



NTNU  
Innovation and Creativity

# Systems engineering saves the day! (0 / 1 / 2)

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**IS2012**

**9 July 2012**



# Shell Eco-marathon Europe

The Shell Eco-marathon challenges high school and college student teams from around the world to design, build and test energy efficient vehicles.

With annual events in the Americas, Europe and Asia, the winners are the teams that go the farthest distance using the least amount of energy.



# Background

- NTNU has participated since 2008
- Team made up of Masters level students from multiple disciplines
- Holds the world record for the Urban Concept Fuel Cell class (2009)
- 2010 ... failed to pass preliminary inspection
- 2011 ... determined to be in the winner's circle again



## Sponsorship

- Students rely on sponsorship to fund the work and travel expenses for competition
- 2009 – 2010 sponsor reluctant to back the team again
- Eventually Den norske Veritas (DNV) agreed, but not until late in December

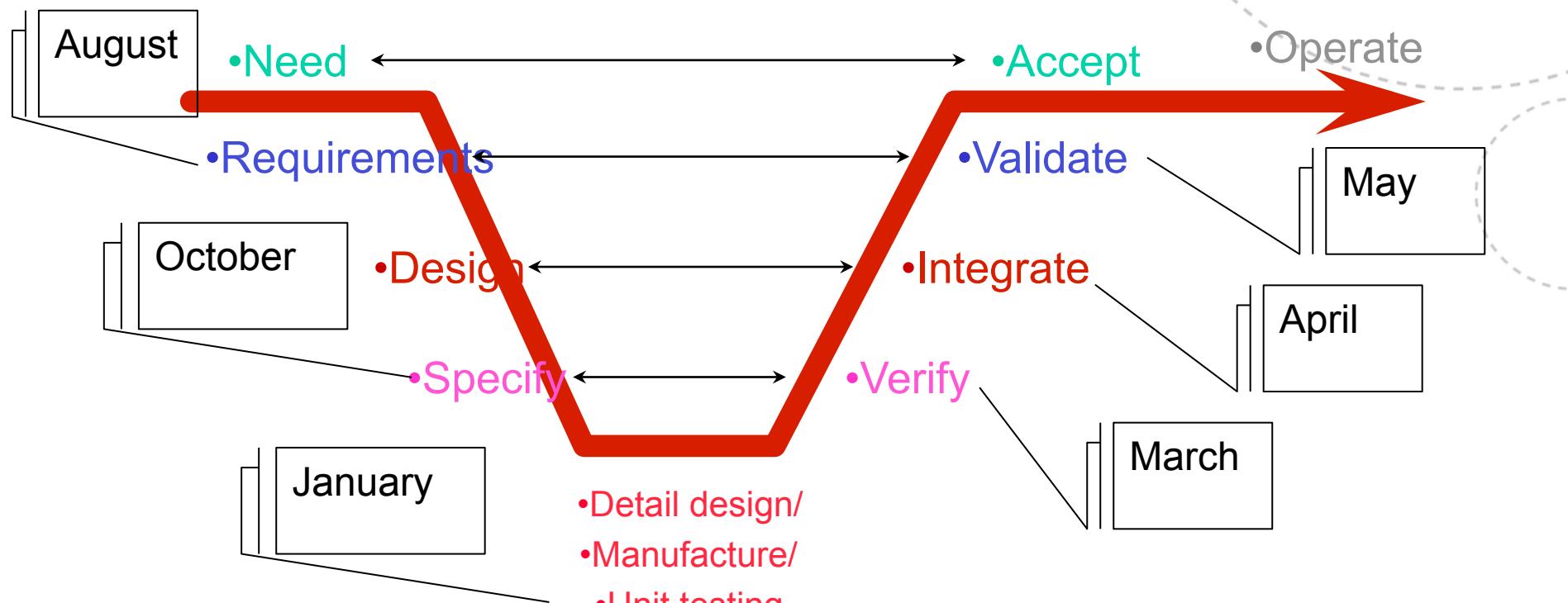


# Project stakeholders

- NTNU faculty
- Students from mechanical and electrical engineering, control systems, and project management studies
- Sponsors
- External entities
- Shell (customer)



# Project timeline





## **Missing: the Systems Engineer**

## **From 0 to 1 SE overnight**



# 6Cs contributions of the systems engineer

- Comprehension - understanding
- Communication – translator services
- Coordination – harmonious functioning
- Cooperation – work toward a goal
- Collaboration – stakeholders, partners
- Continuity – over the life cycle



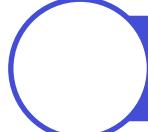
# Pillars of systems engineering



Requirements engineering, well-defined interfaces



Verification and validation, traceability



Risk management is everyone's task



Configuration management, performance





**Team Photo / Before**

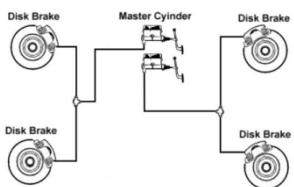


# Systems Engineering within development and construction of the Eco-marathon car:

- Continuous improvement for next year's team
- The car was viewed as a system with individual sub-systems and identified interfaces
- Necessary external technical and organisational support system connecting to building, testing transportation and the race



## •Brake System



## •Rims



## •Suspension



## Complex system of different Components



## •Body



Figure 23: Near- and far front lights working correctly.

## •Dashboard



Figure 26: Inside the cockpit, accelerator encoder lying below the steering wheel, LCD panel active.



Figure 25: LCD panel showing the main menu.

