Hybrid-Electric STOL Air Taxi Design

Background

Recent developments in electric motors, controllers, power generation and most importantly batteries have led to the development of hybrid gas-electric cars such as the Toyota Prius and Chevrolet Volt. These vehicles use a combination of energy storage in fossil fuels and chemical batteries to achieve their fuel efficiency, range, and performance goals. There are also fully electric cars such as the Tesla Model S and Nissan Leaf. The technology for batteries in the next decade will be challenged to store enough energy, by themselves, for practical general aviation travel.

This project is for the design of a STOL Hybrid-Electric air taxi. The entry into service (EIS) is 2031 (10-years) for a STOL 4-seater with 300 nmi of range. The intent is to have energy storage to supplement takeoff, climb, go-around and emergencies via batteries and electric motors with a combustion engine providing additional power and/or direct propulsion for cruise to extend the range and recharge the batteries during cruise.

One potential mission for such a vehicle include air taxi services between metropolitan centers (San Francisco to LA is ~300 nmi) that originate and arrive at small airports closer to urban centers. This would enable point-to-point travel in new markets that otherwise would be difficult to service. Identification of other new markets and how the vehicle can be used to serve them should be considered an important part of the design process.

Engine = fossil fuel engine
Motor = electric motor powered by batteries or generated power

Requirements (M) = Mandatory Requirement (T) = Tradable requirement

- **General Requirements**
  - (M) Capable of taking off and landing from runways (dirt, grass, metal mat, gravel, asphalt & concrete)
  - (M) Minimum cruise speed of 150 knots
    - (T) Target cruise speed: 170 knots or greater
  - (M) Capable of VFR and IFR flight with an autopilot
  - (T) Capable of flight in known icing conditions
  - (M) Meets applicable certification rules in FAA 14 CFR Part 23
    - All missions below assume reserves and equipment required to meet applicable FARs
    - If any exemptions are required due to unique design features a technical analysis for an equivalent level of safety must be shown
  - (M) Engine/propulsion system assumptions documented
    - Use of engine (s) that will be in service by 2031.
      - Assumptions on at least specific fuel consumption/efficiency, thrust/power and weight should be specified.
      - Ensure that the power used by alternators, generators or other devices are accounted for.
    - Use of electric motor(s) that will be in service by 2031 and document battery energy and power density assumptions based on reasonable technology trends.
      - Document system efficiency including at least the efficiency of the batteries, wires, controllers, thermal management system, connectors, motors and propellers to calculate a total propulsive efficiency.
      - Document electric propulsion system component weights, volumes, and

        - locations
        - (M) Minimum State Of Charge (SOC) for batteries of 15%
        - (M) Maximum SOC for batteries of 95%
    - (M) Show the emergency range to get to an alternate airport at the maximum feasible weight from a combustion engine failure at 5000' AGL (ISA+ 18°F) with electric power from batteries alone.
    - (T) Provide systems and avionics architecture that will enable autonomous flight
        - Provide a market justification for choosing to either provide or omit this capability
    - (M) "Utilize Guidelines for Analysis of Hybrid Electric Aircraft System Studies" attached in Appendix 1 of this RFP
- **Mission Requirements**
    - (M) Crew: 1 pilot
    - (M) 3 passengers
    - Passenger/pilot and baggage weight assumptions
        - Passenger/pilot weight of 190 lb
        - Baggage weight per passenger of 30 lb and volume of at least 4 cubic feet per passenger
        - Be able to accommodate infant seat to 99^{th}% adult male passenger height
    - (M) 300 nmi design range mission with IFR reserves
        - Maximum takeoff and landing field lengths of 300' over a 50' obstacle to a runway with dry pavement (sea level ISA + 18°F day).
        - Takeoff, and landing performance should also be shown at 5,000' above mean sea level (ISA + 18°F) as well as for grass & concrete fields at sea level (ISA+18°F)
    - (M) Initial climb rate at sea level (ISA+ 18°F) at least 1500 fpm with both electric and fossil fuel propulsion operating
    - (M) 15-minute time between 50 nmi missions to allow for loading and unloading of passengers and aircraft servicing
    - (T) Meet 14 CFR 23.67 Climb: One engine inoperative requirements with either propulsion type inoperative, if it will be treated as a twin-engine airplane
    - (M) Service ceiling of at least 14,000' for terrain clearance in mountainous areas
        - (T) Higher service ceiling with addition of supplemental oxygen or pressurization systems
    -

Design Objectives

- Minimize production cost by choosing materials and manufacturing methods appropriate for the annual production rate that is supported by the team's assessment of the potential market size.
- Make the aircraft visually appealing so it will be marketable and identify what features are important to the operators for different missions.
- Make the aircraft reliability equal or better than that of comparable aircraft.
- Make the aircraft maintenance equal or better than that of comparable aircraft.

