Korea-Japan Joint Workshop on Rotorcraft 2023

KARI MDAO System Development Plan and Status for the Hybrid eVTOL Aircraft Design

February 10, 2023

Seung-Kil Paek

Korea Aerospace Research Institute

Background

- **Interests in UAM(Urban Air Mobility) or AAM(Advanced Air Mobility) is in full swing.**
  - The Vertical Flight Society (US) counts almost 700 entrants in the AAM industry with new ones added on a weekly basis

- **KARI(Korea Aerospace Research Institute) should provide the Korean industry with the core technology for those types of aircrafts as a Korean government funded research institute since 1989.**
  - Developing also an eVTOL aircraft a.k.a. OPPAV[1]
  - Developing MDAO[2] technology on eVTOL aircraft through an internal project since 2019.
    - Started a new five-year-long internal project to develop a MDAO system.

[1]OPPAV : Optionally Piloted Personal Air Vehicle, 2019 ~ 2023
[2]MDAO : Multi-disciplinary analyses and optimization

Previous Researches

- **There have been various MDAO Frameworks, related software and digital contents:**
  - CEASIOM(CEASIOMpy), pyMDO, OpenMDAO, 3DOPT, MDOPT, CPACS, RCE, and etc.

- **DLR (Germany) started the development of the aircraft design environment from 2005.**

- **DLR created the open-sourced CPACS as a common namespace.**
  - a standard for exchanging aircraft design information among aviation-related institutions of DLR.

- **DLR developed the open-sourced RCE as a process integration framework**
  - It supports collaborative and distributed work.

Previous Researches

- **A collaborative MDAO system**
  - the design tools implemented by each discipline specialist are operated in independent software environments
  - their outputs are shared by design tools in other fields

- **DLR has been conducting collaborative optimization design research in a distributed environment early on.**

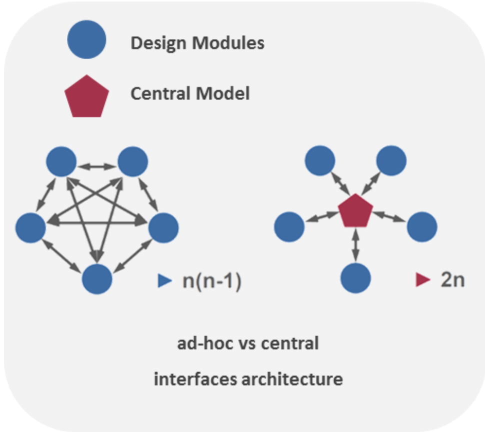
- **In the AGILE project,**
  - AGILE : Aircraft 3rd Generation MDO for Innovative Collaboration of Heterogeneous Teams of Experts
    - from 2015 to 2018, part of the Horizon 2020 program.
  - DLR has reached the level of designing an aircraft by implementing interworking between processes distributed across three continents, 19 institutions, and heterogeneous platforms

KARI MDAO System Development Plan

- **Software structure**
  - Collaborative software structure will be used:
  - The independent analysis method established by using the most familiar software tools such as Excel, script, commercial S/W, and in-house software, in the most appropriate operating environment by each discipline expert will be combined as a process.
  - The concept of establishing a process is not to create a new tool, but to transform an existing tool into a form that can be shared as much as possible on the network
  - In Korea, optimal design researches under such a collaborative system have hardly been conducted.
    - Hence this research will be a big challenge.

KARI MDAO System Development Plan

- **Central Data Model**
  - Central data model will be used to minimize the interfaces.
  - Communication between different disciplines is achieved through design parameters.
  - In KARI, these design variables were independently defined and there was no common parameter pool until now.
  - In this project, CPACS[1] is used to control design variables in all disciplines as much as possible
  - Using CPACS, is like forcing people with different mother tongues to use only one foreign language!
    - Big challenge
  - CPACS is mainly used for conventional fixed wing aircrafts with jet fan engines until now.
    - It needs much enhancements so that it can be used for UAM aircraft design

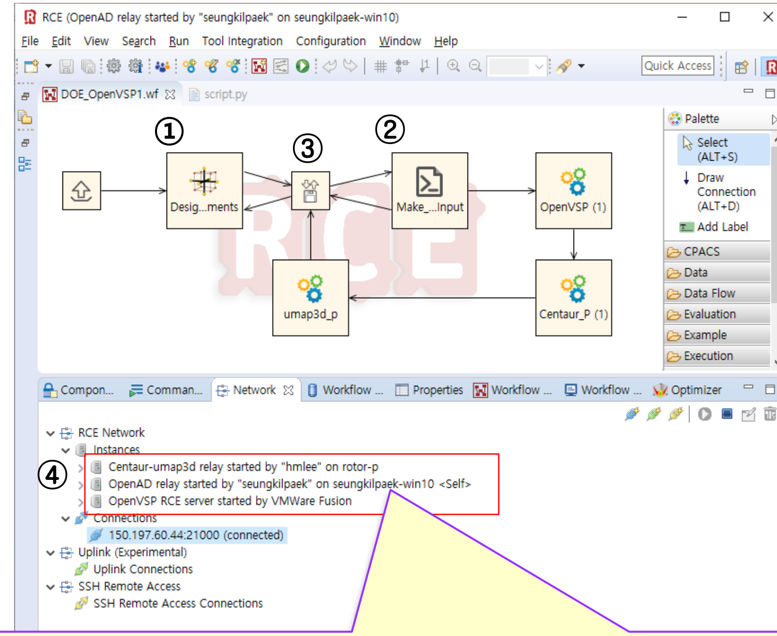


Courtesy of https://github.com/DLR-SL/CPACS

[1]CPACS : Common Parametric Aircraft Configuration Schema. A data definition for the air transportation system. Opensource digital content hosted in github.

KARI MDAO System Development Plan

- **Process Integration**
  - KARI had used ModelCenter® for the process integration
    - Kang, H.-J. "Design optimization of QTP-UAV prop-rotor blade using ModelCenter®". *Journal of Aerospace System Engineering*, Vol. 11, No. 4, pp. 36—43, 2017.
  - Recently, RCE, an open-source replacement have been tested instead.
  - The user experience with RCE was satisfactory.
  - RCE will be used for this project.



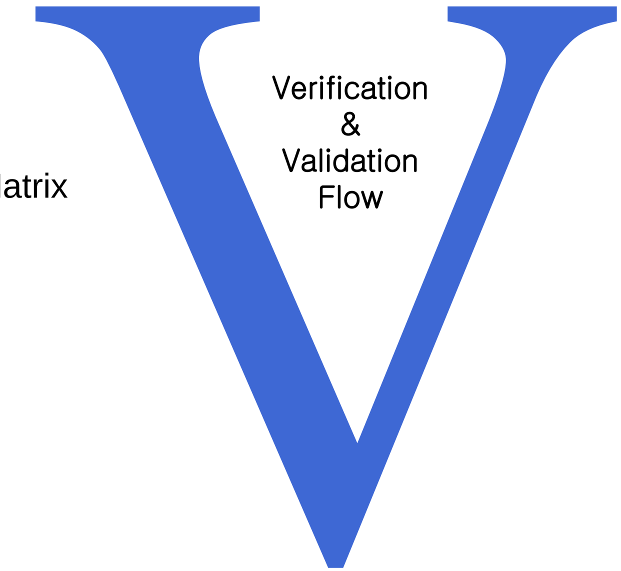
Three engineering tools was integrated:

- an aircraft geometry creating tool using OpenVSP and Rhino®
- a commercial mesh generation tool CENTAUR®
- an inhouse CFD solver to make geometry design study

KARI MDAO System Development Plan

- **2022 : MDO System Requirements & System Architecture Design**
  - Define the requirements for the MDAO system
  - Define the tool list to be integrated in the MDAO system
  - Define the interface using the central data model.
  - Define the workflow of the MDAO system as XDSM[1] format
- **2023 :**
  - Verification of System Architecture
  - Development of tools and discipline workflows
- **2024 : Verification of each discipline workflow**
- **2025 : Verification of the integrated workflow**
- **2026 : Verification of the optimal design capability**

