,219 lb.) 1024 lg (2,221 lb.)	5 in.) albot. Retrocted 3004. 2044.k (g) (5,380 li 2045.k (g) (4,673 li 2045.k (g) (4,673 li 2045.k (g) (4,523 li 1930.k (g) (4,523 li 1930.k (g) (4,523 li 1442.k (g) (3,234 li 1442.k (g) (3,234 li 1232.k (g) (2,84 li 1232.k (g) (2,96 li 1232.k (g) (2,96 li 1234.k (g) (2,96 li 1234.k (g) (2,96 li 1036.k (g) (2,395 li 1006.k (g) (2,395 li 1006.k (g) (2,395 li 1006.k (g) (2,326 li)	With Lo6 Extended 310L EP 4 2878 kg (6 2878 kg (6 1790 kg (1 1802 kg (1 1805 kg (1) 1805 kg (1 1805 kg (1) 1805 kg (1 1805 kg (1) 1805 kg (1		L big (2011 lb.)" big (2011 lb.)" big (3,740 lb.) big (3,380 lb.) big (3,380 lb.) big (3,229 lb.) big (2,229 lb.) big (2,283 lb.) big (2,283 lb.) big (2,288 lb.) big (2,289 lb.) big (2,281 lb.) big (2,299 lb.) big (2,299 lb.) big (2,299 lb.) big (2,299 lb.) big (2,299 lb.)			
A B C D E F G H I J K L M N	Capacities Capacities are over- with Stondard Dire 300, EF 301, EF 302, EF 302, EF 302, EF 303, EF 304, EF 304, EF 305, EF 305	end values in kg (b). serstick 100. 1993 kg (1921 b.) 2666 kg (1922 b.) 2063 kg (1922 b.) 2063 kg (1920 b.) 2073 kg (1966 b.) 1074 kg (1966 b.) 506 kg (1076 b.) 507 kg (1985 b.) 2073 kg (1985 b.) 2093 kg (1985 b.) 2003 kg (1985 b.) 2	With LOS-m B R. Extendeble Dippers JOL EP 4099 lag (9015 las) 4099 lag (9015 las) 2046 lag (5437 las) 2024 lag (4,683 las) 2030 lag (2,234 las) 1409 lag (2,266 las) 2206 lag (2,265 las) 2206 lag (2,265 las) 1229 lag (2,489 las) 1024 lag (2,499 las) 1024 lag (2,206 las) 1024 lag (2,207 las) 1044 lag (2,207 las)	5 m.) 300L 300L 2016 kg (8,478 lb 2016 kg (8,478 lb 2016 kg (4,688 lb 1920 kg (4,688 lb 1920 kg (4,628 lb 1920 kg (4,628 lb 1920 kg (4,229 lb 1920 kg (2,294 lb 1929 kg (2,944 lb 1929 kg (2,944 lb 1929 kg (2,944 lb 1929 kg (2,944 lb 1939 kg (2,949 lb) 1931 kg (2,499 lb) 1066 kg (2,396 lb 1936 kg (2,	With L06 Extended JIOL (P) 210 (200 kg) 200	m [3 ft. 6 in.] ib Opportation, 310 346 [b.]' 318 3950 [b.] 205 9471 [b.] 696 543 [b.] 153 369 [b.] 146 251 [b.] 146 251 [b.] 146 251 [b.] 146 251 [b.] 146 318 [b.] 146 318 [b.] 146 318 [b.] 146 318 [b.] 147 318 [b.] 147 31	L D kg (2011 lb.) ¹ O kg (2,011 lb.) ls (3,340 lb.) ls (3,340 lb.) ls (3,340 lb.) ls (3,340 lb.) ls (3,222 lb.) ls (3,222 lb.) ls (2,293 lb.) ls (2,299 lb.) ls (2,299 lb.) ls (2,299 lb.) ls (3,229 lb.) ls (3			
