A Retrospective Analysis of System Engineering Data Collection Metrics for a 3D Printed UAS Design

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2019 CSER
conference on systems engineering research

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Product Architectures, Design and Manufacturing for Operational Responsiveness

Overarching Goals

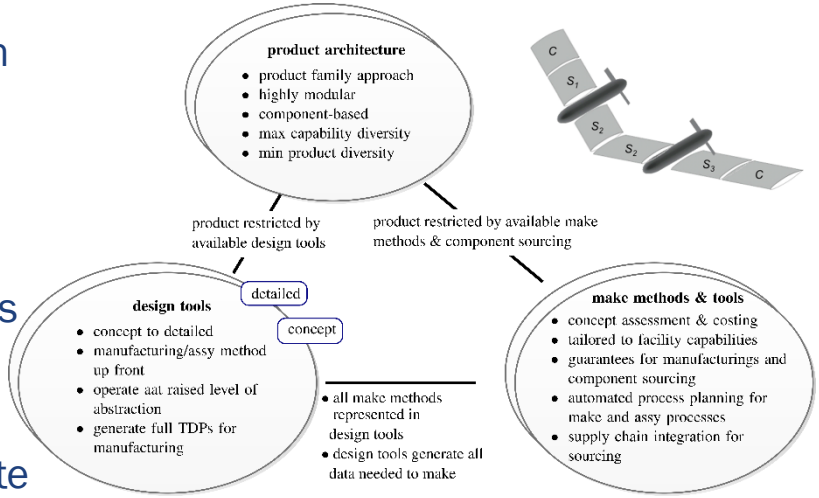
- Demonstrate a *new systems engineering* approach for complex systems
- Develop a new UAS architecture

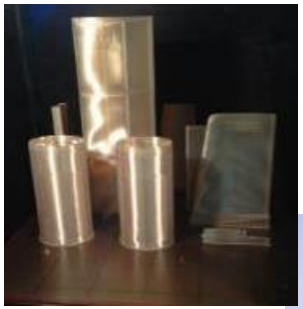
Responsiveness requires specialized…

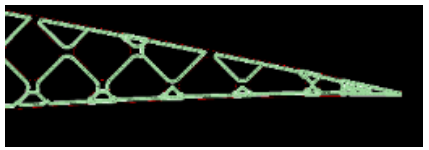
1. Product Architectures: rapidly composable modules
2. Manufacturing Methods: direct from digital, fast, deployable
3. Design Tools: guide, constrain, and assist/automate

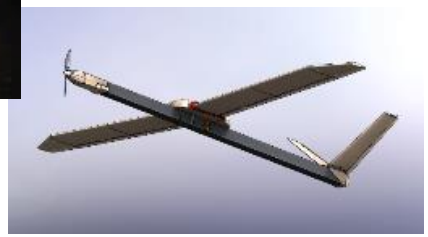
… And critically, synergies between them

- Architecture “fully covered” by manufacturing methods
- Design tools embody all manufacturing constraints
- Design tools tailored to product architecture
- Design tools generate complete data for manufacture







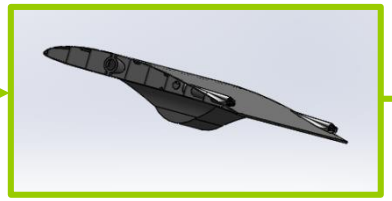


Design process summary for OpRes UAV

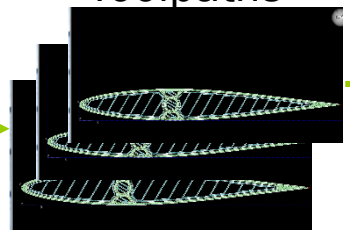
Payload Data
Mission profile
Environment Data

New payload?

Payload Interface DAT



Toolpaths



Manufacture

Custom Sections

Existing payload?

