

MassToGrids

A New Process for Applying Mass to FEMs

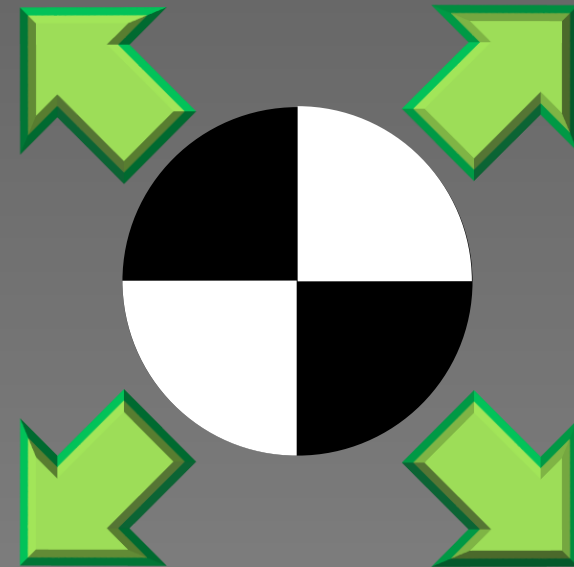
Presented by:

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Mass Properties Group

Gulfstream Aerospace Corporation

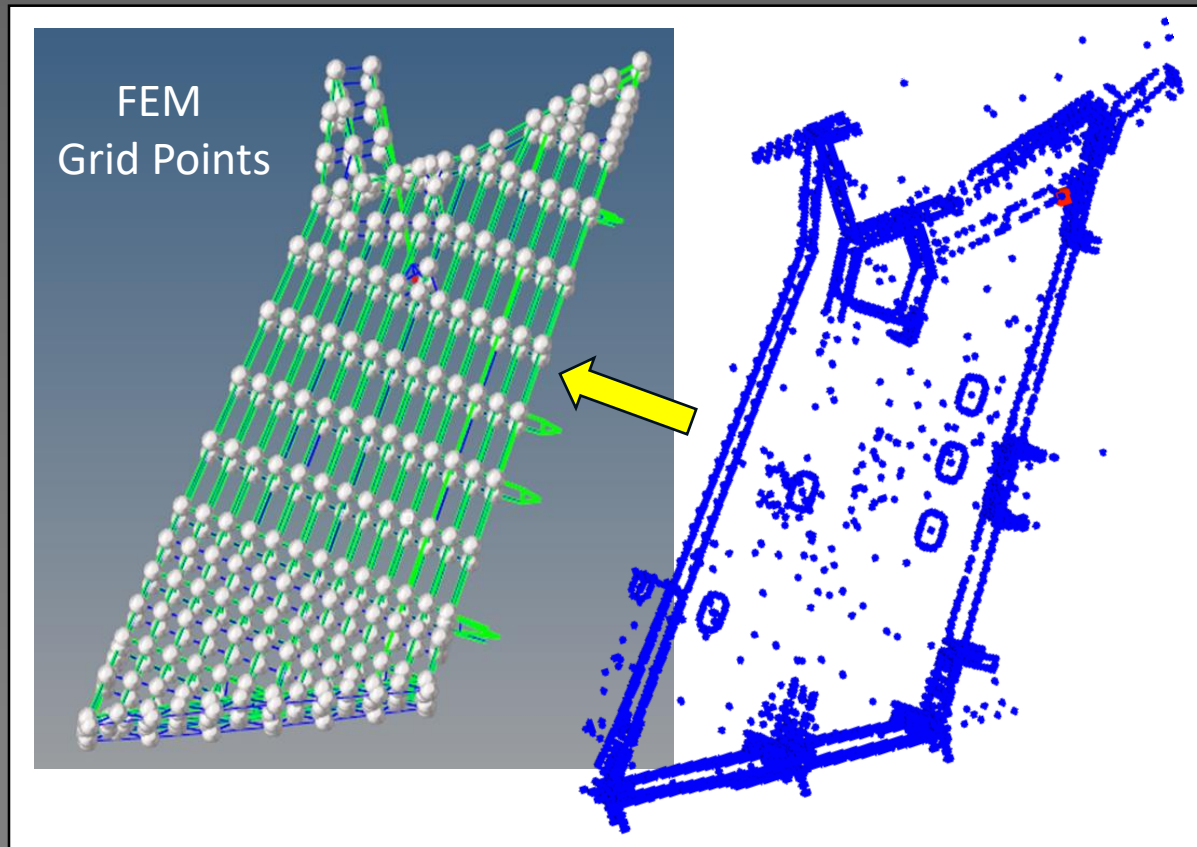
March 18, 2021



BACKGROUND

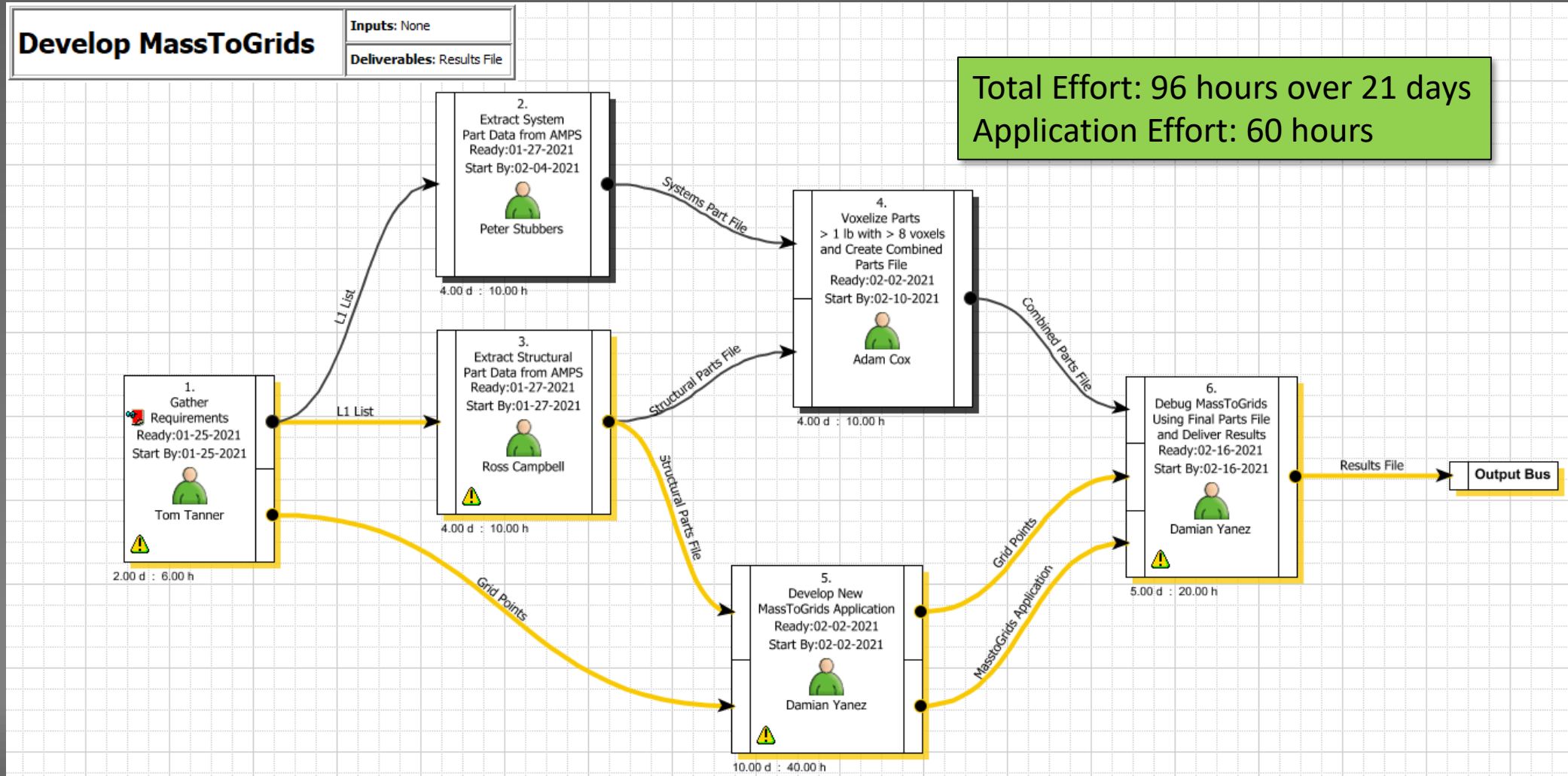
- The Mass Properties Department at Gulfstream developed and maintains an Aircraft Mass Properties System (AMPS) containing the weight and center of gravity (CG) of *millions* of parts for Gulfstream aircraft.
 - AMPS is tied directly to the Engineering product structure in the SmarTeam PLM system for near real-time updates and configuration control.
- Stress and Loads / Dynamics rapidly needed appropriate masses applied to their Finite Element Model (FEM) for an important study.
 - Dynamic and modal analyses of aircraft empennage.
- **Problem:**
 - Number of grid points (~500) much smaller than number of parts (~10,000).
 - Larger parts represented by single CG point with no local inertias.
 - Grid points at different positions than parts in 3D space.
 - Past method was highly simplified with limited accuracy and extremely labor intensive.
 - Time crunch.