[1]XDSM : Extended Design Structure Matrix



- **Based on system engineering methodology for software development.**
  - Project management with Redmine software
  - Configuration control with Git software

Concept Design Study from 2022 to 2023

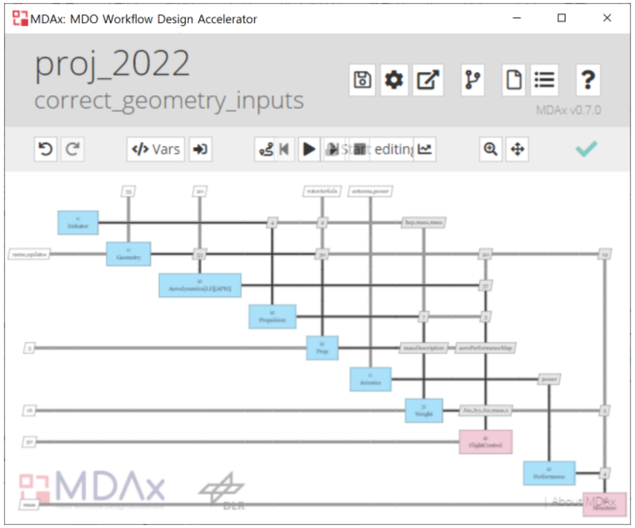
- **KARI is making a concept design of a 6 seated UAM aircraft:**
  - Define the top-level requirement and analysis standard
    - the follow-up study of the OPPAV aircraft
  - Decide the design variables, analysis cases, and major performance objectives
  - Establish an optimal design problem
  - Create a concept design.

Preliminary Design Study from 2024 to 2026

- **2024 :**
  - Build a surrogate model for each discipline workflow
  - The collected surrogate models are integrated into the total workflow.
  - The work will be used for optimal design study
  - The optimal design will be reviewed.
- **2025 :**
  - The discipline workflows will be integrated altogether.
  - DOE using the integrated workflow will be made.
  - Optimal solution using DOE results
- **2026**
  - Direct optimization with the integrated workflow

MDAO System Design Tool

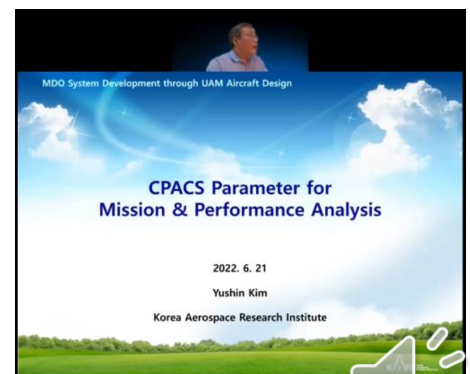
- **For the design of the MDAO system, such as the input/output definition of each component and the workflow design combining each component, tools are needed:**
  - KADMOS
    - An open source python package based on the data schema called CMDOWS
    - Little documentation and not easy to start
  - MDAx : MDO Workflow Design Accelerator
    - A web-based GUI application by DLR
    - An easy-to-use substitute of KADMOS
    - more promising than KADMOS.



KARI-DLR Collaboration for System Design

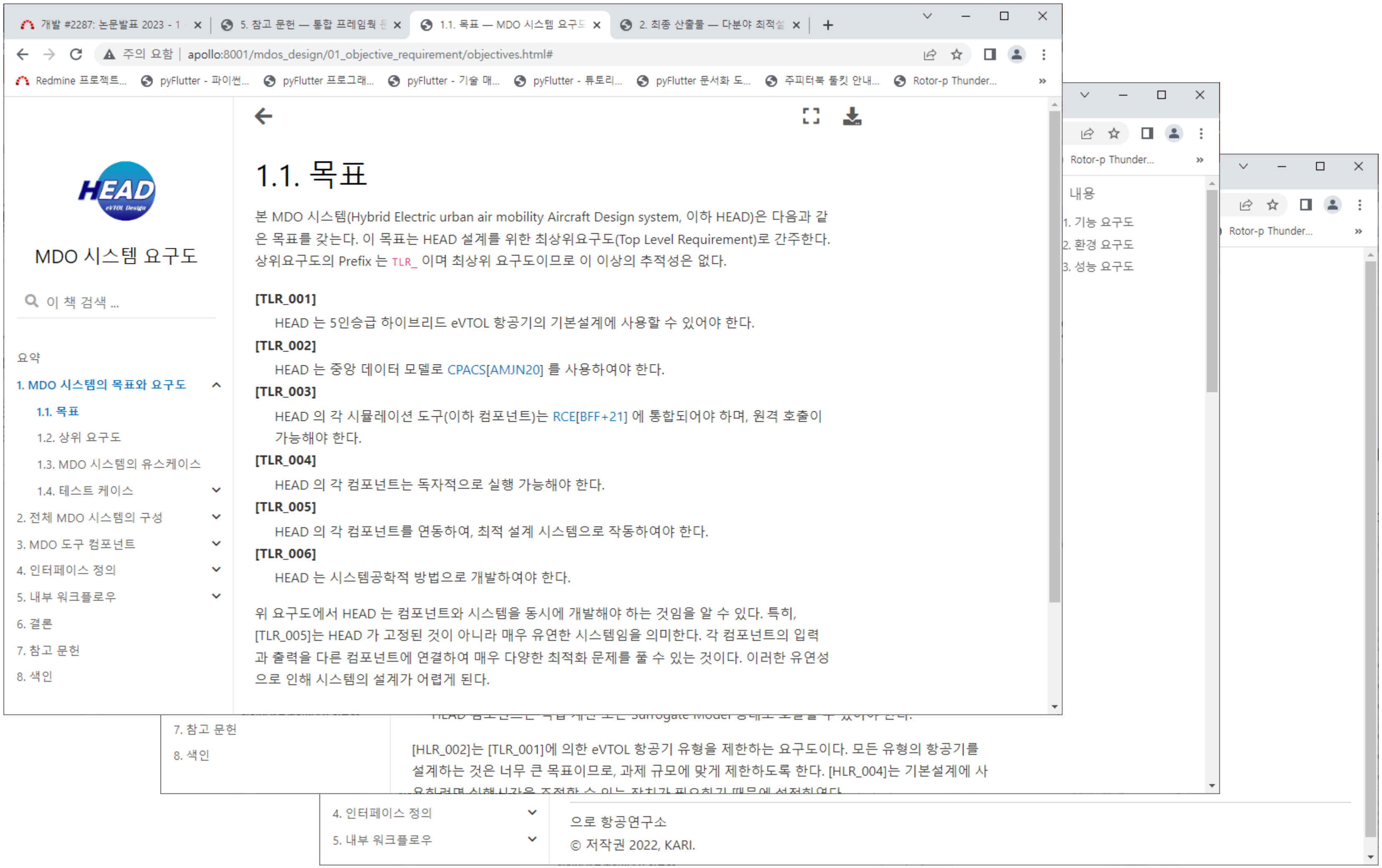
- **KARI have been studying the usability of various DLR software tools:**
  - RCE, TiGL, TiXI, VAMPzero, CPACS and MDAx
- **KARI-DLR cooperation was proposed by KARI in 2020 and welcomed by DLR.**
  - Enhancement of DLR tools through the test and evaluation
  - Discussions were made to materialize the cooperation through 2021.
  - An online meeting was made between the aeronautics research directorate of KARI and the institute of system architecture in aeronautics of DLR in March 2022 to discuss the practical cooperation.

- **Online workshops have been held four times through the video conferencing**
  - from May 2022 to Aug 2022
  - CPACS and TiGL Tutorial and Q&A
  - Hands-on exercises using MDAx via the web “as-a-service”
  - KARI work procedures for flight control, mission analysis, and geometry generation
  - Totally 43 people from KARI side attended the workshops.