Other features and considerations

- Flying qualities should meet CFR Part 23.
- Identify all systems functionality and components that are required for the aircraft to operate in both controlled and uncontrolled airspace.
- List the equipment required.
- Consider what features will be basic and which will be optional to a customer.

Notes and assumptions:

- Assume an EIS of 2031 when making technology decisions

Report and Design Data Requirements

The technical report shall present the design of this aircraft clearly and concisely; it shall cover all relevant aspects, features, and disciplines. Pertinent analyses and studies supporting design choices shall be documented.

Full descriptions of the aircraft are expected along with performance capabilities and operational limits. These include, at a minimum:

1. A description of the design missions defined for the proposed concepts for use in calculations of mission performance as per design objectives. This includes the selection of cruise altitude(s) and cruise speeds supported by pertinent trade analyses and discussion.
2. Thumbprint plot (s) (sizing/constraint plot) showing the airplane sizing with thrust/weight on the vertical axis and wing loading (W/S) on the x axis.
3. Aircraft performance summaries shall be documented and the aircraft flight envelope shall be shown graphically.
4. Payload range chart(s)
5. A V-n diagram for the aircraft with identification of necessary aircraft velocities and design load factors.
    a. Required gust loads are specified in 14 Code of Federal Regulations (CFR) Part 23.
6. Materials selection for main structural groups and general structural design, including layout of primary airframe structure as well as the strength capability of the structure and how that compares to what is required at the ultimate load limits of the aircraft. The maximum dive speed of the aircraft shall be specified.
7. Complete geometric description, including dimensioned drawings, control surfaces sizes and hinge locations, and internal arrangement of the aircraft illustrating sufficient volume for all necessary components and systems.
    a. Scaled three-views (dimensioned) and 3-D model imagery of appropriate quality are expected. The three-view must include at least:
        i. Fully dimensioned front, left, and top views
        ii. Location of aircraft aerodynamic center (from nose)
        iii. Location of average CG location (relative to nose)
        iv. Tail moment arms
    b. Diagrams and/or estimates showing that internal volume requirements are met, including as a minimum the internal arrangements of the passengers and cargo
        i. Cross-section showing passenger seats
        ii. Layout of passenger cabin
        iii. Layout of cockpit
        iv. Layout of cargo and size and location of any unique cargo doors
        v. Fuselage centerline diagram
    c. Diagrams showing the location and functions for all aircraft systems.
8. Important aerodynamic characteristics, coupling with the propulsion system (if any) and aerodynamic performance for key mission segments and requirements
9. Aircraft weight statement, aircraft center-of-gravity envelope reflecting payloads and fuel allocation. Establish a forward and aft center of gravity (CG) limits for safe flight.
    a. Weight assessment summary shall be shown at least at the following level of detail:
        i. Propulsion (engine/motor, batteries, controller, wiring, heat sink, cowl, strut, propeller, spinner etc. as applicable)
        ii. Airframe Structure
            1. Wing
            2. Empennage
            3. Landing Gear (including wheels tires and brakes)
            4. Fuselage

iii. Control system (flight controls linkages, hydraulics, wires, actuators bellcranks, engine controls etc.)
iv. Payloads (seats, seatbelts, cushions and other cabin systems)
v. Systems
1. Instruments and Avionics
2. Fuel/oil (battery if electric)
3. Hydraulic/pneumatic/electrical systems (if chosen)

10. Propulsion system description and characterization including performance, cooling, dimensions, and weights. The selection of the propulsion system(s), sizing, and airframe integration must be supported by analysis, trade studies, and discussion
11. Summary of basic stability and control characteristics; this should include, but is not limited to static margin, pitch, roll and yaw derivatives.
12. Summary of cost estimate and a business case analysis. This assessment should identify the cost groups and drivers, assumptions, and design choices aimed at the minimization of production costs.
    a. Estimate the non-recurring development costs of the airplane including engineering, FAA/EASA certification, production tooling, facilities and labor
    b. Estimate the fly away cost
    c. Estimate the price that would have to be sold for to generate at least a 15% profit
        i. Show how the airplane could be produced profitably at production rates ranging from 4 to 10 airplanes per month or a rate that is supported by a brief market analysis
    d. Estimate of direct operating cost per airplane flight hour
        i. Fuel, oil, tires, brakes, battery cost and other consumable quantities
        ii. Estimate of maintenance cost per flight hour
        iii. Flight and cabin crew costs per hour