Configurator

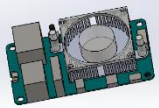
UAV Configuration

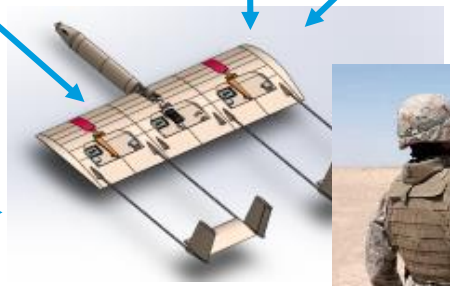
UAV Controls Generation

BOM & Assembly Instructions

Standard Sections

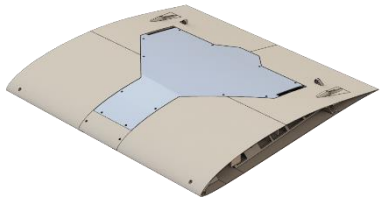
Controller



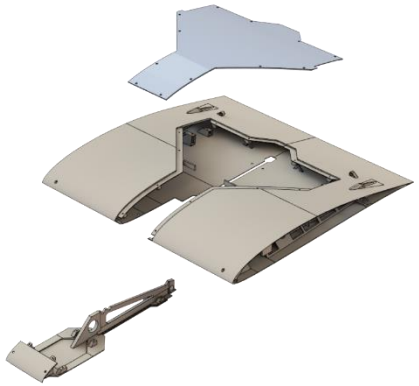


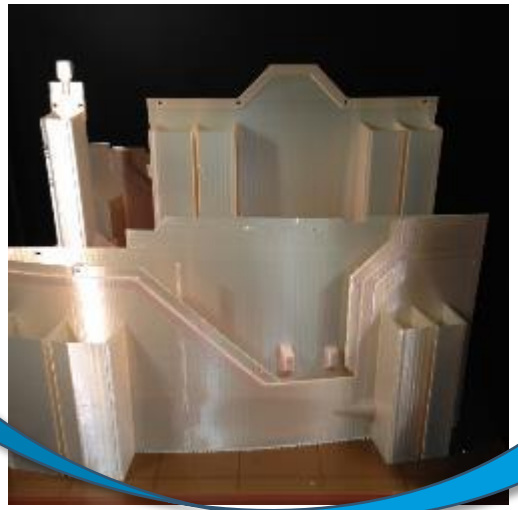
Design build process summary taken in supporting a digital thread