A B C D E F G H I J K L M N O P	Capacities capacities are over- 322 kg (8,204 b). 237 kg (5,206 b). 237 kg (5,206 b). 237 kg (5,206 b). 237 kg (5,206 b). 235 kg (4,729 b). 1662 kg (1,207 b). 1655 kg (1,207 b). 1655 kg (1,207 b). 1655 kg (1,207 b). 1655 kg (1,207 b). 1656 kg (1,207 b). 1645 kg (1,207 b). 1645 kg (1,207 b). 1645 kg (2,256 b). 1245 kg (2,256 b). 1245 kg (2,256 b). 1704 kg (2,551 b).	end values in kg (b.) serstick 1901. 1901. 1903. 1904. 1903. 1906. 1903. 1906. 1907. kg (1907.b.). 1909. kg (1907.b.). 1909. kg (1907.b.). 1909. kg (1907.b.). 1907. kg (1907.b.). 1907	With 106-m B 7t. E Extendeble Dippers 310L IP 40095 lig (SUD5 h.) 2006 lig (SUD5 h.) 210k lig (A268 h.) 210k lig (A268 h.) 210k lig (A268 h.) 120k lig (A268 h.) 1409 lig (1228 h.) 1409 lig (1236 h.) 1206 lig (2296 h.) 120k lig (2296 h.) 1108 lig (2296 h.) 1084 lig (2,206 h.) 1084 lig (2,207 h.)	5 m.) 3046, Retocted 3046, 3	With Lo6 Extendabi JOLL EP JOLD (EP) JO		L D kg (2011 b.) G kg (2021 b.) G kg (2020 b.) S kg (2.29 b.) S kg (2.20			
A B C D E F G H I J K L M N O P Q R S T	Capacities capacities are over- 322 kg (8,204 b). 237 kg (5,206 b). 237 kg (5,206 b). 237 kg (5,206 b). 237 kg (5,206 b). 235 kg (4,729 b). 1662 kg (1,207 b). 1655 kg (1,207 b). 1655 kg (1,207 b). 1655 kg (1,207 b). 1655 kg (1,207 b). 1656 kg (1,207 b). 1645 kg (1,207 b). 1645 kg (1,207 b). 1645 kg (2,256 b). 1245 kg (2,256 b). 1245 kg (2,256 b). 1704 kg (2,551 b).	end values in kg (b.) serstick 1901. 1901. 1903. 1904. 1903. 1906. 1903. 1906. 1907. kg (1907.b.). 1909. kg (1907.b.). 1909. kg (1907.b.). 1909. kg (1907.b.). 1907. kg (1907.b.). 1907	With 106-m B 7t. E Extendeble Dippers 310L IP 40095 lig (SUD5 h.) 2006 lig (SUD5 h.) 210k lig (A268 h.) 210k lig (A268 h.) 210k lig (A268 h.) 120k lig (A268 h.) 1409 lig (1228 h.) 1409 lig (1236 h.) 1206 lig (2296 h.) 120k lig (2296 h.) 1108 lig (2296 h.) 1084 lig (2,206 h.) 1084 lig (2,207 h.)	5 m.) 3046, Retocted 3046, 3	With Lo6 Extendabl SIOL EP SIOL SIOL SIOL SIOL 100 L P 2029 kg) (6 1		L D kg (2011 kJ) G kg (2017 kJ) G kg (2020 kJ) G kg (2020 kJ) Kg (2020 kJ) Kg (2020 kJ) G kg (2020 kJ) G kg (2020 kJ) G kg (2020 kJ) G kg (2020 kJ) Kg (2020 kJ) Kg (2020 kJ) Kg (2041 kJ) Kg (2041 kJ) Kg (2041 kJ) Kg (1920 kJ			
A B C D E F G H I J K L M N O P Q R S T U	Capacities capacities are over- 322 kg (8,204 b). 237 kg (5,206 b). 237 kg (5,206 b). 237 kg (5,206 b). 237 kg (5,206 b). 235 kg (4,729 b). 1662 kg (1,207 b). 1655 kg (1,207 b). 1655 kg (1,207 b). 1655 kg (1,207 b). 1655 kg (1,207 b). 1656 kg (1,207 b). 1645 kg (1,207 b). 1645 kg (1,207 b). 1645 kg (2,256 b). 1245 kg (2,256 b). 1245 kg (2,256 b). 1704 kg (2,551 b).	end values in kg (b.) serstick 1901. 1901. 1903. 1904. 1903. 1906. 1903. 1906. 1907. kg (1907.b.). 1909. kg (1907.b.). 1909. kg (1907.b.). 1909. kg (1907.b.). 1907. kg (1907.b.). 1907	With 106-m B 7t. E Extendeble Dippers 310L IP 40095 lig (SUD5 h.) 2006 lig (SUD5 h.) 210k lig (A268 h.) 210k lig (A268 h.) 210k lig (A268 h.) 120k lig (A268 h.) 1409 lig (1228 h.) 1409 lig (1236 h.) 1206 lig (2296 h.) 120k lig (2296 h.) 1108 lig (2296 h.) 1084 lig (2,206 h.) 1084 lig (2,207 h.)	5 m.) 3046, Retocted 3046, 3	With Lo6 Extendabi JOLL EP JOLD KD	m (3 fc, 6 m.) is Dippersitek, 3146 lb, 1 318 3590 lb, 205 3947 lb, 1 69 3947 lb, 1 69 3947 lb, 1 69 394 lb, 1 64 395 lb, 1 50 3130 lb, 1 04 313 lb, 1 99 313 lb, 1 99 31 lb, 1 99 31 lb,	L L L L L L L L L L L L L L			
