Towards a Model Based Systems Engineering Mass Properties Toolset

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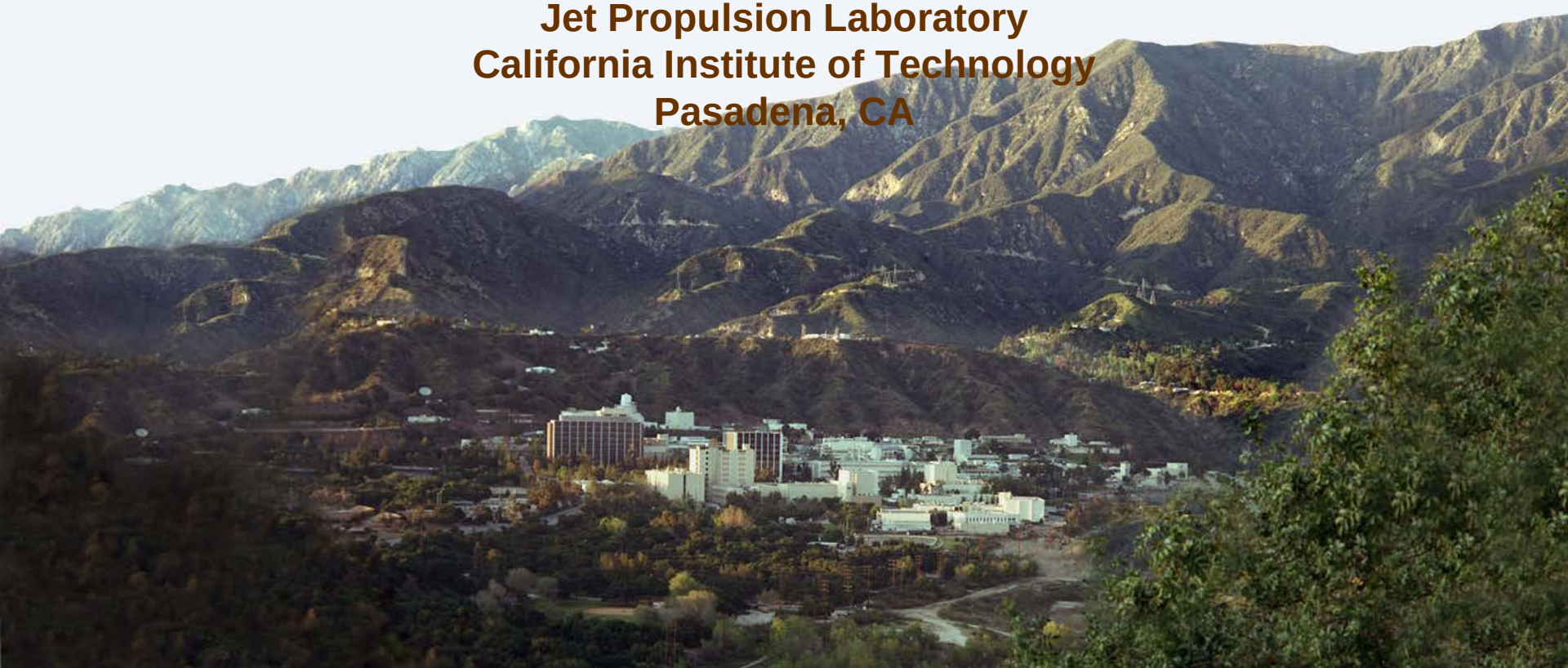


Overview

- Description of mass properties engineering at JPL
- MEL / MP relationship at JPL
- History of JPL mass properties tools
- Deconstruction of mass properties task
- Model-based mass properties implementation
- Ongoing work

JPL Mass Properties Engineer

JPL	Industry
Mechanical Engineering	Systems Engineering
Responsible for Mass Properties	Responsible for Mass Equipment List (MEL) and Mass Properties
One-offs	Assembly line
One-time job	Career

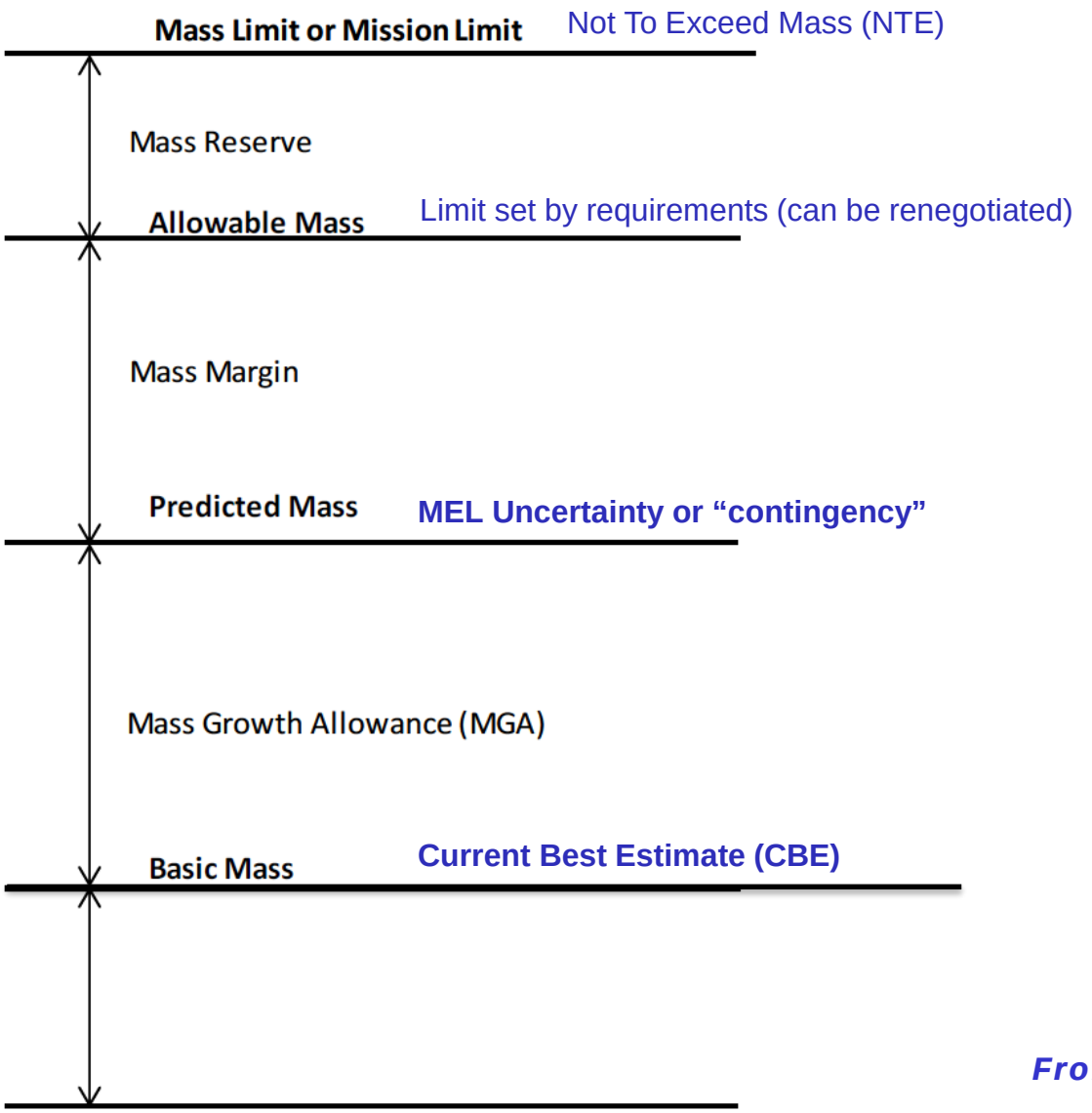
- **Unique position at JPL**
- **Typically must generate new tool set for specific project**
- **Since Mass Properties and MEL managed by different people at JPL, discrepancies must be resolved scrub to scrub**

MEL vs. Mass Properties

MEL*	Mass Properties
Organized using Subsystem Reference Designator, physical decomposition, or Work Breakdown Structure (WBS)	Organized using physical layout (assembly hierarchy)
Tracks major deliverables and lumps together many components (e.g. “structures”, etc.)	Tracks every delivered item on the vehicle, limited grouping (fasteners, as-measured subassemblies)
Tracks positive margin on mass only	Tracks bidirectional uncertainties on the CBE of each of the 10 parameters. *Sometimes* mass uncertainty equals margin.
Manages global maximum mass	Manages vehicle dynamics
Traditionally generated by filtering info from Cog-E to PEM to MEL holder	Generated by directly interfacing with part designers and Cog-E
Represents officially accepted flight system configuration	Current working configuration (which usually becomes official configuration)
“Official” mass during development	“Official” mass for ATLO, launch, and operations
Usually active until majority of hardware is delivered	Active and changing up to launch (into flight if needed)

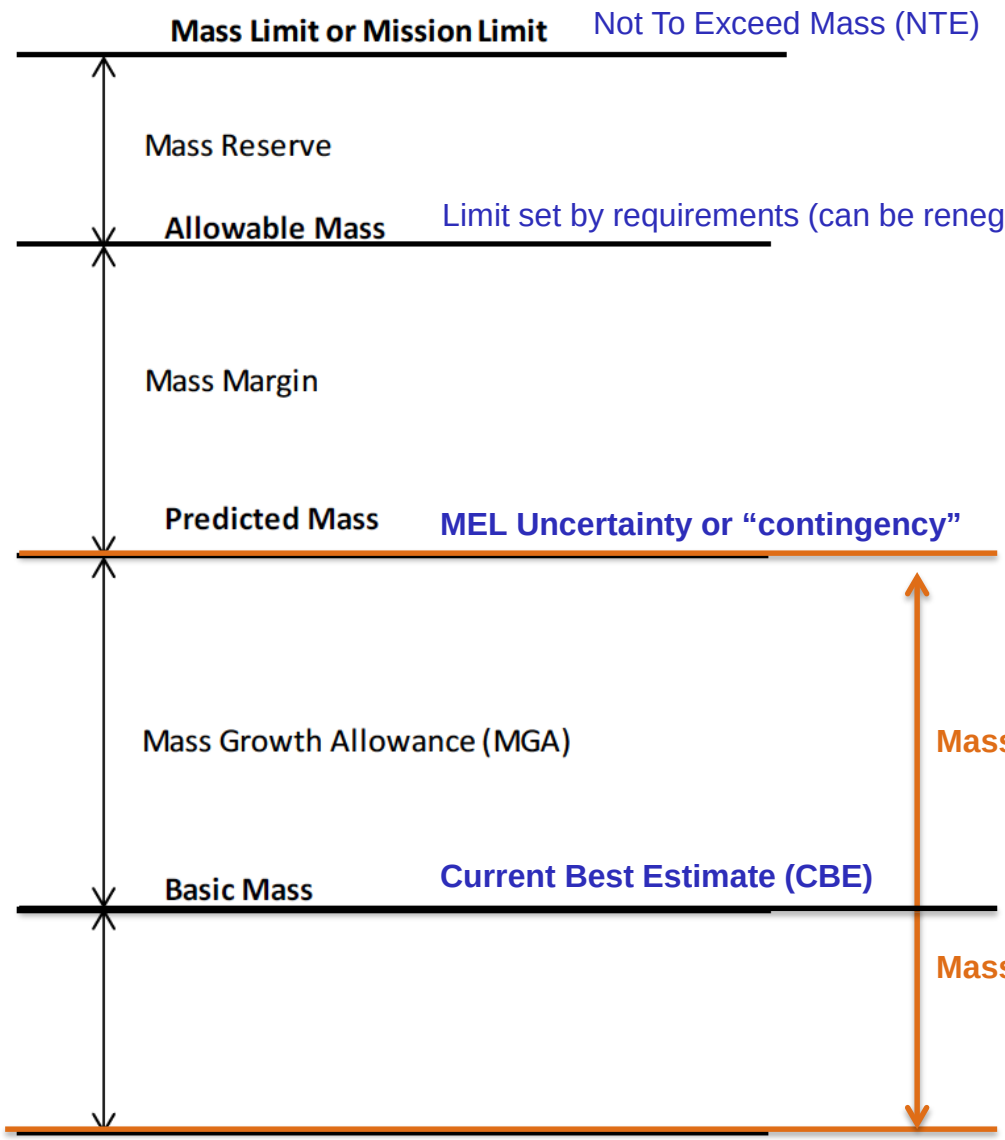
**The MEL is changing with MBSE implementation. Here we refer to a traditional MEL.*

MEL Uncertainty vs. Mass Properties Uncertainty



From ANSI/AIAA S-120A-201X (DRAFT)

MEL Uncertainty vs. Mass Properties Uncertainty

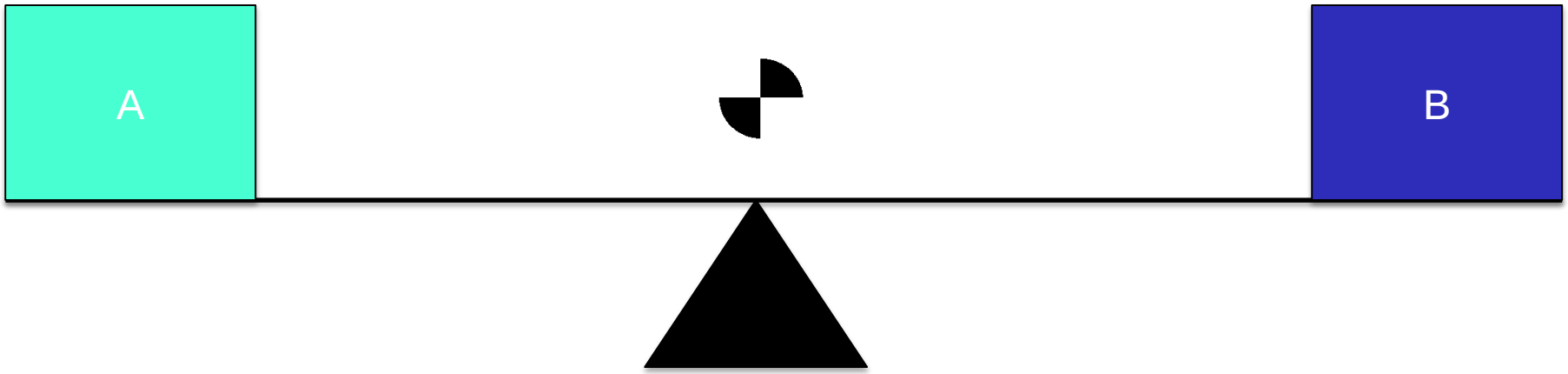


From ANSI/AIAA S-120A-201X (DRAFT)

Worst Case MEL vs. Worst Case Mass Properties

Does worst case MEL equal worst case mass prop?

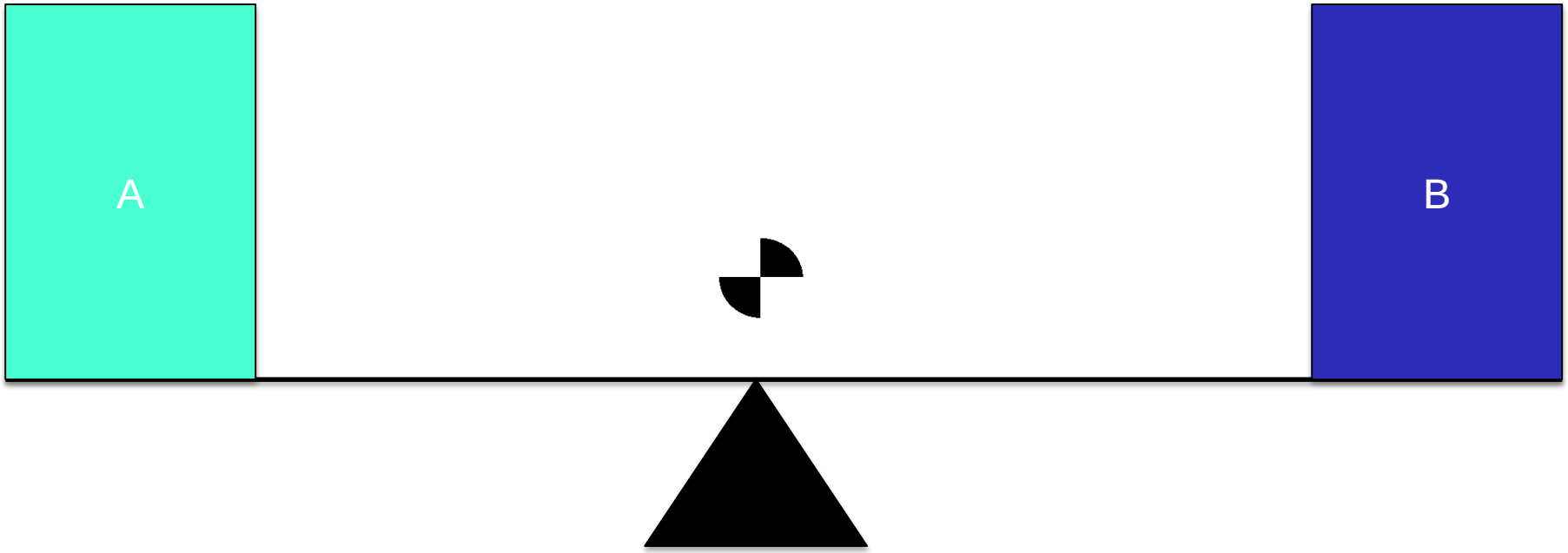
Are you most imbalanced when everything comes in heavy?



Worst Case MEL vs. Worst Case Mass Properties

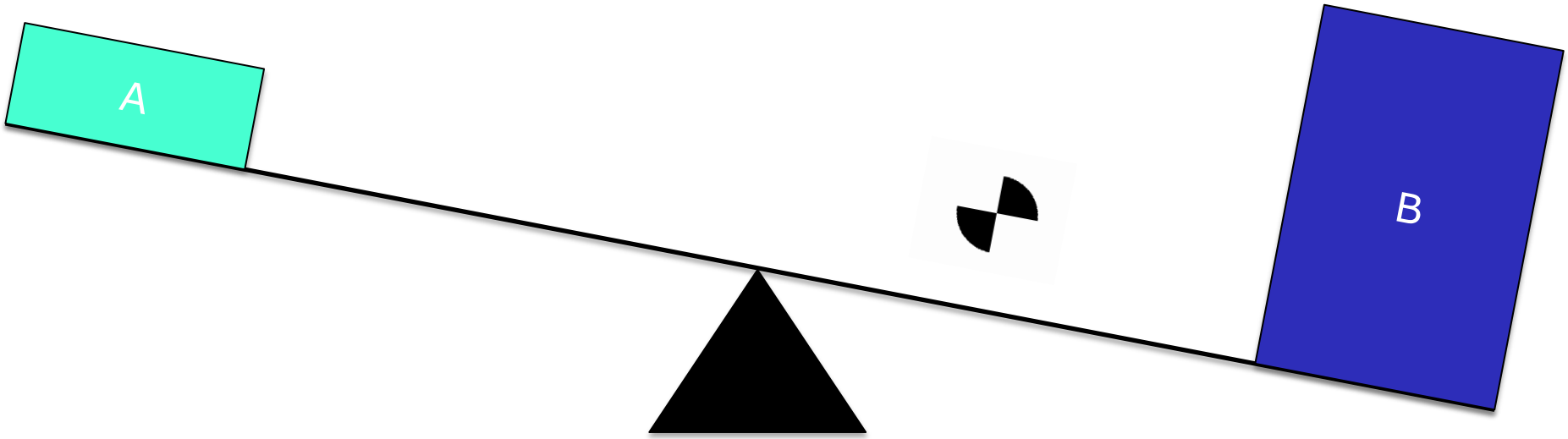
Worst case MEL does not equal worst case mass prop!