## •Engine



## •Fuel Cell



Figure 18: Mark 1020 ACS

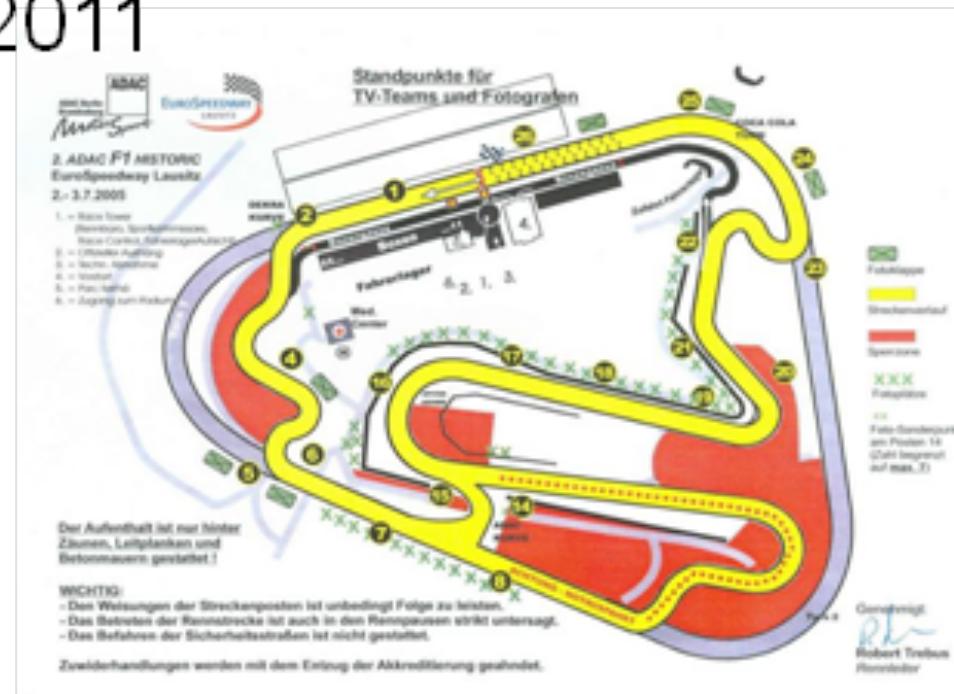


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## •Control System



# •The race track in Germany 2011



## Know your track

Impact on braking functions, suspension, turning radius, etc.



# What did we do?

ID:	Supporting documents:	Description:
D.1	<b>Total requirements document:</b>	Describes all the modules and their requirement according to the Shell Eco-marathon rules
D.2	<b>Architecture design:</b> -Complete system	Describes the complete system
D.3	<b>Architecture design:</b> <b>-Mechanical</b>	Describes the mechanical modules related to the car
D.4	<b>Architecture design:</b> <b>-Electronic</b>	Describes the mechanical modules related to the car
D.5	<b>Architecture design:</b> -Component dependencies	Describes the mechanical modules related to the car
D.X.	<b>Module documents:</b>	Describes a document with the, system architecture, requirements, function, interfaces, interface testing and risk.

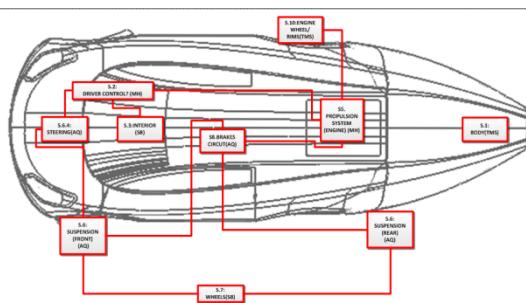
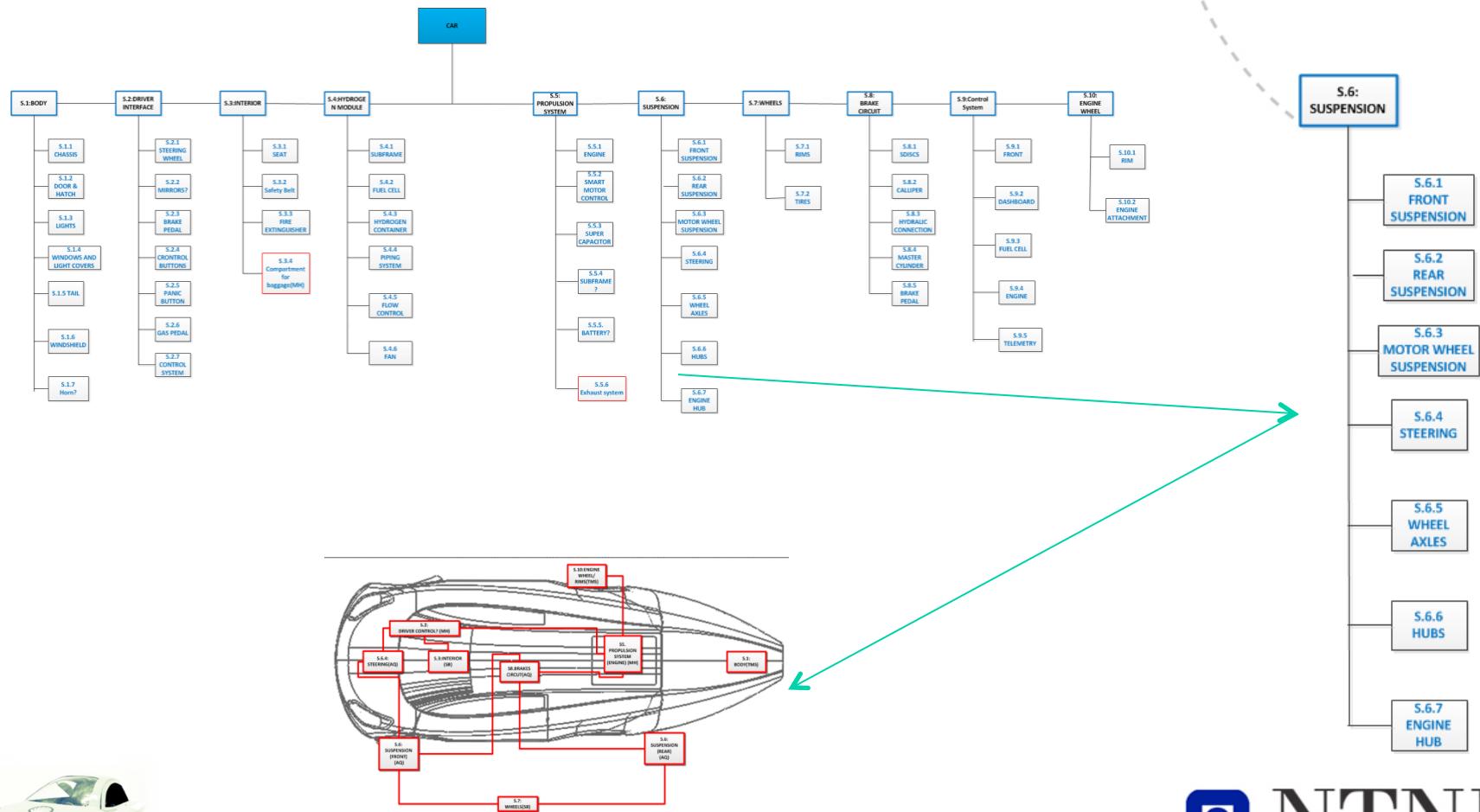