CAD geometry

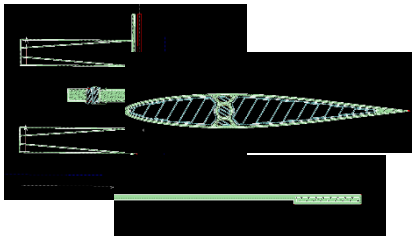


export STL files

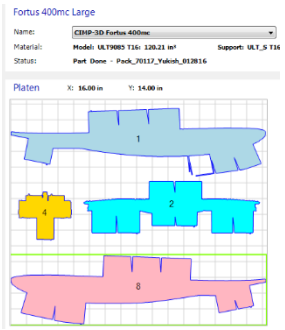




design tool paths
& build parameters

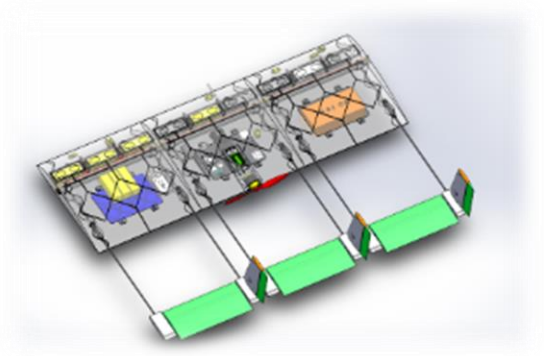


create build sheet

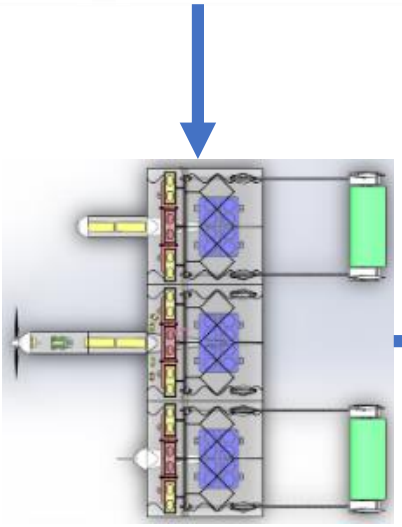


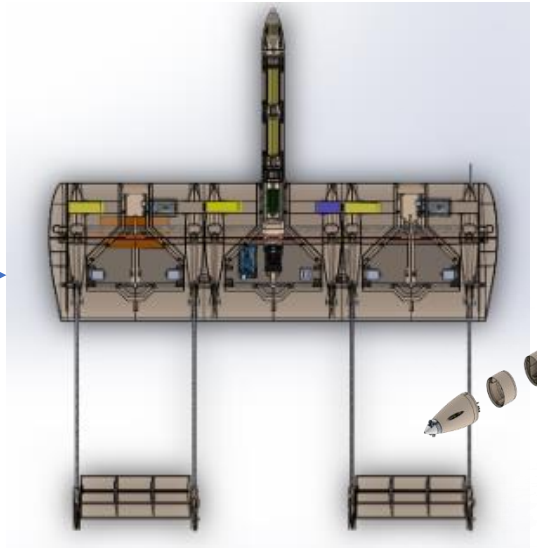
manufacture

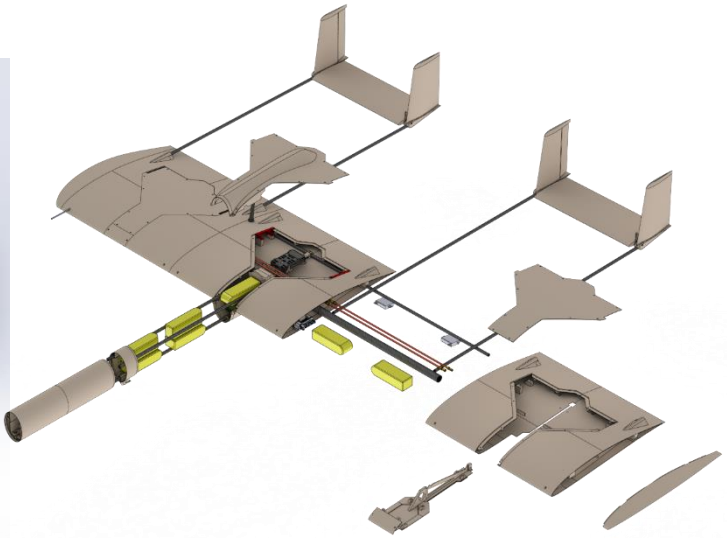
Design evolution for OR1 vehicle



- 200+ parts prototyped in 10 months
- Ability to go from CAD to part in days critical to the design evolution
- A *printed part* is worth a 1000 renders