THE CHALLENGE

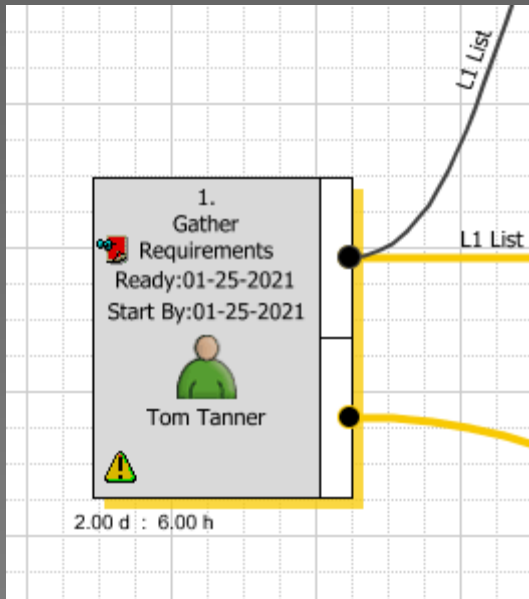


Rapidly distribute thousands of part masses to the FEM grid points while maintaining the overall mass properties

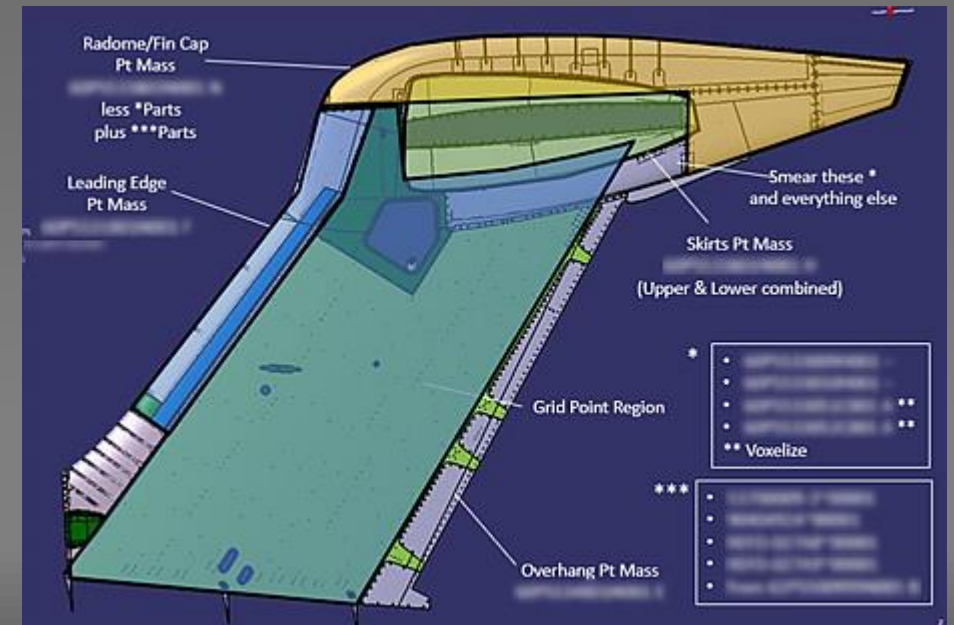
OUR APPROACH – Develop New Process & Tool



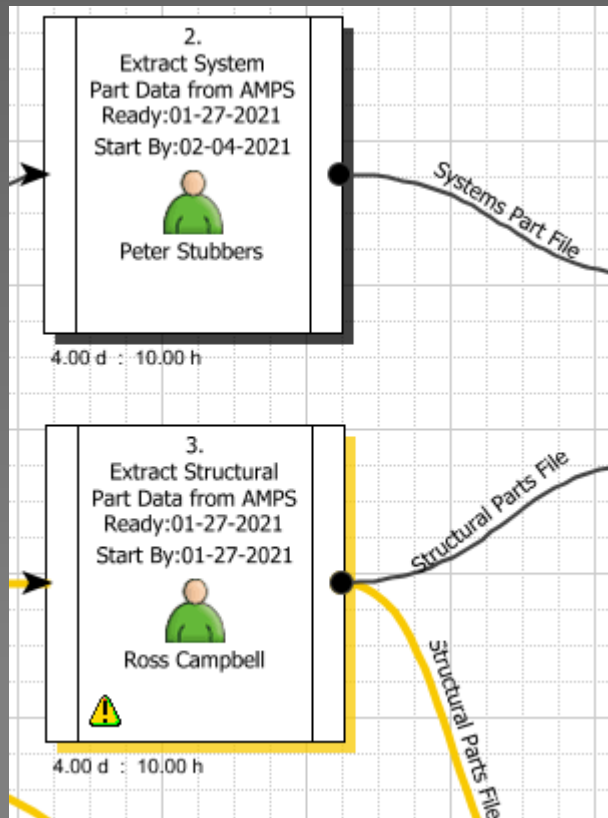
THE SOLUTION – Step 1: Gather Requirements



- Determined the Level 1 (L1) installation drawings to include.
- Obtained the target grid points from our Stress customer.
- Identified large parts and assemblies to be handled as single point masses
- Created this process for producing the desired results.
- Identified requirements for application development.