Article	Requirements	System	Responsible	Status
47	<b>Vehicle Design</b>			
47.1	UrbanConcept vehicles must have <b>exactly four wheels</b> , which under normal running conditions must be all in continuous contact with the road. A fifth wheel for any purpose is forbidden.	S.7 Wheels	SB/TMS	ok
47.2	Aerodynamic appendages, which adjust or are prone to changing shape due to wind whilst the vehicle is in motion, are forbidden (e.g. no shrink wrap allowed).	S.1 Body	TMS	ok
47.3	Vehicle bodies must not include any external appendages that might be dangerous to other Team members; e.g. sharp points must have a radius of 5cm or greater, alternatively they should be made of foam or similar deformable material. <i>This means for example exposed corners of solar panels, pointed parts of the vehicle body, etc.</i>	S.1 Body	TMS	ok
47.4	The vehicle interior must not contain any objects that might injure the Driver during a collision.	S.1 Body	TMS/SB	ok
47.5	Windows must not be made of any material which may shatter into sharp shards. Recommended material: Polycarbonate (e.g. Lexan)	S.1 Body	TMS	ok
48	<b>Dimensions</b>			
48.1	The total vehicle height must be between 100cm and 130cm.	S.1 Body	TMS	99 cm. Does not comply at the moment. Could be adjusted by tire pressure

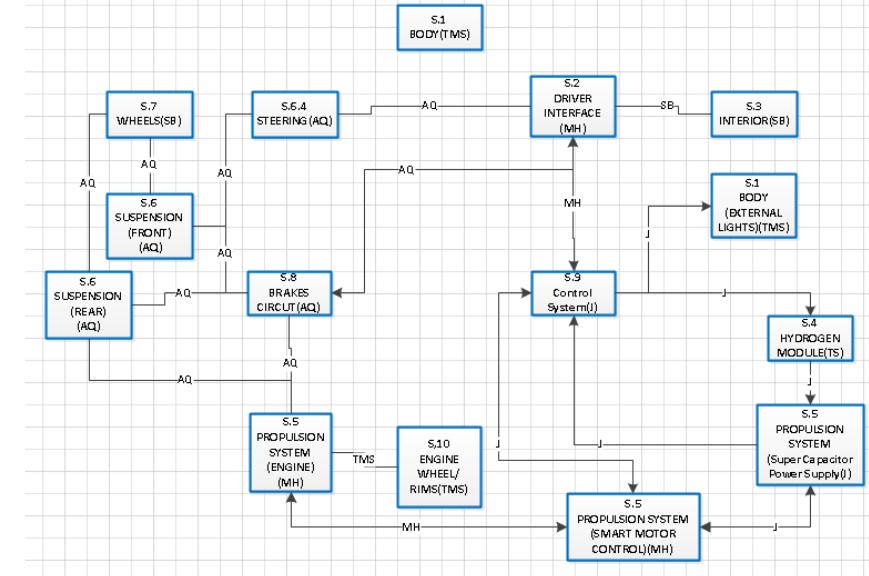
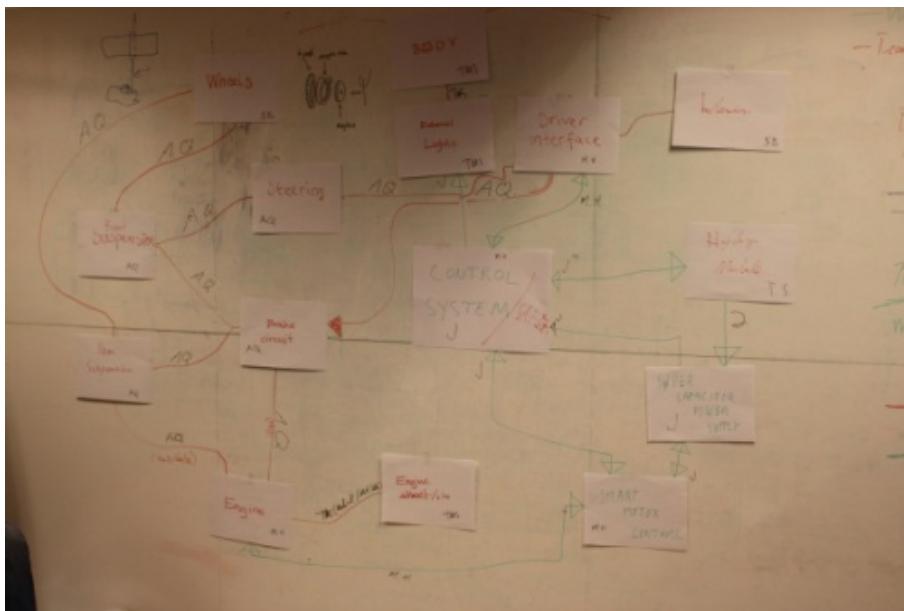
## D.1 Total Requirements checklist Requirements traceability