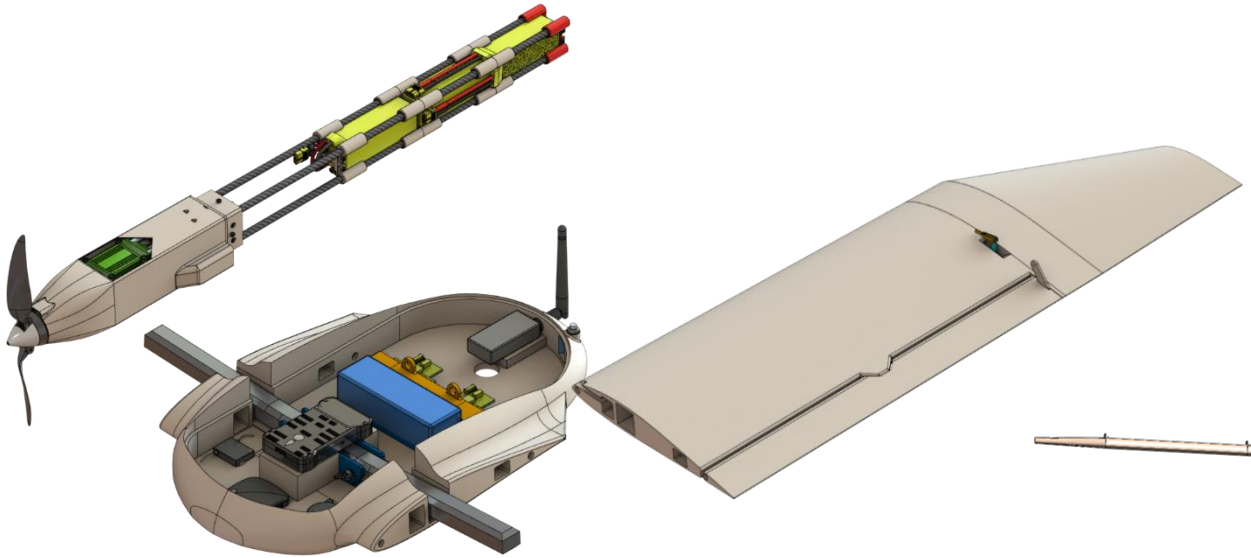


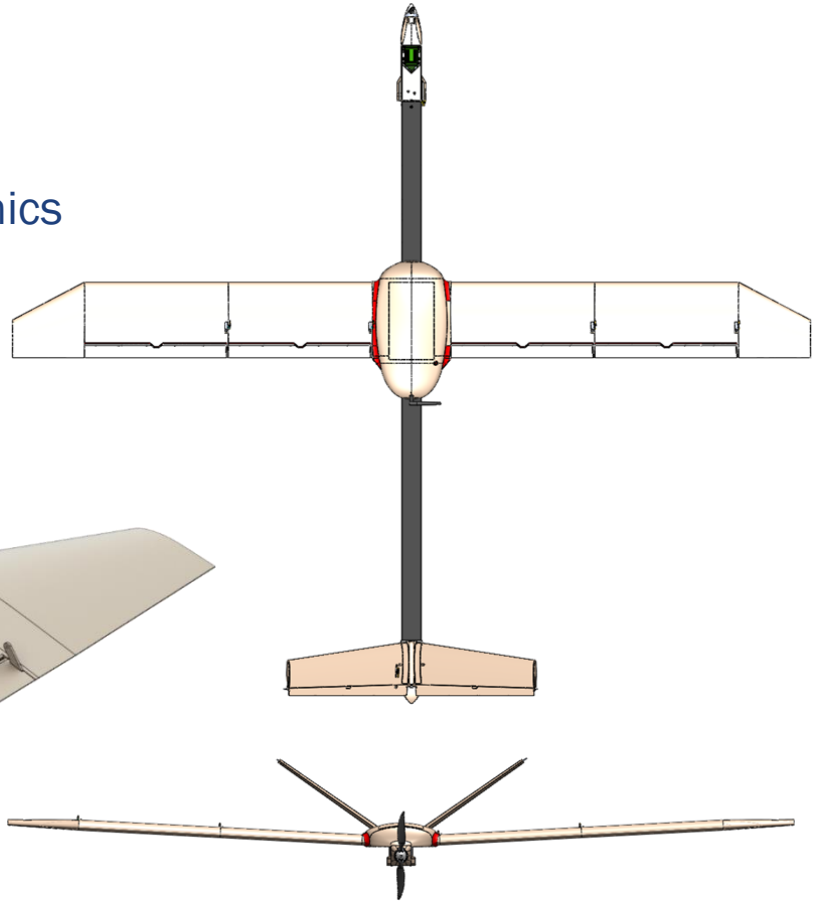
Interoperability through Additive

- A key aspect of operational responsiveness is interoperability
  - Defining the CAD is not enough to build an assembly
  - Many decisions about the final part are made at the slicing stage
- OR1 digital files were sent to various partners, parts were printed and configured on OR1
  - No technical exchange between organizations
- Rapidly configuration of the platform with diverse manufacturing partners increase the responsiveness of the platform