The design report will include trade documentation on the two major aspects of the design development, a) the concept selection trades, and b), the concept development trade studies.
The student(s) is (are) to develop and present the alternative concepts considered leading to the down-select of their preferred concept. The methods and rationale used for the down-select shall be presented. At a minimum a qualitative assessment of strengths and weaknesses of the alternatives shall be given, discussing merits, leading to a justification as to why the preferred concept was the best design. Quantitative justification of why the selected concept is the best at meeting the measures of merit(s) will strengthen the report.
In addition, the submittal shall include the major trade studies conducted justifying the optimization, sizing, architectural arrangement and integration of the specifically selected concept. Quantitative data shall be presented showing why their concept 'works' and is the preferred design compromise that best achieves the design requirements.

Specific analysis and trade studies of interest include:
Mission performance and sizing for the definition of a mission profiles.
Overall aircraft concept selection (airframe and propulsion system) vs. design requirements objectives

All concept and technology assumptions must be reasonable and justified for the EIS year.

Reference Material

FAA Part 23
http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title14/14cfr23_main_02.tpl

Appendix 1 (Or make a reference?)

Guidelines for Analysis of Hybrid Electric Aircraft System Studies

Nomenclature, Pictographic Representations, Standalone and Combined Properties and Attributes, Metrics, and Figures of Merit

AIAA

SHAPING THE FUTURE OF AEROSPACE

Introduction

In 2017, the Aircraft Electric Propulsion and Power (AEPP) Working Group was formed by the AIAA to coordinate across the various technical and program committees that had a stake in aircraft electric and hybrid electric propulsion and power. The AEPP Working Group identified the need for standardization of parameters and metrics for electric and hybrid electric aircraft system studies. An action item (#40) was created and an informal subgroup was created to work on this issue.

One motivation for this action item was the observation from the National Academies report on Low Carbon Aviation [1]. In this report, several serious inconsistencies were identified in the way assumptions were made and input and result parameters were documented. Often key information was not reported at all. Quoting from the report:

> *"…The studies generally assume that energy storage would be provided by advanced secondary (rechargeable) batteries. Calculations of specific energy take into account assumed depth of discharge, efficiency losses, and the weight of the installed system, including structure to support the cells, battery thermal management, and possibly safety containment measures.*
>
> *However, there are likely to be some inconsistencies between the various studies in the installation assumptions and calculation methods.*
>
> *Electrical component specific power is not evaluated in a consistent fashion in all the studies reviewed. Components of interest include motors, generators, inverters, controllers, conductors, switches, and thermal management. Most studies have treated the motors, controllers, and thermal management components as a type of integrated system weight. Similarly, generators, inverters, and their thermal management components are treated as a total power system weight. There may be different assumptions concerning redundancy and safety in each study. Therefore, deducing needed component specific power (for a motor alone for example) may be difficult.*
>
> *The potential reduction in CO2 possible with all-electric, hybrid electric, and turboelectric aircraft is generally much less than some of the "headline" numbers claimed in the studies. Many studies compare their projected reductions to different baselines. Often the large numbers quoted (for example 70 percent fuel burn reduction) include postulated performance improvements arising from improvements in other areas, including aerodynamics, structures, operations, and gas turbines. In addition, the improvements arising from electric propulsion are in comparison to current aircraft, not to future conventional aircraft of the same time period …"*

At the AIAA/IEEE Electric Aircraft Technologies Symposium (EATS) in 2018 in Cincinnati, there were numerous quality papers and presentations on electric and hybrid electric aircraft but it was clear many of them suffered from the same inconsistencies and unreported assumptions that were noted by the National Academies Report from 2016.

In 2018 at the AIAA Aviation Conference short course on "Design for Electric and Hybrid-Electric Aircraft" [2] and at a "Performance Assessment of Hybrid Electric Systems" tutorial [3] at the AIAA Propulsion and Energy Forum, the draft parameter tables developed as part of this activity were shared with audiences for the first time. Comments were favorable and the subgroup embarked to continue the activity and produce a formal set of recommended standard parameters.

This report documents the first version of these recommended standard parameters to document assumptions, performance, and missions for system studies related to many types of electric and hybrid electric components and aircraft.

It is hoped that these parameters will be used by study authors on future system studies for electric and hybrid electric aircraft. This document should assist the authors in their documentation, allow better comparisons between studies, and improve the quality of studies and results across universities, government research labs, and industry. Credible and repeatable results will help the industry mature, decrease "hype," and increase accuracy.