All requirements from Shell

# D.2 Defining the physical Architecture



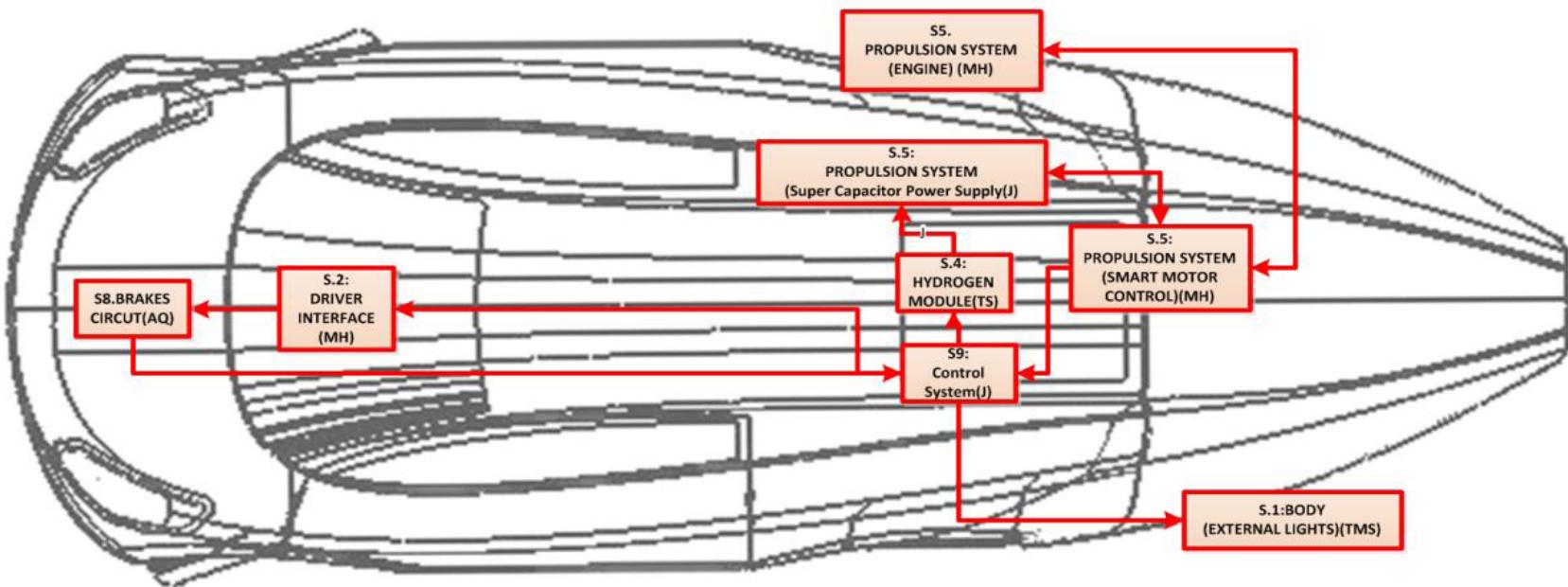
# Interfaces



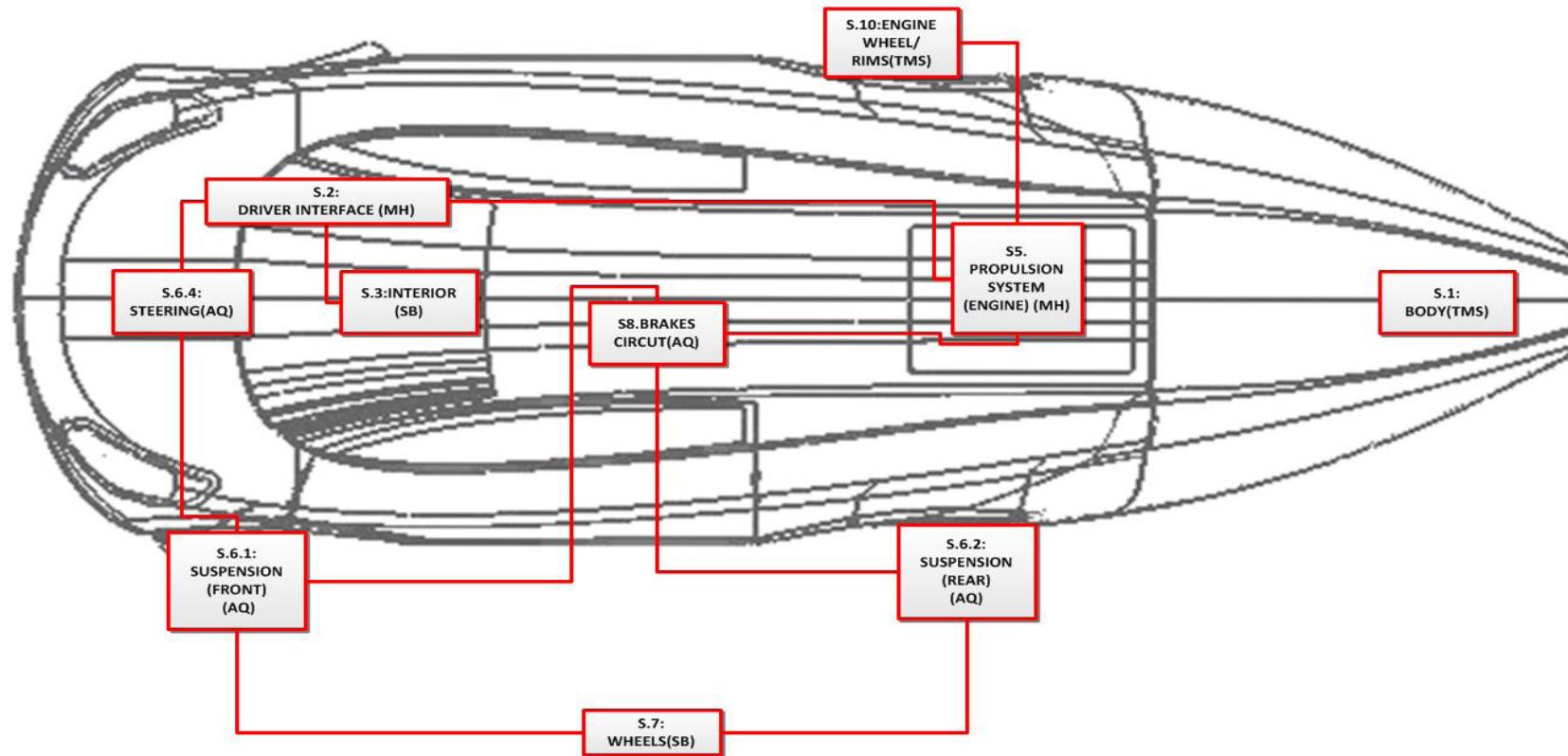
- Each interface had an owner



# Electronic interfaces



# Mechanical interfaces



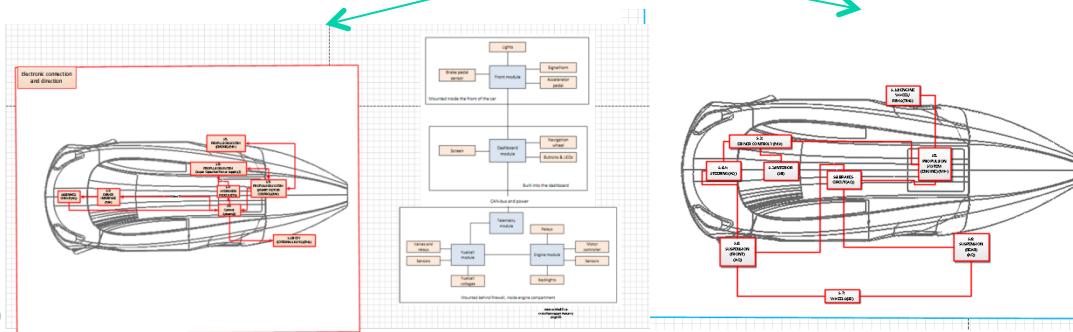
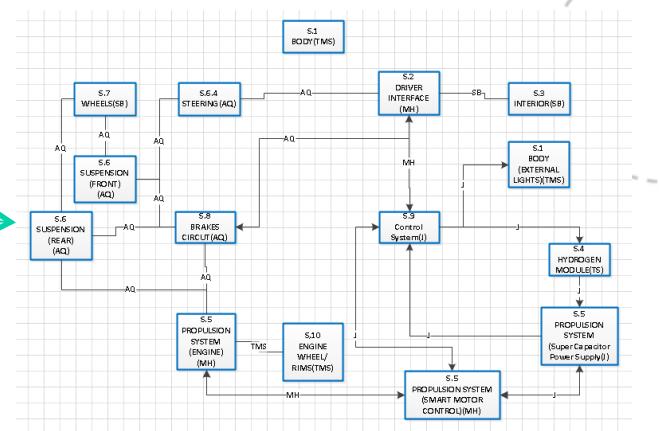
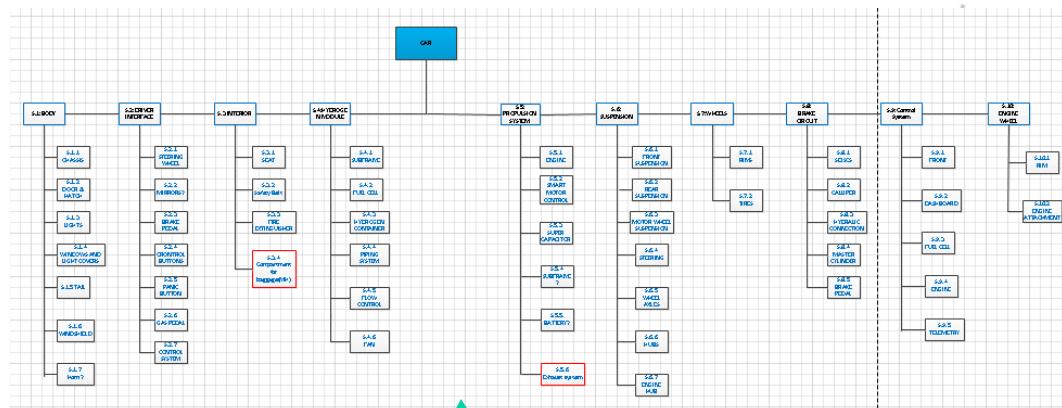
# D.X Sub System Documents

- D.6 Suspension Concept and final design

## 4.2 Requirement document

ID	Requirement	Interface requirement	Function (The System Shall)	Value/Comments	Should	Must
S.6	Article 48.4 Article 48.5 Article 56.1 Article 56.2 Article 56.3 Article 56.4 Article 56.5	S.2 Driver interface S.5 Propulsion System S.7 Wheels S.8 Brake Circuit	Support the wheels and give stable control of the car	Official Shell rules		X
S.6.4	Easily tightened wire		Shall steer the car	We need a new tightening device	X	
S.6.1	Support curve of 6m radius in 30 km/t without fractures		Shall support the wheels and steering			X