A balanced system will stay balanced if equal mass is added to each side
e.g. the center of mass will not move

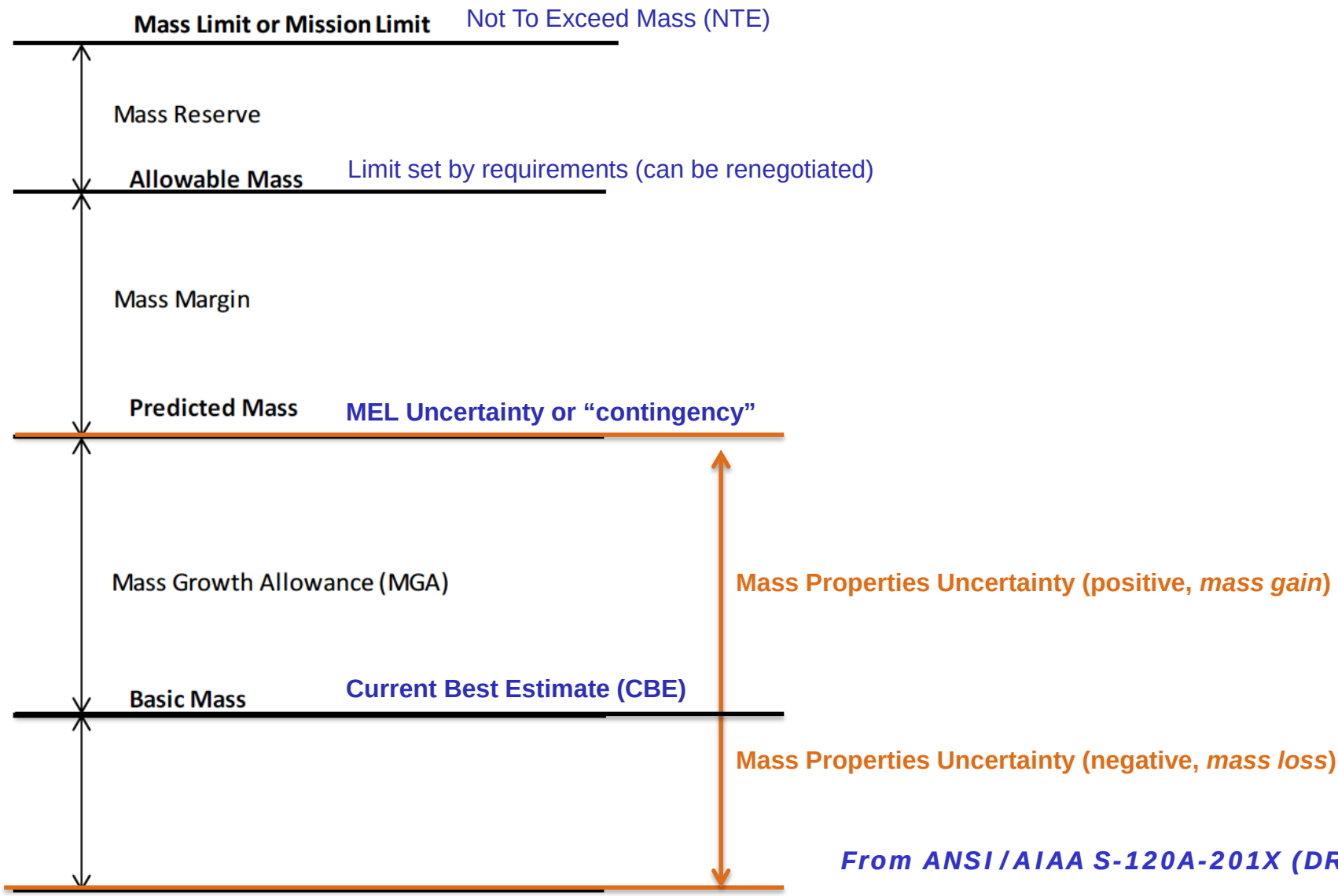


Worst Case MEL vs. Worst Case Mass Properties

Worst case mass properties occurs when some things come in very light and some come in very heavy



MEL Uncertainty vs. Mass Properties Uncertainty



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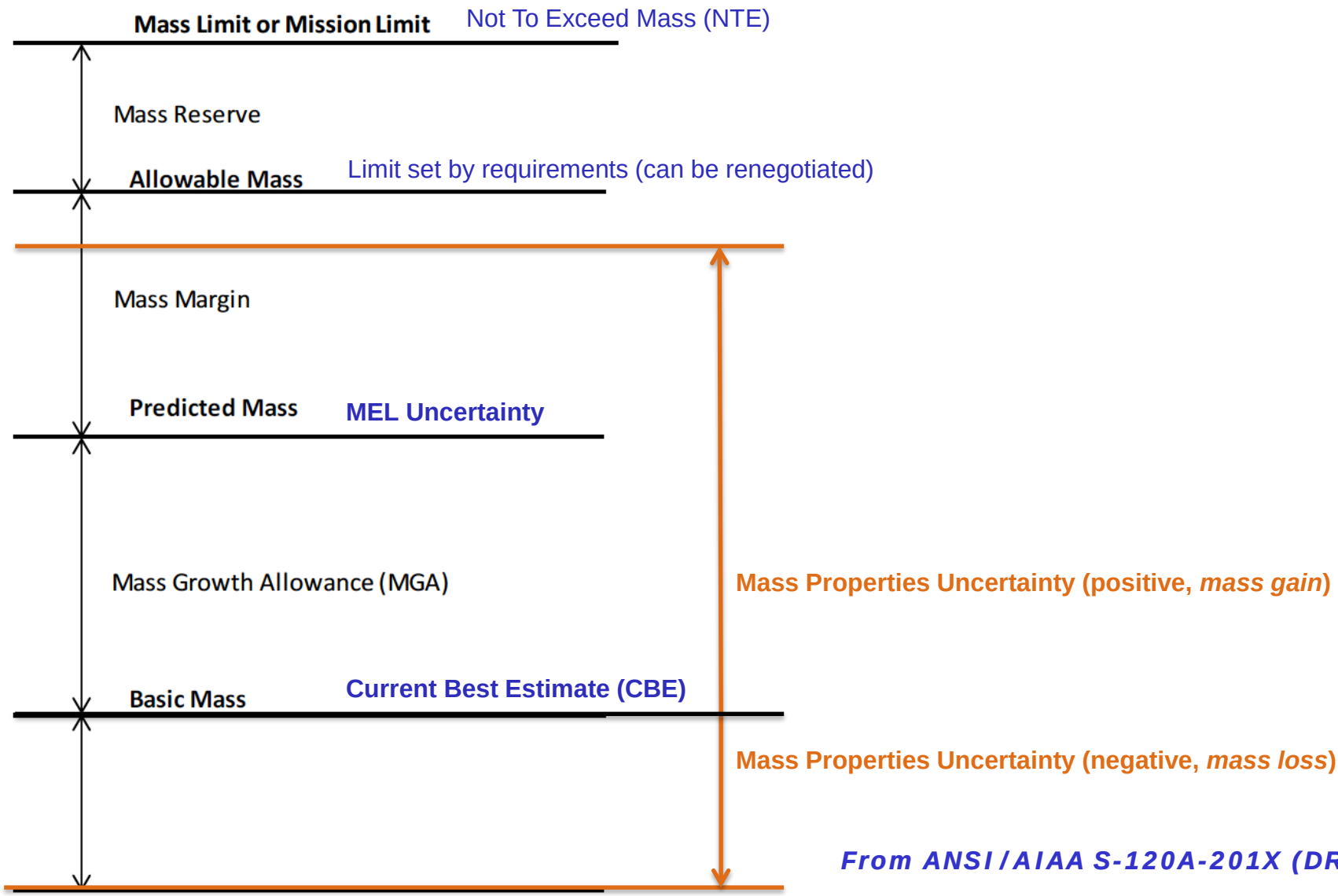

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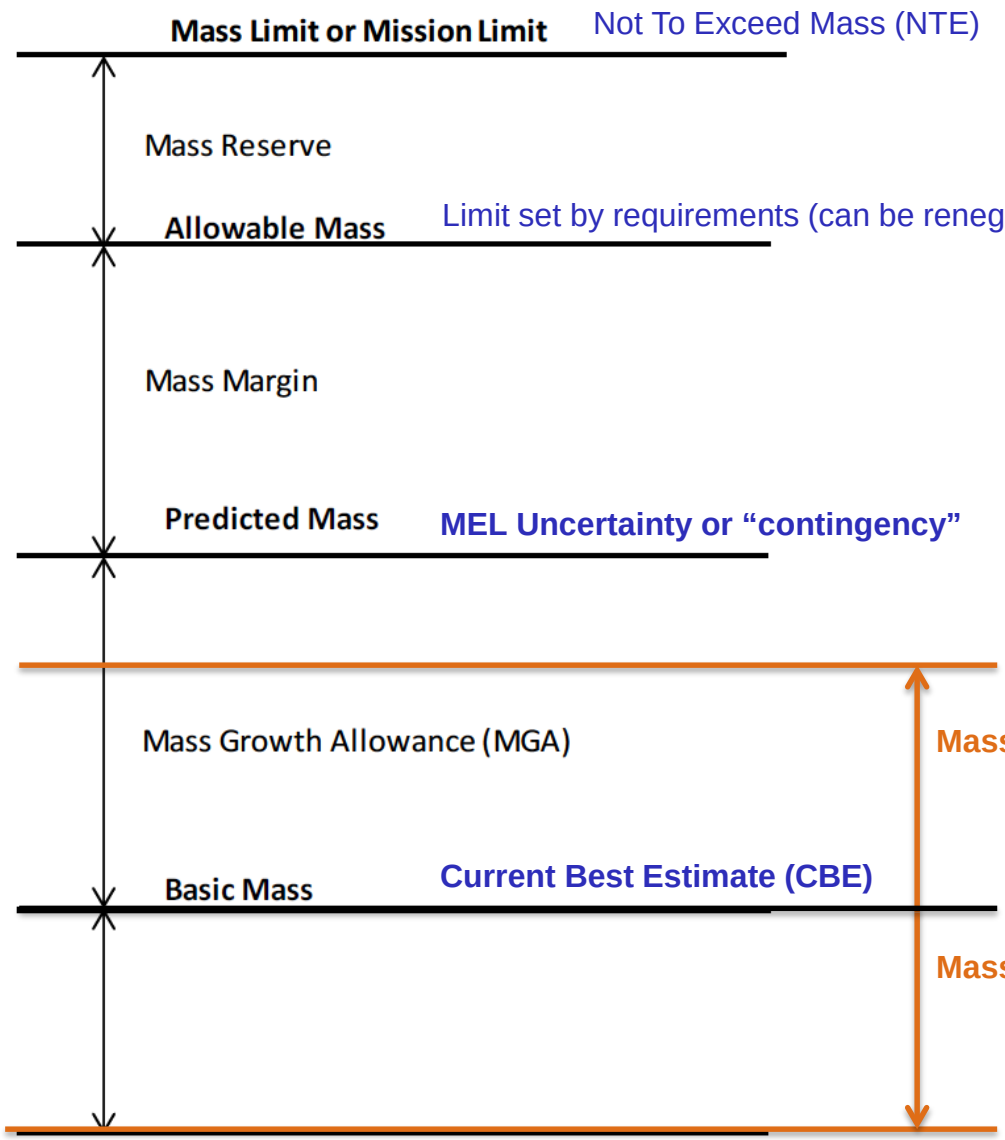
MEL Uncertainty vs. Mass Properties Uncertainty



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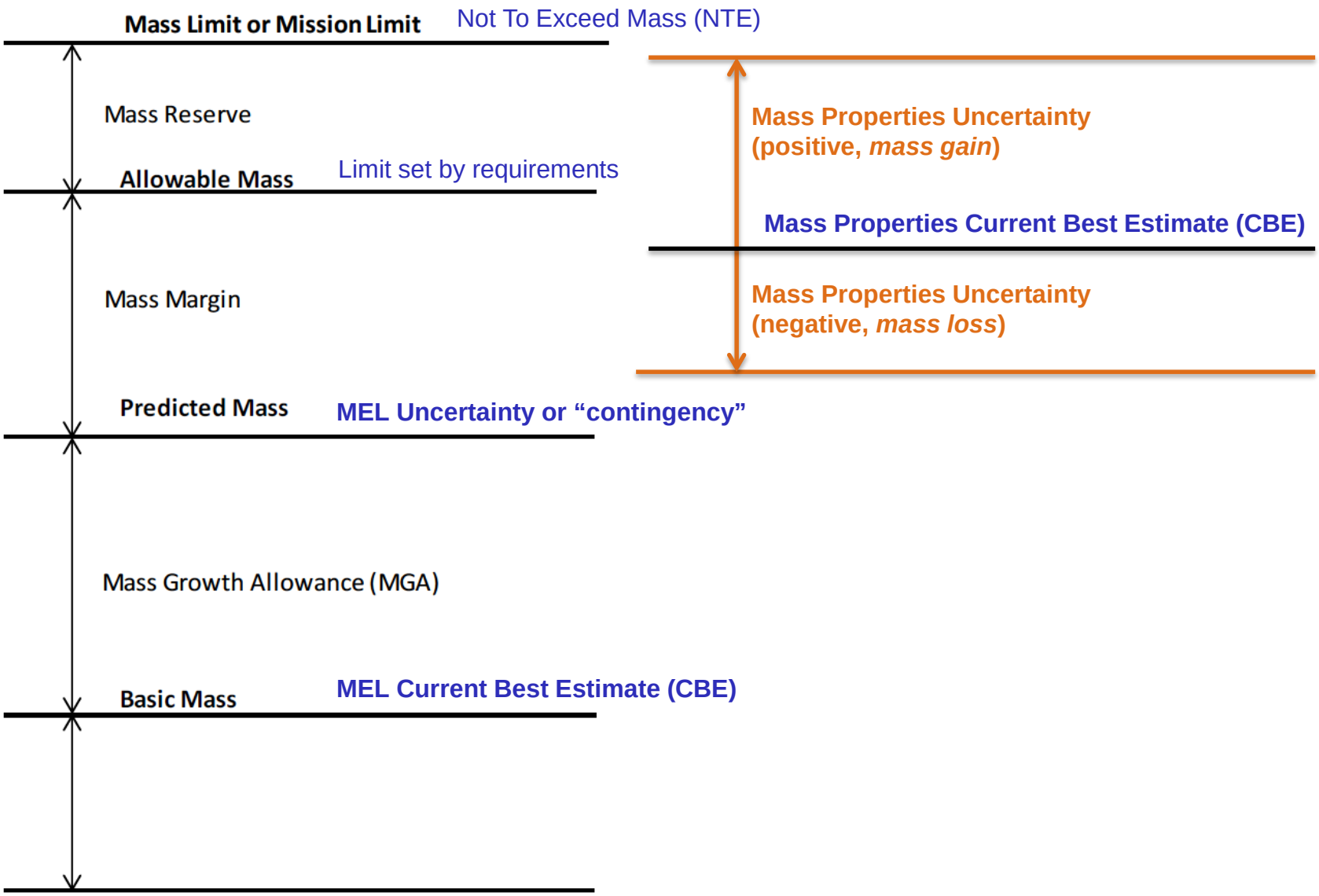
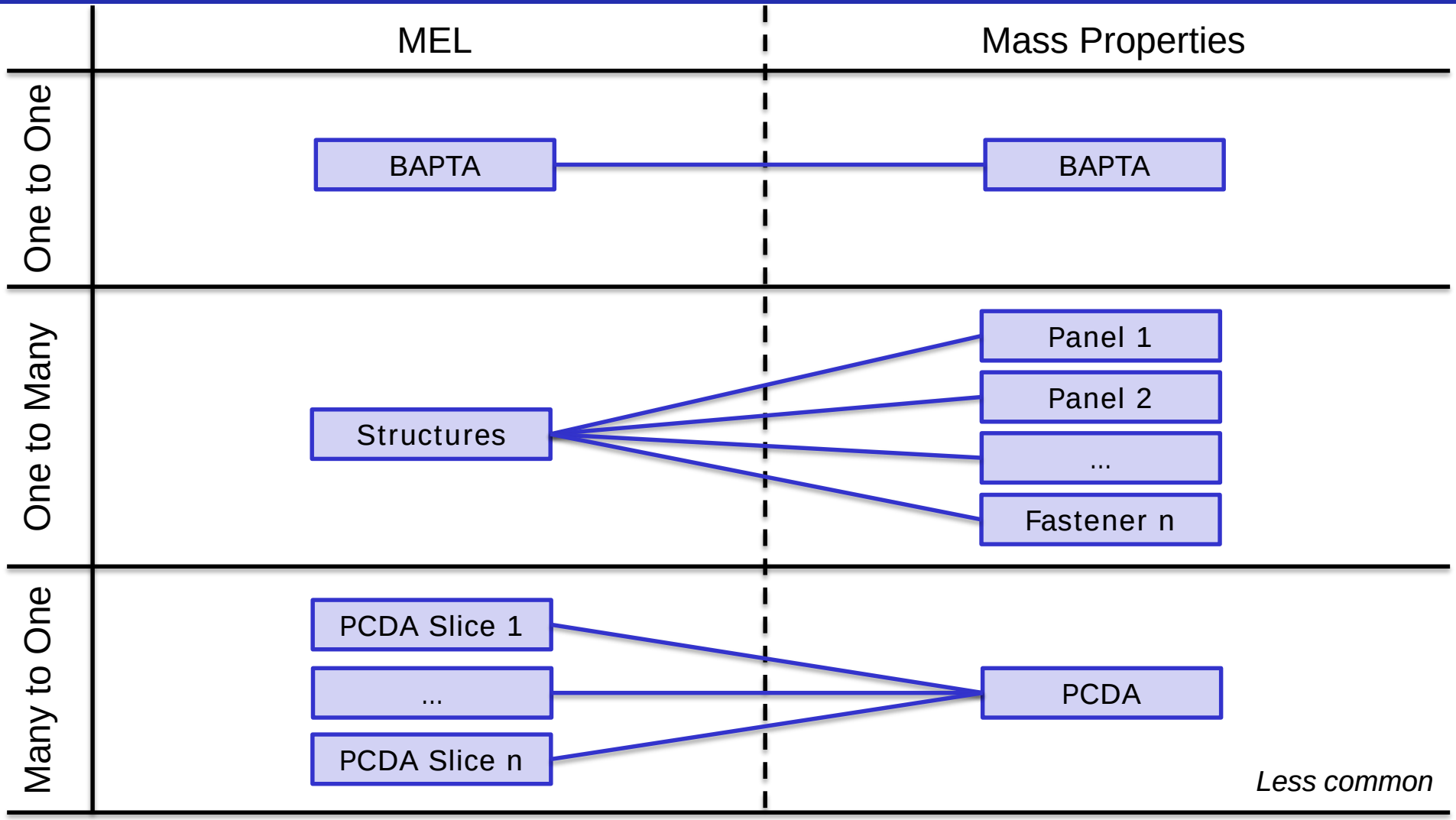
Which Official is Official?

