Adoption of Model-Based Software for Vehicle Systems Development

Presented by:

Marc McClain

Crown Equipment Company

Material prepared for MathWorks Automotive Conference, May 9, 2017



One of the World's Largest Material Handling Companies



5 regional headquarters



2.5 Billion USD FY2014



12,000 employees



17 manufacturing plants in 11 locations worldwide



Over 500 retail locations across 84 countries



Leader in material handling innovation and technology



Global line of trucks designed to local work practices



Innovative fleet management solutions



Family owned and managed industry leader since 1945



Crown Lift Trucks





Adopting Model Based Software

Agenda

- I. Initial Goals
- II. Architecture Decisions
- III. Code Generation Experience
- IV. Virtual Truck Simulations
- V. Performance Improvements
- VI. Verify, Test and Report



I. Model Based Software – Initial Goals

- Code Generation from Reusable Models for All Products
- Support Expansion of Features for New Technology







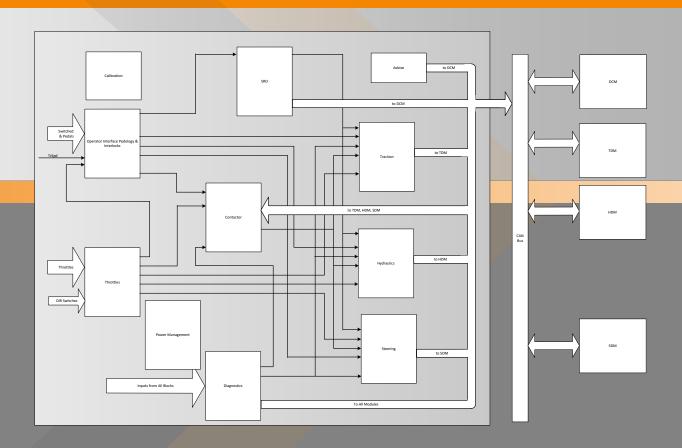
II. Model Based Software – Architecture Decisions

R2011b

Initial MBS Version:

- MATIAF
- Simulink
- Stateflo

Data Dictionary Concept Shared Network Files (8) Legacy MATLAB Users



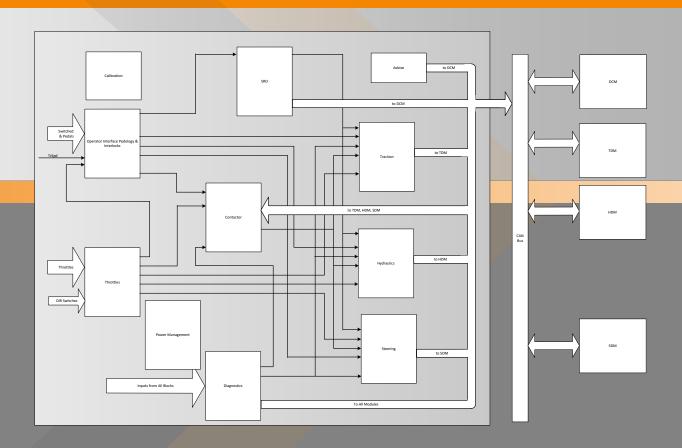
II. Model Based Software – Architecture Decisions

R2011b

Initial MBS Version:

- MATIAF
- Simulink
- Stateflo

Data Dictionary Concept Shared Network Files (8) Legacy MATLAB Users



III. Model Based Software - Code Generation

Modular Model Design

Initial Code Gen:

- MATLAB Coder
- Simulink Coder
- Embedded Coder

(4) System Developers

R2011b

R2012b

Initial MBS Version:

- MATIAR
- Simulinl
- Stateflo

Data Dictionary Concept Shared Network Files

Benefits	Virtual Subsystem	Subsystem Subsystem Ref										
Ease of Use	+	+	-									
Readability	+	+	+									
Traceability		+	+									
Reusability			+									
Concurrent Development			+									
Unit Testing			+									
Performance			+, -									