S.6.1-2	Adjustable in 3 axes		Shall support the wheels and steering			X
S.6.1-2	Toe-in 0 degrees on front and rear wheels		Shall support the wheels and steering			X
S.6.1-3	0 degrees camber when loaded					X
S.6.1	6 degrees caster on front wheels					X
S.6.1	0 mm scrub radius			Impossible without making an entirely new suspension, anchor points and new rim design.	X	
S.6.1	No bump steer			Body and suspension consider stiff enough to minimize bump steer.	X	
S.6.1	6 degrees king-pin angle			Impossible. Previous calculations based on wrong geometry	X	
S.6.1-2 S.6.7	Lowest possible friction in axle bearings			Use hybrid bearings without seals.	X	
S.6.1-3 S.6.6-7	No interference between calipers and rims and vehicle body	S.7 Wheels S.8 Brake				X





# Bringing the team together – the SE Wall



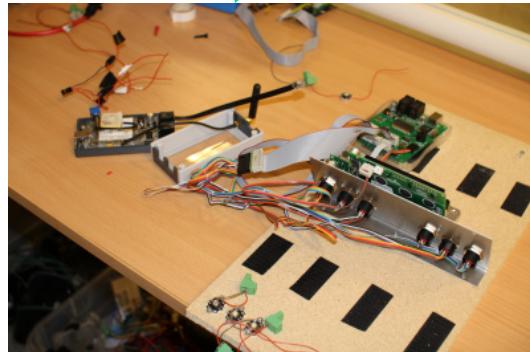


Monday	Tuesday	Wednesday	Thursday	Friday
<b>Team Meeting</b> -5 minute debrief -Week goals		<b>5 Minute debriefing</b> -CM		<b>5 Minute debriefing</b> -Problems -CM -Update