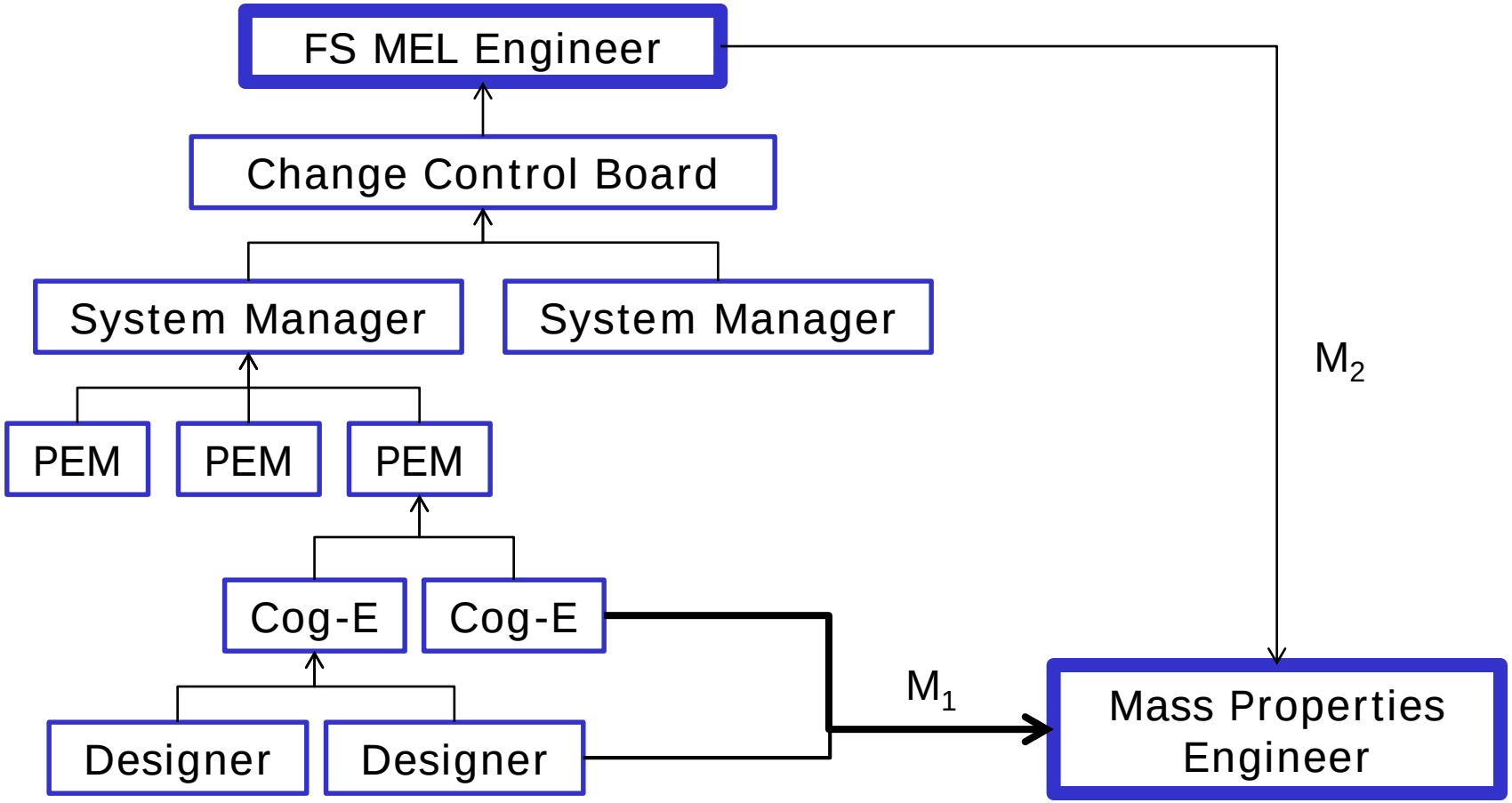


Relating Mass Properties and MEL Line Items



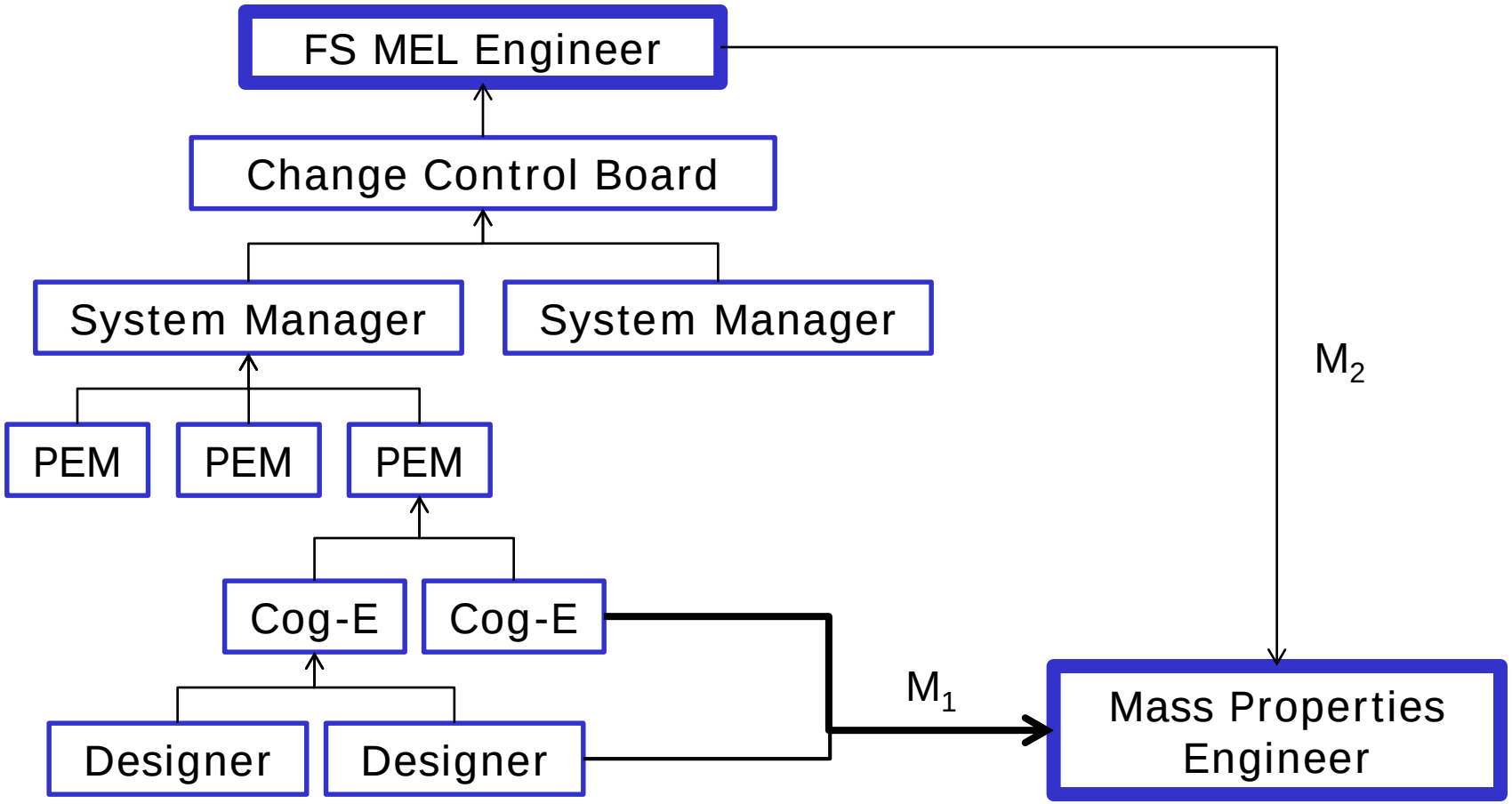
Note: “None to One” and “One to None” are also possible

Mass Flow Through System



Does M1 = M2?

Mass Flow Through System



Does M1 = M2?

Not always!

Takeaways

- **Mass and mass uncertainty has different meanings, representations, and consequences through a system**
- **One part can have multiple masses!**
- **The MEL and Mass Properties calculations are used for fundamentally different purposes**

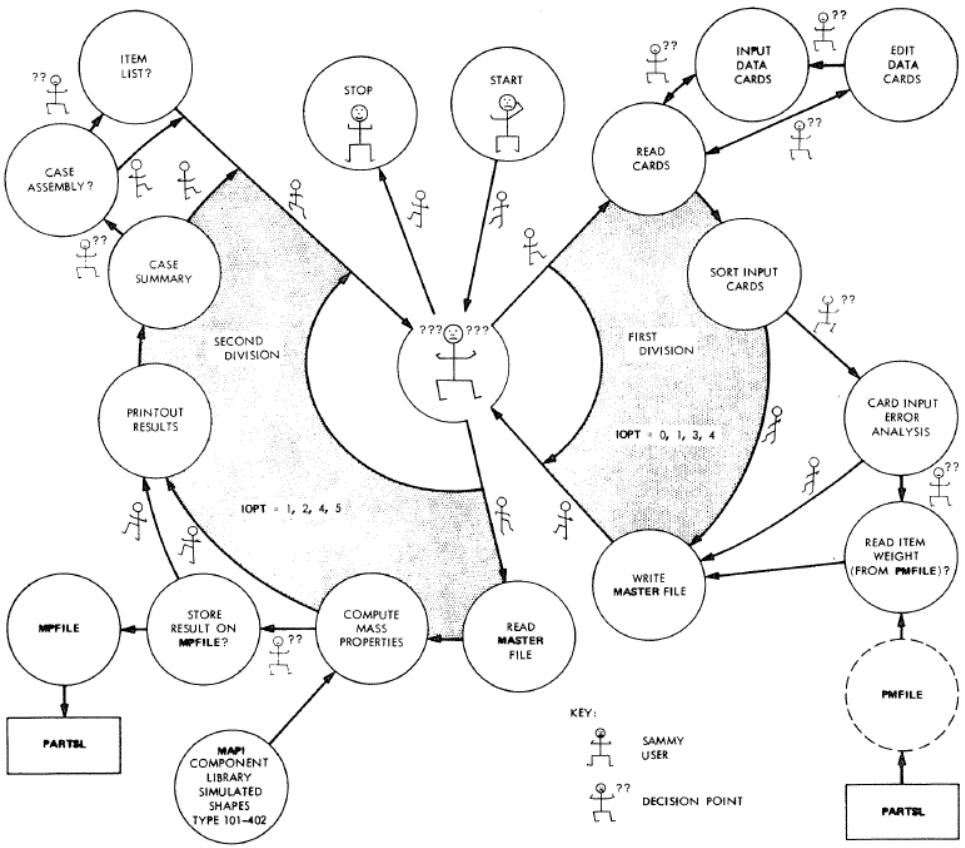
History of JPL Mass Properties (1970 - 1980's)

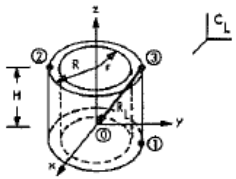
Process:

- Collect component info from Cog-E (verbal, paper form)
- Generate center of mass and inertia tensor approximation for each input (simple solids)
- Manually put data into input format (punch cards)
- Computer generates mass properties (MAPI, 1972)
- Generate report (type)
- Publish (physical memo)

Advances:

- Better organization
- Faster turnaround
- Increased reliability from hand calculations
- (Bad) Monte Carlo uncertainty available on Apple II (1979)



TYPE	FIGURE	CARD 1	ORIGIN DISPLACEMENT FROM ③ TO ⓪	MOMENT OF INERTIA
210	HOLLOW RIGHT CIRCULAR CYLINDER 	W, r, R, H	$R_L = (0, -R, -H/2)$	$I_x = \frac{W}{12}(3R^2 + 3r^2 + H^2)$ $I_y = I_x$ $I_z = \frac{W}{2}(R^2 + r^2)$ VOLUME: $\pi H(R^2 - r^2)$

History of JPL Mass Properties (1990 - 2000's)

Process:

- Collect component info from Cog-E (paper form)
- Generate center of mass and inertia tensor approximation for each input using simple solids and CAD
- Manually put data into input format (Excel table)
- Computer generates mass properties (VBA Excel code, late-project Matlab)
- Generate report (Word, Excel, Matlab)
- Publish (digital memo)

Advances:

- Better organization
- Faster turnaround
- Project-specific aggregation code

JPL

Mars Science Laboratory (MSL)
Mass Properties Reporting Form

Initiator: Morgan Hendry

Date of Report: 9/10/2008

Subassembly/Part Description: **MSL RPFA Accommodation**

Part Number: **See chart**

Serial Number: **See Chart**

Subsystem:

☐ Avionics	☐ Harness	☐ MEDLI	☐ Propulsion	☐ SA-SPAH	☐ Thermal
☐ GNC	☒ Mechanical	☐ Payload/Science	☐ RPS	☐ Telecom	☐ Other: ____

Mass:
X.XXX kg ± X.XXX kg

Basis of Mass Estimate:
☐ Calculated, reason for not measuring: ____
☒ Measured - Scale Model: ____
Serial number: ____ Cal. Date: ____

Coordinate System Used:
☐ Spacecraft ☐ Cruise Stage ☐ Descent Stage ☒ Rover ☐ Other: ____

Center of Mass:
Xcm: ____ mm ± ____ mm
Ycm: ____ mm ± ____ mm
Zcm: ____ mm ± ____ mm

Diagram or drawing indicating Center of Mass location **MUST** be attached to this form.

Basis of Center of Mass Estimate:
☒ Calculated (needs approval if mass > 5kg)
☐ Measured, list equipment used below:
____

Moment of Inertia (MOI) Tensor (not needed for parts <1kg)
Ixx: ____ kg mm² ± ____ %
Iyy: ____ kg mm² ± ____ %
Izz: ____ kg mm² ± ____ %
Ixy: ____ kg mm² ± ____ %
Ixz: ____ kg mm² ± ____ %
Iyz: ____ kg mm² ± ____ %

Moment of Inertia taken about:
☐ Item Center of Mass ☐ Other: ____

Values shall be as defined by the MOI Tensor:

$$I_{xx} = \int (y^2 + z^2)\,dm \qquad I_{xy} = -\int (xy)\,dm$$
$$I_{yy} = \int (x^2 + z^2)\,dm \qquad I_{xz} = -\int (xz)\,dm$$
$$I_{zz} = \int (x^2 + y^2)\,dm \qquad I_{yz} = -\int (yz)\,dm$$

Basis of Inertia Estimate:
☐ Calculated
☐ Measured, list equipment used below:
____

Is any non-flight HW included in the above estimates? ☐ Yes ☒ No
If Yes, list mass and location of all non-flight HW: ____

Is any flight HW missing in the above estimates? ☐ Yes ☒ No
If Yes, list mass and location of all missing flight HW: ____

General Comments:
Thermal Enclosure currently has no IR - it was assembled by an AIDS (253853). Each piece part has an IR (see attached sheet). Enclosure S/N 001 was used to determine the mass (Flight S/N 002 in DHMR bakeout). Mass was measured with closeout epoxy applied, but before paint and final NuSil closeout (marginal weight additions).

Mass Properties Engineer:
Santi Udomkesmalee
Name | Signature | Date

Unit Cognizant Engineer:
Morgan Hendry
Name | Signature | Date

History of JPL Mass Properties (2010's)

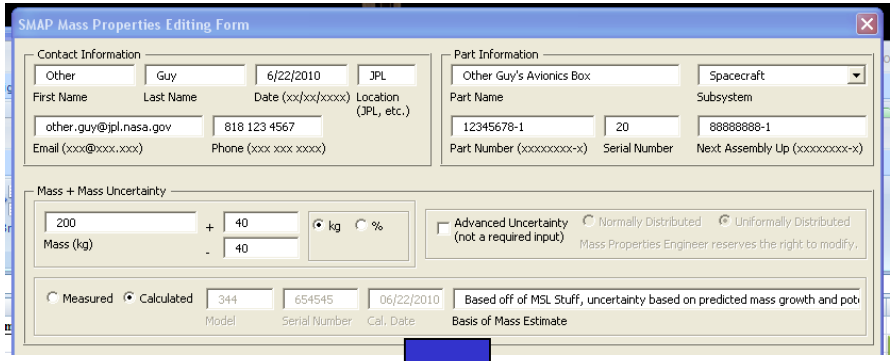
Process:

- Collect component info from Cog-E (digital form)
- Generate center of mass and inertia tensor approximation for each input using CAD
- Manually put data into input format (Excel table)
- Computer generates mass properties (Matlab)
- Generate report (Word, Excel, Matlab)
- Publish (digital memo)

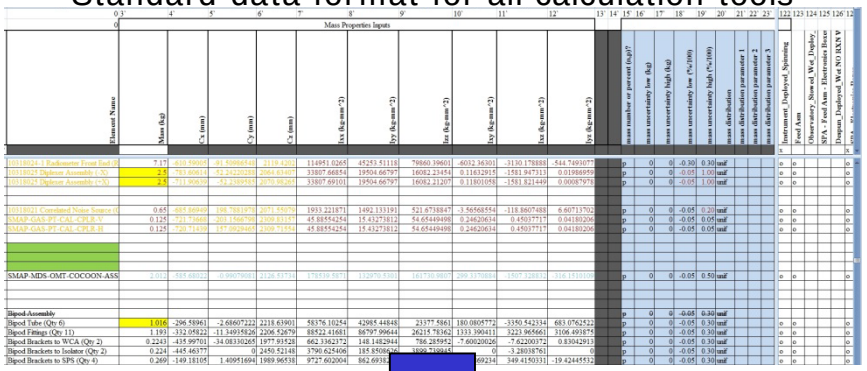
Advances:

- Better organization
- Early project Monte Carlo (better control over component uncertainties)
- Component history
- ~~Faster turnaround~~ [WHY?]

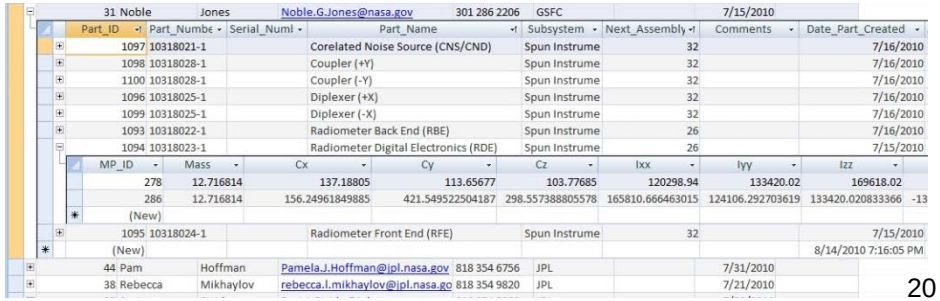
Digital mass properties form with formatted back end



Standard data format for all calculation tools



Access database holds full record of mass properties inputs

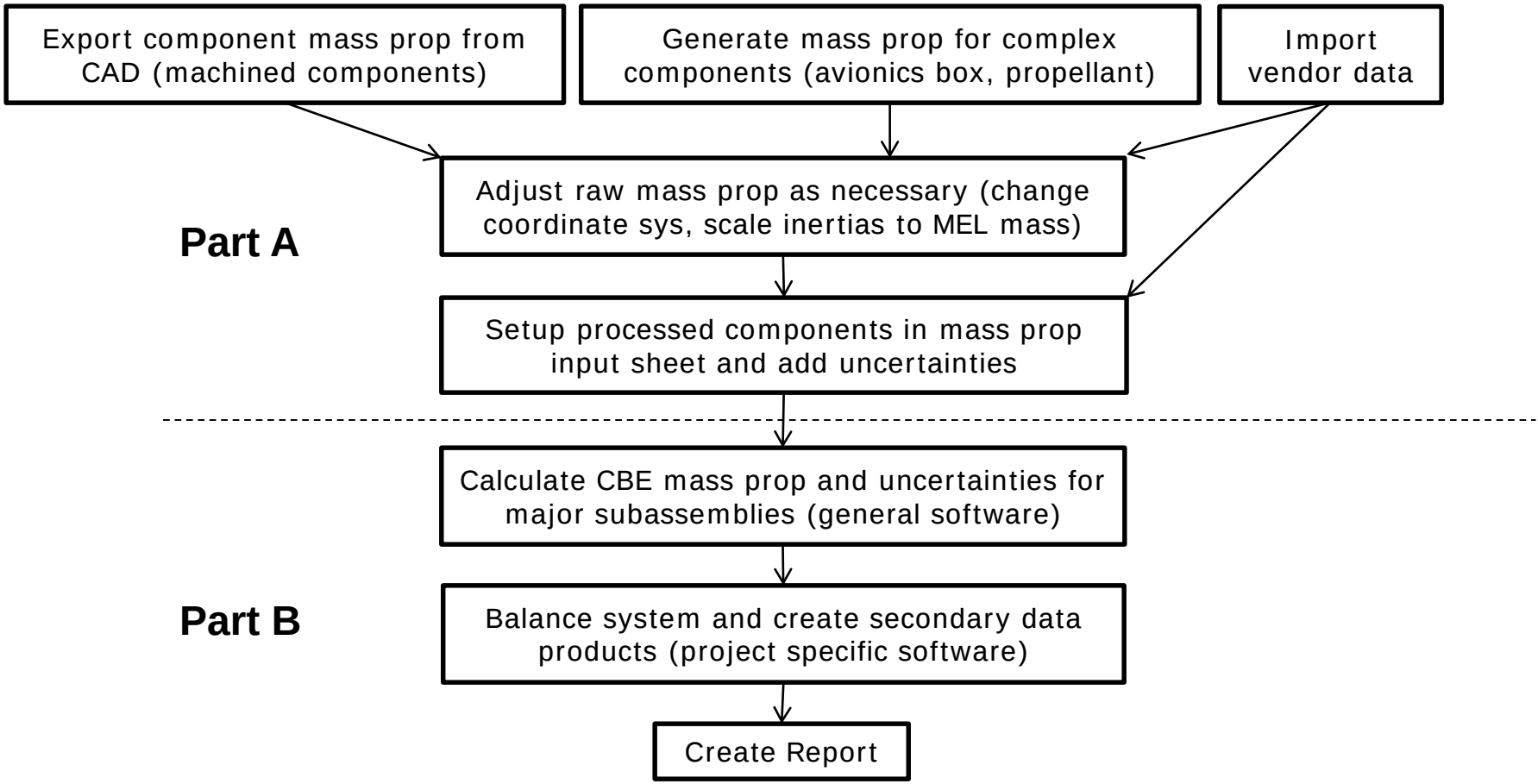


Part_ID	Part_Numbe	Serial_Numl	Part_Name	Subsystem	Next_Assembly	Comments	Date_Part_Created
1097	10318021-1		Corelated Noise Source (CNS/CND)	Spun Instrume	32		7/16/2010
1098	10318028-1		Coupler (+Y)	Spun Instrume	32		7/16/2010
1100	10318028-1		Coupler (-Y)	Spun Instrume	32		7/16/2010
1096	10318025-1		Diplexer (+X)	Spun Instrume	32		7/16/2010
1099	10318025-1		Diplexer (-X)	Spun Instrume	32		7/16/2010
1093	10318022-1		Radiometer Back End (RBE)	Spun Instrume	26		7/16/2010
1094	10318023-1		Radiometer Digital Electronics (RDE)	Spun Instrume	26		7/15/2010
1095	10318024-1		Radiometer Front End (RFE)	Spun Instrume	32		7/15/2010
(New)							8/14/2010 7:16:05 PM

MP_ID	Mass	Cx	Cy	Cz	Ixx	Iyy	Izz
278	12.716814	137.18805	113.65677	103.77685	120298.94	133420.02	169618.02
286	12.716814	156.24961849885	421.549522504187	298.557388805578	165810.666463015	124106.292703619	133420.020833366
(New)							