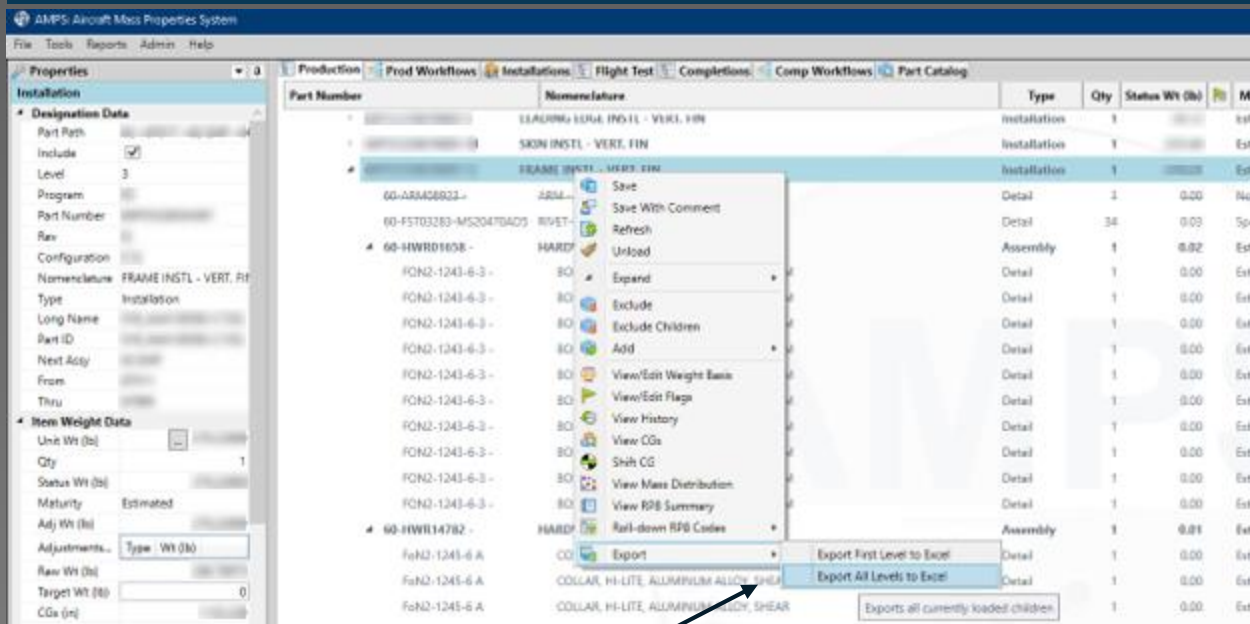
THE SOLUTION – Steps 2 & 3: Extract System & Structural Parts



- Using L1 list, exported required parts from **AMPS** into Excel spreadsheets.
- Removed assemblies from the export, leaving only detail parts.
- Separated point mass parts from parts to be distributed.
- Identified larger parts and calculated local inertias using CATIA.
- Totaled up the mass properties of the details to use as targets.