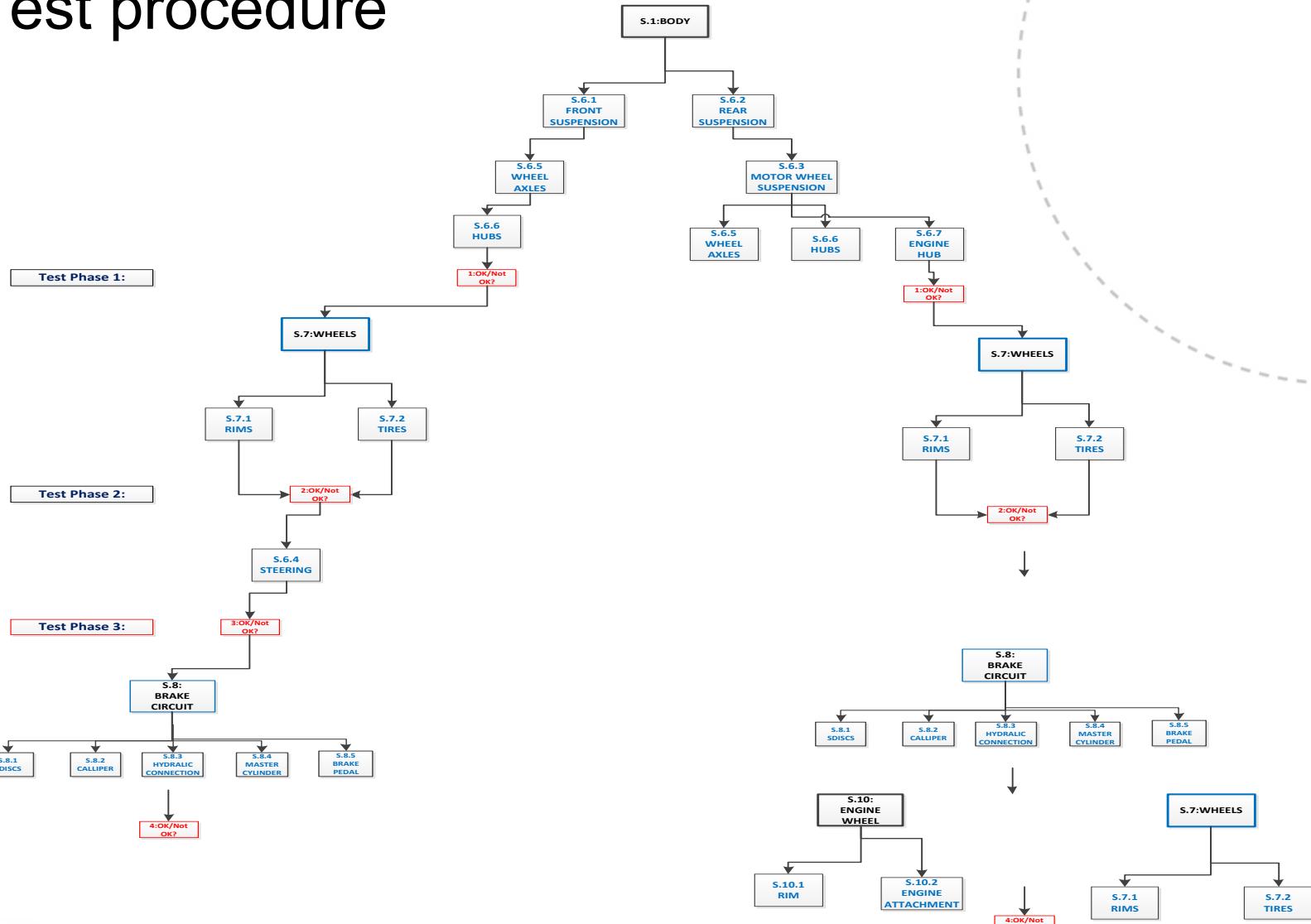


# Testing and test beds

System	Test bed:
<b>S.1 Body</b>	Internal
<b>S.2 Driver interface</b>	Internal
<b>S.3 Interior</b>	Internal
<b>S.4 Hydrogen module</b>	External (Ballard)
<b>S.5 Propulsion system</b>	External (Smart motor)
<b>S.6 Suspension</b>	Internal
<b>S.7 Wheels</b>	Internal/External (Tevo Dekk)
<b>S.8 Brake circuit</b>	Internal
<b>S.9 Control System</b>	Internal
<b>S.10 Engine wheel</b>	External (Smart motor)



# Test procedure



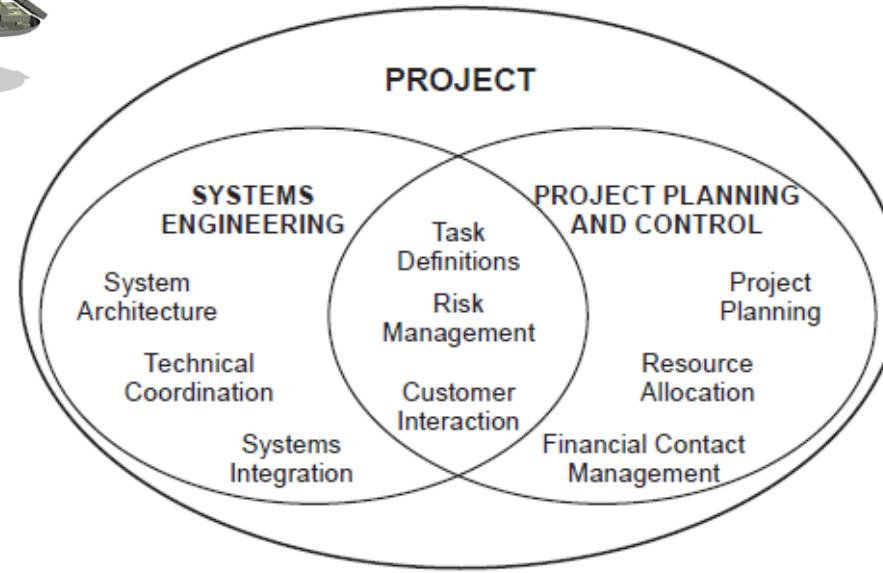


Figure 5-1 Project Management/Systems Engineering Overlap<sup>1</sup>

## Balance

Time management

Risk in all module documents



# Goals achieved:

- SE
  - The use of SE methodology in a practical way
  - How does SE affect the project?
- Continuous improvement
  - Traceability through all documents; from requirements to the test results, and available as legacy for 2012
- Able to recruit 2 SE, more engineers (from 6 to 11), and early sponsorship for the 2012 team!