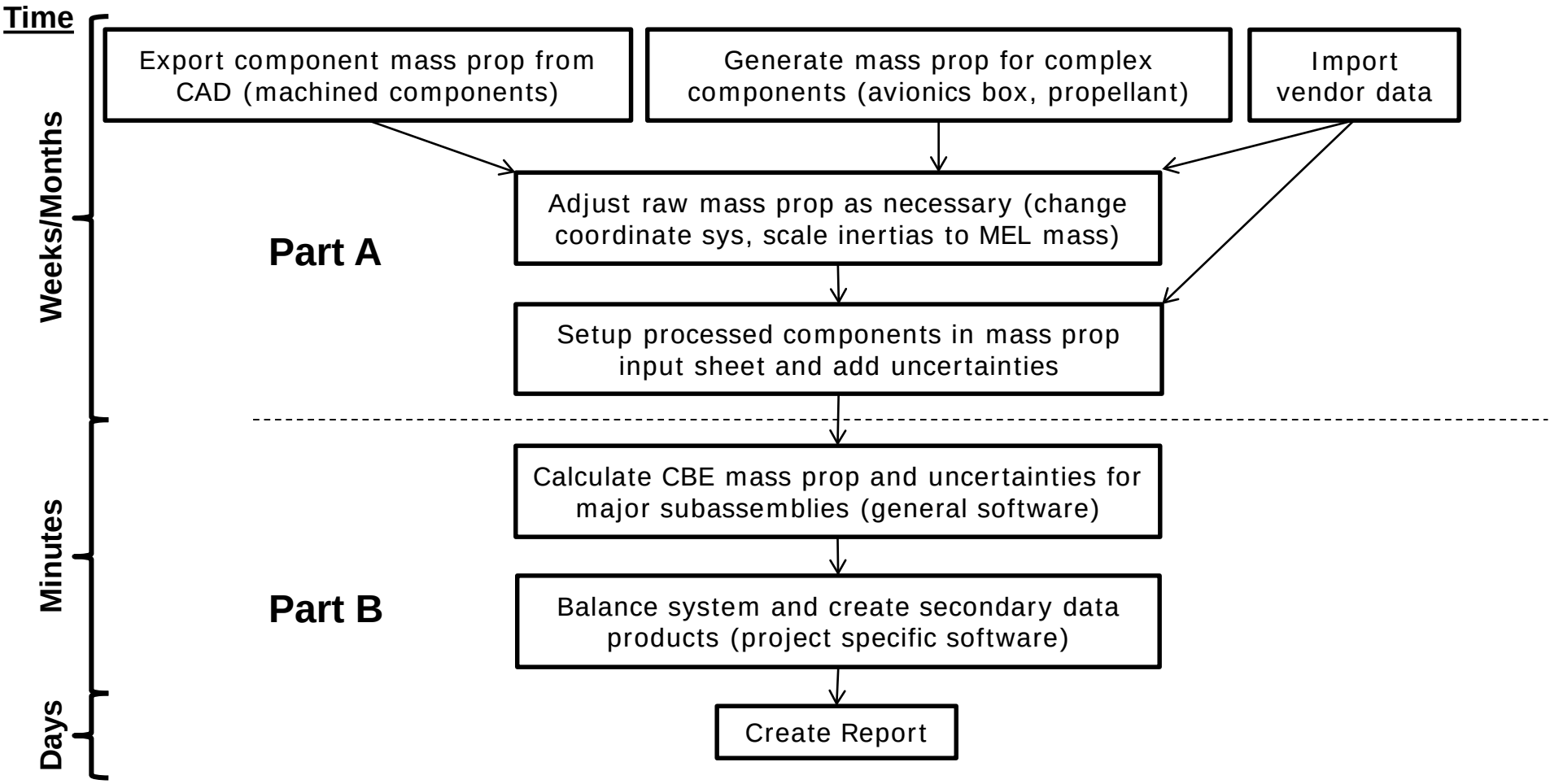
31	Noble	Jones	Noble.G.Jones@nasa.gov	301 286 2206	GSFC	7/15/2010
44	Pam	Hoffman	Pamela.J.Hoffman@jpl.nasa.gov	818 354 6756	JPL	7/31/2010
38	Rebecca	Mikhaylov	rebecca.l.mikhaylov@jpl.nasa.go	818 354 9820	JPL	7/21/2010

Mass Properties Calculation (Scrub) Timeline

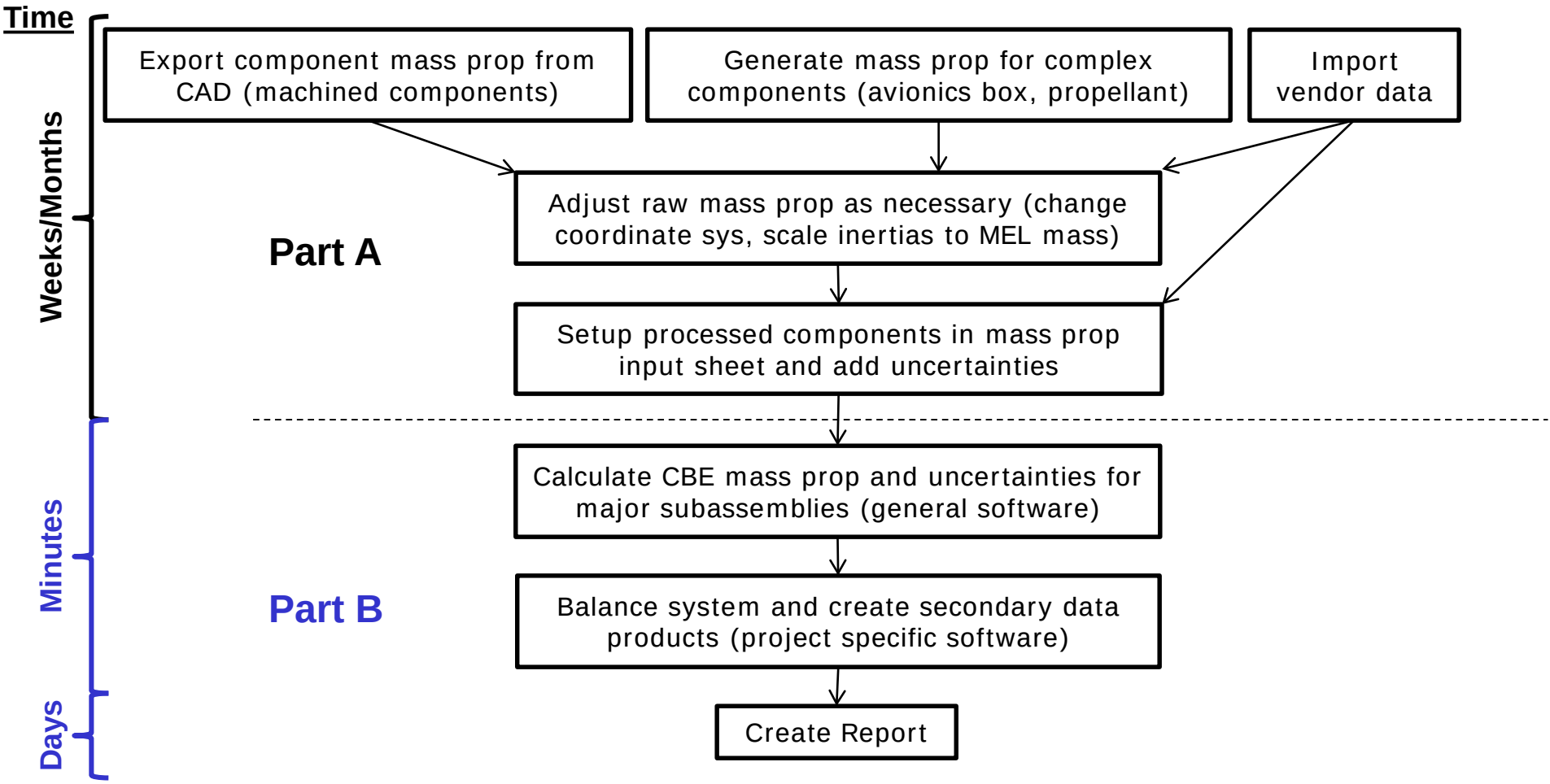


Steps to calculate mass properties have remained largely unchanged through years

Mass Properties Calculation (Scrub) Timeline

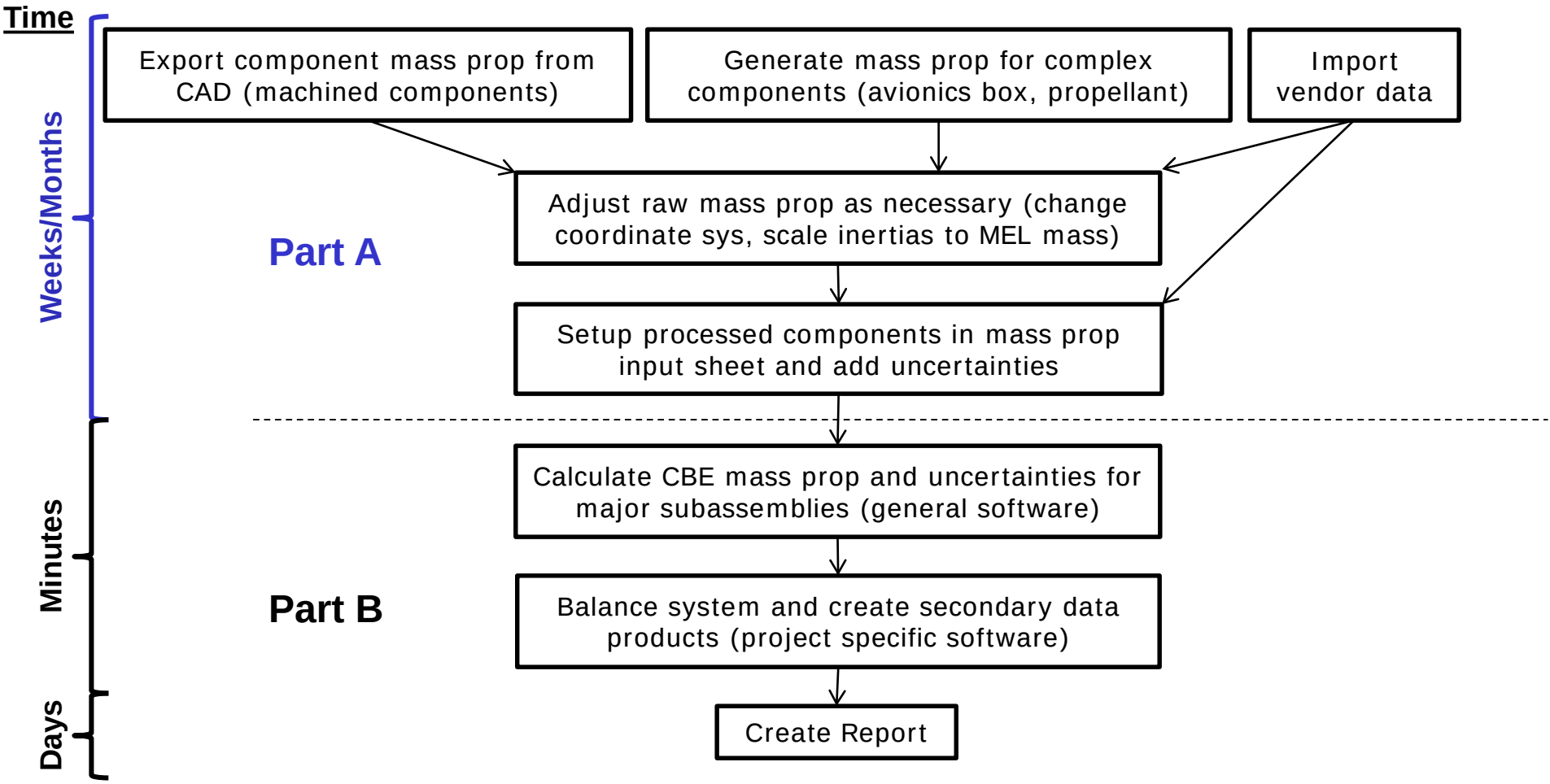


Mass Properties Calculation (Scrub) Timeline



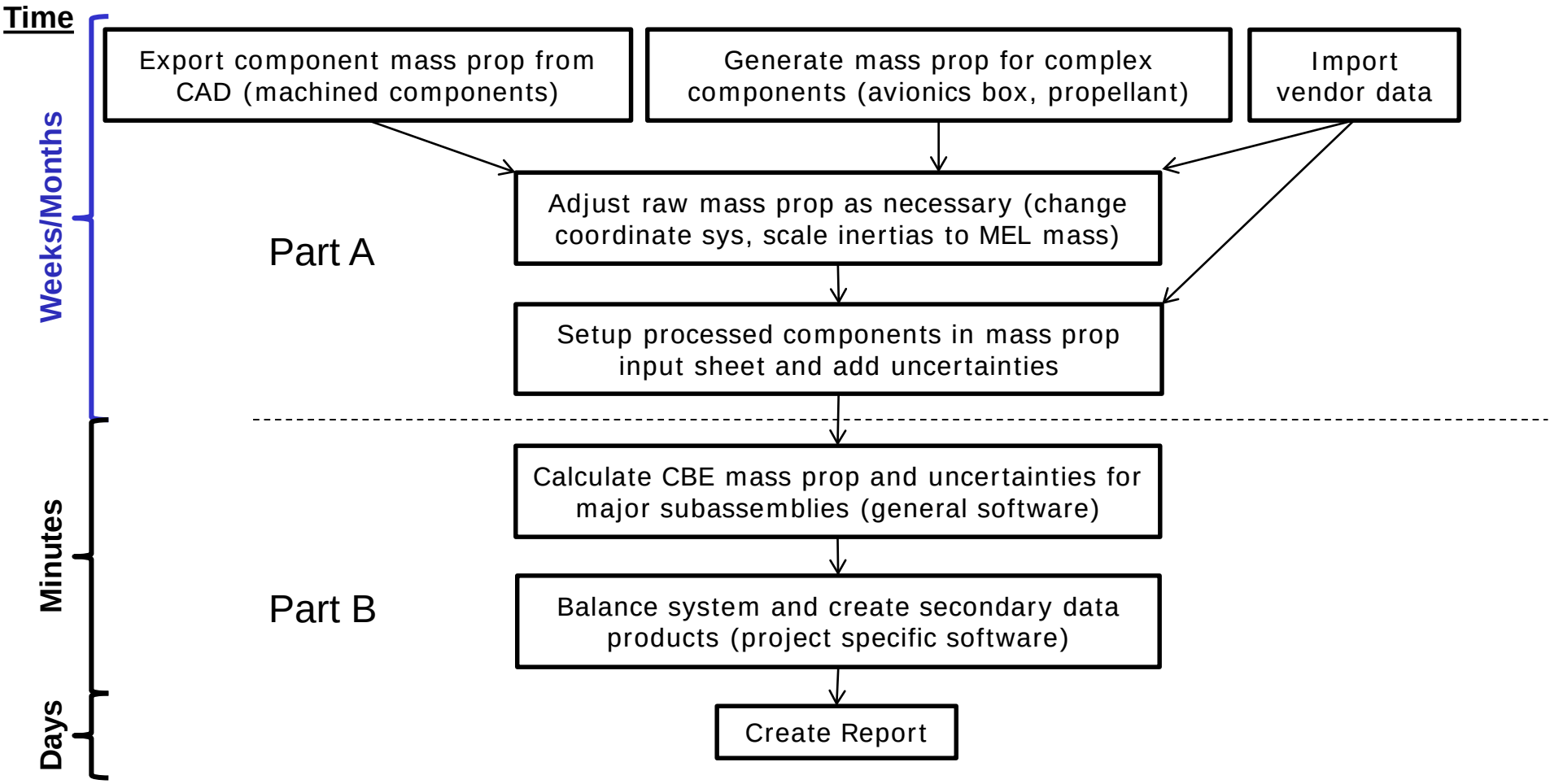
1. Part B of timeline has increased in speed from 1970's until present – *fast enough!*

Mass Properties Calculation (Scrub) Timeline



1. Part B of timeline has increased in speed from 1970's until present – *fast enough!*
2. **Part A has not sped up significantly since CAD was introduced!**

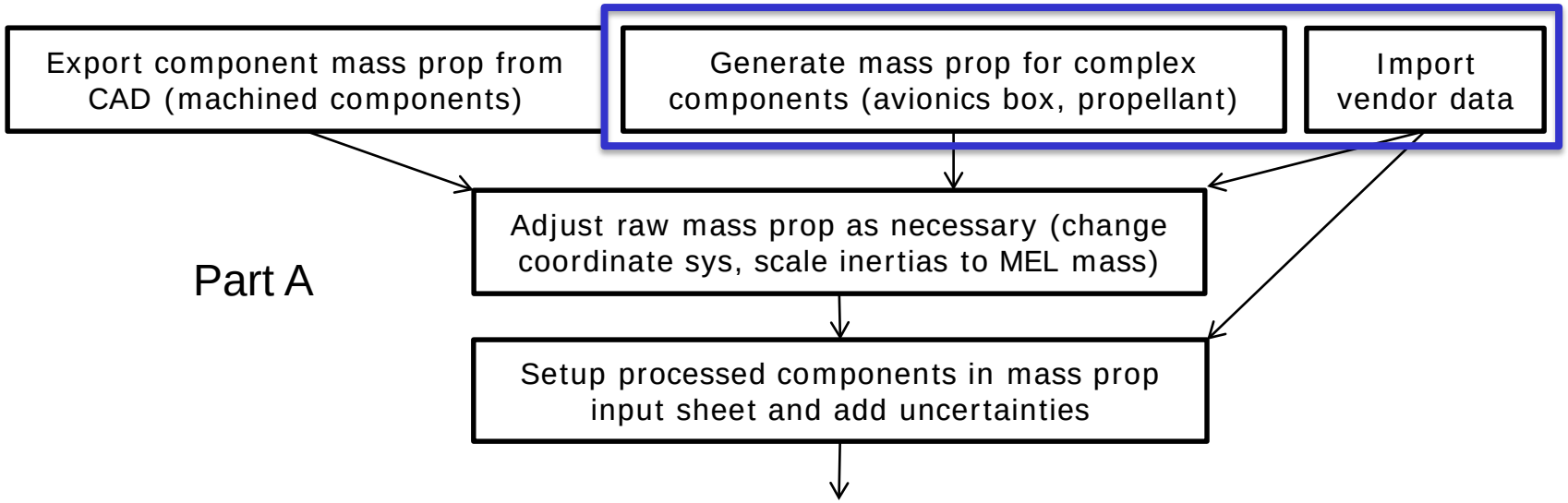
Mass Properties Calculation (Scrub) Timeline



1. Part B of timeline has increased in speed from 1970's until present – *fast enough!*
2. Part A has not sped up significantly since CAD was introduced!

At heart, this is a data management problem!

How Do We Increase the Speed of Part A?



- **Cannot increase the speed of face to face interactions**
  - **Will always need to have discussions to clarify "the black box"**
  - **Vendors will work the way they want to work**
  - **Some part of this will always look the way it has (manual override)**

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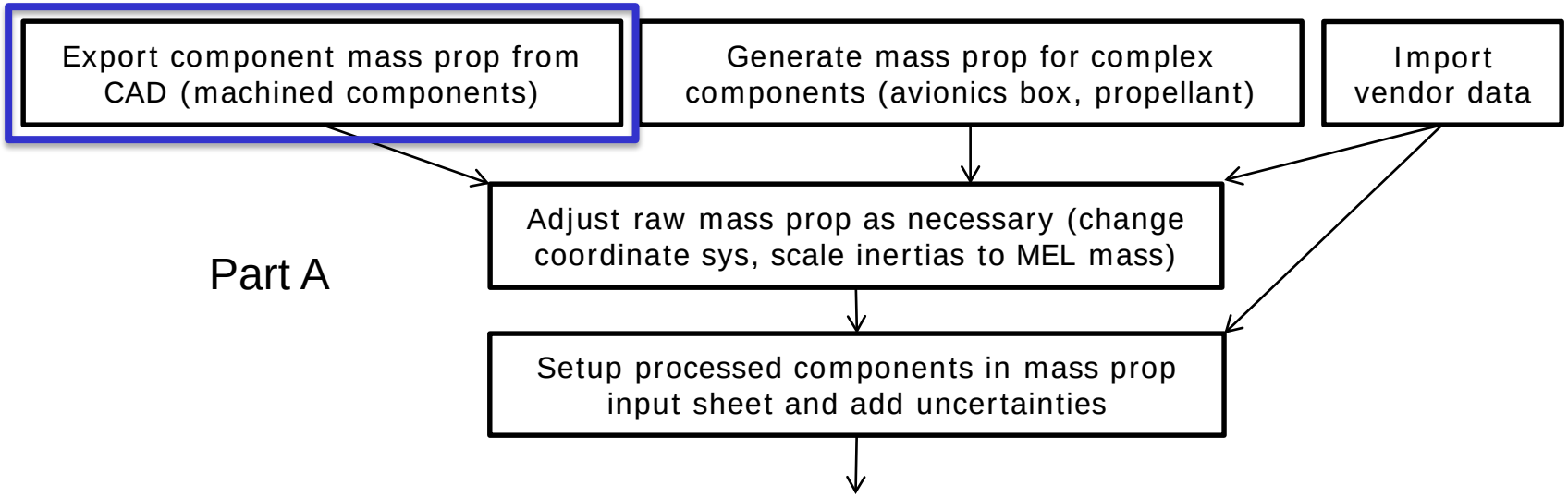

- **Cannot increase the speed of face to face interactions?**
  - **Will always need to have discussions to clarify "the black box"**
  - **Vendors will work the way they want to work**
  - **Some part of this will always look the way it has (manual override)**

- **For certain components, could automate transfer of CAD data**
  - **CAD most accurately captures machined metal components**
  - **Fortunately, this is ~75% of what's on a spacecraft!**
  - **If correct density in CAD, mass properties can be used directly**

Can’t you just do this in CAD?