The current subgroup leader is Askin T. Isikveren (SAFRAN Group), and he has been supported by AEPP Working Group members including Marty Bradley (Boeing), Berton Vite (Romeo Power), Ralph Jansen (NASA), Kurt Papathakis (NASA), Jimmy Tai (Georgia Tech), Michael Patterson (NASA), Jonathan Gladin (Georgia Tech), Ben Schiltgen (ES Aero), Roelof Vos (TU Delft), Phil Ansell (University of Illinois), Sean Clarke (NASA), Neil Garrigan (GE), Gerry Welch (NASA), Rich Ouellette (Boeing), Kiruba Haran (University of Illinois), and Herb Schlickenmaier (HS Advanced Concepts).

References

[1] Committee on Propulsion and Energy Systems to Reduce Commercial Aviation Carbon Emissions, Aeronautics and Space Engineering Board, Division on Engineering and Physical Sciences, National Academies of Sciences,

Engineering, and Medicine, "Commercial Aircraft Propulsion and Energy Systems Research: Reducing Global Carbon Emissions," ISBN 978-0-309-44096-7, DOI: 10.17226/23490, National Academies Press, Washington, DC, USA, 2016.

[2] Short Course: "Design of Electric and Hybrid-Electric Aircraft," Brian German, Marty Bradley, Rob McDonald, and Roelof Vos, AIAA Aviation Conference, Atlanta, Georgia, June 23–24, 2018.

[3] Tutorial: "GTE-04: Performance Assessment of Hybrid Electric Systems," Jon Gladin, AIAA Propulsion and Energy Forum, Cincinnati, Ohio, July 9–11, 2018.

Architecture-Level and Aircraft-Level Evaluation

Propulsion Architectural Schematic	**Aircraft Concept**
image here	image here

Propulsion Architecture Metrics	**Concept SI Units**	**Baseline SI Units**	**Concept Imperial**	**Baseline Imperial**	**Delta**
Specific Power (kW/kg or hp/lbm)	xxx	xxx	xxx	xxx	xxx.x%
Thrust Specific Power Consumption (W/N or hp/lbf)	xxx	xxx	xxx	xxx	xxx.x%
Increment Efficiency due to Aero-propulsion (-)	xx.x%	xx.x%			
Global Chain Efficiency (-)	xx.x%	xx.x%			

Typical Mission Profile		**Power Management, Allocation, and Control Strategy**
Stage Length (nm)	xxxx	
Gate (min.)	xx	xxxxxxxx
Taxi-out (min.)	xx	xxxxxxxx
Hover (min.)	xx	xxxxxxxx
Take-off (min.)	xx	xxxxxxxx
Climb (min.)	xx	xxxxxxxx
Cruise (min.)	xx	xxxxxxxx
Descent (min.)	xx	xxxxxxxx
Approach/Hover (min.)	xx	xxxxxxxx
Landing (min.)	xx	xxxxxxxx
Taxi-in (min.)	xx	xxxxxxxx
Holding/Loiter (min.)	xx	xxxxxxxx
Contingency (min. or %)	xx	xxxxxxxx
Diversion (nm)	xx	xxxxxxxx
xxxxxxx	xx	xxxxxxxx, add/delete lines where required

Aircraft Design Weights	**Concept SI Units**	**Baseline SI Units**	**Concept Imperial**	**Baseline Imperial**	**Delta**
Maximum Take-off Weight (kg or lbm)	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxx.x%
Maximum Landing Weight (kg or lbm)	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxx.x%
Manufacturer’s Weight Empty, Green (kg or lbm)	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxx.x%
Operating Weight Empty or Basic Oper. Weight (kg or lbm)	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxx.x%
Maximum Payload Weight (kg or lbm)	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxx.x%
Maximum Zero-Fuel Weight (kg or lbm)	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxx.x%
Total Release Energy Weight (kg or lbm)	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxx.x%
Release Fuel Weight (kg or lbm)	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxx.x%
Release Ancillary Energy Source Weight (kg or lbm)	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxx.x%