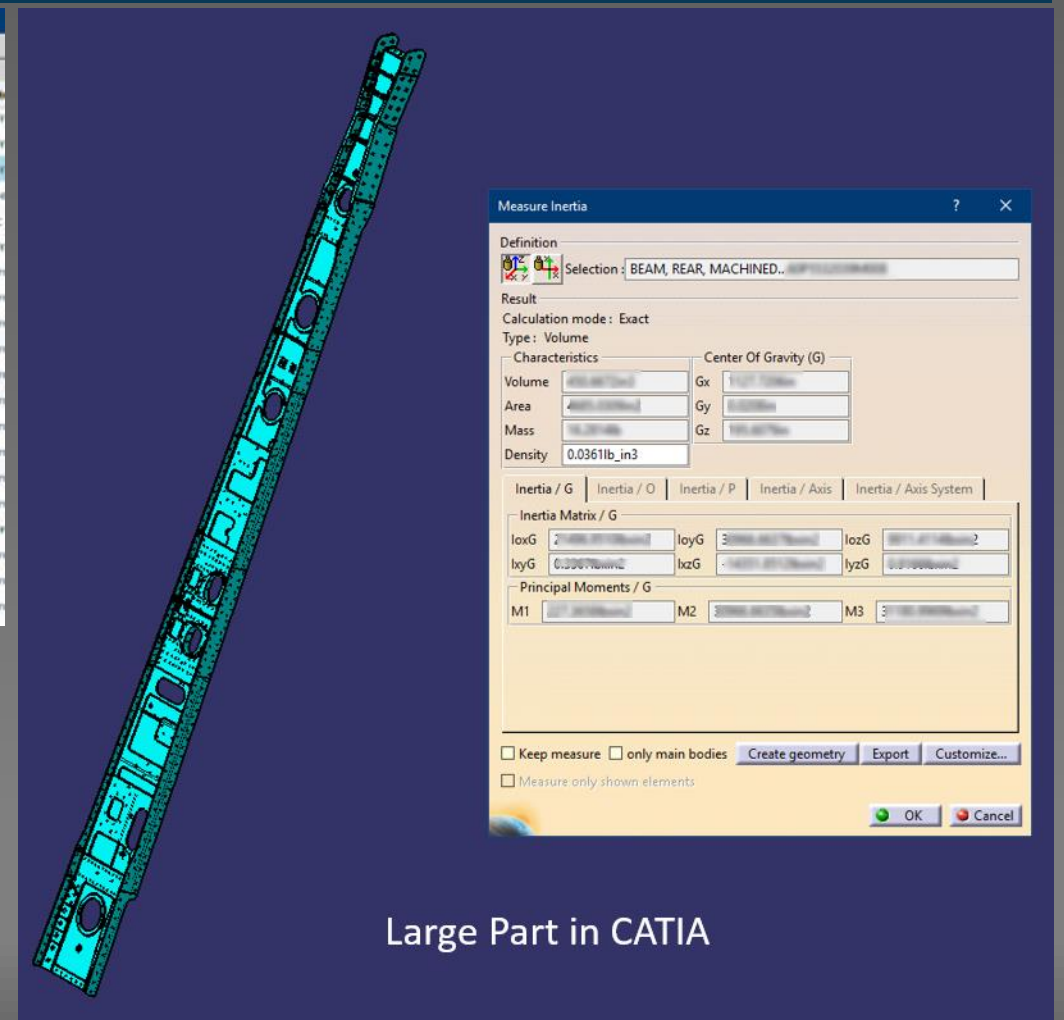


THE SOLUTION – Steps 2 & 3 Details



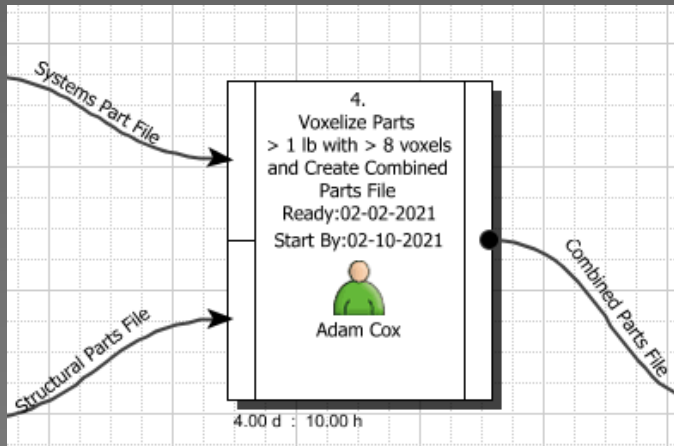
AMPS L1 Export

- Expand each L1 in AMPS and export with right click.
- Add inertias for parts > 1 lb using CATIA (adjust density)