**Team Photo / After**  
Systems Engineer Front and Center

**Result: 1000 km/l in Shell Eco-Marathon 2011**

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# Thank you

## Q&A



# Extra Slides



## •Example: MEL (Master Equipment List) V.1

RTP Master Equipment list - Atla												
Product Info												
Description	Material	Equipment no:	quant	Location	required for EFAT(10th October)	Required SIT(10th November 2001)	Comments	Action responsibl	Action date	Suggested qty for purchase	OMM - Doc #	Spare parts list
WP04 - Wellhead tooling												
NA												
WP05 - XMT tooling												
TEST FIXTURE FOR MRT	10031638	new	1				RFQ	MD				
HANG-OFF TOOL, EMERGENCY, F/PROD TUBING	(10050803)10142475	?	1				Awaiting company approval to procure slick joint					
HANG-OFF TOOL, EMER DRILL PIPE 4 1/2"	(10062392)10142473	10456872	1	TRANDBY			Awaiting company approval to procure slick joint					
LIFTING TEST PLUG, 5 1/2" FH PIN, ASSY	10019818	new	1			1	RFQ	MD				
ASSY, TEST PLUG, 4 1/2" API FH PIN, 9/16"	BBH-H50002-17	new	1			1	RFQ	MD				
CASING ADAPTER/FTHR	BBJ-S6192A	10376357	1	MY		1	Marjan to ship	MA				
HANDLING & TEST TOOL, THRT, ASSEMBLY, SVT	BBH1-200123-00	new	1			1	RFQ, check with availability at Trandby for SIT					
RUNNING TOOL TH, 18-3/4" 10K SVTBT, ASSY	10015983	10278037	2	MY AND?		1	Marjan to ship 1st one, 2nd potentially switch with Trym 2) Verify with Marjan that nut on top of THRT is in place	HPØ 2) HCS				
HANDLING TOOL, FOR TH/ITC/BP	BBJ-S5230A	10404368 / 10558264	2	ÅGOTNES		1	checked	MD				
VASHOUT TOOL, TBG HGR AND SPOOL, ASSY	BBH1-H50002-34	10390758	1	ÅGOTNES		1	checked	MD				
TUBING HANGER/HANDLING TOOL, 350 TON	BBH1-H50001-01	10456878	1	MY			Marjan to ship, make sure SRT is done once back in Agøtnes. Spanner to be placed on order	MD				
MECHANICAL TH & BP RECOVERY TOOL	10077251	10628856	1	ÅGOTNES		1	checked	MD				
THRT RACKING PROTECTOR, ASSY	10016290	new	2				RFQ					
STUMP, TEST FOR THRT WITH PASS THRU	10017774	10368632	1	MY			Marjan to ship	MA				
Sling set, THRT Test Stump	BBH1-H50001-67	new	1			1	RFQ					
CONTROL CPLR/CHARGE, TEST TOOL, ASSY	10023324	10394219 / 10403913	2	ÅGOTNES		1	I haven't seen the second one	MD				
PLATE, SUPPORT, TUBING HANGER, ASSY	10030093	11202348	1	NEW		1	On order, send drawing through SWIMS to Total	MD				
TOOL, BP SETTING/UNSETTING, 5 KSI HYD VP	10019613	10410193	1	ÅGOTNES			Verify physical location and condition	MD				
TEST PLUG, ASSY, 15K, BOP	10018623	we work the one from Mar	1	MY/NEW			Marjan to ship(MN-), request quotes from vendors for re-machining to Atla MN.	HCS				
GUIDE BUSHING, TUBING HANGER	10017968	11202049	1	NEW			On order, send drawing through SWIMS to Total	MD				
HANDLING TOOL, XT, 70T	10014224	10407051	1	ÅGOTNES			checked	MD				
TREE RUNNING TOOL, 18-3/4" 15M, ASSEMBLY	10097308	10773460	1	TRYM?			1) Verify reduced testing scope at SIT 2) New MN for Hydraulic flying lead, arrange re-routing of lines with Agøtnes 3) Discuss with Trym/Oslovar project swap of TRT with REPSOL	1) HCS 2) HCS 3) HPØ				
TOOL, ISOLATION, TREE SPOOL, TEST TOOL	10019616	10403604	1	ÅGOTNES			Verify physical location and condition					