OR2 design evolution

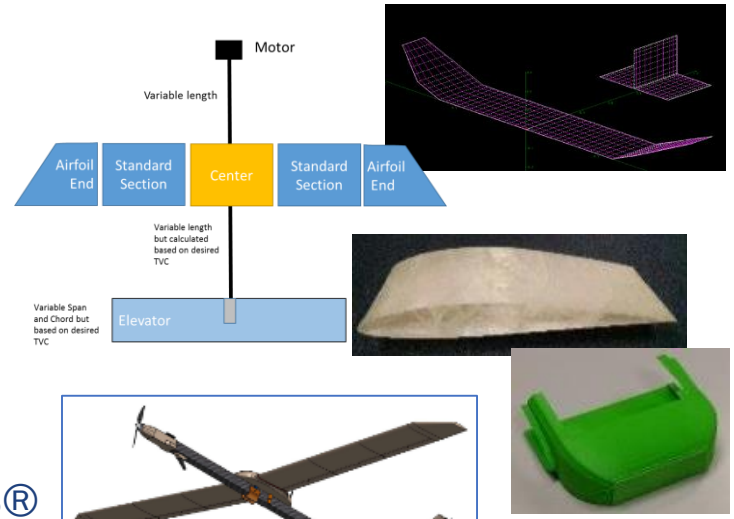
- Started new design from scratch
  - Traditional planform
  - 3D print complex parts
  - Carbon fiber structure and COTS electronics
- Instrumented the design process
  - All times, files, models, effort recorded





Design process tracking of OR2 UAV

- From concept to fly-able UAV in 6 months
  - ~1000 man-hours for 5 people:
    - Conceptual through detailed design
    - Polymer test and final part printing
    - UAV and deployment assets assembly (sabot, camera mounts, controls, etc)
- Main software used:
  - MATLAB®, Excel®, AVL, XFOIL, SOLIDWORKS®
- Polymer Printers used:
  - Stratasys Fortus400mc, Fusion3, Makergear M2, Lulzbot TAZ6



Design review milestones for OR2

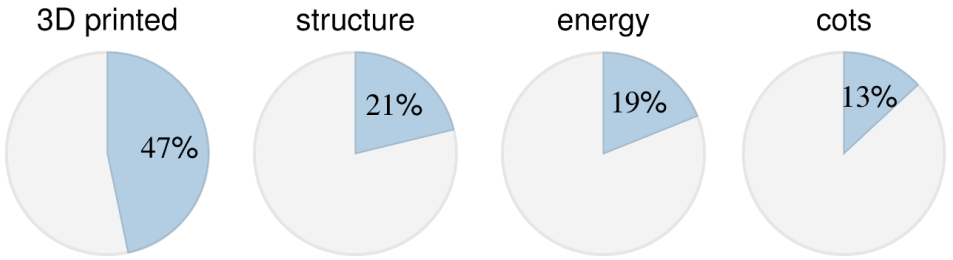
Event	Timeline (week)	Support / Engineering Hours	Description / Outcomes
SRR	0	211 / 371	System Requirements Review (SRR) ensures that system requirements have been completely and properly identified and that a mutual understanding stakeholders exist
PDR	10	132 / 414	Preliminary Design Review (PDR) demonstrates that the preliminary design meets all system requirements with acceptable risk and within the cost and schedule constraints and establishes the basis for proceeding with detailed design
CDR	18	256 / 279	Conceptual Design Review (CDR) demonstrates that the maturity of the design is appropriate to support proceeding with full-scale fabrication, assembly, integration, and test
FRR	28	180 / 430	Flight Readiness Review (FRR) assesses the readiness to initiate and conduct flight tests or flight operations.
Field Event 1	29	—	UAV, launcher, and ground station prepared. Flight canceled due to weather conditions
Field Event 2	30	—	UAV, launcher, and ground station prepared. Launcher failed to produce desired speeds during dry test, flight canceled
Field Event 3	33	—	UAV, launcher, and ground station prepared. Mechanical failure occurred at interface between UAV and launcher. Flight canceled
Field Event 4	34	—	Successful UAV launch and flight. Flight ended with UAV stall, flat spin, harsh landing
Field Event 5	35	—	Successful UAV launch, flight and recovery