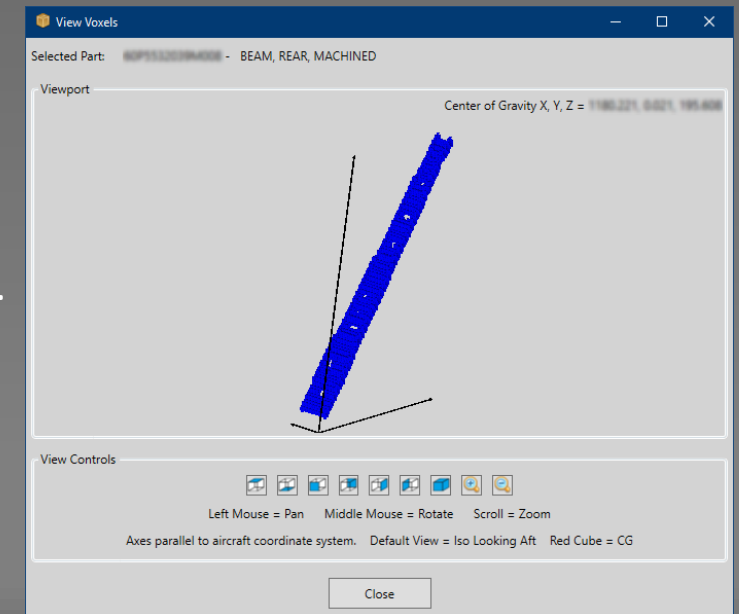


Large Part in CATIA

THE SOLUTION – Step 4: Voxelize Large Parts & Combine

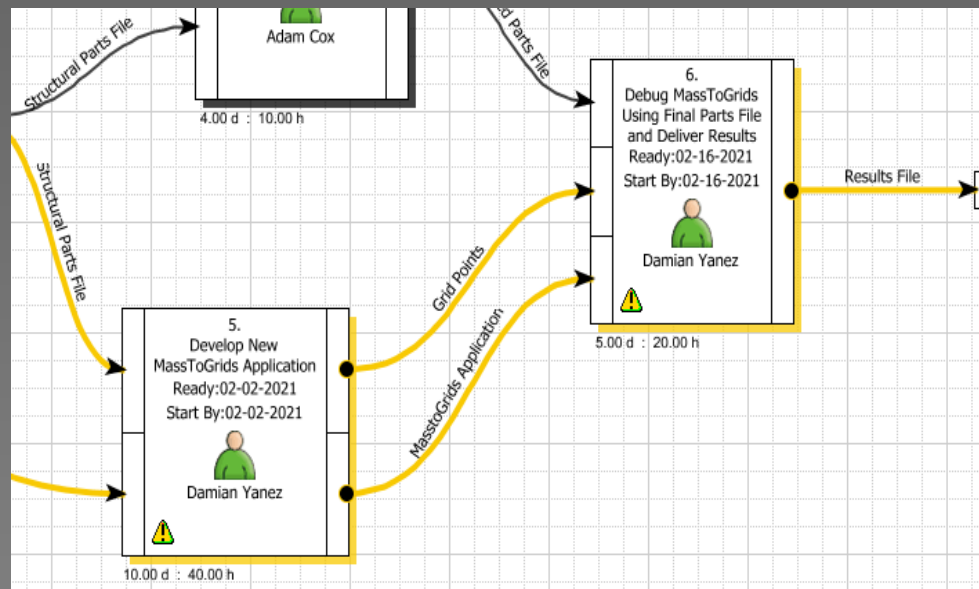


- Combined the system and structural part files into a single spreadsheet.
- Queried PLM tables for detail parts contained in the L1s from the L1 list having > 8 voxels (1" cube per voxel)
 - Resulted in 193,680 records.
 - Each record consists of an instance identifier, part number and the centroid of the voxel.
- “Voxelized” these parts by evenly dividing the weight into separate subparts at the voxel centroids.
 - Improves accounting for local inertias and geometry distribution.
- Replaced the single line parts in the combined spreadsheet with the voxelized parts.
- Delivered the combined parts file for import into the new MassToGrids tool.



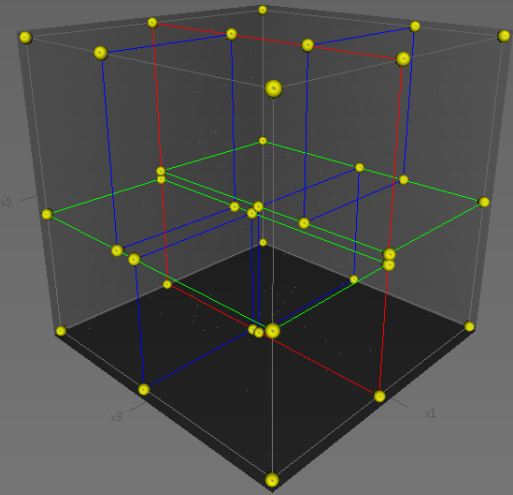
AMPS Voxel Viewer

THE SOLUTION – Steps 5 & 6: Develop MassToGrids Application



- Created new ClickOnce C#/WPF/.Net project using Visual Studio.
 - Base objects for Parts, GridPoints, ...
 - List objects for Parts, GridPoints, Results, ...
- Set up application GUI using XAML with data binding.
 - Input mechanisms for Parts and Grid Points files.
 - Run options, threading, error handling, ...
 - Output tables
 - Export
- Developed distribution algorithm

THE SOLUTION – MassToGrids Distribution Algorithm



- Grid points sorted into 3D K-d tree for quick nearest neighbor search. (Binary space partitioning – Bentley)
- For each part:
 - K-nn search for nearest 4 grid points to part CG.
 - Divide the part weight and distribute to 4 points based on distance to each point (nearest point gets the most weight, furthest gets least).
 - Add part weights to any existing weight at the 4 grid points.