III. Model Based Software - Code Generation

Initial Code Gen:

- MATLAB Coder
- Simulink Coder
- Embedded Coder
- (4) System Developers

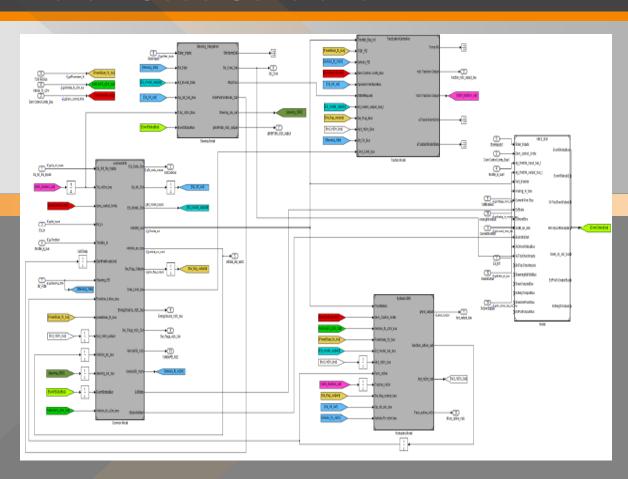
R2011b

R2012b

Initial MBS Version:

- MATIAR
- Simulinl
- Stateflo

Data Dictionary Concept Shared Network Files (8) Legacy MATLAB User:



III. Model Based Software - Code Generation

Initial Code Gen:

> 2 Hrs to Generate Code Single Core - 8 GB RAM SVN Source Control (4) System Developers

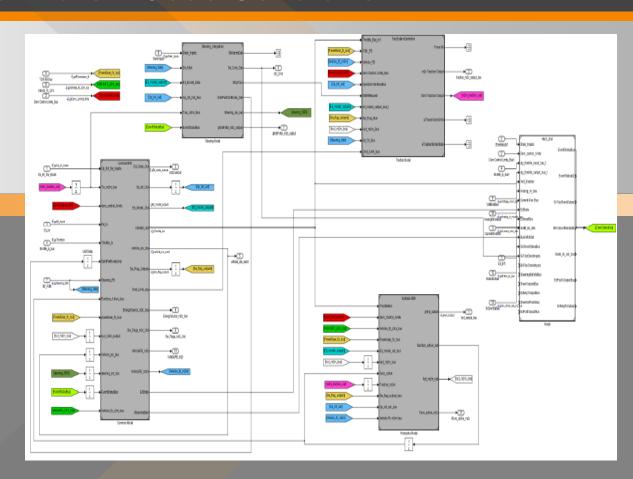
R2011b

R2012b

Initial MBS Version:

- MATIAR
- Simulinl
- Stateflo

Data Dictionary Concept Shared Network Files (8) Legacy MATLAB Users



III. Model Based Software – Signals and Parameters

Signal	Bus		CommonSIMu1	H	gdraulicSIMu1	TractionSIMu1	SteeringSIMu1		rgySourceSIMu1	Hen	nsSim_Brake Variable	VehicleFBSIMu1	CalibrationSIMu1	HmsSim_Communication itructure Variable		HmsSim_Ed	HmsSim_Gpd Structure Variable	HmsSim_HemTem	HmxSim_Hgdraulic tructure Variable	HmsSim	PowerSupplies	Hm	sSim_Steering
gpOp_int_inputs	op_int_input_bus_t	Importer	Variable d ImportedExternPointer	tructure 	Variable 	Structure Variable	Itructure Variable	itruetur	Variable	···	Variable	Structure Variable	tructure Variable	itructure Variable		variable	Structure Variable	tructure Variable	tructure Variable	itrueture	Variable	trueture	Variable
gOperator_interface_output	operator interface output bus t	Esporter	d EsportToFile	Imported	ImportedExtern	Imported ImportedExtern	Imported ImportedEstern						Imported ImportedExtern									Imported	ImportedEstern
gsPowerbase_fb gSteet_m2m_outputs	poverbase_fb_main_bus_t steer_m2m_output_bus_t	Importer	d ImportedEsternPointer d ImportedEstern	Imported	ImportedExternPointer	Imported ImportedExternPointer Imported ImportedExtern	Exported ExportToFile	Imported	ImportedEsternPointer			Imported ImportedExtemPointer	Imported ImportedExtern						Imported ImportedExternPointe			Imported	ImportedEstern
gpSteering_fdbk	steering_ms_fdbk_bus_t	Importer	d ImportedExternPointer			Imported ImportedExternPointer	Imported ImportedExternPointe	4				Imported ImportedExternPointer											ImportedExternPointer
gSteering_sro gSteering_sim_sro	steering sro bus t steering sro bus t	Importer	d importedEatern	***			Exported ExportToFile			***												***	
gSv_flag_outputs	sw_flag_output_bus_t throttle_bus_t	Esporter		imported	ImportedEstern	Imported ImportedExtern	Imported ImportedExtern					Imported ImportedExtern	Imported ImportedExtern						Imported ImportedExtern			***	
gSv_flag_outputs gThrottle_out gpThrottlein	throttle_bus_t throttle_in_bus_t	Esporter	d EsportToFile d ImportedExternPointer	Imported	ImportedEstern	Imported ImportedExtern	Imported ImportedExtern						Imported ImportedExternPointer				Imported ImportedExtern	Imported ImportedExternPointer	Imported ImportedExtern				
gTraction_output	traction output bus t	***		***				***		***				***						***		***	
gTraction_sim_output gpVehicle_fb_c2m_bus	traction_output_bus_t vehicle_fb_c2m_bus_t	Importer	d ImportedEstern d ImportedEsternPointer	Imported	ImportedExtern ImportedExternPointer	Exported ExportToFile Imported ImportedExternPointer	Imported ImportedExtern			Imported	ImportedExtern	Imported ImportedExtern Imported ImportedExternPointer	Imported ImportedExtern Imported ImportedExternPointer				Imported ImportedExtern		Imported ImportedExternPointe			Imported	ImportedEstern
gvehicle_sro_word gVehicleFB_output		Esporte	d EsportToFile					***	***	***				***	***					***	***	***	
gVehicleFB_output gSv_debounce_outputs	YehicleFB_output_bus_t sv_debounce_output_bus_t	Importer	d ImportedExtern Auto	Imported	ImportedExtern	Imported ImportedExtern	Imported ImportedExtern	Imported	ImportedEstern			Exported ExportToFile	Imported ImportedExtern						Imported ImportedExtern				
gTraction_sro	traction are bus t	Auto	Auto	***				***		***					***					***		***	
gSv_tiedown_outputs	sw_tiedown_output_bus_t	Auto	Auto																				
gSv_test_outputs gHydPlun_Processed_Svitches	sw_test_output_bus_t run_processed_sws_bus_t SlowUn_bus_t	Auto Auto	Auto Auto																		***		
	SlowDn_bus_t			Auto	Auto			***		***										***		***	
gpTitSlovDown gpReachSlovDown	SlowDn_bus_t SlowDn_bus_t			Auto	Auto																***	***	
gpReachStovDown StovDovnMap	SlowDn_bus_t Slow_down_map_bus_t			Auto	Auto					***										***	***	***	
golamp gAocyMadipds	olamp_bus_t Accessory_Max_Spd_bus_t			Auto	Auto																		