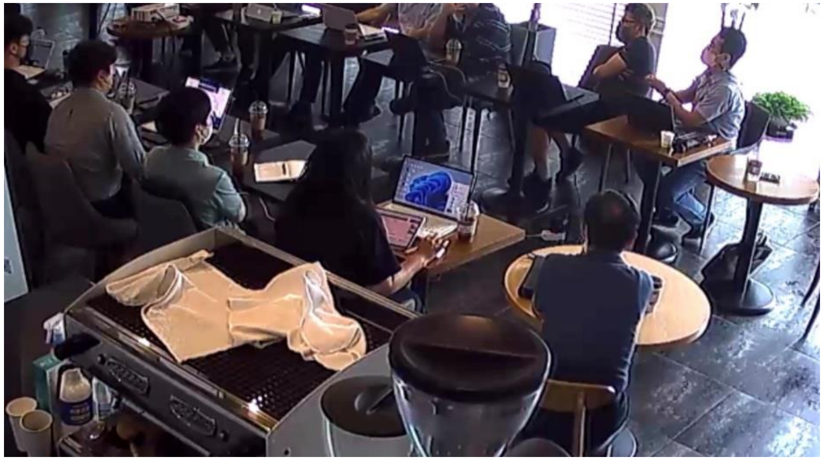
MDAO System Design Status

- **MDO System Requirement Documentation**



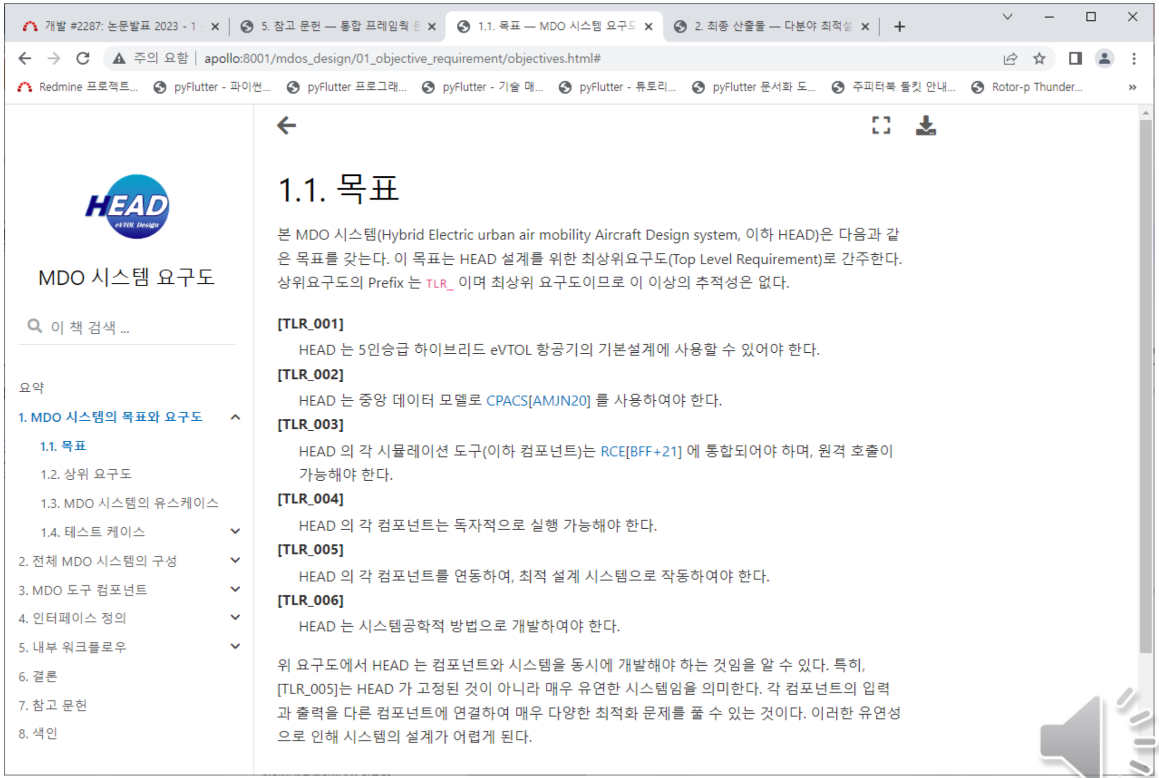
Internal Workshops

- **MDO System design needs the cooperation between the experts on physical models constituting the system.**
- **Intensive discussions and brain storming were needed in a short time.**
- **Six internal workshops were made in 2022.**
  - February : eVTOL concept design seminar
  - March : 1st optimal design problem definition
  - May : CPACS-RCE basics and 1st N2 chart build
  - July : 2nd N2 chart build
  - August : 2nd optimal design problem definition
  - September : MDO system design



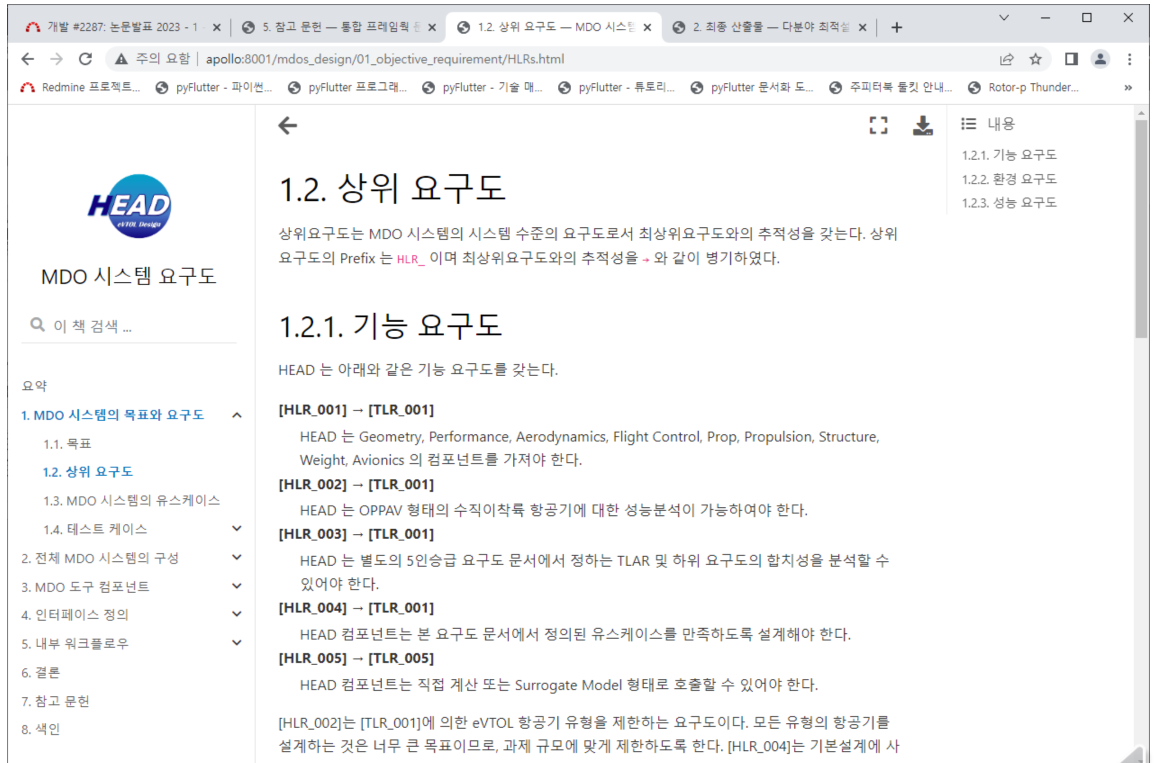
MDAO System Design Status

- **MDO System Requirement – Top Level Requirements**
  - Six top level requirements
    - Preliminary design for 5 seated hybrid eVTOL aircrafts
    - CPACS as central data model
    - RCE as the process integrator
    - Each Component to be able to separate execution
    - Interoperable components
    - System engineering to be followed