- **Is CAD important in mass properties – YES!**
  - **Has greatly improved our estimate of nominal mass properties for machined components**
  - **Helps understand how mass is distributed through system**

- **Can you get everything you need from CAD – NO!**
  - **No uncertainties**
  - **Parts evolve and mature (do not materialized fully modeled)**
  - **Not everything is modeled (harness, blankets, electronics, etc)**
  - **Not everything in CAD is real (envelopes, etc.)**
  - **Densities can be inconsistent or in error**
  - **Forcing a mass on a part means management through sub-menus**

- **In short:**
  - **Must decide how to process every part on the vehicle**
  - **Must constantly reverify / refine / correct every part on the vehicle**

- ***It would be wonderful if our decisions could persist…***

What Would Be Needed?

- **Goal: auto generation of most of the mass properties <u>inputs</u>**

- **This new mass properties data management system must:**
  - **(Automatically) import data from CAD system(s) in both a single component and bulk format to serve as basis of inputs**
  - **Group or split raw CAD data automatically to create desired input hierarchy (project drawing tree, current configuration, etc.)**
  - **Automatically adjust inputs to MEL "official" mass (if desired)**
  - **Automatically perform coordinate transforms**
  - **Override CAD mass properties when needed (electronics boxes, propellant, etc.)**
  - **Catalog and represent non-modeled objects (blankets, etc.)**
  - **Clearly represent the state of the object (e.g. stowed or deployed)**
  - **Define configurations of interest**
  - **Export the mass properties for external calculations**

- **JPL/industry are working to solve similar problems using Model Based Systems Engineering**

What Would This Look Like?

What Would This Look Like?

- **Today:**
  - **Tabular input sheet for mass properties, uncertainties, and configuration**
  - **Manual line by line sync with CAD, Cog-Es, and MEL quarterly**

	Part Number	Element Name	Mass (kg)	Cx (mm)	Cy (mm)	Cz (mm)	Ixx (kg-mm^2)	Iyy (kg-mm^2)	Izz (kg-mm^2)	Ixy (kg-mm^2)	Ixz (kg-mm^2)	Iyz (kg-mm^2)	mass number or percent (n,p)?	mass uncertainty low (kg)	mass uncertainty high (kg)	mass uncertainty low (%/100)	mass uncertainty high (%/100)	Spun Side (Operational) - RBA	Despun (Dry, Operational) UNBALANCED	Despun (Dry, Launch) UNBALANCED	RBA (INSR, Launch)	Despun - Fwd Sep Ring (Dry, Launch) UNBALAN	Despun Instrument (Launch)	Residual Prop and Pressure (Operational)
1	1'	2'	3'	4'	5'	6'	7'	8'	9'	10'	11'	12'	13' 14	15'	16'	17'	18'	19'	112'	120'	125'	126'		
2			Mass Properties Inputs																		11'			
61	10317005-1	BAPTA (stationary) (deployed)	11.3360	-0.0300	-0.1000	2075.0548	321947.0000	321920.0000	53887.0000	-8.0000	69.0000	270.0000	n	-0.136	0.136					o				
62	10317005-1	BAPTA (stationary) (stowed)	11.3360	-0.0300	-0.1000	2069.8548	321947.0000	321920.0000	53887.0000	-8.0000	69.0000	270.0000	n	-0.136	0.136						o		o	o
63	10317212-2	Bracket Tie Down MLI-6	0.0400	-134.4000	270.1000	1937.2000	188.0000	639.0000	824.0000	303.0000	1.0000	-1.0000	n	-0.010	0.010					o	o		o	o
64	10317212-1	Bracket Tie Down MLI-5	0.0500	-274.3000	-128.3000	1937.8000	748.0000	224.0000	968.0000	-359.0000	0.0000	3.0000	n	-0.010	0.010					o	o		o	o
65	10317212-1	Bracket Tie Down MLI-5 (#2)	0.0500	128.3000	-274.3000	1937.8000	224.0000	748.0000	968.0000	359.0000	-3.0000	0.0000	n	-0.010	0.010					o	o		o	o
66	10317212-1	Bracket Tie Down MLI-5 (#3)	0.0500	274.3000	128.3000	1937.8000	748.0000	224.0000	968.0000	-359.0000	0.0000	-3.0000	n	-0.010	0.010					o	o		o	o
67	10316006-2	Pin Retainer (stowed)	0.0083	89.6000	-2.3000	1879.9000	3.0000	3.0000	0.0000	0.0000	0.0000	0.0000	n	-0.001	0.001						o		o	o
68	10316006-3	Pin Retainer (deployed)	0.0083	89.6000	-2.3000	1885.1000	3.0000	3.0000	0.0000	0.0000	0.0000	0.0000	n	-0.001	0.001					o				
69	1031XXXX-1	Reflector Launch Restraint (Stowed)	7.5814	675.8489	14.8527	1152.8912	1169311.5399	1046676.8850	597406.8032	6049.7127	68620.4436	-31002.8189	n	-0.14	0.2						o		o	
70	1031XXXX-1	Reflector Launch Restraint (Deployed)	7.5814	673.6606	14.1876	1117.8625	1316429.3969	1041491.2846	679194.7366	14952.9509	53816.1013	-27774.2534	n	-0.14	0.2					o				
71	1031XXXX-1	Instrument Cradle Mounting Hardware	0.2897	497.6078	17.0528	937.3105	91948.2526	60002.6061	31982.1741	1061.8123	-4.8015	19.0848	p			-0.30	0.30			o	o		o	
72	10311010-1	PURGE INSTALLATION (including purge line)	0.2500	-30.3440	357.6913	1154.1484	93053.2605	106700.0461	18001.6389	1001.2562	-34631.0180	-6282.4117	p			-0.10	0.27			o	o		o	
73	10252288-1	Tie Mount (Qty 12) (Purge Installation)	0.0240	-44.8249	461.5831	1017.8864	4250.7870	5554.0213	1318.4237	26.2575	-2085.9423	-86.5780	p			-0.10	0.10			o	o		o	
74	10311700-1	OUTRIGGER STRUCTURAL ASSY	2.2950	4.2996	-782.5888	117.4307	57956.5501	23753.3309	56706.7522	-1504.5835	-458.9322	20738.4586	n	-0.04	0.002					o	o		o	
75	10311306-1	Bracket, Torque Rod (-Y)	0.0850	350.1657	-446.2530	1829.2459	89.8903	116.3923	55.4022	-7.9939	29.8833	-9.7247	n	-0.002	0.002					o	o		o	
76	10311307-1	Bracket, Torque Rod (-Y)	0.091	18.4166	-446.2986	1830.7515	84.0534	115.0049	58.4185	-7.8132	28.2582	-6.8898	n	-0.002	0.002					o	o		o	
77	10311306-1	Bracket, Torque Rod (-Y)	0.0850	-310.2343	-446.2530	1829.2459	89.8903	116.3923	55.4022	-7.9939	29.8833	-9.7247	n	-0.002	0.002					o	o		o	
78	10311303-1	Bracket, Torque Rod (-X)	0.0750	-448.4940	-330.2000	1828.1857	60.6681	57.2304	24.3356	0.0000	-7.6798	0.0000	p			-0.05	0.06			o	o		o	
79	10311304-1	Bracket, Torque Rod (-X)	0.08	-448.5642	0.0000	1828.8890	55.0680	50.9253	22.5353	0.0000	-5.8726	0.0000	n	-0.002	0.002					o	o		o	
80	10311303-1	Bracket, Torque Rod (-X)	0.0750	-448.4940	330.2000	1828.1857	60.6681	57.2304	24.3356	0.0000	-7.6798	0.0000	n	-0.002	0.002					o	o		o	
81	10312104-1	MAGNETOMETER, 3 AXIS	0.5700	-24.7162	-900.2917	130.6872	1.0500	5.8200	6.5900	0.0000	0.0000	0.0000	n	-0.01	0.01					o	o		o	
82	10312107-1	MAGNETIC TORQUER (-X+Y)	4.7770	-523.2700	424.7900	952.7394	337500.0000	337500.0000	675.0000	3.0031	-277.4134	-0.0443	n	-0.01	0.01					o	o		o	
83	10312107-1	MAGNETIC TORQUER (-X+Z)	4.7770	-483.7700	2.2606	1845.2100	337500.0000	675.0000	337500.0000	277.4134	3.0031	0.0443	n	-0.01	0.01					o	o		o	
84	10312107-1	MAGNETIC TORQUER (-Y+Z)	4.7770	39.5400	-483.7700	1845.2100	675.0000	337500.0000	337500.0000	-277.4134	-0.0443	3.0031	n	-0.01	0.01					o	o		o	
85	10312109-1	ANTENNA, LOW GAIN, S-BAND	0.2300	-178.0000	-912.2916	31.7154	8877.0000	6784.2079	2636.7855	0.0000	0.0000	3583.7765	n	-0.001	0.001					o	o		o	
86	10312110-1	X-BAND ANTENNA	0.3370	162.9957	-900.2959	45.7000	1588.0000	1590.0000	119.0000	0.0000	0.0000	10.0000	n	-0.001	0.001					o	o		o	
87	10311901-1	Sun Sensor Cluster (Solar Array)	0.1210	527.3911	571.5900	64.9989	54.3681	80.5344	55.5033	-0.4872	-0.0017	0.1510	n	-0.000013	0.000013					o	o		o	
88	10311901-1	Sun Sensor Cluster (Outrigger)	0.1210	88.5503	-998.8817	75.9525	54.3681	80.5344	55.5033	-0.4872	0.0017	-0.1510	n	-0.000013	0.000013					o	o		o	
89	1031XXXX-1	Upper Bus Structure (Instrument Deck, Longerons, Mid De	110.7810	14.4258	-0.0160	1214.0890	18675863.4930	18855193.3128	12545174.6719	-23017.7456	-824272.2092	-12884.2000	n	-1.36078	1.3108					o	o		o	
90	10311115-1	BRACKET, FIELD JOINT, PYRO HARNESS CUTTER	0.0620	-304.5623	317.4018	1824.8572	114.9895	47.9999	87.5642	-0.0012	10.7364	-0.0028	n	-0.002	0.002					o	o		o	
91	10311180-1	PANEL ASSEMBLY, +Y	14.0350	-8.0308	476.0959	1032.9318	2893231.4970	3980785.0090	1089120.1740	-2542.1567	-2689.9421	-794.4055	n	-0.09	0.09					o	o		o	
92	**10311200-1**	**PANEL ASSY, +X (GNC/TELECOM) (ID 16)**	49.6100	449.0800	24.6300	975.6400	12018526.4700	8655560.2800	3494782.7700	10766.4600	136823.6100	-50650.1400	n	-1.01426	1.01426					o	o		o	
93	**10311300-1**	**PANEL ASSY -X (AVIONICS/GNC/POWER) (ID 13**	78.7400	-416.4463	58.2048	1061.4186	16887835.9000	12582410.1100	5620695.3820	591597.3582	-197464.7166	-730452.4449	n	-1.01426	1.01426					o	o		o	
94	10312102-1	STAR REFERENCE UNIT (SRU)	2.6216	-639.6231	-306.6456	1593.3424	15605.9082	30842.0387	26961.1642	1574.2472	-8166.5359	-841.5227	n	-0.01	0.01					o	o		o	
95	10312048-1	Bracket Wall Support	0.0573	-413.2549	28.3712	556.2184	101.2252	78.9267	174.8653	84.3575	0.0000	0.0000	n	-0.0004	0.0004					o	o		o	
96	10312048-2	Bracket Wall Support	0.0666	-383.9611	33.6623	920.0000	90.4371	194.4121	278.7553	127.5251	0.0000	0.0000	n	-0.0004	0.0004					o	o		o	
97	10312048-3	Bracket Wall Support	0.0534	-411.3887	35.0458	717.0000	77.2988	72.8970	145.1785	70.3815	0.0000	0.0000	n	-0.0004	0.0004					o	o		o	

Inputs | Sheet2 | Check inputs

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Subject: Mass properties updates (7/7/15)

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BAPTA (stationary) (stowed)
Bracket Tie Down MLI-5
Bracket Tie Down MLI-6

The following components were deleted from the CAD model:
RDE Harness

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Configuration	M (kg)		Cx (m)		Cy (m)		Cz (m)		Ixx (kg-m^2)		Iyy (kg-m^2)		Izz (kg-m^2)		Ixy (kg-m^2)		Ixz (kg-m^2)		Iyz (kg-m^2)	
Spun (unbalanced)	202	+1 -1	0.008	+0.002 -0.002	0.003	+0.002 -0.002	1.110	+0.006 -0.007	663	+3 -2	752	+3 -2	236	+1 -1	-3	+1 -1	-3	+1 -1	-3	+1 -1
Spun (balanced)	202	+1 -1	0.008	+0.002 -0.002	0.005	+0.002 -0.002	1.112	+0.006 -0.007	666	+3 -2	755	+3 -2	237	+1 -1	-3	+1 -1	-3	+1 -1	-1	+1 -1

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Despun (wet, operational)	744	+6 -7	-0.026	+0.007 -0.006	0.001	+0.006 -0.006	0.838	+0.006 -0.006	346	+9 -8	430	+13 -12	240	+7 -6	2	+1 -1	-11	+3 -3	-2	+3 -3
Despun (wet, launch)	750	+5 -6	-0.026	+0.007 -0.007	0.008	+0.007 -0.006	0.834	+0.006 -0.006	353	+9 -8	365	+12 -12	179	+7 -6	2	+1 -1	-11	+3 -3	-1	+3 -3
Despun (dry, operational)	669	+6 -6	-0.029	+0.005 -0.005	0.001	+0.004 -0.004	0.912	+0.005 -0.005	308	+8 -7	393	+13 -11	239	+7 -6	2	+1 -1	-9	+2 -2	-2	+2 -2
Despun (dry, launch)	669	+5 -6	-0.029	+0.005 -0.005	0.009	+0.005 -0.005	0.913	+0.006 -0.006	314	+9 -8	326	+12 -11	179	+7 -6	2	+1 -1	-9	+2 -2	-1	+2 -2

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Links between the MEL and mass properties persist, even when changes occur - STRATEGIC

What Would This Look Like?

- **Future:**
  - **Still have to pay initial setup cost for each part**
  - **Ways to make initial (and touchup) MP / MEL linking easier**

Mass Equipment List

Instrument System

Component	Num of Units						Mass/Unit (kg)	Total Flt Mass (kg)
	Flt	Spare	EM	BB	Spare Kit	Tot		
Component	Flt	Spare	EM	BB	Spare Kit	Tot	(kg)	(kg)
CSS (Coarse Sun Sensor)	8	1	0	0	0	9	0.02	0.14
SRU (Star Tracker)	1	0	0	0	0	1	3.50	3.50
MIMU (Gyro)	2	0	2	0	0	4	4.80	9.60
TAM (Three Axis Magnetometer)	1	0	0	1	0	2	0.64	0.64
RWA (Reaction Wheels) - HR-18	3	0	0	0	1	4	17.50	52.50
RWA (Reaction Wheels) - HR-16	1	0	0	0	1	2	9.31	9.31
WDE (Wheel Drive Electronics Box)	4	0	0	0	1	5	2.00	8.00
MTR (Magnetic Torquer)	3	0	0	1	0	4	5.15	15.45
TDE (Torquer Drive Electronics Box)	1	0	0	0	0	1	1.59	1.59
Subtotal	**24**	**1**	**2**	**2**	**3**	**29**		**100.73**

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MIMU (Gyro)	2	0	2	0	0	4	4.80	9.60
TAM (Three Axis Magnetometer)	1	0	0	1	0	2	0.64	0.64
RWA (Reaction Wheels) - HR-18	3	0	0	0	1	4	17.50	52.50
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SRU (Star Tracker)	1	0	0	0	0	1	3.50	3.50
MIMU (Gyro)	2	0	2	0	0	4	4.80	9.60
TAM (Three Axis Magnetometer)	1	0	0	1	0	2	0.64	0.64
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Many to one link selected. Split mass evenly?

Yes

No

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SRU (Star Tracker)	1	0	0	0	0	1	3.50	3.50
MIMU (Gyro)	2	0	2	0	0	4	4.80	9.60
TAM (Three Axis Magnetometer)	1	0	0	1	0	2	0.64	0.64
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Confirm link?

Yes

No

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TDE (Torquer Drive Electronics Box)	1	0	0	0	0	1	1.59	1.59
Subtotal	**24**	**1**	**2**	**2**	**3**	**29**		**100.73**

Link confirmed!

Are We There Yet?

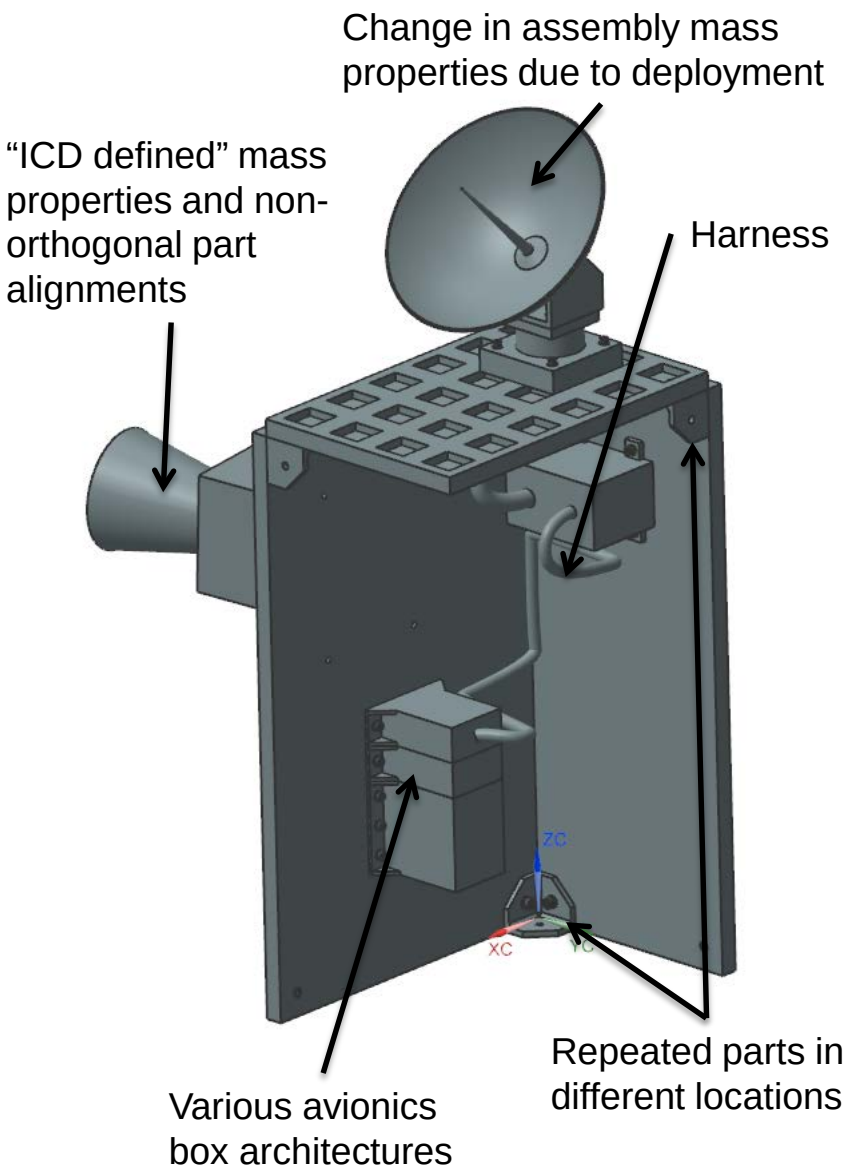
- **No**
  - **What was just shown is very simplistic**
- **However:**
  - **Have demonstrated the building blocks for a system like this**

- **Work this year shows that a mass properties system like this is technically possible**
  - **Starts a discussion of whether this is something worth pursuing in full or in part**
  - **Input of practitioners and subject matter experts will be paramount**

- ***Work this year speaks to mechanical systems in general***
  - ***Better ways to manage our information?***
  - ***Make our lives easier?***
  - ***Give us a deeper appreciation of where our vehicle stands through the course of development?***

Mass Properties Generation

- **Example CAD test case created**
- **Demonstrates several challenges encountered in flight project mass properties management**
  - **Different MEL/MP organizational structures**
  - **Harness**
  - **Fasteners**
  - **Erroneous components**
  - **Erroneous component hierarchy**
- **Want a way to take this system and auto update the mass properties of each component as the system changes**
  - **Challenge of repeated components**
  - **Resolved using unique CAD ID**



Initial Setup

Teamcenter

CAD (*NX*) Assembly

Update Script (*Matlab*)

Database (*Access*)

Part "Sheet"

Part ID	Unique CAD ID	Name	Asm

Mass Properties (MP) "Sheet"

MP ID	Part ID	Mass Properties

System uses two programs:

1. Mass Properties Database (*currently Access*)
2. Update Script (*currently Matlab*)

Initial Setup

Teamcenter

CAD (*NX*) Assembly

Unique CAD ID for each part and subassembly in master assembly

Mass Properties (MP) (new) for each part and subassembly in master assembly (Adv. Weight Management)

Update Script (*Matlab*)

Database (*Access*)

Part "Sheet"

Part ID	Unique CAD ID	Name	Asm

Mass Properties (MP) "Sheet"

MP ID	Part ID	Mass Properties

Teamcenter and NX provide two outputs:

1. Unique CAD ID for each part in an assembly
2. Bulk output of the mass properties for each part in an assembly

Initial Setup

Teamcenter

CAD (*NX*) Assembly

Unique CAD ID for each part and subassembly in master assembly

Mass Properties (MP) (new) for each part and subassembly in master assembly (Adv. Weight Management)

Update Script (*Matlab*)

Database (*Access*)

Part "Sheet"

Part ID	Unique CAD ID	Name	Asm
	iPWRtGwHxAY9gC	Top Lvl	
	iXWRtGwHxAY9gC	Asm A	
	ibfRtGwHxAY9gC	Asm B	
	ifbRtGwHxAY9gC	Comp D	
	ijdRtGwHxAY9gC	Comp E	
	ivZRtGwHxAY9gC	Comp F	

Mass Properties (MP) "Sheet"

MP ID	Part ID	Mass Properties
		Mass, Cx, Cy, ...
		Mass, Cx, Cy, ...
		Mass, Cx, Cy, ...
		Mass, Cx, Cy, ...
		Mass, Cx, Cy, ...
		Mass, Cx, Cy, ...