A B C D E F G H I J K L M N O P Q R S T	Capacities capacities are over- 322 kg (8,204 b). 237 kg (5,206 b). 237 kg (5,206 b). 237 kg (5,206 b). 237 kg (5,206 b). 235 kg (4,729 b). 1662 kg (1,207 b). 1655 kg (1,207 b). 1655 kg (1,207 b). 1655 kg (1,207 b). 1655 kg (1,207 b). 1656 kg (1,207 b). 1645 kg (1,207 b). 1645 kg (1,207 b). 1645 kg (2,256 b). 1245 kg (2,256 b). 1245 kg (2,256 b). 1704 kg (2,551 b).	end values in kg (b.) serstick 1901. 1901. 1903. 1904. 1903. 1906. 1903. 1906. 1907. kg (1907.b.). 1909. kg (1907.b.). 1909. kg (1907.b.). 1909. kg (1907.b.). 1907. kg (1907.b.). 1907	With 106-m B 7t. E Extendeble Dippers 310L IP 40095 lig (SUD5 h.) 2006 lig (SUD5 h.) 210k lig (A268 h.) 210k lig (A268 h.) 210k lig (A268 h.) 120k lig (A268 h.) 1409 lig (1228 h.) 1409 lig (1236 h.) 1206 lig (2296 h.) 120k lig (2296 h.) 1108 lig (2296 h.) 1084 lig (2,206 h.) 1084 lig (2,207 h.)	5 m.) 3046, Retocted 3046, 3	With LOS Stretendos JIOL EP JON EP	m (3 fc 6 m.) is Dippertick, (3 m) 346 hJ, 310 350 hJ, 205 350 hJ, 205 350 hJ, 205 369 hJ, 166 353 hJ, 165 369 hJ, 166 373 hJ, 195 375 hJ, 165 375 hJ, 175 hJ, 17	L Diag (2011 b.) do (a) (A607 b.) do (a) (A606 b.) do (a) (A60			
Lift A B C D E F G H I J K L M N O P Q R S T U V	Capacities capacities are over- 322 kg (8,204 b). 237 kg (5,206 b). 237 kg (5,206 b). 237 kg (5,206 b). 237 kg (5,206 b). 235 kg (4,729 b). 1662 kg (1,207 b). 1655 kg (1,207 b). 1655 kg (1,207 b). 1655 kg (1,207 b). 1655 kg (1,207 b). 1656 kg (1,207 b). 1645 kg (1,207 b). 1645 kg (1,207 b). 1645 kg (2,256 b). 1245 kg (2,256 b). 1245 kg (2,256 b). 1704 kg (2,551 b).	end values in kg (b.) serstick 1901. 1901. 1903. 1904. 1903. 1906. 1903. 1906. 1907. kg (1907.b.). 1909. kg (1907.b.). 1909. kg (1907.b.). 1909. kg (1907.b.). 1907. kg (1907.b.). 1907	With 106-m B 7t. E Extendeble Dippers 310L IP 40095 lig (SUD5 h.) 2006 lig (SUD5 h.) 210k lig (A268 h.) 210k lig (A268 h.) 210k lig (A268 h.) 120k lig (A268 h.) 1409 lig (1228 h.) 1409 lig (1236 h.) 1206 lig (2296 h.) 120k lig (2296 h.) 1108 lig (2296 h.) 1084 lig (2,206 h.) 1084 lig (2,207 h.)	5 m.) 3046, Retocted 3046, 3	With Lo6 Extendabi JOLL EP JOLD STARD JOLD STA	m (3 fc 6 m) is Dippertick, (3 346 hJ, 318 350 hJ, 305 350 hJ, 305 369 hJ, 165 369 hJ, 166 369 hJ, 166 369 hJ, 166 369 hJ, 166 370 hJ, 166 371 hJ, 167 371 hJ, 175 371 hJ, 175	L L L L L L L L L L L L L L			