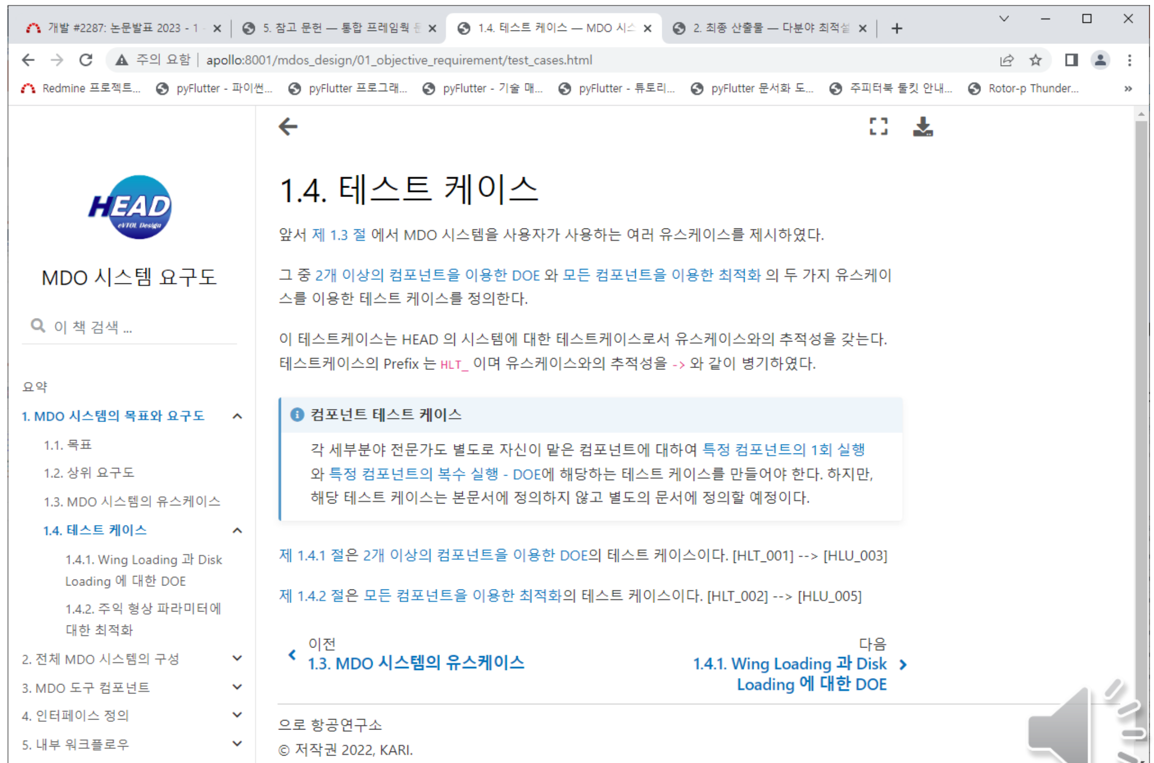
MDAO System Design Status

- **MDO System Requirement – High Level Requirement**
  - Five functional requirements
  - Six environment requirements
  - One Performance requirement



MDAO System Design Status

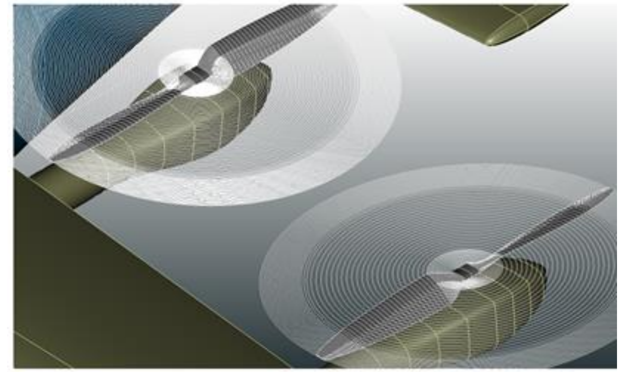
- **MDO System Requirement – Use Cases and Test Cases**
  - Five use cases
    - One execution of a specific component
    - Design of Experiment (Multiple executions) using a specific component
    - Design of Experiment (Multiple executions) using plural components
    - Optimization using plural components
    - Optimization using all components

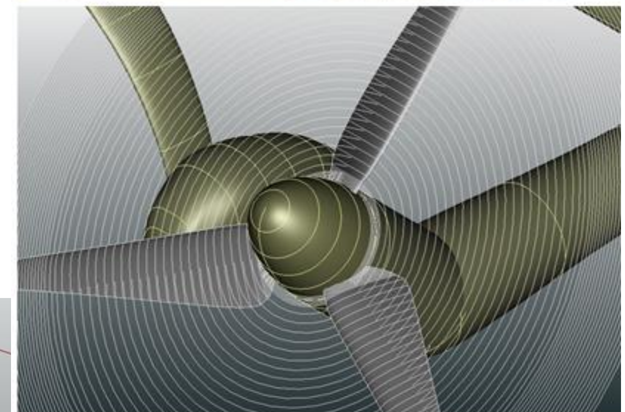


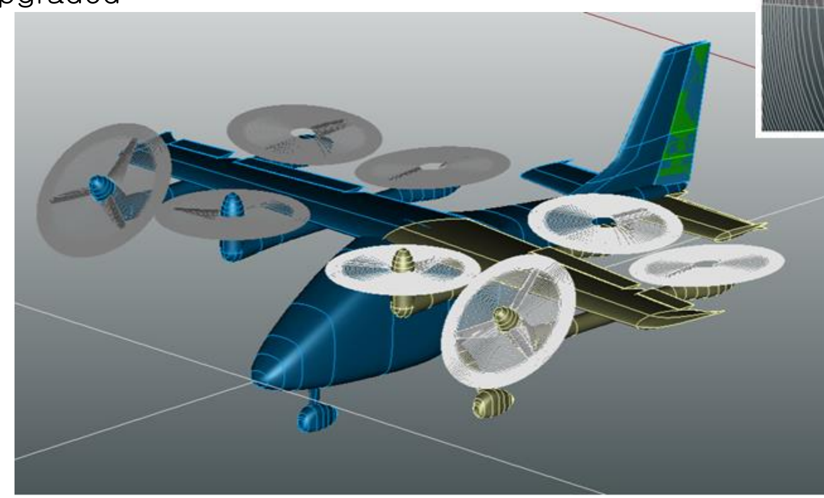
MDAO System Design Status

- **Major tools to be integrated into the MDAO system:**
  - Geometry : inhouse software using CPACS, TiXI, TiGL, Python
  - Aerodynamics* :
    - Athena Vortex Lattice (AVL) code
    - Inhouse source doublet panel method + actuator disk theory
    - OpenFOAM + actuator disk model
  - Flight control : inhouse flight model, MATLAB, CONDUIT
  - Mission performance and Prop* : inhouse software, CAMRAD II
  - Noise* : inhouse software
  - Structure* : inhouse FE modeler, MSC/NASTRAN, Hypersizer
  - Hybrid electric propulsion* : inhouse software in MATLAB and SIMULINK