Add outputs of Teamcenter/NX (and mass properties engineer's defined values) to database to initialize a configuration

Initial Setup

Teamcenter

CAD (*NX*) Assembly

Update Script (*Matlab*)

Database (*Access*)

Part "Sheet"

Part ID	Unique CAD ID	Name	Asm
101	iPWRtGwHxAY9gC	Top Lvl	
105	iXWRtGwHxAY9gC	Asm A	
107	ibfRtGwHxAY9gC	Asm B	
109	ifbRtGwHxAY9gC	Comp D	
110	ijdRtGwHxAY9gC	Comp E	
111	ivZRtGwHxAY9gC	Comp F	

Mass Properties (MP) "Sheet"

MP ID	Part ID	Mass Properties
322		Mass, Cx, Cy, ...
588		Mass, Cx, Cy, ...
622		Mass, Cx, Cy, ...
701		Mass, Cx, Cy, ...
887		Mass, Cx, Cy, ...
988		Mass, Cx, Cy, ...

Part ID and MP ID are unique identification numbers generated by database.

Initial Setup

Teamcenter

CAD (*NX*) Assembly

Update Script (*Matlab*)

Database (*Access*)

Part "Sheet"

Part ID	Unique CAD ID	Name	Asm
101	iPWRtGwHxAY9gC	Top Lvl	
105	iXWRtGwHxAY9gC	Asm A	
107	ibfRtGwHxAY9gC	Asm B	
109	ifbRtGwHxAY9gC	Comp D	
110	ijdRtGwHxAY9gC	Comp E	
111	ivZRtGwHxAY9gC	Comp F	

Mass Properties (MP) "Sheet"

MP ID	Part ID	Mass Properties
322	109	Mass, Cx, Cy, ...
588	110	Mass, Cx, Cy, ...
622	109	Mass, Cx, Cy, ...
701	111	Mass, Cx, Cy, ...
887	111	Mass, Cx, Cy, ...
988	109	Mass, Cx, Cy, ...

Part ID (in MP "Sheet") is defined by user to link two sheets together.

Initial Setup

Teamcenter

CAD (*NX*) Assembly

Update Script (*Matlab*)

Database (*Access*)

Part "Sheet"

Part ID	Unique CAD ID	Name	Asm
101	iPWRtGwHxAY9gC	Top Lvl	N/A
105	iXWRtGwHxAY9gC	Asm A	101
107	ibfRtGwHxAY9gC	Asm B	101
109	ifbRtGwHxAY9gC	Comp D	105
110	ijdRtGwHxAY9gC	Comp E	107
111	ivZRtGwHxAY9gC	Comp F	107

Mass Properties (MP) "Sheet"

MP ID	Part ID	Mass Properties
322	109	Mass, Cx, Cy, ...
588	110	Mass, Cx, Cy, ...
622	109	Mass, Cx, Cy, ...
701	111	Mass, Cx, Cy, ...
887	111	Mass, Cx, Cy, ...
988	109	Mass, Cx, Cy, ...

Assembly (Asm) link can be added to recreate drawing tree structure from flat database structure if desired.

Auto Update – Data Extraction

Teamcenter

CAD (*NX*) Assembly

→ **Unique CAD ID** for each part and subassembly in master assembly

→ **Mass Properties (MP) (new)** for each part and subassembly in master assembly (Adv. Weight Management)

Update Script (*Matlab*)

Database (*Access*)

Part "Sheet"

Part ID	Unique CAD ID	Name	Asm
101	iPWRtGwHxAY9gC	Top Lvl	N/A
105	iXWRtGwHxAY9gC	Asm A	101
107	ibfRtGwHxAY9gC	Asm B	101
109	ifbRtGwHxAY9gC	Comp D	105
110	ijdRtGwHxAY9gC	Comp E	107
111	ivZRtGwHxAY9gC	Comp F	107

Mass Properties (MP) "Sheet"

MP ID	Part ID	Mass Properties (old)
322	109	Mass, Cx, Cy, …
588	110	Mass, Cx, Cy, …
622	109	Mass, Cx, Cy, …
701	111	Mass, Cx, Cy, …
887	111	Mass, Cx, Cy, …
988	109	Mass, Cx, Cy, …

Unique CAD ID and bulk output Mass Properties are exported from Teamcenter/NX.

Auto Update – Processing

Teamcenter

CAD (*NX*) Assembly

Unique CAD ID for each part and subassembly in master assembly

Mass Properties (MP) (new) for each part and subassembly in master assembly (Adv. Weight Management)

Update Script (*Matlab*)

Database (*Access*)

Part "Sheet"

Part ID	Unique CAD ID	Name	Asm
101	iPWRtGwHxAY9gC	Top Lvl	N/A
105	iXWRtGwHxAY9gC	Asm A	101
107	ibfRtGwHxAY9gC	Asm B	101
109	ifbRtGwHxAY9gC	Comp D	105
110	ijdRtGwHxAY9gC	Comp E	107
111	ivZRtGwHxAY9gC	Comp F	107

Mass Properties (MP) "Sheet"

MP ID	Part ID	Mass Properties (old)
322	109	Mass, Cx, Cy, …
588	110	Mass, Cx, Cy, …
622	109	Mass, Cx, Cy, …
701	111	Mass, Cx, Cy, …
887	111	Mass, Cx, Cy, …
988	109	Mass, Cx, Cy, …

A Matlab script draws in these two data sets along with the previous mass properties and Unique CAD ID records from the database.

Auto Update – Processing

Teamcenter

CAD (*NX*) Assembly

Unique CAD ID for each part and subassembly in master assembly

Mass Properties (MP) (new) for each part and subassembly in master assembly (Adv. Weight Management)

Update Script (*Matlab*)

[Unique CAD ID, MP (new)] |?| [Unique CAD ID, MP (old)]

Database (*Access*)

Part "Sheet"

Part ID	Unique CAD ID	Name	Asm
101	iPWRtGwHxAY9gC	Top Lvl	N/A
105	iXWRtGwHxAY9gC	Asm A	101
107	ibfRtGwHxAY9gC	Asm B	101
109	ifbRtGwHxAY9gC	Comp D	105
110	ijdRtGwHxAY9gC	Comp E	107
111	ivZRtGwHxAY9gC	Comp F	107

Mass Properties (MP) "Sheet"

MP ID	Part ID	Mass Properties (old)
322	109	Mass, Cx, Cy, …
588	110	Mass, Cx, Cy, …
622	109	Mass, Cx, Cy, …
701	111	Mass, Cx, Cy, …
887	111	Mass, Cx, Cy, …
988	109	Mass, Cx, Cy, …

The script first links the Teamcenter Unique CAD ID to the appropriate NX Mass Properties line item.

Auto Update – Sorting

Teamcenter

CAD (*NX*) Assembly

Unique CAD ID for each part and subassembly in master assembly

Mass Properties (MP) (new) for each part and subassembly in master assembly (Adv. Weight Management)

Update Script (*Matlab*)

[Unique CAD ID, MP (new)] |?| [Unique CAD ID, MP (old)]

1. **Part Update**
2. **New Part in CAD**
3. **Deleted Part in CAD**
4. **New Part in Database**

Database (*Access*)

Part "Sheet"

Part ID	Unique CAD ID	Name	Asm
101	iPWRtGwHxAY9gC	Top Lvl	N/A
105	iXWRtGwHxAY9gC	Asm A	101
107	ibfRtGwHxAY9gC	Asm B	101
109	ifbRtGwHxAY9gC	Comp D	105
110	ijdRtGwHxAY9gC	Comp E	107
111	ivZRtGwHxAY9gC	Comp F	107

Mass Properties (MP) "Sheet"

MP ID	Part ID	Mass Properties (old)
322	109	Mass, Cx, Cy, …
588	110	Mass, Cx, Cy, …
622	109	Mass, Cx, Cy, …
701	111	Mass, Cx, Cy, …
887	111	Mass, Cx, Cy, …
988	109	Mass, Cx, Cy, …

Script compares MP (new) to MP (old). Sends results to appropriate "bin".

Auto Update – Sorting

Teamcenter

CAD (*NX*) Assembly

Unique CAD ID for each part and subassembly in master assembly

Mass Properties (MP) (new) for each part and subassembly in master assembly (Adv. Weight Management)

Update Script (*Matlab*)

[Unique CAD ID, MP (new)] |?| [Unique CAD ID, MP (old)]

1. **Part Update**
2. **New Part in CAD**
3. **Deleted Part in CAD**
4. **New Part in Database**

Database (*Access*)

Part "Sheet"

Part ID	Unique CAD ID	Name	Asm
101	iPWRtGwHxAY9gC	Top Lvl	N/A
105	iXWRtGwHxAY9gC	Asm A	101
107	ibfRtGwHxAY9gC	Asm B	101
109	ifbRtGwHxAY9gC	Comp D	105
110	ijdRtGwHxAY9gC	Comp E	107
111	ivZRtGwHxAY9gC	Comp F	107

Mass Properties (MP) "Sheet"

MP ID	Part ID	Mass Properties (old)
322	109	Mass, Cx, Cy, ...
588	110	Mass, Cx, Cy, ...
622	109	Mass, Cx, Cy, ...
701	111	Mass, Cx, Cy, ...
887	111	Mass, Cx, Cy, ...
988	109	Mass, Cx, Cy, ...

Change Log

1.
2.
3.

Bulk Update

Auto Update – Updated Parts

Teamcenter

CAD (*NX*) Assembly

Unique CAD ID for each part and subassembly in master assembly

Mass Properties (MP) (new) for each part and subassembly in master assembly (Adv. Weight Management)

Update Script (*Matlab*)

[Unique CAD ID, MP (new)] |?| [Unique CAD ID, MP (old)]

1. **Part Update**
   Unique CAD ID matches existing Unique CAD ID
   New mass prop sent to Change Log (Update), Bulk Update
2. **New Part in CAD**
3. **Deleted Part in CAD**
4. **New Part in Database**

Database (*Access*)

Part "Sheet"

Part ID	Unique CAD ID	Name	Asm
101	iPWRtGwHxAY9gC	Top Lvl	N/A
105	iXWRtGwHxAY9gC	Asm A	101
107	ibfRtGwHxAY9gC	Asm B	101
109	ifbRtGwHxAY9gC	Comp D	105
110	ijdRtGwHxAY9gC	Comp E	107
111	ivZRtGwHxAY9gC	Comp F	107

Mass Properties (MP) "Sheet"

MP ID	Part ID	Mass Properties (old)
322	109	Mass, Cx, Cy, …
588	110	Mass, Cx, Cy, …
622	109	Mass, Cx, Cy, …
701	111	Mass, Cx, Cy, …
887	111	Mass, Cx, Cy, …
988	109	Mass, Cx, Cy, …

Change Log
1. Update
2.
3.

Bulk Update

Auto Update – Newly Added Parts

Teamcenter

CAD (*NX*) Assembly

Unique CAD ID for each part and subassembly in master assembly

Mass Properties (MP) (new) for each part and subassembly in master assembly (Adv. Weight Management)

Update Script (*Matlab*)

[Unique CAD ID, MP (new)] |?| [Unique CAD ID, MP (old)]

1. **Part Update**
   Unique CAD ID matches existing Unique CAD ID
   New mass prop sent to Change Log (Update), Bulk Update
2. **New Part in CAD**
   Unique CAD ID doesn't match existing Unique CAD ID
   New mass prop sent to Change Log (New)
3. **Deleted Part in CAD**
4. **New Part in Database**

Database (*Access*)

Part "Sheet"

Part ID	Unique CAD ID	Name	Asm
101	iPWRtGwHxAY9gC	Top Lvl	N/A
105	iXWRtGwHxAY9gC	Asm A	101
107	ibfRtGwHxAY9gC	Asm B	101
109	ifbRtGwHxAY9gC	Comp D	105
110	ijdRtGwHxAY9gC	Comp E	107
111	ivZRtGwHxAY9gC	Comp F	107

Mass Properties (MP) "Sheet"

MP ID	Part ID	Mass Properties (old)
322	109	Mass, Cx, Cy, …
588	110	Mass, Cx, Cy, …
622	109	Mass, Cx, Cy, …
701	111	Mass, Cx, Cy, …
887	111	Mass, Cx, Cy, …
988	109	Mass, Cx, Cy, …

Change Log
1. Update
2. New
3.

Bulk Update

Auto Update – Deleted Parts

Teamcenter

CAD (*NX*) Assembly

Unique CAD ID for each part and subassembly in master assembly

Mass Properties (MP) (new) for each part and subassembly in master assembly (Adv. Weight Management)

Update Script (*Matlab*)

[Unique CAD ID, MP (new)] |?| [Unique CAD ID, MP (old)]

1. **Part Update**
   Unique CAD ID matches existing Unique CAD ID
   New mass prop sent to Change Log (Update), Bulk Update
2. **New Part in CAD**
   Unique CAD ID doesn't match existing Unique CAD ID
   New mass prop sent to Change Log (New)
3. **Deleted Part in CAD**
   Unique CAD ID has no match from CAD
   New mass prop sent to Change Log (Deleted)
4. **New Part in Database**

Database (*Access*)

Part "Sheet"

Part ID	Unique CAD ID	Name	Asm
101	iPWRtGwHxAY9gC	Top Lvl	N/A
105	iXWRtGwHxAY9gC	Asm A	101
107	ibfRtGwHxAY9gC	Asm B	101
109	ifbRtGwHxAY9gC	Comp D	105
110	ijdRtGwHxAY9gC	Comp E	107
111	ivZRtGwHxAY9gC	Comp F	107

Mass Properties (MP) "Sheet"

MP ID	Part ID	Mass Properties (old)
322	109	Mass, Cx, Cy, …
588	110	Mass, Cx, Cy, …
622	109	Mass, Cx, Cy, …
701	111	Mass, Cx, Cy, …
887	111	Mass, Cx, Cy, …
988	109	Mass, Cx, Cy, …

Change Log
1. Update
2. New
3. Deleted

Bulk Update

Auto Update – New Parts in MP Database

Teamcenter

CAD (*NX*) Assembly

Unique CAD ID for each part and subassembly in master assembly

Mass Properties (MP) (new) for each part and subassembly in master assembly (Adv. Weight Management)

Update Script (*Matlab*)

[Unique CAD ID, MP (new)] |?| [Unique CAD ID, MP (old)]

1. **Part Update**
   Unique CAD ID matches existing Unique CAD ID
   New mass prop sent to Change Log (Update), Bulk Update
2. **New Part in CAD**
   Unique CAD ID doesn't match existing Unique CAD ID
   New mass prop sent to Change Log (New)
3. **Deleted Part in CAD**
   Unique CAD ID has no match from CAD
   New mass prop sent to Change Log (Deleted)
4. **New Part in Database**
   Added via database, Unique CAD ID not assigned, no update

Database (*Access*)

Part "Sheet"

Part ID	Unique CAD ID	Name	Asm
101	iPWRtGwHxAY9gC	Top Lvl	N/A
105	iXWRtGwHxAY9gC	Asm A	101
107	ibfRtGwHxAY9gC	Asm B	101
109	ifbRtGwHxAY9gC	Comp D	105
110	ijdRtGwHxAY9gC	Comp E	107
111	ivZRtGwHxAY9gC	Comp F	107

Mass Properties (MP) "Sheet"

MP ID	Part ID	Mass Properties (old)
322	109	Mass, Cx, Cy, …
588	110	Mass, Cx, Cy, …
622	109	Mass, Cx, Cy, …
701	111	Mass, Cx, Cy, …
887	111	Mass, Cx, Cy, …
988	109	Mass, Cx, Cy, …

Change Log
1. Update
2. New
3. Deleted

Bulk Update

Auto Update – Bulk Update of MP Database Values

Teamcenter

CAD (*NX*) Assembly

Unique CAD ID for each part and subassembly in master assembly

Mass Properties (MP) (new) for each part and subassembly in master assembly (Adv. Weight Management)

Update Script (*Matlab*)

[Unique CAD ID, MP (new)] |?| [Unique CAD ID, MP (old)]

1. **Part Update**
   Unique CAD ID matches existing Unique CAD ID
   New mass prop sent to Change Log (Update), Bulk Update
2. **New Part in CAD**
   Unique CAD ID doesn't match existing Unique CAD ID
   New mass prop sent to Change Log (New)
3. **Deleted Part in CAD**
   Unique CAD ID has no match from CAD
   New mass prop sent to Change Log (Deleted)
4. **New Part in Database**
   Added via database, Unique CAD ID not assigned, no update

Database (*Access*)

Part "Sheet"

Part ID	Unique CAD ID	Name	Asm
101	iPWRtGwHxAY9gC	Top Lvl	N/A
105	iXWRtGwHxAY9gC	Asm A	101
107	ibfRtGwHxAY9gC	Asm B	101
109	ifbRtGwHxAY9gC	Comp D	105
110	ijdRtGwHxAY9gC	Comp E	107
111	ivZRtGwHxAY9gC	Comp F	107

Mass Properties (MP) "Sheet"

MP ID	Part ID	Mass Properties (old)
322	109	Mass, Cx, Cy, ...
588	110	Mass, Cx, Cy, ...
622	109	Mass, Cx, Cy, ...
701	111	Mass, Cx, Cy, ...
887	111	Mass, Cx, Cy, ...
988	109	Mass, Cx, Cy, ...

Bulk Update

Change Log
1. Update
2. New
3. Deleted

Bulk update values added to mass prop "sheet".