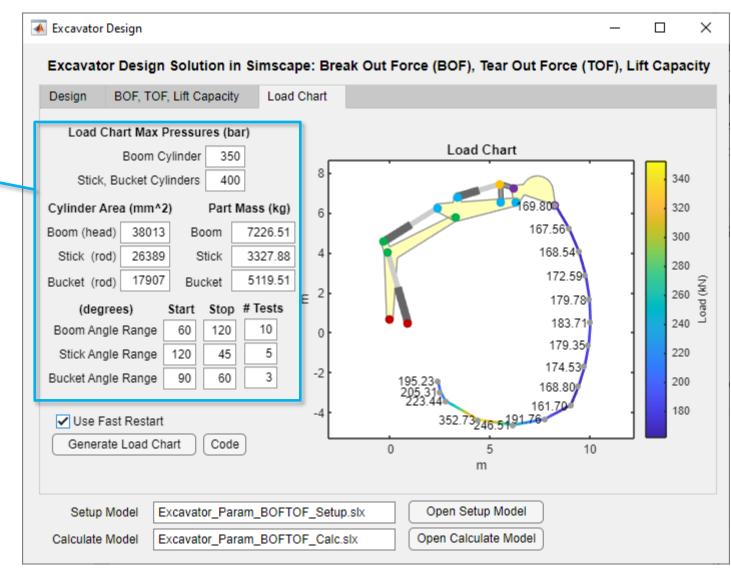


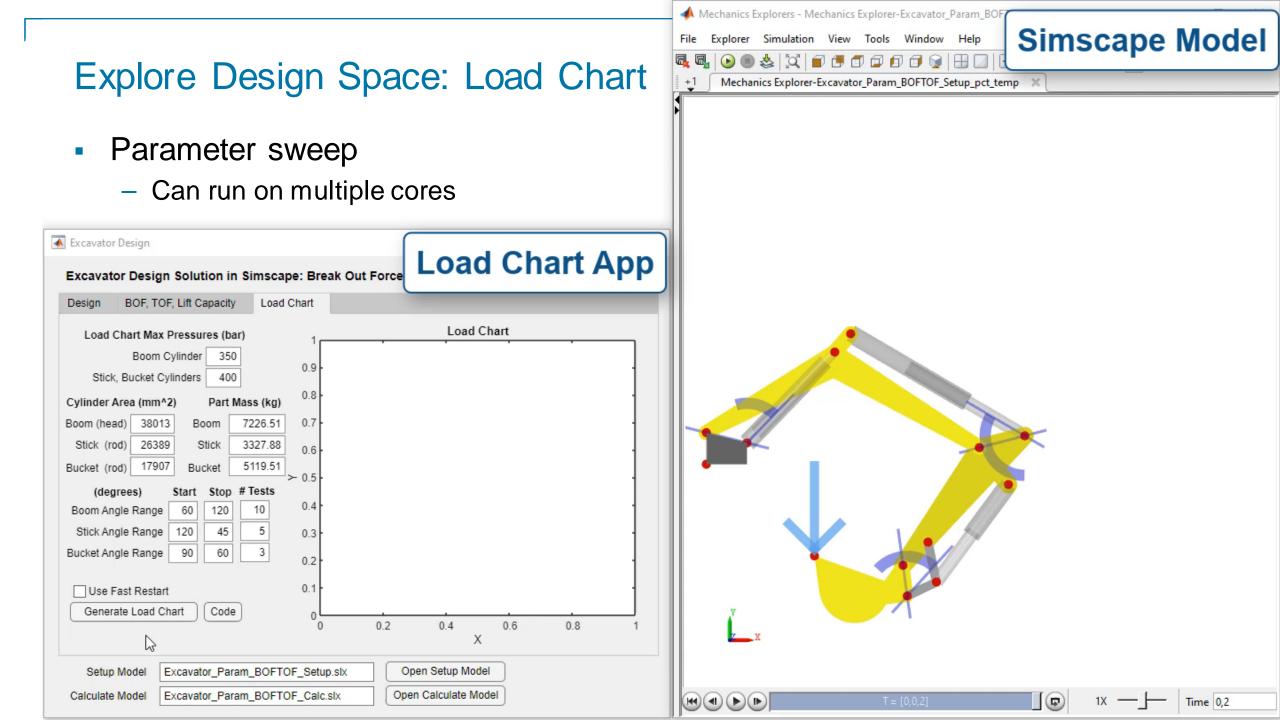


Explore Design Space: Load Chart

- MATLAB App lets you specify design space for load chart
 - Test positions
 - Pressure limits, actuator sizes
 - Part masses
- Results displayed in a plot