Aircraft Sizing Parameters and Metrics					
Wing Loading (kg/m^2 or lbm/sq.ft)	xxxx	xxxx	xxxx	xxxx	xxx.x%
Reference Wing Area (m^2 or sq.ft)	xxxx	xxxx	xxxx	xxxx	xxx.x%
Reference Wing Aspect Ratio (-)	xx.x	xx.x			xxx.x%
Disc Loading (kg/m^2 or lbm/sq.ft)	xxxx	xxxx	xxxx	xxxx	xxx.x%
Reference Disc Area (m^2 or sq.ft)	xxxx	xxxx	xxxx	xxxx	xxx.x%
Number of Rotors and Number of Blades for Each Rotor (-) Maximum Mechanical Speed (RPM)	x [x] xxxxx	x [x] xxxxx			
MWE/MTOW (-)	0.xxx	0.xxx			
OWE (BOW)/MTOW (-)	0.xxx	0.xxx			
OWE (BOW)/PAX (kg/PAX or lbm/PAX)	xxx.x	xxx.x	xxx.x	xxx.x	xxx.x%
Release Energy Weight/MTOW (-)	0.xxx	0.xxx			
MLW/MTOW (-)	0.xxx	0.xxx			
Conditions Describing Total Maximum Thrust or Power			xxxxx		
Total Maximum Thrust (kN or lbf)	xxxxx	xxxxx	xxxxx	xxxxx	xxx.x%
Total Maximum Shaft Power (kW or hp)	xxxxx	xxxxx	xxxxx	xxxxx	xxx.x%
All-Engines Operational Thrust-to-Weight (-)	0.xxx	0.xxx			
One-Engine Inoperative Thrust-to-Weight (-)	0.xxx	0.xxx			
AEO Maximum Power-to-Weight (kW/kg or hp/lbm)	0.xxx	0.xxx	0.xxx	0.xxx	
AEO Maximum Power Loading (kg/kW or lbm/hp)	0.xxx	0.xxx	0.xxx	0.xxx	
OEI Maximum Power-to-Weight (kW/kg or hp/lbm)	0.xxx	0.xxx	0.xxx	0.xxx	