OR2 breakdown for cost and mass

Cost Breakdown

Category	Amount	Percent
Small Hardware	$252	2.72%
Power	$256	2.77%
Misc Electronics	$316	3.41%
Camera	$356	3.85%
Carbon fiber	$400	4.33%
Flight controller	$512	5.54%
Ground station	$2,483	26.84%
3D printed	$4,676	50.54%
Total	**$9,251**	**100%**

Mass Breakdown total=6020g



2812g 1277g 1140g 791g

OR2 flight testing @Ag Fields

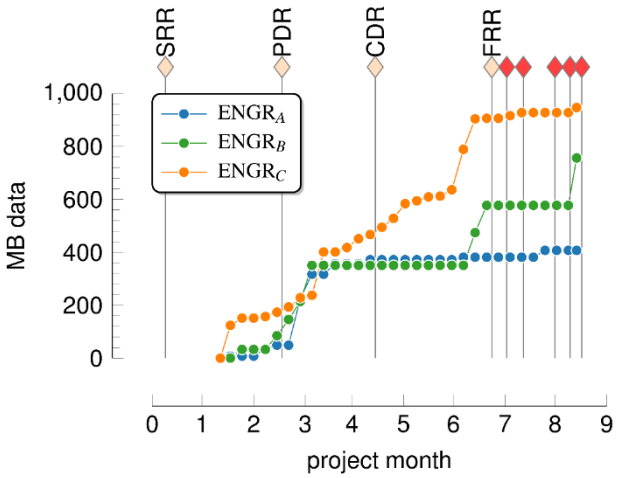
Value of a tightly coupled Product Architectures, Design, and Manufacturing UAV

- Modularity allowed us *reconfigure, redesign, and replace* select components
- 3D printing makes production fast and revisions cheap
- Outboard Ailerons were reflexed to prevent stall off the wing

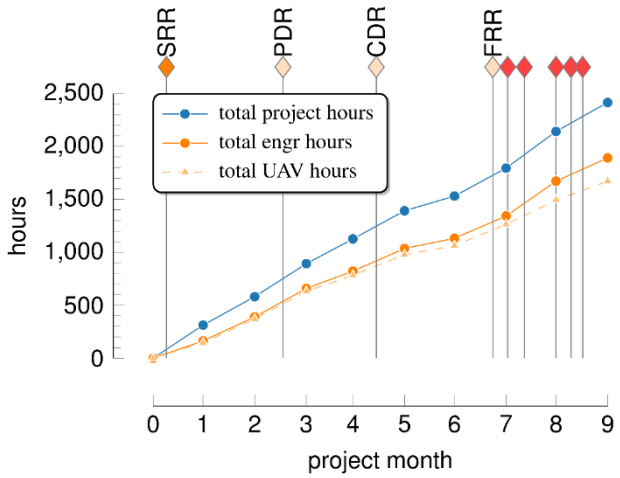
- UAV was fly-able within 1 week

revise, print, fly

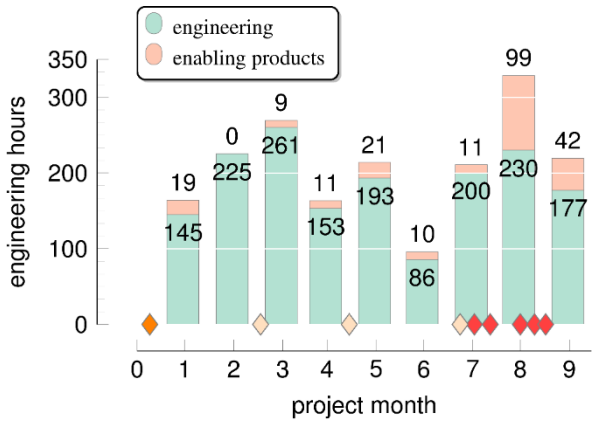
Data captured and time allocated by engineers to the project in fixed date intervals



cumulative digital data generated by engineers (summed weekly)