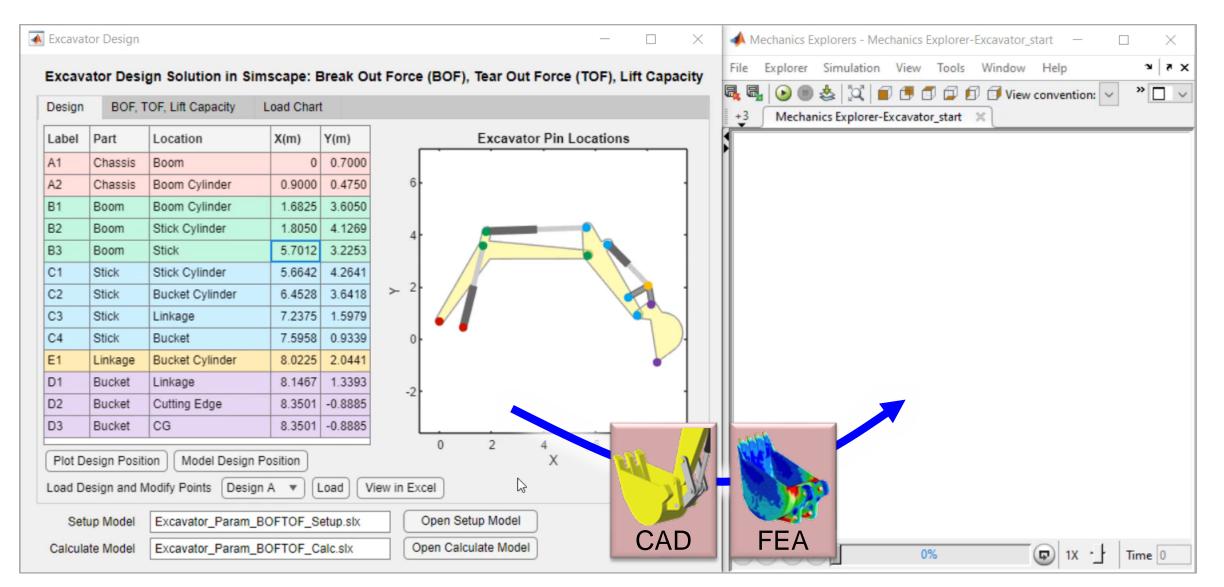






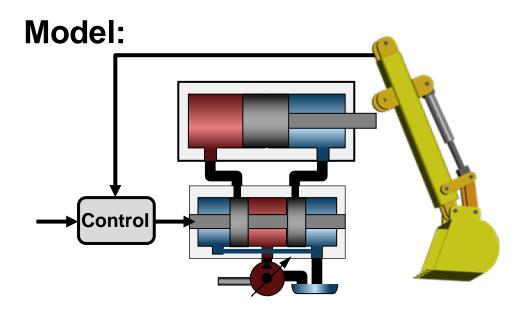
A MathWorks

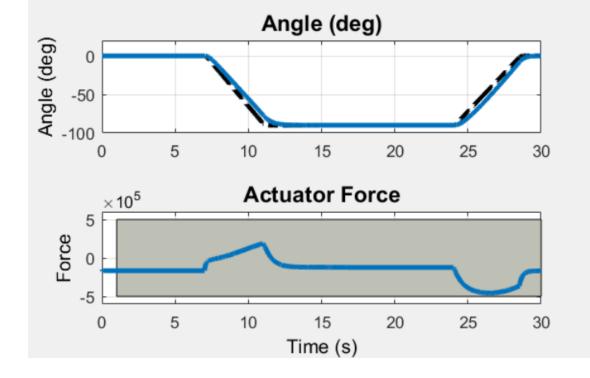
Roles of Design Solution and Full Actuation Model