gpSteer_inputs	steer inputs bus t	***		100			Imported ImportedEsternPointe			***			Imported ImportedExternPointer		***					***		Imported	ImportedExternPointer
gSteer_outputs	steer_outputs_bus_t steer_outputs_bus_t						Exported ExportToFile															Imported	ImportedEstern
gSteer_sim_outputs gSteer_alarms				***																		7	
gliteer_sim_alarms gpVoltage_mon_bus	steer alarms bus t voltage mon bus t						Exported ExportToFile			Imported I	importedExternPointer			Imported ImportedEsternPointe			Imported ImportedExternPointer	Imported ImportedExternPointer		Imported I	mportedEsternPointer		
gpAnalog in monitor bus gpCurrent mon bus																		Imported ImportedExternPointer					
gpCurrent_mon_bus gpBrake_ds_in_bus	ourrent mon_bus_t brake_dr_in_bus_t									Imported I	ImportedExternPointer ImportedExternPointer						Imported ImportedExternPointer						
gpSv driver req sts bus gBrake do out bus										Imported I							Imported ImportedExternPointer Imported ImportedExternPointer						
gBrake do out bus	brake do out bus t SOC_input_bus_t	***		***		Imported ImportedExtern		Imported	ImportedFiteroReleter													***	
gpSOC_input gpQP_throttle_input	qp_throttle_in_bus_t	Importer	d ImportedExternPointer					godea	ImportedEsternPointer							-	Imported ImportedExternPointer						
gpSteer_ds_inputs	steer_ds_inguts_bus_t																					Imported	ImportedExternPointer
gliteer_dr_out_bus gAutoCalActive	steer_ds_out_bus_t AutoCal_Active_bus_t	Importer	d ImportedEstern	Imported	ImportedEstern	Imported ImportedExtern	Imported ImportedExtern					Imported ImportedExtern	Exported ExportToFile						Imported ImportedExtern			Imported	EsportToFile ImportedEstern
gpAutoCallmmStat	AutoCal Cm Calib bus t												Imported ImportedExternPointer										
gpAutoCallmmStat gAutoCallMooStat gAutoCallPvFormat	AutoCal Cm Callb bus t AutoCal Mos Callb bus t AutoCal PsFormat bus t			***									Exported ExportedGlobal Exported ExportedGlobal									***	
gpThrottle_cals_c2m gAutoCalDataEntryFormat	throttle_calb_c2m_main_bus_t AutoCal_DeFormat_bus_t	Importer	d ImportedExternPointer										Imported ImportedExternPointer										
gpAutoCalStatus	AutoCal Status bus t	Importer	d ImportedExternPointer	***		Imported ImportedExternPointer		***		***			Exported ExportedGlobal Imported ImportedExternPointer							***		***	
gHms_sro_bus	hms_sro_bus_t	Importer		***				***									Esported EsportToFile				***	***	
gTd_signal_bus gBrakeHistory_output	td_signal_bus_t ElirakeHistory_output_bus_t																					***	
gBrakeHistory sim output	BrakeHistory output bur t			***		Exported ExportToFile			***												***	***	
gpVirtualPowerbase_fb gTractionPlant_output	virtual powerbase fb main bus t traction plant output bus t					Auto Auto																	
gTractionFlant_sim_output	traction_plant_output_bus_t			***		Exported ExportToFile				***										***		***	
qpSensor cals c2m	sensor callb_c2m_bus_t AutoCal_Callb_Output_bus_t			Imported	ImportedExtemPointer	Imported ImportedExternPointer	Imported ImportedEsternPointe	4				Imported ImportedExternPointer	Imported ImportedExtemPointer Exported ExportedGlobal						Imported ImportedExternPointe			Imported	ImportedExternPointer
gAutoCal_Output gpValve_cals_c2m	valve_calb_c2m_bus_t			Imported	ImportedExternPointer								Imported ImportedExternPointer								***		
gpSlave_steer_status gpFeatureEnabledEvents	slave_steer_status_bus_t Feature_Enabled_Events_bus_t			****			Imported ImportedEsternPointe	4															
	fan outgut bus t	***		***				***		Imported I	ImportedExternPointer			Imported ImportedEsternPointe	Imported	d ImportedEsternPointer	Imported ImportedExternPointer	Imported ImportedExternPointer	Imported ImportedEsternPointe	imported i	mportedEsternPointer	imported	ImportedEsternPointer
gFan_sim_outputs gpSaveToFRAM gpFRAMSaveStatus	fan output bus t Save to FRAM bus t FRAM Save Status bus t	Esporter	d EsportToFile	***				***		***										***		***	