*Need to be developed or upgraded

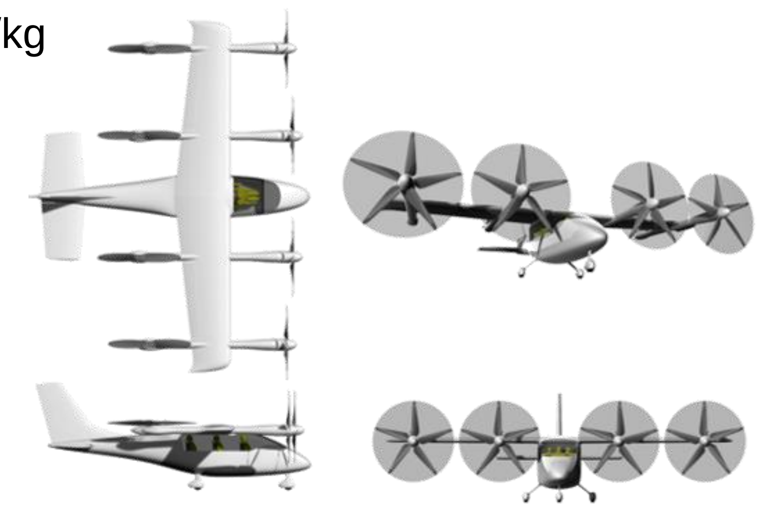




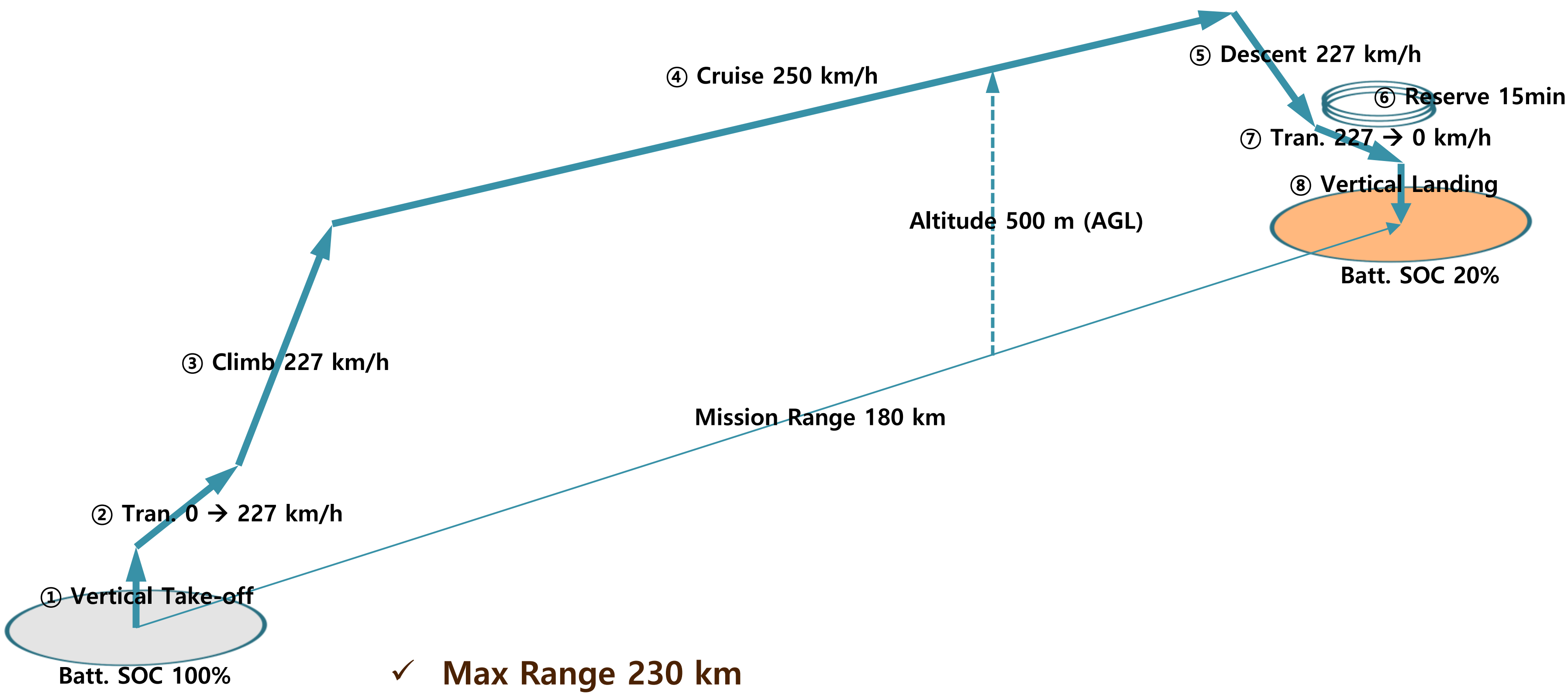


Requirements for a UAM Design

- **TLAR**
  - Payload : more than 550 kg (1 pilot and 5 passengers)
  - Cruise speed : more than 250 km/h
  - Maximum speed : more than 300 km/h
  - Maximum range : more than 200 km
  - Maximum endurance : more than 60 minutes
  - Maximum altitude : 2 km
  - Noise : less than 65dBA at T/O and Landing (100 m distant and at 100 m altitude)
- **Assumption**
  - Battery Pack Energy Density : more than 250 Wh/kg



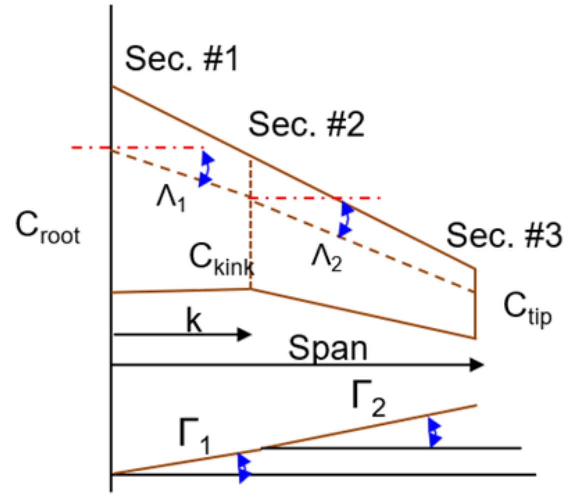
Mission Profile



- ✓ Max Range 230 km
- ✓ Max Endurance 60 min

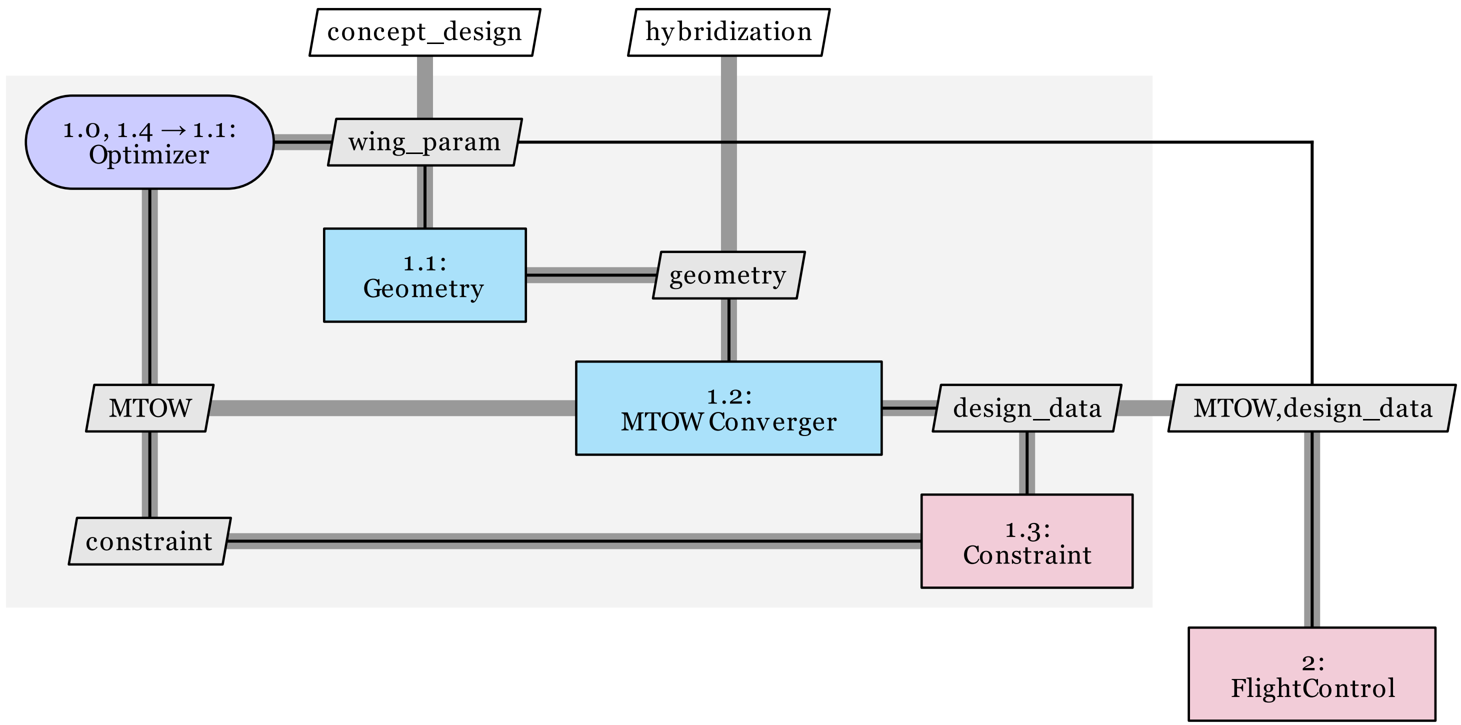
Optimization Problem

- **Design Parameters**
  - k, b : the kink position and span of the main wing
  - $C_{root}, C_{kink}, C_{tip}$: the chord lengths of the root, kink, and tip sections of the main wing
  - Λ_1, Λ_2: the sweep angles of the root and kink sections of the main wing
  - θ_1, θ_2 : the twist angles of the kink and tip sections of the main wing
  - Γ_1, Γ_2 : the dihedral angles of the root and kink sections of the main wing
  - Hybridization factor