Total MOI (about axis parallel to X axis at total CG) $I_{Oxx_T} =$

Local MOIs (about parallel axis at item CG) $\sum_{i=1}^n I_{Oxx_i}$	+	Transfer Terms (to global reference) $\sum_{i=1}^n m_i (y_i^2 + z_i^2)$	-	Transfer Term (to total CG) $m_T (y_T^2 + z_T^2)$
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Where:

$m_T = \sum_{i=1}^n m_i$	————— Total Mass
$y_T = \frac{\sum_{i=1}^n m_i y_i}{m_T}$	————— Total CG in y direction
$z_T = \frac{\sum_{i=1}^n m_i z_i}{m_T}$	————— Total CG in z direction

Similar for I_{Oyy_T}, I_{Ozz_T}

- Compute total mass properties of all the parts as target.
- Compute total mass properties of all the grid points.
- Compare and adjust the inertias if desired.

THE RESULTS

MassToGrids

Select the file containing part masses to be distributed: ...

Select the file containing the grid points to be used: ...

Force Inertia Match?:

* NOTES: - Part file must include columns labeled 'Include, PartNumber, Revision, Nomenclature, Status Weight, CGx, CGy, CGz, lxx, lyy, lzz, Pxy, Pxz, Pyz'
 - Grid file must include columns labeled 'Node ID, X, Y, Z'
 - Exported files may be found in your 'MassToGrids Exports' directory on your Desktop.

Data Display

Input Masses | Grid Points | Results

Grid ID	Grid Wt	X	Y	Z	lxx	lyy	lzz	Pxy	Pxz	Pyz	
500001	2.3957	1056.250	6.090	140.835	345	1010	641	0	358	17	
500002	3.13504	1056.250	4.050	140.835	452	1322	839	-1	468	23	
500004	3.22065	1056.250	-4.050	140.835	464	1358	862	-1	481	23	
500005	2.65264	1056.250	-6.090	140.835	382	1119	710	0	396	19	
500011	0.45881	1063.430	7.022	139.874	66	193	123	0	68	3	
500013	3.21931	1056.250	2.296	140.835	464	1358	862	-1	481	23	
500015	0.58083	1063.430	-7.022	139.874	84	245	155	0	87	4	
500021	0.52202	1070.640	7.767	138.908	75	220	140	0	78	4	
500022	0.59282	1070.660	6.127	138.934	85	250	159	0	89	4	
500023	3.51555	1056.250	-2.296	140.835	507	1483	941	-1	525	25	
500024	0.44584	1070.660	-6.127	138.934	64	188	119	0	67	3	
500025	0.43142	1070.640	-7.767	138.908	62	182	115	0	64	3	
500031	0.54034	1077.880	8.324	137.938	78	228	145	0	81	4	
500032	0.61323	1077.900	6.784	137.964	88	259	164	0	92	4	
500034	0.46827	1077.900	-6.784	137.964	67	197	125	0	70	3	
500035	0.39346	1077.880	-8.324	137.938	57	166	105	0	59	3	
500041	0.31512	1085.160	8.698	136.963	45	133	84	0	47	2	
500042	0.43665	1085.180	7.158	136.989	63	184	117	0	65	3	
Title	Description	Weight	Xcg	Ycg	Zcg	lxx	lyy	lzz	Pxy	Pxz	Pyz
Total at Grid Points	389 Items	875.2188	1147.175	-0.000	186.132	1804620	3493430	1748510	-2413	1170065	4542
Total of Parts	111450 Items	875.2188	1148.362	-0.000	186.795	1804620	3493430	1748510	-2413	1170065	4542
	Delta	0	-1.186	0.000	0.663	0	0	0	0	0	0

Done.

- 111,450 part items distributed to 450 grid points in 8 seconds.
- Overall weight and inertias matched exactly.
- Xcg within 0.78 in., Ycg within 0.24 in. , Zcg within 0.27 in.