gpSaveToFHAM gpFBAMSaveStatus	FRAM Save Status bus I			***									Exported ExportedGlobal Imported ImportedExternPointer									***	
		Importer	d importedExternPointer	imported	ImportedExternPointer	Imported ImportedExternPointer	Imported ImportedEsternPointe					Imported ImportedDitemPointer							Imported ImportedExternPointe			***	
AutoCal to Hyd Map_02PT Map_03PT	AutoCal to High bus t Map_02PT_bus t Map_03PT_bus t			Esported Esported	ImportedExtern ExportToFile							Imported ImportedExtern	Exported ExportToFile										
Map_03PT	Map_03PT_bus_t			Exported	EsportToFile																***		
	Velocity_Fuse_bus_t HighSpdLower_bus_t	Importer	d ImportedExtern	Imported Exported	ImportedExternPointer ExportedGlobal							Imported ImportedExternPointer ImportedExtern							Imported ImportedExtern		-		
gpHghSpdLover gpSOC_c2m	SOC_c2m_bus_t		1000000					Imported	ImportedEsternPointer		***	- Portugues			***							***	
gEvent_status_brake_bus gEvent_status_comm_bus	event_status_brake_bus_t event_status_comm_bus_t									Esported	EsportToFile			Exported ExportToFile									
gEvent_status_ed_bus	event status ed bus t			***											Esported	d EsportToFile							
glivent status gpd bus glivent status homtom bus	event_status_gpd_bus_t event_status_homitom_bus_t			Imported	ImportedExtern												Esported EsportToFile	Exported ExportToFile					
gEvent status hyd bus	event_status_hgd_bus_t	Importer	d ImportedEstern	Imported	ImportedEstern							Imported ImportedExtern							Exported ExportToFile				
gEvent_status_svrsup_bus gEvent_status_steer_bus	event_status_pursup_bus_t event_status_steer_bus_t						Imported ImportedExtern													Esported	ExportToFile	Esported	EsportToFile
gEvent_status_ten_bus	event_status_bin_bus_t											Imported ImportedExtern											
gEvent_status_vomin_bus	event_status_vomin_bus_t steer_sp_calc_out_bus_t						Imported ImportedEstern														-	Esported	EsportToFile
gSteer_sp_calc_out gHyd_Throt_Select	higd_throt_select_bus_t	Esporter	d EsportToFile	Imported	ImportedEstern						***												
gpAccelerometerDs gAutoCatiliteps	accelerometer_di_bus_t AutoCal_Steps_bus_t	Importer	d ImportedExternPointer			Imported ImportedExternPointer							Exported ExportedGlobal										
gRackDefTspe	Rack_Def_Type_bus_t			Esported	EsportToFile								Exported ExportedGlobal										
gpFlackSelectSetups_cals_c2m	FlackSelectSetups_callb_c2m_bus												Imported ImportedExternPointer										
gRS_Curr_Loc gpFlack_Status	RS_Current_Location_bus_t Flack_Status_bus_t	Importer	d ImportedExternPointer	Imported	EsportToFile ImportedExternPointer																		
gpAGV_input	AGV_input_bus_t															-							
gAGV_output	AGV_output_bus_t	Importer	d ImportedEstern	Imported	ImportedExtern	Imported ImportedExtern	Imported ImportedEstern																
gpAGV_picking_input gAGV_picking_output	AGV_picking_input_bus_t AGV_picking_output_bus_t															-							
gpAGV_robot_feedback	AGV_robot_feedback_bus_t																						
gAGV_robot_output gpUserCutoutSetup	ACiV_robot_output_bus_t UserCutOuts_oalib_o2m_bus_t			Imported	ImportedExternPointer								Imported ImportedExternPointer										
	hour_meter_input_bus_t																						
gpTestOutputhputs gTestOutputs	TestOutput_input_bus_t TestOutput_output_bus_t	Import	d Importedfater	***																			
gHsd_test_output	had output bus t	Importer	d ImportedExtern													-							
gTraction_test_output gSteer_test_outputs																							
gFan_test_outputs gFan_test_outputs gTruckMode	steer_outputs_bus_t fan_output_bus_t TruckMode_bus_t																		-				
gTruckMode	TruckMode_bux_t	Esporter	d EsportToFile	Imported	ImportedEstern																	***	
gDiag_Control_Limits gHydraulic_dt_output_bus	dem_control_limits_t hydraulic_ds_output_bus_t			***															Exported ExportToFile			***	