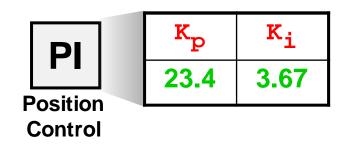
Optimizing System Performance





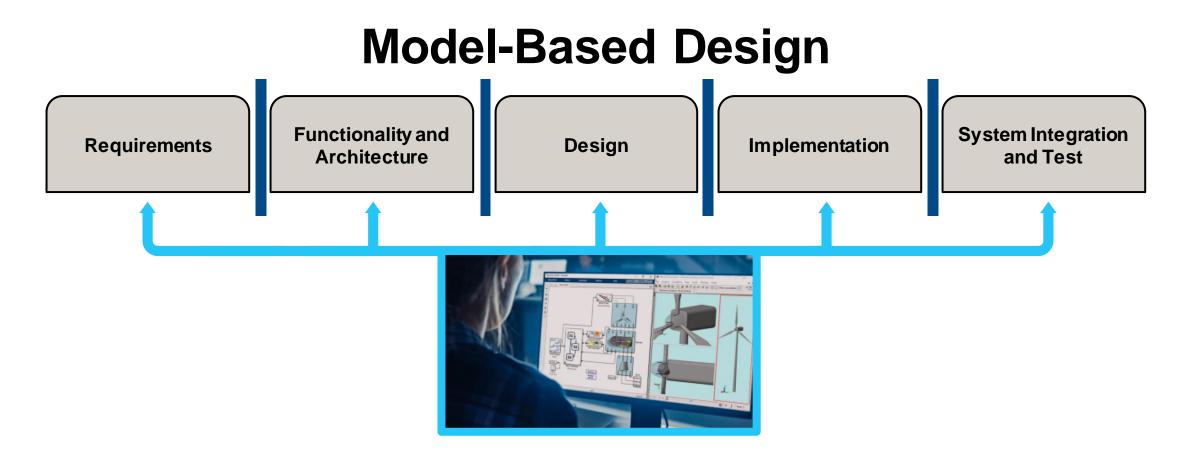
Problem: Optimize the position controller to meet system requirements