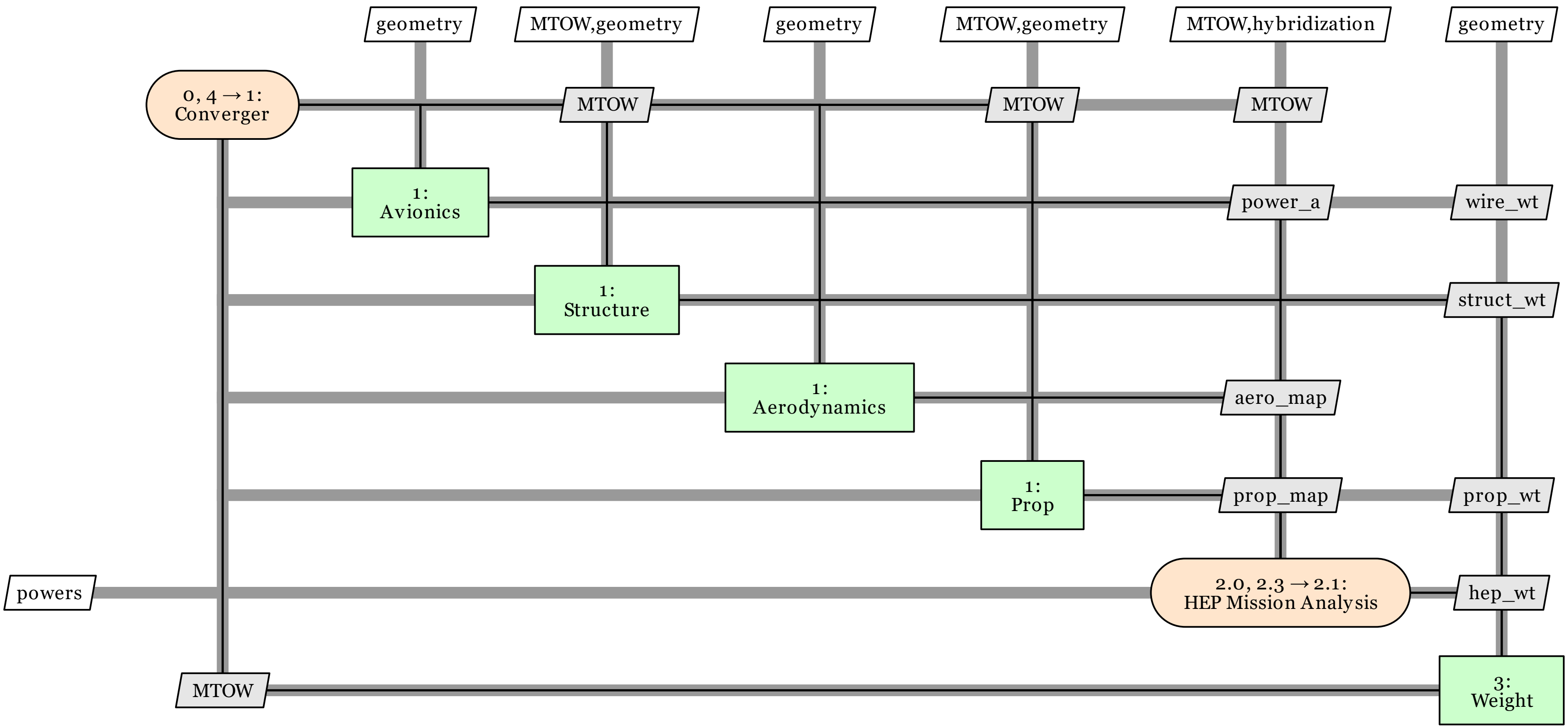


- **Objective**
  - Minimize the maximum take-off weight

Optimization Problem

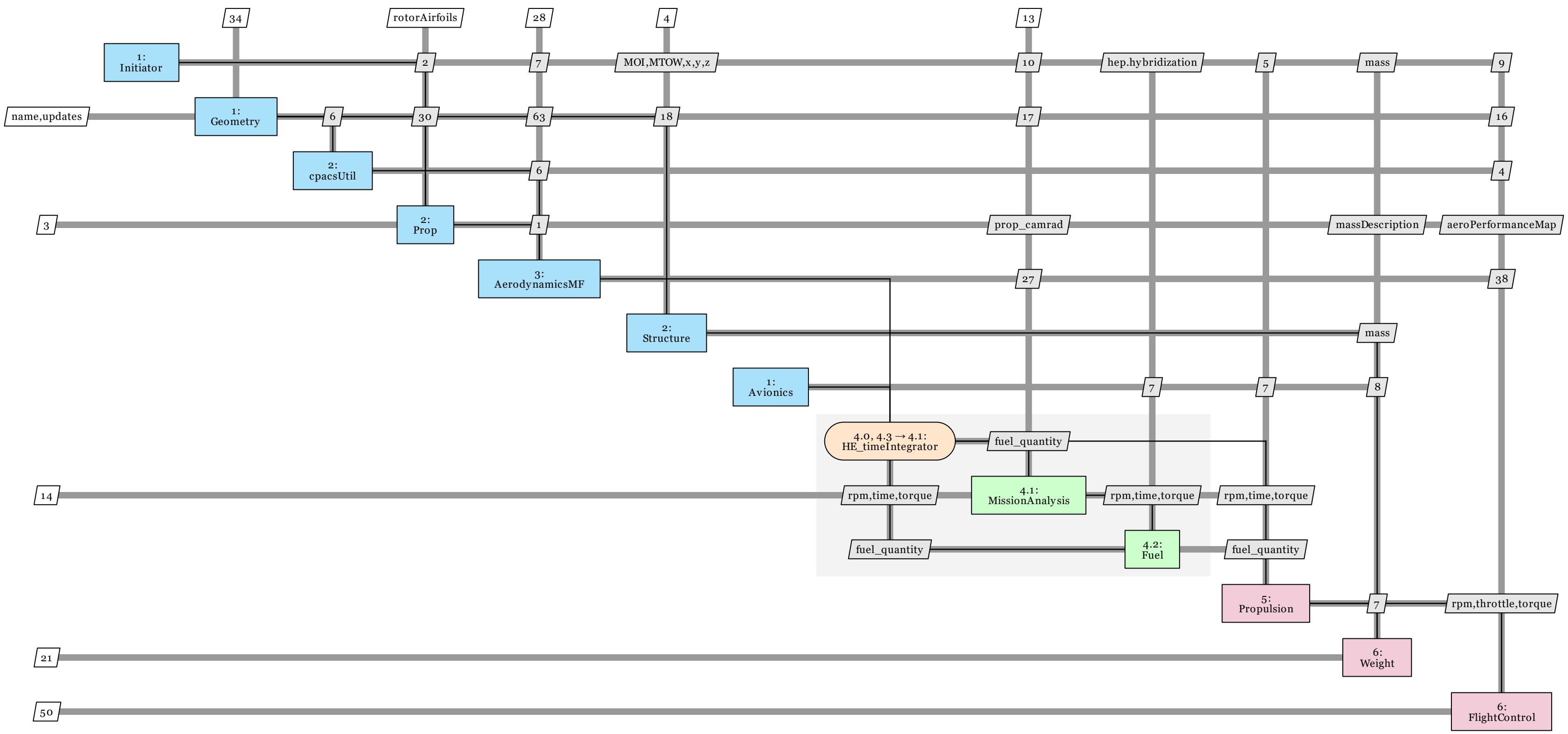


Optimization Problem – MTOW Converger



MDAO System Design Status - XDSM

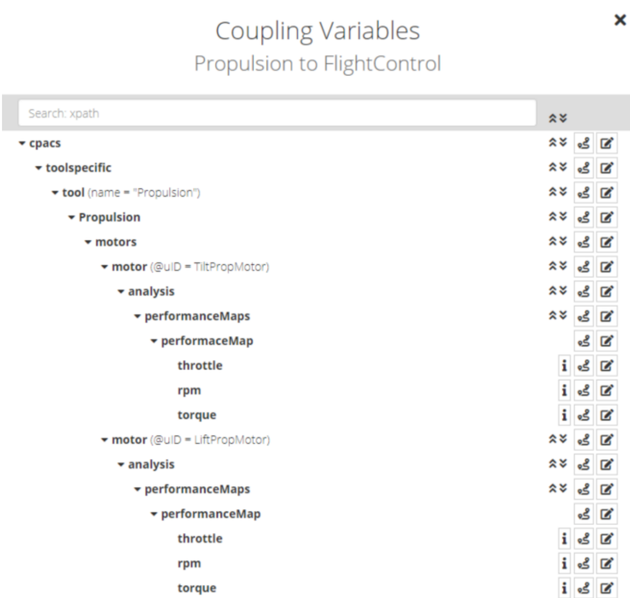
- **Draft XDSM chart**

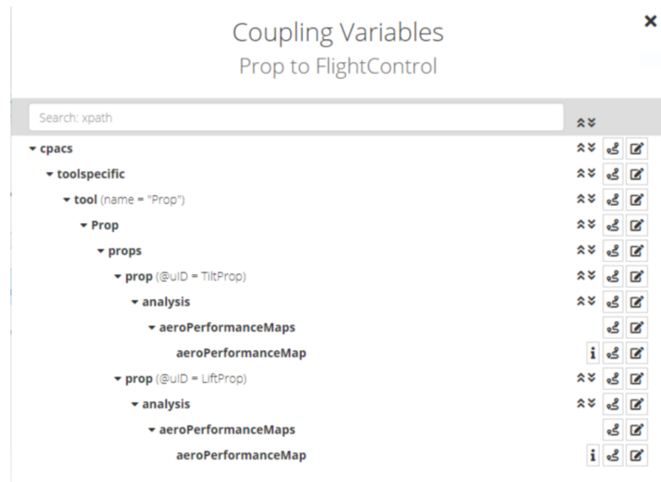


cpacsUtil : from CPACS to higher level parameter

MDAO System Design Status - CPACS

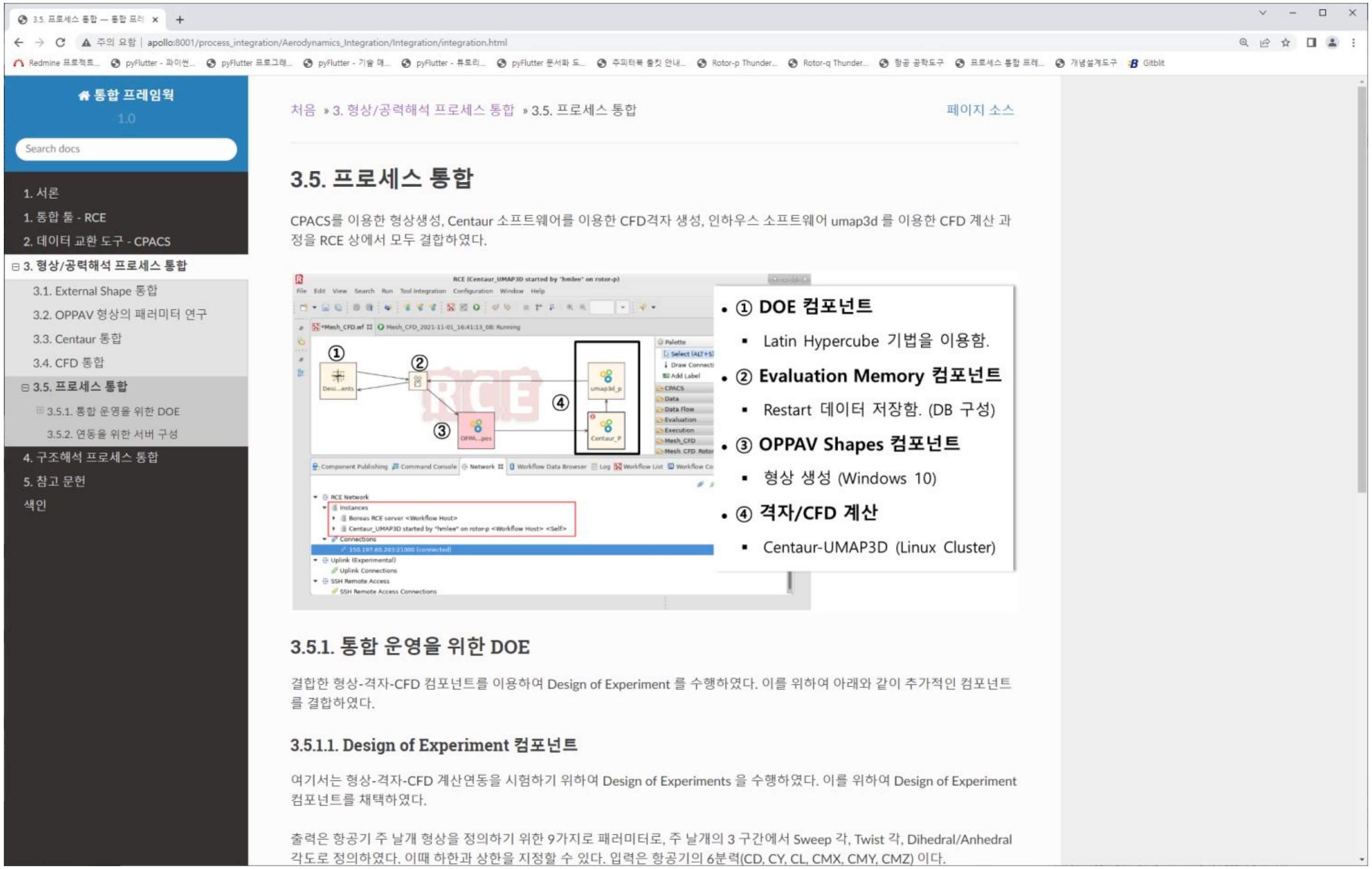
- **Enhancement being devised**
  - Elements for UAM specific systems
  - Performance Map for Propellers and Motors





User Manual

- **User manual is being made**



3.5. 프로세스 통합 — 통합 프레

apollo:8001/process_integration/Aerodynamics_Integration/Integration/integration.html

통합 프레임웍
1.0

처음 » 3. 형상/공력해석 프로세스 통합 » 3.5. 프로세스 통합 페이지 소스

3.5. 프로세스 통합

CPACS를 이용한 형상생성, Centaur 소프트웨어를 이용한 CFD격자 생성, 인하우스 소프트웨어 umap3d 를 이용한 CFD 계산 과정을 RCE 상에서 모두 결합하였다.

- ① DOE 컴포넌트
  - Latin Hypercube 기법을 이용함.
- ② Evaluation Memory 컴포넌트
  - Restart 데이터 저장함. (DB 구성)
- ③ OPPAV Shapes 컴포넌트
  - 형상 생성 (Windows 10)
- ④ 격자/CFD 계산
  - Centaur-UMAP3D (Linux Cluster)

3.5.1. 통합 운영을 위한 DOE

결합한 형상-격자-CFD 컴포넌트를 이용하여 Design of Experiment 를 수행하였다. 이를 위하여 아래와 같이 추가적인 컴포넌트를 결합하였다.