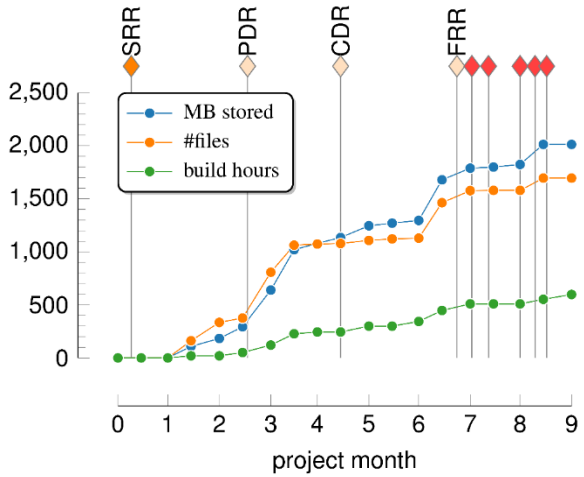


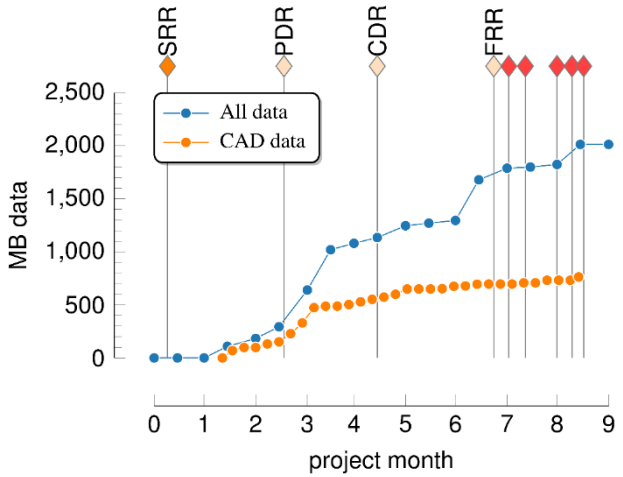
project and tasking hours accumulated per month