	OEI Maximum Power Loading (kg/kW or lbm/hp)	0.xxx	0.xxx	0.xxx	0.xxx	
	Anti-Torque or Tail Rotor Power (kW or hp)	xxx	xxx	xxx	xxx	xxx.x%
	Aircraft Sizing Parameters and Metrics	**Concept SI Units**	**Baseline SI Units**	**Concept Imperial**	**Baseline Imperial**	**Delta**
	Maximum Non-Propulsive Power/Total Max. Power (-)	0.xxx	0.xxx			
	Total Thermal Management [kg/kW(th) or lbm/hp(th)]	x.xx	x.xx	x.xx	x.xx	
	Peak Thermal Load (kW or hp)	xxx	xxx	xxx	xxx	
	Operational Performance					
	Take-off Field Length, MTOW, ISA, SL (m or ft)	xxxx	xxxx	xxxx	xxxx	xxx.x%
	TOFL (m or ft)	xxxx	xxx	xxxx	xxx	xxx.x%
	Payload (kg or lbm)	xxxx	xxxx	xxxx	xxxx	xxx.x%
	Take-off Gross Weight (kg or lbm)	xxxxxx	xxxxxx	xxxxxx	xxxxxx	xxx.x%
	Specified ISA Deviation (°C or °F)	+xx	+xx	+xx	+xx	
	Specified Airport Elevation, AGL (ft)	xxxx	xxxxx			
	Stall Speed and Flap Setting, MTOW, ISA, SL (KCAS)			xxx [xx]	xxx [xx]	xxx.x%
	Reference Speed and Flap Setting, MLW, ISA, SL (KCAS)			xxx [xx]	xxx [xx]	xxx.x%
	Landing Field Length, MLW ISA, SL (m or ft)	xxxx	xxxx	xxxx	xxxx	xxx.x%
	ICAO Cumulative Noise Margin to Chapter 14 (EPNdB)	xx	xx			
	ICAO NO_x-Emissions Level (g/kN)	xx	xx			xxx.x%
	LTO NO_x-Emissions (kg/LTO)	xx.x	xx.x			xxx.x%
	ICAO Metric Value $MVCO_2$ ($kg/km.m^n$)	xx	xx			xxx.x%
	Maximum Operating Altitude (ft)			xxxxx	xxxxx	xxx.x%
	Maximum Hover Altitude (ft)			xxxxx	xxxxx	xxx.x%
	Glide Ratio (nm/ft)			xxx	xxx	xxx.x%
	Maximum Endurance Speed (KCAS [KTAS])			xxx [xxx]	xxx [xxx]	xxx.x%
	Maximum Endurance Time (h)	xx	xx			xxx.x%
	Climb Speed Schedule (KCAS [Mach])			xxx [0.xxx]	xxx [0.xxx]	
	Maximum Rate-of-Climb, MTOW b.r., ISA, SL (fpm)			xxxx	xxxx	xxx.x%
	Rate-of-Climb, MTOW b.r., ISA (fpm)			xxxx	xxxx	xxx.x%
	Specified Altitude (ft)			xxxxx	xxxxx	
	Time-to-Climb to Initial Cruise Altitude (min.)	xx	xx			xxx.x%
	Initial or Fixed Cruise Altitude, MTOW b.r., ISA (ft)			xxxxx	xxxxx	
	Typical Cruise Speed (Mach [KTAS])			0.xx [xxx]	0.xx [xxx]	xxx.x%
	Typical Cruise Lift-to-Drag (-)					xxx.x%
Max. PAX/Payload Design Range	Range and PAX (nm)	xxxx [xxx]				
	Payload (kg or lbm)	xxxx	xxxx	xxxx	xxxx	xxx.x%
	Block Fuel (kg or lbm)	xxxxx	xxxxx	xxxxx	xxxxx	xxx.x%
	CO_2-Emissions (kg or lbm)	xxxxx	xxxxx	xxxxx	xxxxx	xxx.x%
	Block Fuel per PAX (kg/PAX or lbm/PAX)	xx.x	xx.x	xx.x	xx.x	xxx.x%
	CO_2-Emissions per PAX (kg/PAX or lbm/PAX)	xx.x	xx.x	xx.x	xx.x	xxx.x%
	[Fuel] Specific Air Range (nm/kg or nm/lbm)	xxx	xxx	xxx	xxx	xxx.x%
	Block Energy (MW.h or BTU)	xx	xx	xx	xx	xxx.x%
	Block Energy per PAX (MW.h/PAX or BTU/PAX)	xx	xx	xx	xx	
	Degree-of-Hybridisation for Block Energy (-)	0.xxx	0.xxx			
	Energy Specific Air Range (nm/kW.h or nm/BTU)	xxx	xxx	xxx	xxx	xxx.x%
	Miss. Energy Index (kW.h/kg.nm or BTU/lbm.nm)	xxx	xxx	xxx	xxx	xxx.x%
	Operating Economics Assumptions			xxxxx		
	Operating Cost (USD)	xxx	xxx			xxx.x%
	Operating Cost per PAX (USD/PAX)	xxx	xxx			xxx.x%
Max. PAX/Payload Off-Design Stage Length	Stage Length and PAX (nm)	xxxx [xxx]				
	Payload (kg or lbm)	xxxx	xxxx	xxxx	xxxx	xxx.x%
	Block Fuel (kg or lbm)	xxxxx	xxxxx	xxxxx	xxxxx	xxx.x%
	CO_2-Emissions (kg or lbm)	xxxxx	xxxxx	xxxxx	xxxxx	xxx.x%
	Block Fuel per PAX (kg/PAX or lbm/PAX)	xx.x	xx.x	xx.x	xx.x	xxx.x%
	CO_2-Emissions per PAX (kg/PAX or lbm/PAX)	xx.x	xx.x	xx.x	xx.x	xxx.x%
	[Fuel] Specific Air Range (nm/kg or nm/lbm)	xxx	xxx	xxx	xxx	xxx.x%
	Block Energy (MW.h or BTU)	xx	xx	xx	xx	xxx.x%
	Block Energy per PAX (MW.h/PAX or BTU/PAX)	xx	xx	xx	xx	
	Degree-of-Hybridization for Block Energy (-)	0.xxx	0.xxx			

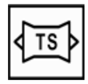
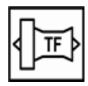
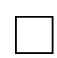
	Energy Specific Air Range (nm/kW.h or nm/BTU)	xxx	xxx	xxx	xxx	xxx.x%
	Operating Cost (USD)	xxx	xxx			xxx.x%
	Operating Cost per PAX (USD/PAX)	xxx	xxx			xxx.x%

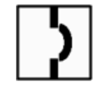
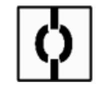
Block Fuel Cascade Chart: Max. PAX Design Range	**Block Fuel Cascade Chart: Max. PAX Stage Length**
image here	image here

Suggested Mission Profiles

The next revision of this document will include illustrations depicting typical mission profiles, including ground maneuvering allowances and contingency/reserves policies, for executives/commuters/regionals/narrow-bodies/ODMs/UAVs.