Auto Update – Manual Processing, New and Deleted

Teamcenter

CAD (*NX*) Assembly

Unique CAD ID for each part and subassembly in master assembly

Mass Properties (MP) (new) for each part and subassembly in master assembly (Adv. Weight Management)

Update Script (*Matlab*)

[Unique CAD ID, MP (new)] |?| [Unique CAD ID, MP (old)]

1. **Part Update**
   Unique CAD ID matches existing Unique CAD ID
   New mass prop sent to Change Log (Update), Bulk Update
2. **New Part in CAD**
   Unique CAD ID doesn't match existing Unique CAD ID
   New mass prop sent to Change Log (New)
3. **Deleted Part in CAD**
   Unique CAD ID has no match from CAD
   New mass prop sent to Change Log (Deleted)
4. **New Part in Database**
   Added via database, Unique CAD ID not assigned, no update

Database (*Access*)

Part "Sheet"

Part ID	Unique CAD ID	Name	Asm
101	iPWRtGwHxAY9gC	Top Lvl	N/A
105	iXWRtGwHxAY9gC	Asm A	101
107	ibfRtGwHxAY9gC	Asm B	101
109	ifbRtGwHxAY9gC	Comp D	105
110	ijdRtGwHxAY9gC	Comp E	107
111	ivZRtGwHxAY9gC	Comp F	107

Mass Properties (MP) "Sheet"

MP ID	Part ID	Mass Properties (old)
322	109	Mass, Cx, Cy, …
588	110	Mass, Cx, Cy, …
622	109	Mass, Cx, Cy, …
701	111	Mass, Cx, Cy, …
887	111	Mass, Cx, Cy, …
988	109	Mass, Cx, Cy, …

Change Log

1. Update
2. New – *process manually*
3. Deleted – *process manually*

New and Deleted values processed manually.

Auto Update – Export of New Properties for MP Calc

Teamcenter

CAD (*NX*) Assembly

Update Script (*Matlab*)

Database (*Access*)

Part "Sheet"

Part ID	Unique CAD ID	Name	Asm
101	iPWRtGwHxAY9gC	Top Lvl	N/A
105	iXWRtGwHxAY9gC	Asm A	101
107	ibfRtGwHxAY9gC	Asm B	101
109	ifbRtGwHxAY9gC	Comp D	105
110	ijdRtGwHxAY9gC	Comp E	107
111	ivZRtGwHxAY9gC	Comp F	107

Mass Properties (MP) "Sheet"

MP ID	Part ID	Mass Properties (old)
322	109	Mass, Cx, Cy, ...
588	110	Mass, Cx, Cy, ...
622	109	Mass, Cx, Cy, ...
701	111	Mass, Cx, Cy, ...
887	111	Mass, Cx, Cy, ...
988	109	Mass, Cx, Cy, ...

Export of latest values to mass properties calculation software via SQL query.

Auto Update – Processing

Teamcenter

CAD (*NX*) Assembly

Unique CAD ID for each part and subassembly in master assembly

Mass Properties (MP) (new) for each part and subassembly in master assembly (Adv. Weight Management)

Update Script (*Matlab*)

[Unique CAD ID, MP (new)] |?| [Unique CAD ID, MP (old)]

Database (*Access*)

Part "Sheet"

Part ID	Unique CAD ID	Name	Asm
101	iPWRtGwHxAY9gC	Top Lvl	N/A
105	iXWRtGwHxAY9gC	Asm A	101
107	ibfRtGwHxAY9gC	Asm B	101
109	ifbRtGwHxAY9gC	Comp D	105
110	ijdRtGwHxAY9gC	Comp E	107
111	ivZRtGwHxAY9gC	Comp F	107

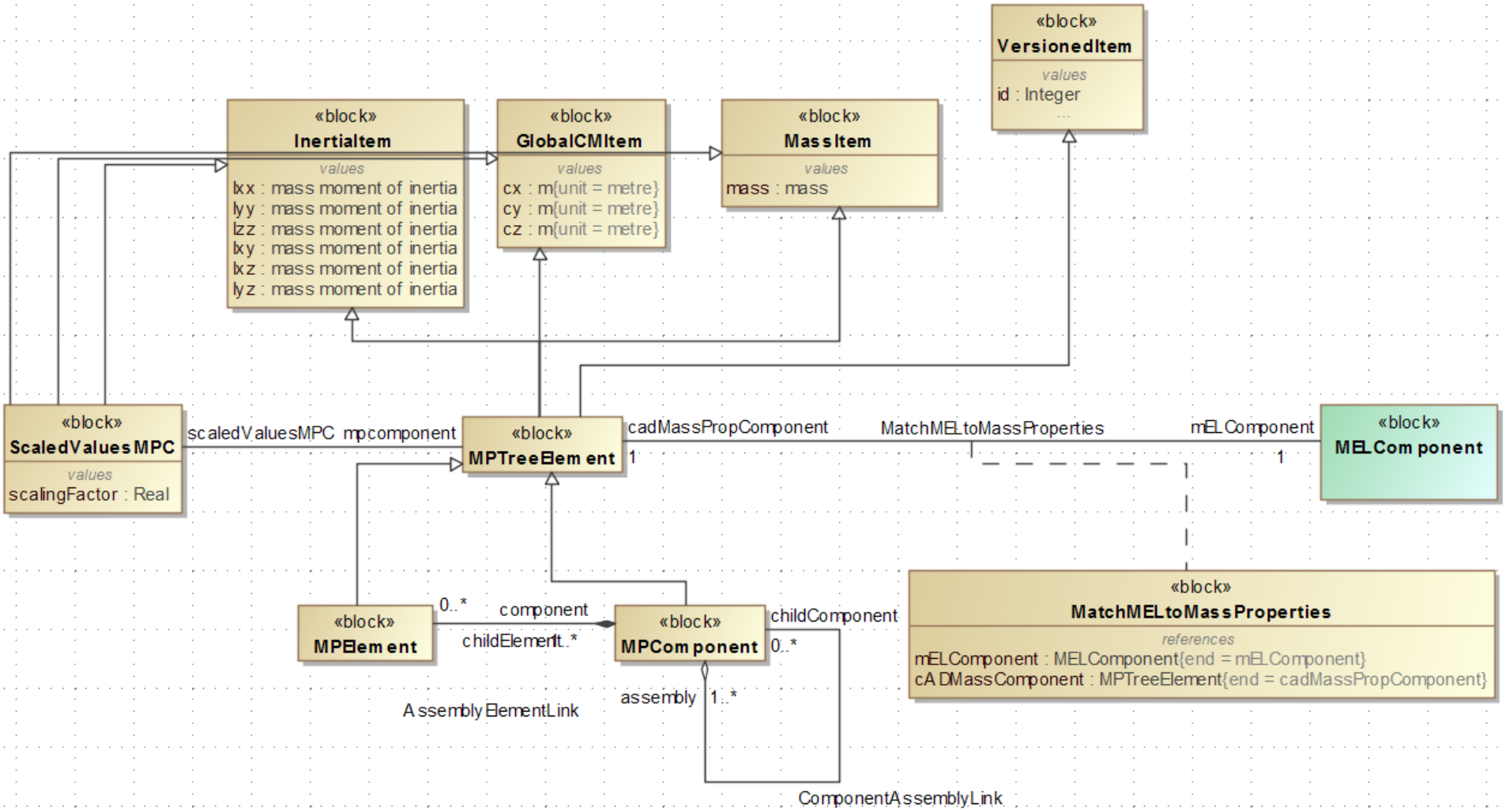
Mass Properties (MP) "Sheet"

MP ID	Part ID	Mass Properties (old)
322	109	Mass, Cx, Cy, …
588	110	Mass, Cx, Cy, …
622	109	Mass, Cx, Cy, …
701	111	Mass, Cx, Cy, …
887	111	Mass, Cx, Cy, …
988	109	Mass, Cx, Cy, …

Repeat process for future updates. All previous decisions regarding part properties persist. Only need to update <u>changes</u> to model.

Mass Properties Representation in SysML

ESD IMCE



Example

- MLH_MMP_CHK_Full_Asm_021115
  - Relations
  - MLH_MMP_CHK_AVIONICS_ASM_021115
  - MLH_MMP_CHK_INSTRUMENT_ASM_021115
    - Relations
    - MLH_MMP_CHK_PANEL_2_021115
      - KNCM4X0.7_0211151 : IMCE_MassProperties::MPElement
        - component = MLH_MMP_CHK_PANEL_2_021115
        - cx = -2.6249999999999996
        - cy = 119.99999999999999
        - cz = 360.0
        - id = "yMQRtAUWxAY9gC"
        - Ixx = 0.00499131019552961 5
        - Ixy = -3.273308780237184E-19
        - Ixz = -2.4132258842238493E-36
        - Iyy = 0.004508428186320358
        - Iyz = 2.843961495817627E-36
        - Izz = 0.0045084281863203585
        - mass = 8.763093718881308E-4
      - KNCM4X0.7_0211152 : IMCE_MassProperties::MPElement
      - KNCM4X0.7_0211153 : IMCE_MassProperties::MPElement
      - KNCM4X0.7_0211154 : IMCE_MassProperties::MPElement
      - KNM5X0.5_0211151 : IMCE_MassProperties::MPElement
      - KNM5X0.5_0211152 : IMCE_MassProperties::MPElement
      - KNM5X0.5_0211153 : IMCE_MassProperties::MPElement
      - KNM5X0.5_0211154 : IMCE_MassProperties::MPElement
      - MLH_MMP_CHK_PANEL_2-101_021115 : IMCE_MassProperties::MPElement
      - MLH_MMP_CHK_PANEL_2_021115 : IMCE_MassProperties::MPComponent
        - assembly = MLH_MMP_CHK_INSTRUMENT_ASM_021115
        - childElement = MLH_MMP_CHK_PANEL_2-101_021115, KNM5X0.5_0211154, KNM5.
        - cx = -6.514835875455663
        - cy = 99.99900519446552
        - cz = 248.84883361368009
        - Ixx = 1278437.30998466
        - Ixy = -10856.647577320256
        - Ixz = -26995.11416637382
        - Iyy = 1101573.9375298934
        - Iyz = 414687.2341125224
        - Izz = 178391.81778179278
        - mass = 3.2606867828737607
        - mELComponent = Panel 2

- MLH_MMP_CHK_Full_Asm_021115 (Order: Chronological)
  - Constraints
  - MLH_MMP_CHK_Inter_Panel_Harness_021115
  - MLH_MMP_CHK_Instrument_Harness_021115
  - MLH_MMP_CHK_Q-36_Asm_021115
    - Constraints
    - NA0069-040014_021115 x 4
    - st12259-040_021115 x 8
    - NA0069-040024_021115 x 4
    - MLH_MMP_CHK_Q-36_Inst_Asm_021115
    - MLH_MMP_CHK_Q-36_CCA_Stow_021115
    - MLH_MMP_CHK_Panel_3_021115
  - MLH_MMP_CHK_Instrument_Asm_021115
    - Constraints
    - NA0069-040016_021115 x 4
    - st12259-040_021115 x 4
    - MLH_MMP_CHK_Basic_Box_021115
    - MLH_MMP_CHK_Panel_2_021115
      - Constraints
      - KNCM4X0.7_021115 x 4
      - KNM5x0.5_021115 x 4
      - MLH_MMP_CHK_Panel_2-101_021115

Demonstration of MBSE Implementation

Requirements

Check against the requirements:

- **This new mass properties data management system must:**
  - **(Automatically) import data from CAD system(s) in both a single component and bulk format to serve as basis of inputs**
  - **Group or split raw CAD data automatically to create desired input hierarchy (project drawing tree, current configuration, etc.)**
  - **Automatically adjust inputs to MEL "official" mass (if desired)**
  - **Automatically perform coordinate transforms**
  - **Override CAD mass properties when needed (electronics boxes, propellant, etc.)**
  - **Catalog and represent non-modeled objects (blankets, etc.)**
  - **Clearly represent the state of the object (e.g. stowed or deployed)**
  - **Define configurations of interest**
  - **Export the mass properties for external calculations**

Work to Go

- User interface needs improvement
  - Managing mass properties through SysML diagram and/or sub menus is not a transparent workflow
- Continue to work with and coordinate mass properties modeling efforts with I-MEL modeling development task
- Import mass properties from CAD directly
- Incorporate unique CAD ID for each part
- Incorporate CAD auto updates

Conclusion

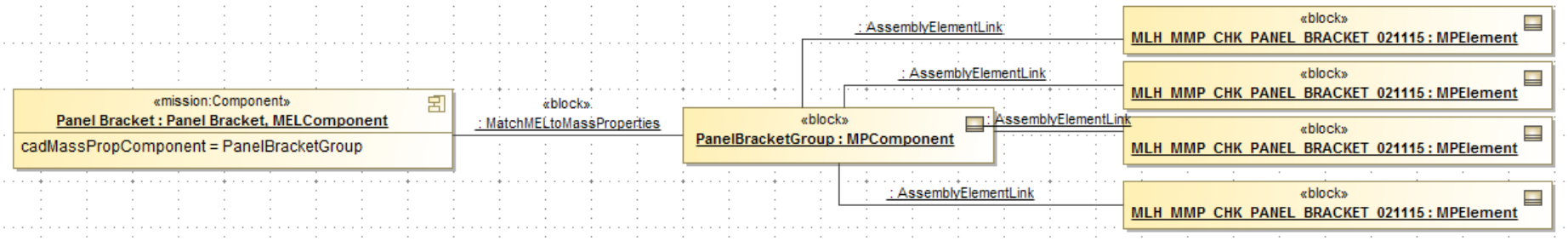
- Clarified roles for MEL and mass properties
- Formalized concepts for mass properties
- Model that can be queried and validated
- Created backbone for mass properties toolset
- Demonstrated the flow of data through system
- Moving to discussions with subject matter experts and mass properties user community

Backup

What are Mass Properties?

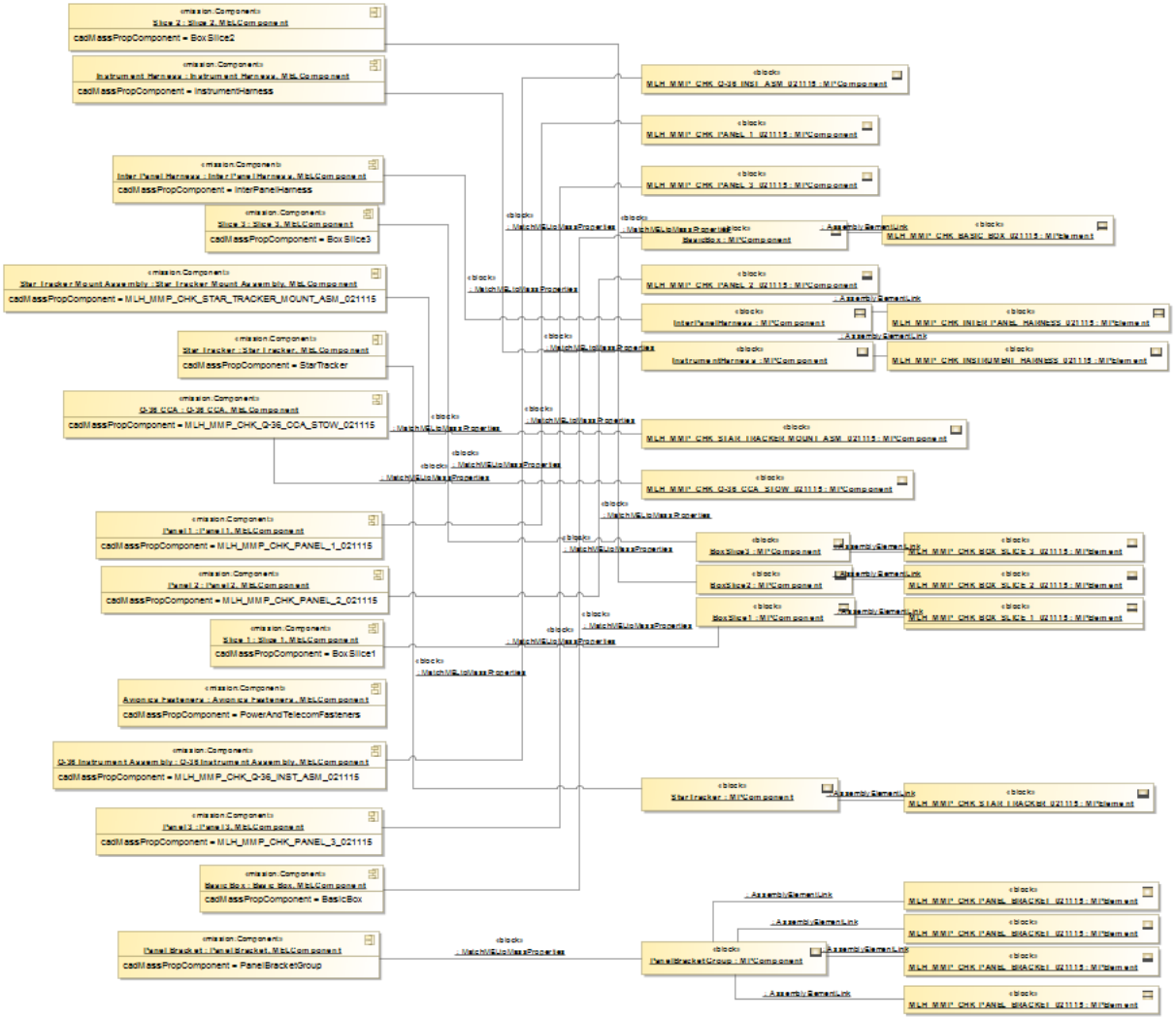
- The mass properties refer to 10 numerical parameters that define the dynamic behavior of an object:
  - Mass
  - Center of mass (x, y, z)
  - Inertia tensor:
    - Moment of Inertia: (Ixx, Iyy, Izz)
    - Product of Inertia: (Ixy, Ixz, Iyz)
- In reality this number is actually over 30, as each parameter has a positive and negative uncertainty applied to it
- An object can be anything: a bolt, a box, or a spacecraft
- Parts aggregate to the whole through 10 equations
- Mass properties are during all project phases to design, handle (lifts, turnovers), test (modal), launch, and fly a spacecraft

Linking Mass Properties and MEL in SysML



- **Currently, parts are linked manually using SysML diagrams**
- **This illustration is a One to Many relationship**
  - **Note that the current iteration supports only One to One links**
  - **A mass properties "sub assembly" is required here**
- **Must ensure that output of linking maintains format desired by mass properties engineer**
  - **Sub assembly block must be a transparent link**
  - **Each Panel Bracket gets ¼ of the mass represented in MEL (or whatever percentage is desired)**

Linking Mass Properties and MEL in SysML



Not the clearest (or safest) way to manage large, shifting assemblies.

User interface work will be critical for flight project adoption and use.

CAD Mass Properties and Unique ID Output

- **NX provides a method to output the estimated mass properties for each individual part file in an assembly**
- **However, notice that there are four different parts of the same exact name with four different mass properties.**

		Center of Mass			Moments of Inertia (Centroidal)			Products of Inertia (Centroidal)		
Component	**Mass**	**Xchar**	**Ychar**	**Zchar**	**Ixx**	**Iyy**	**Izz**	**Pyz**	**Pxz**	**Pxy**
MLH_MMP_CHK_PANEL_BRACKET	0.049164	13.51636	186.4836	486.4836	13.25278	13.25278	13.252778	-1.93229	1.932286	1.932286
MLH_MMP_CHK_PANEL_BRACKET	0.049164	13.51636	13.51636	13.51636	13.25278	13.25278	13.252778	-1.93229	-1.93229	-1.93229
MLH_MMP_CHK_PANEL_BRACKET	0.049164	286.4836	13.51636	486.4836	13.25278	13.25278	13.252778	1.932286	-1.93229	1.932286
MLH_MMP_CHK_PANEL_BRACKET	0.049164	13.51636	13.51636	486.4836	13.25278	13.25278	13.252778	1.932286	1.932286	-1.93229

- **Teamcenter holds unique identification numbers that differentiate each component within an assembly.**

BOM Line	bl_occ_fnd0objectId	Relative Transformation Matrix
MLH_MMP_CHK_Panel_Bracket/A1	SleRtAUWxAY9gC	-1 0 0 0 0 1 0 0 0 0 -1 0 0.3 0 0.5 1
MLH_MMP_CHK_Panel_Bracket/A1	SpURtAUWxAY9gC	1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1
MLH_MMP_CHK_Panel_Bracket/A1	SpaRtAUWxAY9gC	0 1 0 0 1 0 0 0 0 0 -1 0 1.70530256582424e-016 7.105427357601e-018 0.5 1
MLH_MMP_CHK_Panel_Bracket/A1	StWRtAUWxAY9gC	1 0 0 0 0 -1 0 0 0 0 -1 0 0 0.2 0.5 1

- **Unique ID maintained until a part is deleted from an assembly, meaning that once linked to mass properties, <u>it persists</u>**

CAD Mass Properties and Unique ID Linking

- **There is likely a way to export these data products together within Teamcenter / NX**
- **For this study, we put together a simple linking script**

		Center of Mass			Moments of Inertia (Centroidal)			Products of Inertia (Centroidal)		
Component	**Mass**	**Xchar**	**Ychar**	**Zchar**	**Ixx**	**Iyy**	**Izz**	**Pyz**	**Pxz**	**Pxy**
MLH_MMP_CHK_PANEL_BRACKET	0.049164	13.51636	186.4836	486.4836	13.25278	13.25278	13.252778	-1.93229	1.932286	1.932286
MLH_MMP_CHK_PANEL_BRACKET	0.049164	13.51636	13.51636	13.51636	13.25278	13.25278	13.252778	-1.93229	-1.93229	-1.93229
MLH_MMP_CHK_PANEL_BRACKET	0.049164	286.4836	13.51636	486.4836	13.25278	13.25278	13.252778	1.932286	-1.93229	1.932286
MLH_MMP_CHK_PANEL_BRACKET	0.049164	13.51636	13.51636	486.4836	13.25278	13.25278	13.252778	1.932286	1.932286	-1.93229

Step 1: Locates one to one name matches

BOM Line	**bl_occ_fnd0objectId**	**Relative Transformation Matrix**
MLH_MMP_CHK_Panel_Bracket/A1	SleRtAUWxAY9gC	-1 0 0 0 0 1 0 0 0 0 -1 0 0.3 0 0.5 1
MLH_MMP_CHK_Panel_Bracket/A1	SpURtAUWxAY9gC	1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1
MLH_MMP_CHK_Panel_Bracket/A1	SpaRtAUWxAY9gC	0 1 0 0 1 0 0 0 0 0 -1 0 1.70530256582424e-016 7.105427357601e-018 0.5 1
MLH_MMP_CHK_Panel_Bracket/A1	StWRtAUWxAY9gC	1 0 0 0 0 -1 0 0 0 0 -1 0 0 0.2 0.5 1

CAD Mass Properties and Unique ID Linking

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		Center of Mass			Moments of Inertia (Centroidal)			Products of Inertia (Centroidal)		
Component	**Mass**	**Xchar**	**Ychar**	**Zchar**	**Ixx**	**Iyy**	**Izz**	**Pyz**	**Pxz**	**Pxy**
MLH_MMP_CHK_PANEL_BRACKET	0.049164	13.51636	186.4836	486.4836	13.25278	13.25278	13.252778	-1.93229	1.932286	1.932286
MLH_MMP_CHK_PANEL_BRACKET	0.049164	13.51636	13.51636	13.51636	13.25278	13.25278	13.252778	-1.93229	-1.93229	-1.93229
MLH_MMP_CHK_PANEL_BRACKET	0.049164	286.4836	13.51636	486.4836	13.25278	13.25278	13.252778	1.932286	-1.93229	1.932286
MLH_MMP_CHK_PANEL_BRACKET	0.049164	13.51636	13.51636	486.4836	13.25278	13.25278	13.252778	1.932286	1.932286	-1.93229

Step 2: Sorts multiples by X, Y, and Z.
Pairs with closest relative transform matrix.