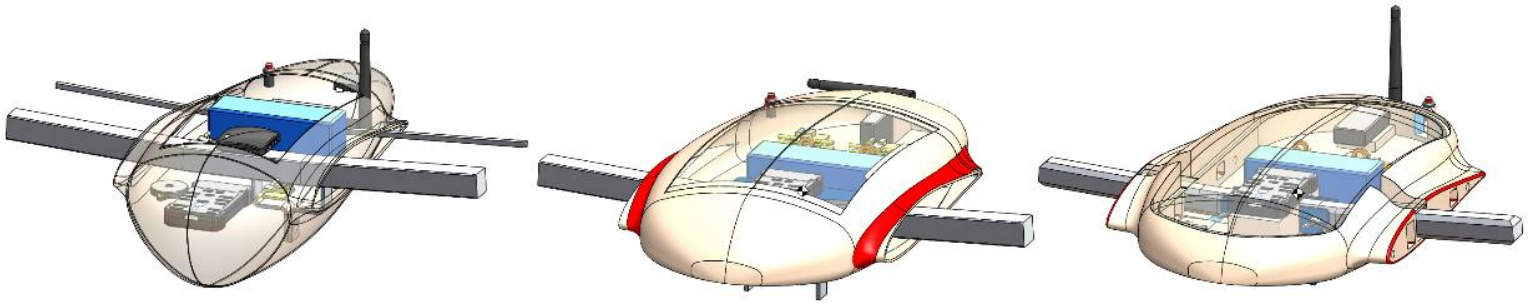


engineering and enabling technology hours at the start of each month

Example data collected time-series showing data types and quantities

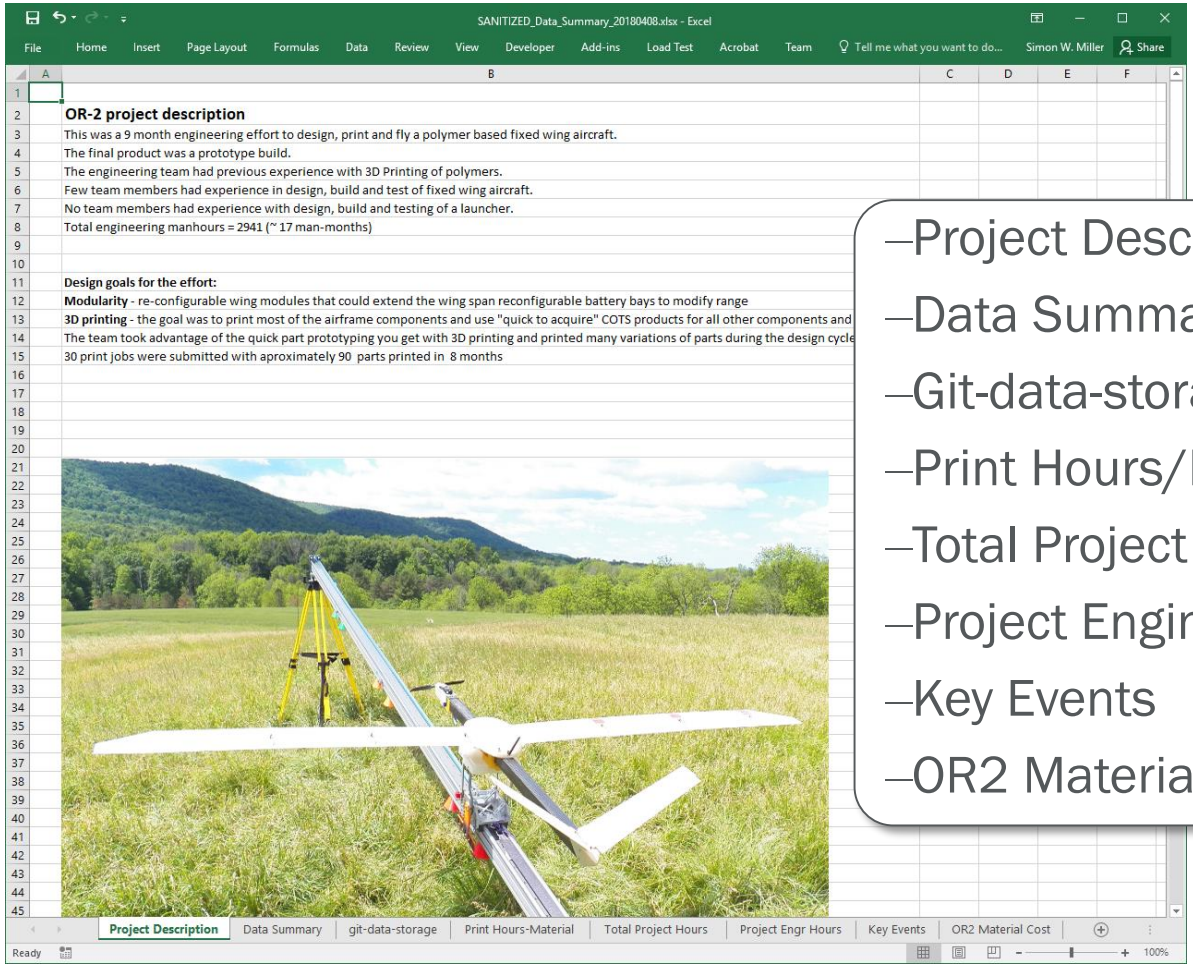






Design evolution of the center section from
(l) PDR, (c) CDR, and (r) FRR

Additional Metadata on OR2 Program



- Project Description
- Data Summary
- Git-data-storage
- Print Hours/Material
- Total Project Hours
- Project Engineering Hours
- Key Events
- OR2 Material Cost