Pictographs for Architectural Schematics

Component	Pictograph	Component	Pictograph
Turboshaft Engine		Battery	
Turbofan Engine		Fuel Tank	
Main Rotor (Clockwise Rotation)		Electrical Network Model	
Main Rotor (Counterclockwise Rotation)		Cooler (passive)	
Forward-Facing Propeller (Clockwise Rotation)		Cooler (active)	
Forward-Facing Propeller (Counterclockwise Rotation)		Load (Electrical)	
Tail Rotor (Clockwise Rotation)		Load (Mechanical)	
Tail Rotor (Counterclockwise Rotation)		Load (Pneumatic)	
Piston Engine		Load (Hydraulic)	
Diesel Piston Engine		Load (Engine Bleed Air)	
Ground Power Unit		Electrical Transmission Routing Node	
Fuel Cell		AC-DC Rectifier	
Generator		DC-AC Inverter	
Motor		DC-DC Converter	
Transformer		Contactor - Open	
Pneumatic Compressor		Contactor - Closed	

Hydraulic Pump		Breaker - Unidirectional	
Gearbox		Breaker - Bidirectional	
		Electrical Bus	

Glossary for Architecture-Level and Aircraft-Level Evaluation

This section has been itemized and sequenced according to the classifications shown in the **Architecture-Level and Aircraft-Level Evaluation** table.

In order to appropriately understand the terminology relating to thrust and power presented in this section, the convention presented by Seitz, Schmitz, Isikveren and Hornung [4] has been adopted. The overall propulsion system efficiency is defined as the ratio of propulsion system useful power (utilized for actual aircraft motive power) and the power supplied by the energy source. Correspondingly, an elaboration of the overall propulsion system efficiency is declared as a product of energy conversion efficiency, transmission efficiency, and the propulsive efficiency. Energy conversion efficiency covers the complete chain of conversion from energy source (providing supplied power) to a point where installed power is offered to drive the propulsor(s), or, propulsion device(s). Transmission efficiency captures a relationship between power delivered by the propulsive jet, to that of installed power. Propulsive efficiency compares useful power to the power delivered by the propulsive jet.

Reference

[4] Seitz, A., Schmitz, O., Isikveren, A. T., and Hornung, M. "Electrically Powered Propulsion: Comparison and Contrast to Gas Turbines." Deutscher Luft- und Raumfahrtkongress 2012, Paper 1358. Berlin, Germany.

Propulsion Architecture Metrics

Specific Power: The gravimetric specific power of the complete propulsion architecture, based upon the useful power.

Thrust Specific Power Consumption: Relates the supplied power to the useful thrust generated by the complete propulsion system architecture. Algebraically, this quantity is also equivalent to the freestream forward speed divided by the overall propulsion system (global chain) efficiency.

Increment Efficiency due to Aero-propulsion: The increment in overall propulsion system efficiency attributable to aero-propulsion effects only, e.g. Boundary Layer Ingestion, Wake Filling, Distributed Propulsion.

Global Chain Efficiency: The complete exergetic efficiency with the chain ranging from stored energy to the propulsor(s) that delivers motive/useful thrust.

Typical Mission Profile

Many of the fields stated below have scope to input relevant comments under the column "Power Management, Allocation, and Control Strategy." Pertinent information should include (but should not be limited to) aspects like Degree-of-Hybridization for Useful Power, Degree-of-Hybridization for Useful Thrust, as well as the speed schedule of the aircraft. Degree-of-Hybridization for Useful Power/Thrust is defined as a non-dimensional quantity that expresses the instantaneous amount of useful power/thrust delivered by the electrically sourced propulsors divided by the total power/thrust delivered by the combined thermal engine and electrically sourced propulsors.

Stage Length: The distance flown by an aircraft between take-off and landing. The average stage length is commonly used, which is on an annual basis the ratio of total distance flown to the number of departures by an aircraft.

Gate: The mission phase where departure is initiated, consisting of the aircraft push-back from the gate. During this time, a tug or other towing system is typically used to prepare the aircraft for taxiing.

Taxi-out: The mission phase between the aircraft push-back from the gate (off-block time) and take-off. During this time the aircraft is maneuvered from the gate to the take-off runway through a series of taxiways.

Hover: Relevant to Vertical Take-off and Landing (VTOL) vehicles, or other systems with thrust-to-weight ratios greater than 1. This phase constitutes flying the vehicle from the ground vertically, typically before initiating climb or during the final stages of approach before landing.

Take-off: This mission phase occurs after taxi-out and continues until clearance of a critical obstacle height. For Conventional Take-off and Landing (CTOL) aircraft, the aircraft is accelerated across the runway in a high-lift configuration and eventually lifts off of the ground. This phase features several regulatory V-speeds, such as V_1 (Take-off Decision Speed), V_2 (Take-off Safety Speed), V_R (Rotation Speed), and V_{LOF} (Lift-off Speed). During this phase the Take-off Field Length required serves as a useful metric to determine runway infrastructure requirements, which consists of the ground distance traveled from rest to clearance of a critical obstacle height.