III. Model Based Software – Code Generation

Initial Code Gen:

- MATIAR Coder
- Simulink Coder
- Embedded Coder
- (4) System Developers

Software environment

Code replacement library: None

Shared code placement: Shared location

▼

R2011b

R2012b

R2014a

Initial MBS Version:

- MATI AF
- Simulir
- Stateflo

Data Dictionary Concept Shared Network Files

Individual Builds:

- Simscape
- MATLAB Report Generator
- Simulink Report Generator

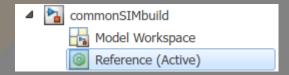
Virtual Truck, HiL, Shared Code Placement Reference Config Sets (8) System Developers

Normal

Normal Accelerator

Rapid Accelerator

Software-in-the-Loop (SIL) Processor-in-the-Loop (PIL) External



III. Model Based Software – Code Generation

Initial Code Gen:

- MATLAR Coder
- Simulink Coder
- Embedded Coder

(4) System Developers

R2011b

R2012b

R2014a

Initial MBS Version:

- MATIAF
- Simulin
- Stateflo

Data Dictionary Concept Shared Network Files

(8) Legacy MATLAB Users

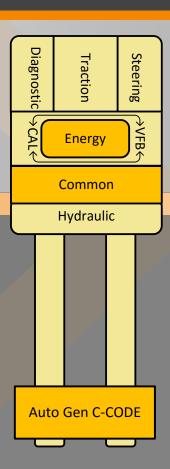
Individual Builds:

- Simscape
- MATLAB Report Generator
- Simulink Report Generato

Virtual Truck, HiL, Shared Code Place

Silareu Guue Flacellielli Reference Confin Sets

(8) System Developers



III. Model Based Software – Code Generation

Initial Code Gen:

> 2 Hrs to Generate Code Single Core - 8 GB RAM SVN Source Control (4) System Developers

R2011b

R2012b

R2014a

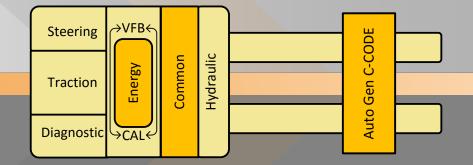
Initial MBS Version:

- MATLA
- Simulir
- Statefli

Data Dictionary Concept Shared Network Files (8) Legacy MATLAB User

Individual Builds:

10-20 Minute Code Gen Single Core - 16 GB RAM 1BM's RTC Source Control



Vehicle Apps

20

System Apps

200

Simulink Models

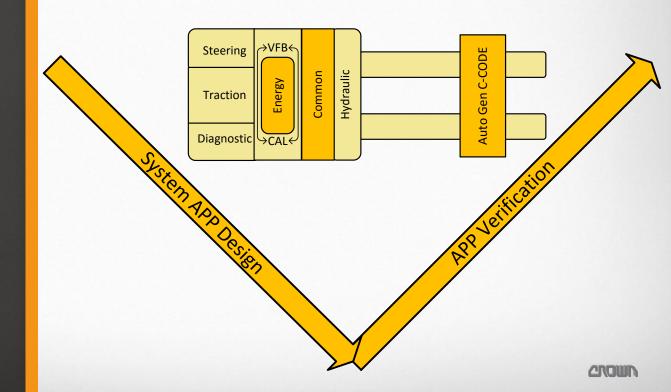
2000

Model Parameters

1

Auto Gen C-Code 325K Lines of Code

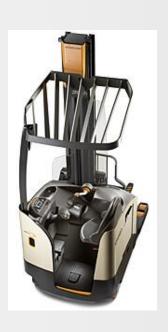
Model Based Vehicle System Apps

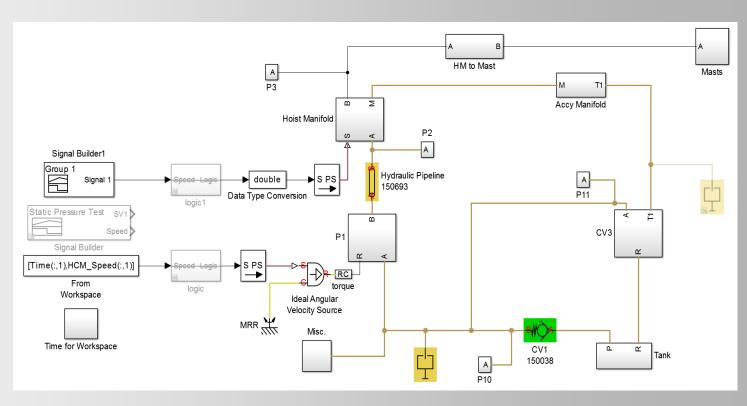


OnTrac[™] Traction Control



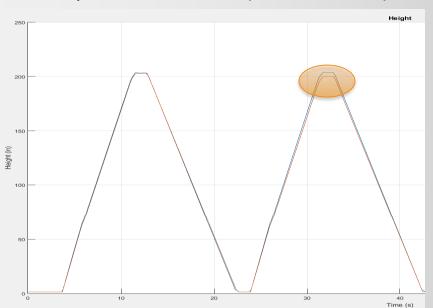
IV. Model Based Software – Virtual Truck



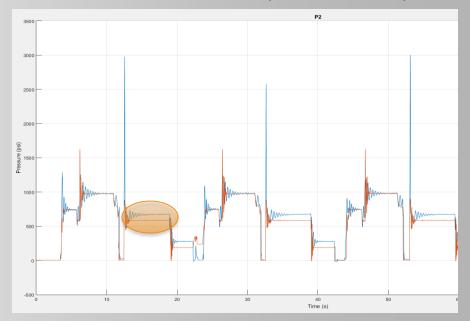


IV. Model Based Software – Virtual Truck

Lift Speed Correlation (test vs model)



Pressure Correlation (test vs model)





V. Model Based Software – Improved Performance

Initial Code Gen:

- MATLAR Coder
- Simulink Coder
- Embedded Coder
- (4) System Developers

Parallel Builds:

- Parallel Computing Toolbox
- Polyspace Static Analysis
- V&V Toolhox

Parallel Simulation and Build (12) System Developers

R2011b

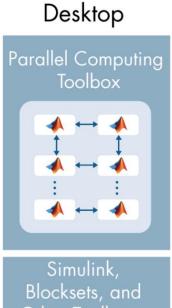
R2012b

R2014a

R2015b

Initial MBS Version:

Individual Builds:



Other Toolboxes

MATLAB[®]

V. Model Based Software – Improved Performance

Initial Code Gen:

> 2 Hrs to Generate Code Single Core - 8 GB RAM SVN Source Control (4) System Developers

Parallel Builds:

5-10 Minute Code Gen Quad Core - 32 GB RAM GIT Distributed Source Control (12) System Developers