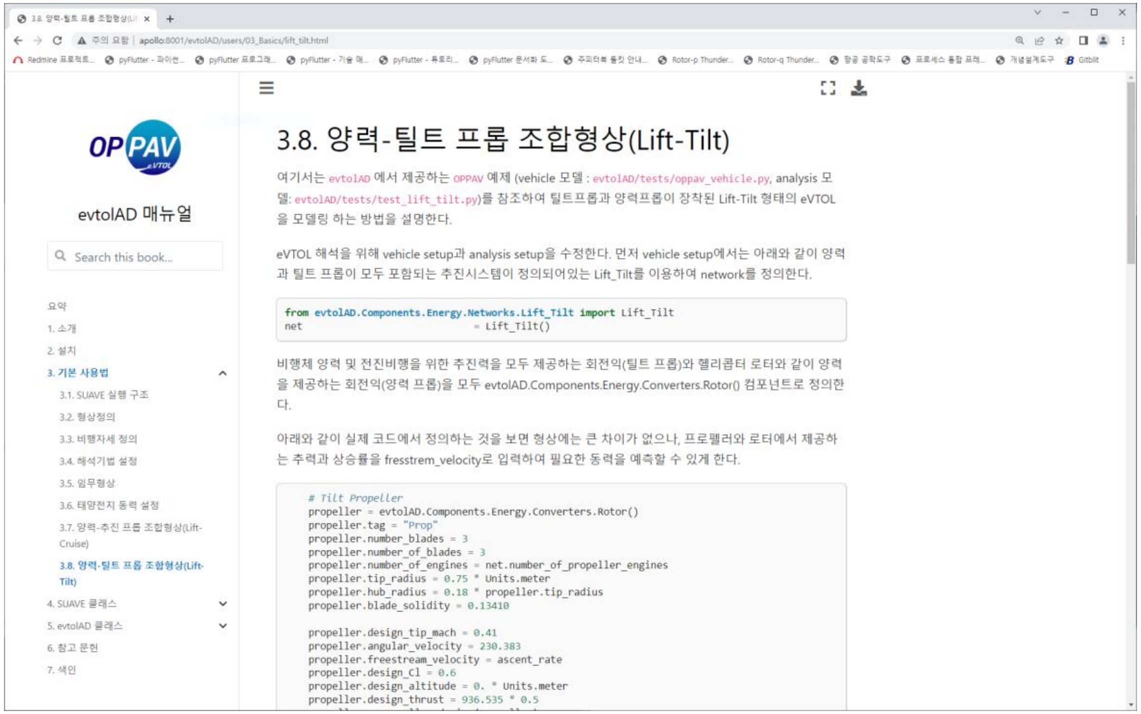
3.5.1.1. Design of Experiment 컴포넌트

여기서는 형상-격자-CFD 계산연동을 시험하기 위하여 Design of Experiments 을 수행하였다. 이를 위하여 Design of Experiment 컴포넌트를 채택하였다.

출력은 항공기 주 날개 형상을 정의하기 위한 9가지로 패러미터로, 주 날개의 3 구간에서 Sweep 각, Twist 각, Dihedral/Anhedral 각도로 정의하였다. 이때 하한과 상한을 지정할 수 있다. 입력은 항공기의 6분력(CD, CY, CL, CMX, CMY, CMZ) 이다.

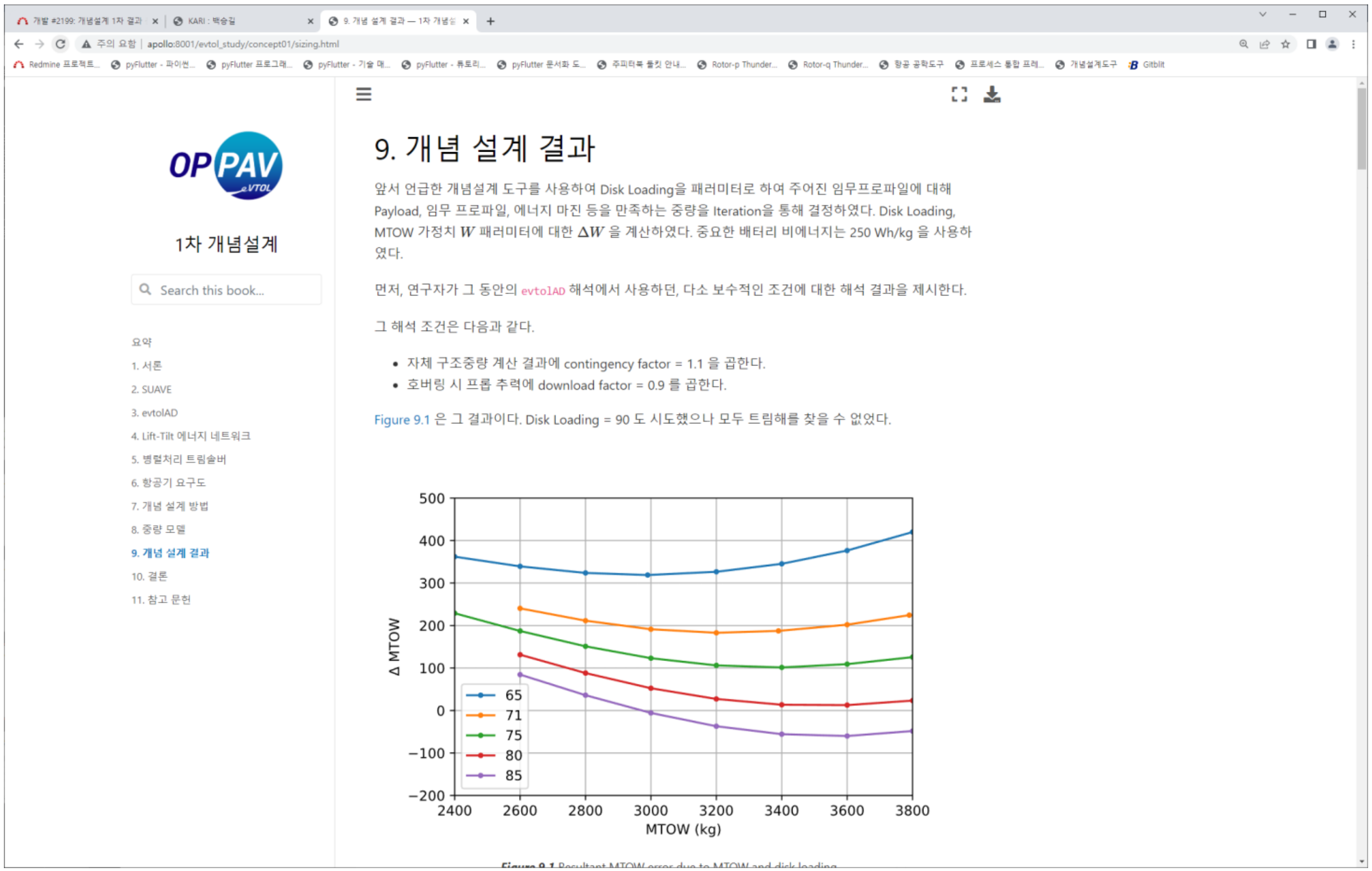
Initial Sizing

- **Concept Design Tool**
  - Based on SUAVE(an open source concept design tool by Stanford Univ)
  - Devised a component for the Lift-Tilt configuration



Initial Sizing

- **The first sizing**
  - Based on OPPAV, one-seated vehicle, the sizing was made with the six-seater requirement.



Conclusion

- **The KARI plan, from 2022 to 2026, on the overall MDAO system development was explained**

- **KARI-DLR cooperations until now were explained.**

- **MDAO system design and concept design in 2022 were explained**
  - Requirements
  - System design
  - Interfaces
  - Component workflows