BOM Line	**bl_occ_fnd0objectId**	**Relative Transformation Matrix**
MLH_MMP_CHK_Panel_Bracket/A1	SleRtAUWxAY9gC	-1 0 0 0 0 1 0 0 0 0 -1 0 0 3 0 0.5 1
MLH_MMP_CHK_Panel_Bracket/A1	SpURtAUWxAY9gC	1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1
MLH_MMP_CHK_Panel_Bracket/A1	SpaRtAUWxAY9gC	0 1 0 0 1 0 0 0 0 0 -1 0 1.70530256582424e-016 7.105427357601e-018 0.5 1
MLH_MMP_CHK_Panel_Bracket/A1	StWRtAUWxAY9gC	1 0 0 0 0 -1 0 0 0 0 -1 0 0 0.2 0.5 1

CAD Mass Properties and Unique ID Linking

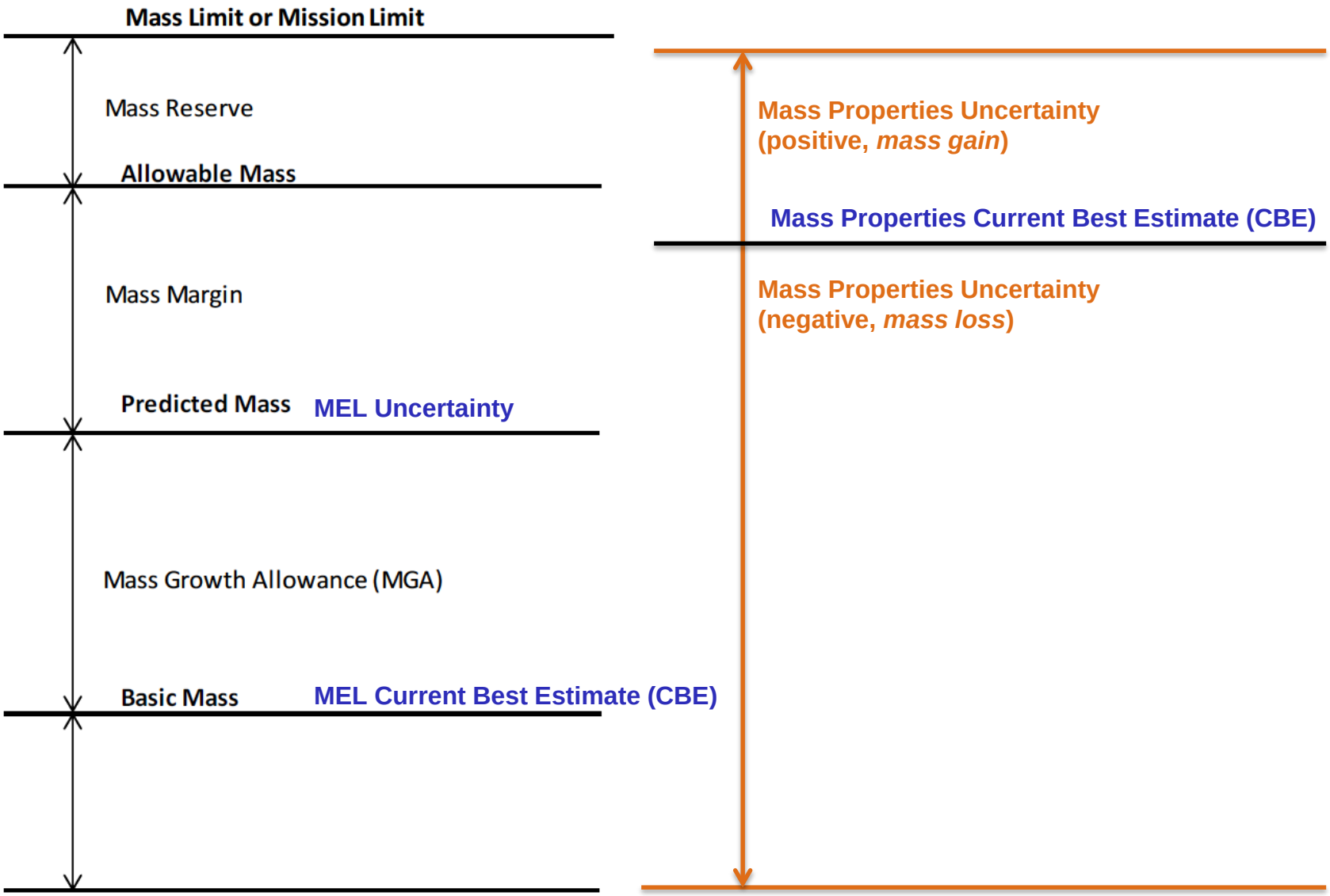
- **There is likely a way to export these data products together within Teamcenter / NX**
- **For this study, we put together a simple linking script**

		Center of Mass			Moments of Inertia (Centroidal)			Products of Inertia (Centroidal)		
Component	**Mass**	**Xchar**	**Ychar**	**Zchar**	**Ixx**	**Iyy**	**Izz**	**Pyz**	**Pxz**	**Pxy**
MLH_MMP_CHK_PANEL_BRACKET	0.049164	13.51636	186.4836	486.4836	13.25278	13.25278	13.252778	-1.93229	1.932286	1.932286
MLH_MMP_CHK_PANEL_BRACKET	0.049164	13.51636	13.51636	13.51636	13.25278	13.25278	13.252778	-1.93229	-1.93229	-1.93229
MLH_MMP_CHK_PANEL_BRACKET	0.049164	286.4836	13.51636	486.4836	13.25278	13.25278	13.252778	1.932286	-1.93229	1.932286
MLH_MMP_CHK_PANEL_BRACKET	0.049164	13.51636	13.51636	486.4836	13.25278	13.25278	13.252778	1.932286	1.932286	-1.93229

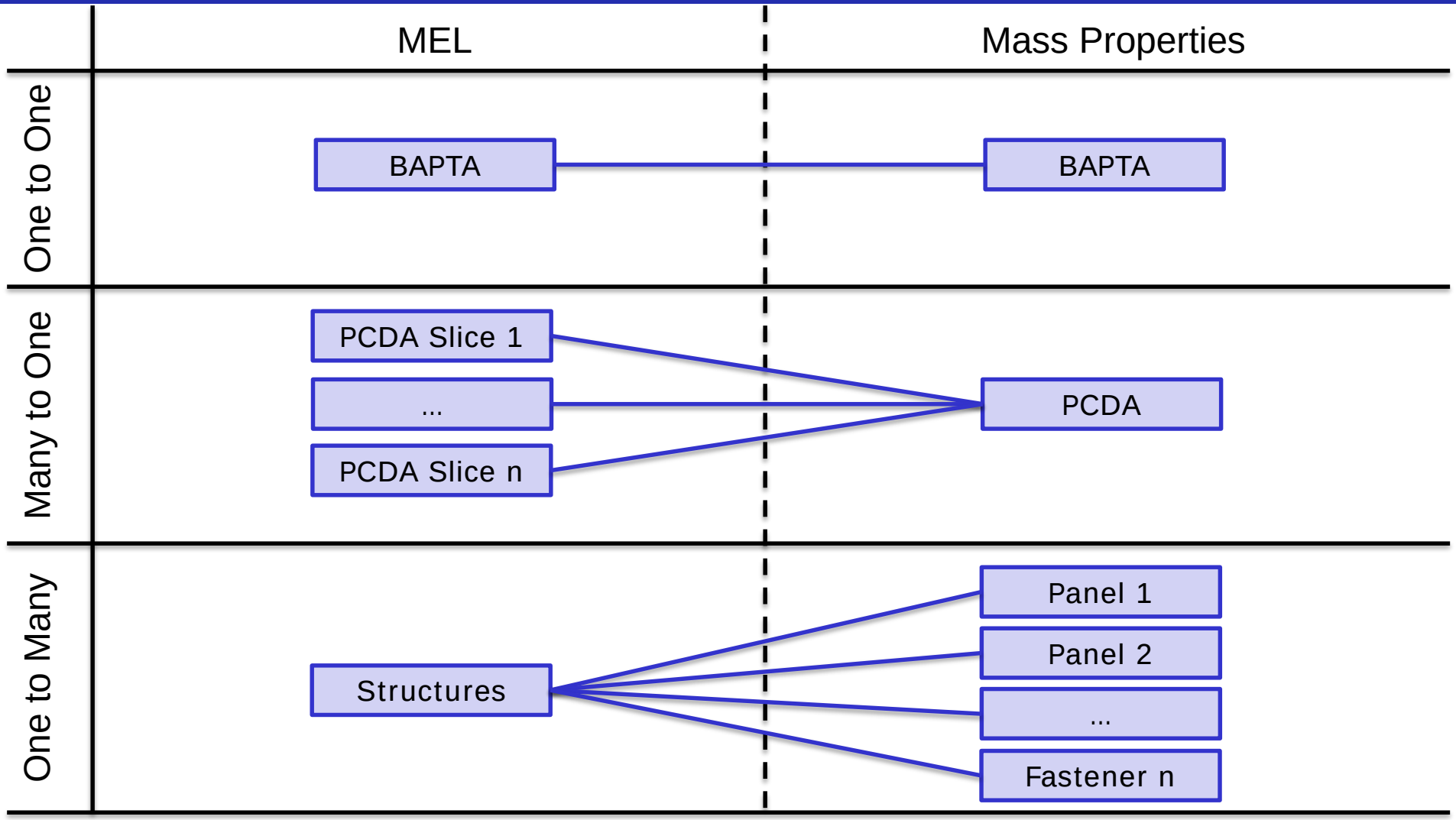
Step 3: Pairs unique ID with appropriate line of mass properties data

BOM Line	**bl_occ_fnd0objectId**	**Relative Transformation Matrix**
MLH_MMP_CHK_Panel_Bracket/A1	SleRtAUWxAY9gC	-1 0 0 0 0 1 0 0 0 0 -1 0 0.3 0 0.5 1
MLH_MMP_CHK_Panel_Bracket/A1	SpURtAUWxAY9gC	1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1
MLH_MMP_CHK_Panel_Bracket/A1	SpaRtAUWxAY9gC	0 1 0 0 1 0 0 0 0 0 -1 0 1.70530256582424e-016 7.105427357601e-018 0.5 1
MLH_MMP_CHK_Panel_Bracket/A1	StWRtAUWxAY9gC	1 0 0 0 0 -1 0 0 0 0 -1 0 0 0.2 0.5 1

Which Official is Official?

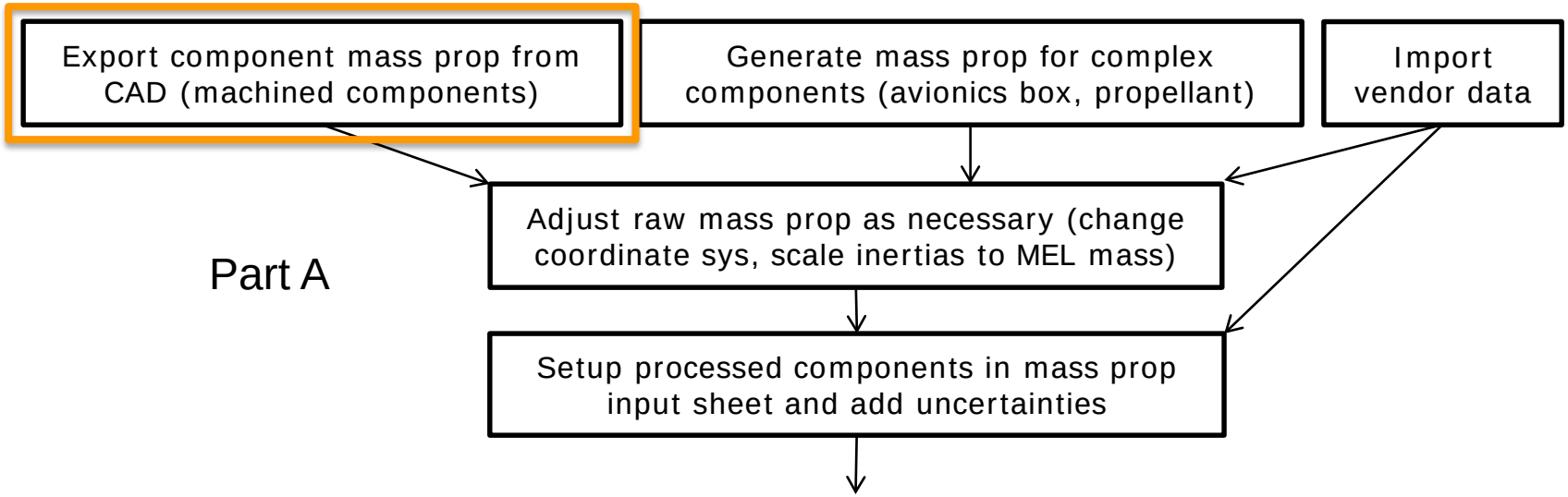


Linking Mass Properties and MEL



Note: “None to One” and “One to None” are also possible

How Do We Increase the Speed of Part A?



- **Cannot increase the speed of face to face interactions?**
  - **Will always need to have discussions to clarify "the black box"**
  - **Vendors will work the way they want to work**
  - **Some part of this will always look the way it has (manual override)**

- **For certain components, could automate transfer of CAD data**
  - **CAD most accurately captures machined metal components**
  - **Fortunately, this is ~75% of what's on a spacecraft!**
  - **If correct density in CAD, mass properties can be used directly**
  - **Currently manual transfer, must be checked quarterly for changes**

Potential of Model Based Systems Engineering

- **Model Based Systems Engineering is not about:**
  - **A unified mother of all models**
  - **Forcing new modeling tools on a project**
  - **Powerful calculation tools or graphical vehicle representations**

- **Model Based Systems Engineering is about:**
  - **Breaking down information silos**
  - **Centralizing information storage**
  - **Pipeline for information distribution**

- **MBSE has the potential to improve the Mass Properties task in several ways:**
  - **Provide single source of truth for component mass**
  - **Streamline / remove last bottleneck in automating data processing**
  - **Automate the generation of regular reports and HRCR paperwork**

- **MBSE is already being used for MEL management on Mars 2020 and Europa Clipper**

- **Since future mass properties engineers will likely have to interface with a MBSE MEL, how can we use MBSE to our advantage?**

What Would This Look Like?

- **Future:**
  - ***(Tabular input sheet for mass properties, uncertainties, and configuration)***
  - **Steady, targeted sync with CAD, Cog-Es, and MEL**

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	1'	2'	3'	4'	5'	6'	7'	8'	9'	10'	11'	12'	13'
2			Mass Properties Inputs										
3	Part Number	Element Name	Mass (kg)	Cx (mm)	Cy (mm)	Cz (mm)	Ixx (kg-mm^2)	Iyy (kg-mm^2)	Izz (kg-mm^2)	Ixy (kg-mm^2)	Ixz (kg-mm^2)	Iyz (kg-mm^2)	
61	10317005-1	BAPTA (stationary) (deployed)	11.3360	-0.0300	-0.1000	2075.0548	321947.0000	321920.0000	53887.0000	-8.0000	69.0000	270.0000	
62	10317005-1	BAPTA (stationary) (stowed)	11.3360	-0.0300	-0.1000	2069.8548	321947.0000	321920.0000	53887.0000	-8.0000	69.0000	270.0000	
63	10317212-2	Bracket Tie Down MLI-6	0.0400	-134.4000	270.1000	1937.2000	188.0000	639.0000	824.0000	303.0000	1.0000	-1.0000	
64	10317212-1	Bracket Tie Down MLI-5	0.0500	-274.3000	-128.3000	1937.8000	748.0000	224.0000	968.0000	-359.0000	0.0000	3.0000	

Sent: Monday, July 06, 2015 7:17 PM
To: Hendry, Morgan L (352M)
Subject: Mass properties updates (7/7/15)

Good Morning!

Yesterday, the following components were added to the CAD system:

BAPTA (stationary) (deployed)
BAPTA (stationary) (stowed)
Bracket Tie Down MLI-5
Bracket Tie Down MLI-6

The following components were deleted from the CAD model:
RDE Harness

This morning, the mass properties for the baseline system are:

Configuration	M (kg)		Cx (m)		Cy (m)		Cz (m)		Ixx (kg-m^2)		Iyy (kg-m^2)		Izz (kg-m^2)		Ixy (kg-m^2)		Ixz (kg-m^2)		Iyz (kg-m^2)	
Spun (unbalanced)	202	+1 -1	0.008	+0.002 -0.002	0.003	+0.002 -0.002	1.110	+0.006 -0.007	663	+3 -2	752	+3 -2	236	+1 -1	-3	+1 -1	-3	+1 -1	-3	+1 -1
Spun (balanced)	202	+1 -1	0.008	+0.002 -0.002	0.005	+0.002 -0.002	1.112	+0.006 -0.007	666	+3 -2	755	+3 -2	237	+1 -1	-3	+1 -1	-3	+1 -1	-1	+1 -1

Configuration	M (kg)		Cx (m)		Cy (m)		Cz (m)		Ixx (kg-m^2)		Iyy (kg-m^2)		Izz (kg-m^2)		Ixy (kg-m^2)		Ixz (kg-m^2)		Iyz (kg-m^2)	
Despun (wet, operational)	744	+6 -7	-0.026	+0.007 -0.006	0.001	+0.006 -0.006	0.838	+0.006 -0.006	346	+9 -8	430	+13 -12	240	+7 -6	2	+1 -1	-11	+3 -3	-2	+3 -3
Despun (wet, launch)	750	+5 -6	-0.026	+0.007 -0.007	0.008	+0.007 -0.006	0.834	+0.006 -0.006	353	+9 -8	365	+12 -12	179	+7 -6	2	+1 -1	-11	+3 -3	-1	+3 -3
Despun (dry, operational)	669	+6 -6	-0.029	+0.005 -0.005	0.001	+0.004 -0.004	0.912	+0.005 -0.005	308	+8 -7	393	+13 -11	239	+7 -6	2	+1 -1	-9	+2 -2	-2	+2 -2
Despun (dry, launch)	669	+5 -6	-0.029	+0.005 -0.005	0.009	+0.005 -0.005	0.913	+0.006 -0.006	314	+9 -8	326	+12 -11	179	+7 -6	2	+1 -1	-9	+2 -2	-1	+2 -2