XMT tooling



## •Example: MEL(Master Equipment List) V.2

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	AB	AC																
BTP Master Equipment List - BILs																																											
Description		Material		Serial no.		Equipment no.		In Contract		ST Location		Required for Contract Execution Value		Required 2 off Per Value		Maintenance needs		BMT Requirement		Sourcing and Requirements		Maintenance status		Serial order reference		Purchase order reference		Estimated Serial Number (if applicable)		Estimated Serial Number (if applicable)		Estimated Serial Number (if applicable)		Serial reference		Serial status		PO/BIL serial number		Internal serial		Comments	
BURNING TOOL,TW,18-5/4"X6",ASSTY	18815583	4580110032-200-2	18374446	Y	4	Applera										Will be required for assembly and assembly of Burner	Y,THT,T,LH,DL,DL,DL, Screw,THT,Applera	Operating Status: Maintenance required and/or repair required and/or repair possible and/or repair not possible	4851103		26.12.2011																						
HANDLING TOOL,PORT/ITC/BP	00-152284	1111415-1	18358024	Y	4	Applera		1								Maintenance, need repair	X,HD,T,LH,DL,DL,DL, Screw,HD,Applera	Operating Status: Maintenance required and/or repair required and/or repair possible and/or repair not possible	4851102	4851108	18.12.2011		18.11.2012	CR															18808202825 18808202826 18808202827				
HANDLING TOOL,PORT/ITC/BP	00-152284	1111518-1	183494518	Y	4	Applera										Maintenance, need repair	X,HD,T,LH,DL,DL,DL, Screw,HD,Applera	Operating Status: Maintenance required and/or repair required and/or repair possible and/or repair not possible	4851102		18.12.2011			CR																			
WASHOUT TOOL,CG/CHG AND SP/CHG,ASSTY	00-15-HS0820-24	181705-1	18359758	Y	4	Applera		1								Requires washout after 100	4852205	Planned	4851102			18.11.2012	Alm/W													18808202816 18808202817 18808202818							
TUBING HANDELL HANDEL TOOL,ASSTY	00-15-HS0820-24	1807780-1	18357780	Y	4	Applera										Maintenance, need repair	4852205	Planned	4851101			Alm/W													18808202845 18808202846 18808202847								
MECHANICAL THIN SP/RECOVERY TOOL,ASSTY	18802256	58027-001	18328556	Y	4	Applera		1								Requires washout after 100	X,HD,T,LH,DL,DL,DL, Screw,HD,Applera	Operating Status: Maintenance required and/or repair required and/or repair possible and/or repair not possible	4851102	4851103	18.11.2012	Alm/W																					
THIN TRACING PROTECTOR,ASSTY	18814228	2480573837-100-1	11140775	Y	4	Applera																28.11.2011																					
THIN TRACING PROTECTOR,ASSTY	18814228	4580392802-500-2	11140808	Y	4	Applera																28.11.2011	Alm/W																				
STUDY,TEST FOR THIN	18802274	1880110032-701-1	18361555	Y	4	Applera		1								Maintenance, need repair	4851102	Planned	4851102			Alm/W													18808202845 18808202846 18808202847								
STUDY,TEST FOR THIN	18802274	1880110032-701-1	18361555	Y	4	Applera																Alm/W																					
SLICE,THIN TRACING,ASSTY	00-15-HS0820-24	**-**	18357780	Y	4	Applera										X,HD						MD													18808202845 18808202846 18808202847								
CONTROL CFC/CHARGE,TEST TOOL,ASSTY	18802256	111077-1	18357785	Y	4	Applera		1								Maintenance, need repair	4851102	Planned	4851102			CR													18808202845 18808202846 18808202847								
PLATE,SUPPORT, TUBING HANDEL,ASSTY	18800000	458038217-000-001	11120008	Y	4	Applera		1								Maintenance, need repair	4851102	Planned	4851102			MD													18808202845 18808202846 18808202847								
TOOL,BP SETTING/UNSETTING,SKS/HW/DP	18815103	1111915-1	18110103	Y	4	Applera													4851102	4851104			Alm/W/CR													18808202845 18808202846 18808202847							
TEST PLUG,HSV,15M,BSF	18814228	4580110034-10-100	18361555	Y	4	Applera										Maintenance, need repair	4851102	Planned	4851102			Alm/W/BSF													18808202845 18808202846 18808202847								
TOOL,HSV,15M,BSF	18814228	**-**	18361555	Y	4	Applera															22.01.2012		Alm/W/BSF													18808202845 18808202846 18808202847							
TOOL,HSV,15M,BSF,TEST TOOL	18814228	1880110034-10-100	18361555	Y	4	Applera													4851102	4851104	18.12.2011	21.01.2012	CR													18808202845 18808202846 18808202847							
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TOOL,HSV,15M,BSF,TEST TOOL	18814228	1880110034-10-100	18361555	Y	4	Applera															22.01.2012		Alm/W/BSF													18808202845 18808202846 18808202847							
TOOL,HSV,15M,BSF,TEST TOOL	18814228	1880110034-10-100	18361555	Y	4	Applera															22.01.2012		Alm/W/BSF													18808202845 18808202846 18808202847							
TOOL,HSV,15M,BSF,TEST TOOL	18814228	1880110034-10-100	18361555	Y	4	Applera															22.01.2012		Alm/W/BSF													18808202845 18808202846 18808202847							
TOOL,HSV,15M,BSF,TEST TOOL	18814228	1880110034-10-100	18361555	Y	4	Applera															22.01.2012		Alm/W/BSF													18808202845 18808202846 18808202847							
TOOL,HSV,15M,BSF,TEST TOOL	18814228	1880110034-10-100	18361555	Y	4	Applera															22.01.2012		Alm/W/BSF													18808202845 18808202846 18808202847							
TOOL,HSV,15M,BSF,TEST TOOL	18814228	1880110034-10-100	18361555	Y	4	Applera															22.01.2012		Alm/W/BSF													18808202845 18808202846 18808202847							
TOOL,HSV,15M,BSF,TEST TOOL	18814228	1880110034-10-100	18361555	Y	4	Applera															22.01.2012		Alm/W/BSF													18808202845 18808202846 18808202847							
TOOL,HSV,15M,BSF,TEST TOOL	18814228	1880110034-10-100	18361555	Y	4	Applera															22.01.2012		Alm/W/BSF													18808202845 18808202846 18808202847							
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TOOL,HSV,15M,BSF,TEST TOOL	18814228	1880110034-10-100	18361555	Y	4	Applera															22.01.2012		Alm/W/BSF													18808202845 18808202846 18808202847							
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TOOL,HSV,15M,BSF,TEST TOOL	18814228	1880110034-10-100	18361555	Y	4	Applera															22.01.2012		Alm/W/BSF													18808202845 18808202846 18808202847							
TOOL,HSV,15M,BSF,TEST TOOL	18814228	1880110034-10-100	18361555	Y	4	Applera															22.01.2012		Alm/W/BSF													18808202845 18808202846 18808202847							
TOOL,HSV,15M,BSF,TEST TOOL	18814228	1880110034-10-100	18361555	Y	4	Applera															22.01.2012		Alm/W/BSF													18808202845 18808202846 18808202847							
TOOL,HSV,15M,BSF,TEST TOOL	18814228	1880110034-10-100	18361555	Y	4	Applera															22.01.2012		Alm/W/BSF													18808202845 18808202846 18808202847							
TOOL,HSV,15M,BSF,TEST TOOL	18814228	1880110034-10-100																																									



## •Example: MEL(Master Equipment List) V.3

- Requirements added to every tool:

- Lifting certification
- NDT certification
- Torque reports
- Maintenance need