AutoSave G700 Vertical Tail Mass Distribution to Grids Rev A... Yanez, Damian

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M5

	A	B	C	D	E	F	G	H	I	J	K
	Grid ID	Weight	Xcg	Ycg	Zcg	lxx	lyy	lzz	Pxy	Pxz	Pyz
1	500005	2.6526426	1056.25	-6.08973	140.835	382.2405592	1118.676192	710.0231439	-0.4781	396.0304654	15.1062356
6	500011	0.4588092	1063.43	7.02235	139.874	66.11350497	193.4896813	122.8077909	-0.08269	68.49846564	3.30467338
7	500013	3.2193058	1056.25	2.29645	140.835	463.8956036	1357.650189	861.6998038	-0.58023	490.681339	23.1877504
8	500015	0.5808278	1063.43	-7.02235	139.874	83.69613936	244.9475238	155.4680543	-0.10468	86.71560415	4.18353866
9	500021	0.5220233	1070.64	7.76674	138.908	75.22252012	220.1483865	139.7280559	-0.09409	77.93628628	4.2699234
10	500022	0.5928212	1070.66	6.12701	138.934	85.42435795	250.0053779	158.6782714	-0.10685	88.50617085	4.2699234
11	500023	3.5155492	1056.25	-2.29645	140.835	506.5836917	1482.582373	940.99419	-0.63362	524.8594644	25.3215079
12	500024	0.4458385	1070.66	-6.12701	138.934	64.24444459	188.0196355	119.3359559	-0.08036	66.56216008	3.21124868
13	500025	0.431418	1070.64	-7.76674	138.908	62.16648534	181.9382204	115.4760851	-0.07776	64.4092353	3.10788221
14	500031	0.540338	1077.88	8.32413	137.938	77.96163587	227.8729864	144.6302915	-0.09739	80.67051212	3.8919019
15	500032	0.6132345	1077.9	6.7844	137.964	88.36587866	258.6141169	164.1422331	-0.11053	91.55381136	4.41695486
16	500034	0.4682744	1077.9	-6.7844	137.964	67.47740828	197.4813199	125.3412816	-0.0844	69.91175782	3.37284788
17	500035	0.3934554	1077.88	-8.32413	137.938	56.6961411	165.9285539	105.3147589	-0.07091	58.74154012	2.83394859
18	500041	0.315115	1085.16	8.69779	136.963	45.40745368	132.8907573	84.34568818	-0.05679	47.04596204	2.26968459
19	500042	0.4366481	1085.18	7.15806	136.989	62.92012169	184.1438341	116.875987	-0.0787	65.19006023	3.14505261
20	500044	0.5108324	1085.18	-7.15806	136.989	73.60994335	215.428973	136.7326468	-0.09207	76.26553337	3.6793817
21	500045	0.4325247	1085.16	-8.69779	136.963	62.329173	182.4134367	117.7828223	-0.07796	64.57779217	3.11551413
22	500051	0.6577328	1092.47	8.89433	135.984	94.77799286	277.3799943	176.0529249	-0.11855	98.19725228	4.73746623
23	500052	1.0204568	1092.49	7.3546	136.01	147.0458139	430.3484995	273.1419483	-0.18392	152.350714	7.35006239
24	500054	1.0099978	1092.49	-7.3546	136.01	145.5386853	425.9376957	270.3424123	-0.18204	150.7892134	7.2747288
25	500055	0.8497329	1092.47	-8.89433	135.984	122.4446324	358.350561	227.4448976	-0.15315	126.8622149	6.12038612
26	500061	2.8328692	1100.06	8.9211	134.967	408.2108473	1194.681583	758.263722	-0.51058	422.9376709	20.4043564
27	500062	5.526189	1100.06	7.27	134.967	508.1211795	1487.082028	943.850119	-0.63554	526.4524194	25.398359
28	500064	3.4945117	1100.06	-7.27	134.967	503.5523332	1473.710419	935.3631662	-0.62983	521.7186415	25.1699809
29	500065	0.0620134	1100.06	-8.9211	134.967	441.2300823	1291.316624	819.5979276	-0.55188	457.1481247	22.0548178
30	500071	0.3503755	1105.81	8.83077	134.198	50.48841643	147.7608487	93.78372676	-0.06315	52.3098624	2.52365573
31	500072	1.2602027	1105.81	7.18295	134.198	181.5927141	531.4544493	337.3138372	-0.22713	188.1439459	9.07688389
32	500074	1.2296435	1105.81	-7.18295	134.198	177.1891919	518.5669958	329.1341777	-0.22162	183.5815673	8.85677487
33	500075	0.7291244	1105.81	-8.83077	134.198	105.0653865	307.4873758	195.1620628	-0.13141	108.8557792	5.25167719

Distribution to Grids Distribution Results Point M ...

FUTURE OPPORTUNITIES FOR IMPROVEMENT

- Integrate MassToGrids into AMPS.
- Automate most steps.
- Refine CG matching algorithm.
- Allow user to select number of grid points for nearest neighbor search.
- Find a better way to apportion voxel weights.





QUESTIONS?