R2011b

R2012b

R2014a

R2015b

Initial MBS Version:

- MATI AF
- alliullii
- Stateflo

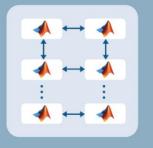
Data Dictionary Concept Shared Network Files (8) Legacy MATLAB User

Individual Builds:

10-20 Minute Cade Gen Single Core - 16 GB RAM IBM's RTC Source Contro (8) System Developers

Desktop

Parallel Computing Toolbox



Simulink, Blocksets, and Other Toolboxes

MATLAB[®]

VI. Model Based Software – Verify, Test & Report

Initial Code Gen:

- MATIAR Coder
- Simulink Coder
- Embedded Coder
- (4) System Developers

Parallel Builds:

- Parallel Computing Toolbox
- Polyspace Static Analysis
- V&V Tnnlhnx

Parallel Simulation and Build (12) System Developers

Test & Report:

- Simulink Test
- MATLAB Compiler

Bi-Directional Reg's Links (20) System Developers

R2011b

R2012b

R2014a

R2015b

R7N16

2017?

Initial MBS Version:

- MATIAR
- Simulin
- Stateflo

Data Dictionary Concep Shared Network Files (8) Lenary MATLAR Use

Individual Builds:

- Simscape
- MATLAB Report Generator
- Simulink Report Generato

Virtual Truck, HiL, Shared Code Placement Reference Config Sets (8) System Developers

Verification:

Dependency Analysis Simulink Design Verifier 3-way compare and merge (16) System Developers

VI. Model Based Software – Verify, Test & Report

Initial Code Gen:

> 2 Hrs to Generate Code Single Core - 8 GB RAM SVN Source Control (4) System Developers

Parallel Builds:

5-10 Minute Code Gen Quad Core - 32 GB RAM GIT Distributed Source Control (12) System Developers

Test & Report:

Simulink Test, MATLAB Compiler, Bi-Directional Req's Links (20) System Developers

R2011b

R2012b

R2014a

R2015b

R7N1F

2017?

Initial MBS Version:

- MATI AF
- Simulin
- Stateflo

Shared Network Files
(8) Legacy MATLAB User

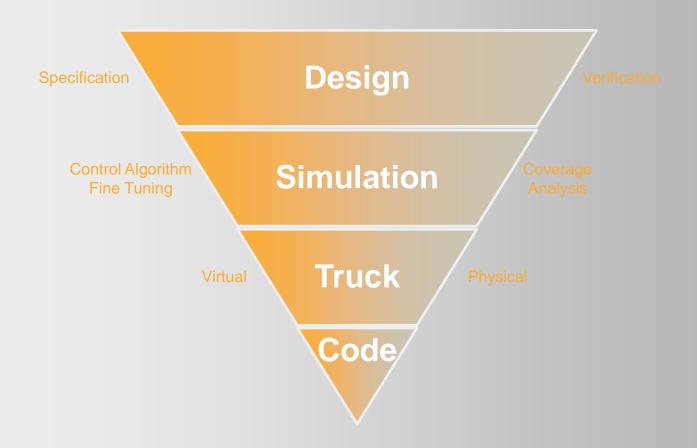
Individual Builds:

10-20 Minute Code Gen Single Core - 16 GB RAM 18M's RTC Source Control (8) System Developers

Verification:

5-10 Minute Code Gen Quad Core with 32 GB RAM GIT Distributed Source Contro (16) System Developers

VI. Model Based Software – Verify, Test & Report





Global Locations



USA

New Bremen, Ohio New Castle, Indiana Greencastle, Indiana Kinston, North Carolina Celina, Ohio Minster, Ohio New Bremen, Ohio New Knoxville, Ohio

EUROPE

Munich, Germany Roding, Germany

MEXICO

Querétaro

CHINA

Suzhou Suzhou

AUSTRALIA

Sydney

SINGAPORE

Singapore