Solution: Tune controller parameters with Simulink Design Optimization





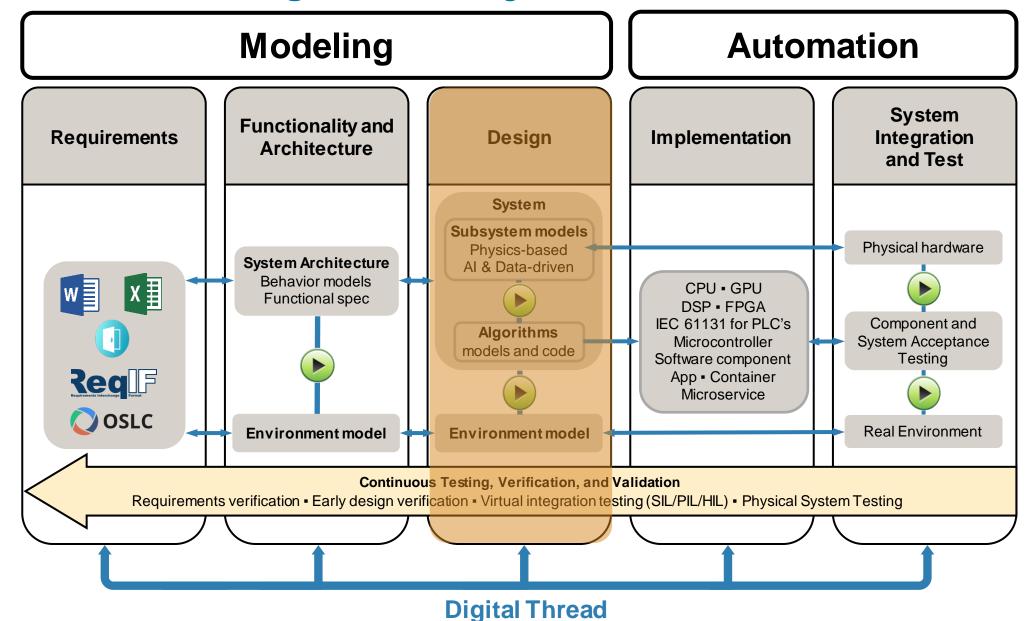
Use Physical Model in Model-Based Design Workflow



Models are at the **center** of your development process Create a **digital thread**



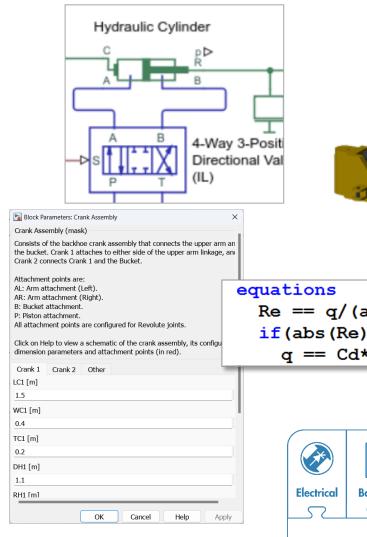
Model-Based Design = Modeling + Automation





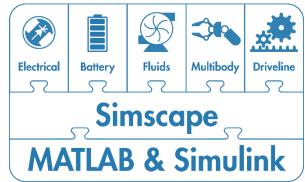
Key Points

- Simscape provides powerful libraries of component models for multi-domain systems
- Models can be adapted to your needs
 - Create reusable assemblies
 - Adjust parameterization
 - Define custom components
- Leverage MATLAB and Simulink
 - Use powerful analysis tools
 - Perform parameter sweeps and optimization





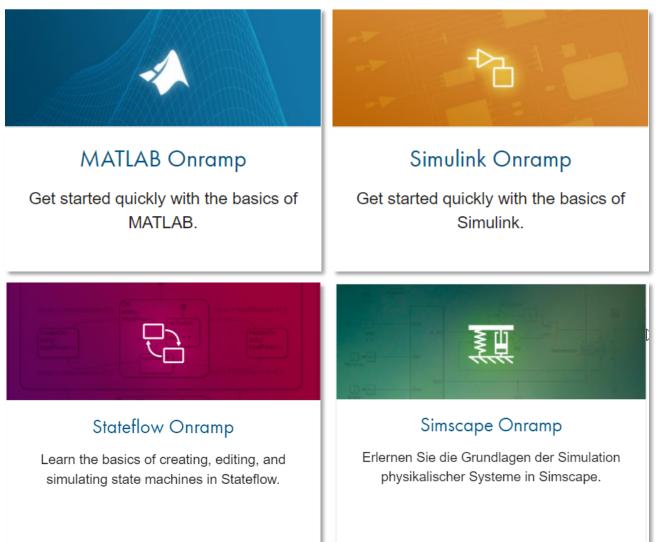
Re == q/(area*viscosity_kin)*I
if(abs(Re)>=Recr) % Turbulent
q == Cd*area*sqrt(2/density)





Start with free Onramp Training

- Free hands-on tutorials
- Short videos and hands-on exercises with feedback
- Get up and running with MATLAB, Simulink and Simscape in hours



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