Climb: During this phase, the aircraft is configured to increase its altitude by utilizing excess useful power available on the vehicle, beyond that required for steady, level flight. Generally, the climb phase occurs immediately following take-off and before cruise, though climb segments are also often alternated with cruise segments during long flights to permit the aircraft to cruise at higher altitudes if the gross weight is decreased (e.g. due to fuel burn-off) across the mission.

Cruise: This phase consists of flight at a constant airspeed and altitude with the goal of efficiently covering the majority of the stage length. During this phase the flight crew may change the heading of the aircraft to remain along a desired flight path or implement changes in cruise altitude.

Descent: This phase of a standard mission occurs after cruise and prior to approach. During this phase the altitude of the aircraft is reduced, typically at a constant airspeed and constant angle of descent. Intentional descent phases also can be executed in order to avoid other air traffic or undesirable weather patterns along the flight path.

Approach: This phase of an aircraft mission occurs following descent and prior to landing. During this phase the aircraft orients its heading angle with the runway and descends with a constant approach angle. The approach phase ends when the aircraft altitude falls below the critical obstacle height, after which it enters the landing phase. Different methods exist in practice for conducting the approach phase depending on the approach speed of the aircraft and instrumentation. These methods can be broadly separated into instrument approach and visual approach.

Landing: The landing phase of an aircraft mission occurs following the approach phase and ends after the aircraft is safely oriented on the ground for taxi-in. During this phase a landing flare maneuver is performed to allow the landing gear to make contact with the ground, and brakes are applied to slow the aircraft, either to rest or to a speed appropriate for taxi-in. For fixed-wing aircraft, spoilers will often be deployed to decrease the lift produced by the wings and increase the vehicle drag, which aids in reducing the speed of the aircraft.

Taxi-in: This phase of an aircraft mission occurs following the landing phase. During this phase the aircraft leaves the runway and is maneuvered to the arrival gate, following the direction of the local air traffic control. After arriving at the gate at the conclusion of taxi-in, the aircraft mission has been completed.

Holding/Loiter: The hold phase of an aircraft mission consists of intentionally cruising in the air along a specified pattern over a region of airspace. For commercial vehicles, hold phases can occur toward the end of a mission near the destination airports in order to permit extra time for landing clearance to be granted by local air traffic control. The loiter phase of an aircraft mission consists of intentionally cruising in the air over a pre-defined region of ground space.

Contingency: As a part of planning a mission, aircraft are required to carry sufficient energy in reserve to be able to stay aloft in the event of unforeseen delays in the nominal flight plan. This contingency required is typically identified either as a certain percentage of the total supplied energy or calculated based on an additional time aloft requirement.

Diversion: This phase of flight occurs in the event where an aircraft is unable to land at the airport originally scheduled. The aircraft is instead routed to an alternate arrival airport. A diversion may be necessary in the event of inclement weather, medical emergencies on-board the aircraft, or unforeseen circumstances at the original arrival airport.

Aircraft Design Weights

Maximum Take-off Weight: The certified maximum mass in which an aircraft is permitted to take-off taking into consideration design and/or operational limitations.

Maximum Landing Weight: The certified maximum mass in which an aircraft is permitted to land taking into consideration design and/or operational limitations.

Manufacturer's Weight Empty, Green: Empty mass of an aircraft that comprises structures, non-propulsive systems, the complete propulsion system, and any other items or equipment deemed necessary. This mass excludes any furnishings related to passengers and operational items.

Operating Weight Empty or Basic Operating Weight: The summation of Manufacturer's Weight Empty Green, cabin furnishings, flight crew, cabin crew, catering, emergency equipment, and all operational fluids (e.g. engine oil, coolants, trapped fuel). This value excludes the useful load (useable fuel and payload) of an aircraft defined for a flight/mission. By virtue of industry convention, the term OWE is used to describe commercial transports and BOW is used to describe executive transports.

Maximum Payload Weight: The maximum mass an aircraft is permitted to accommodate for transportation. Payload can comprise any combination of passengers, baggage, cargo, freight, instruments, specialized equipment, or munitions.

Maximum Zero-Fuel Weight: The certified maximum mass of an aircraft equal to the summation of Operating Weight Empty or Basic Operating Weight and the maximum payload. It is equivalent to the maximum permissible mass of an aircraft with no useable fuel.

Total Release Energy Weight: Amount of chemical fuel mass plus ancillary energy source mass in order to complete a given flight/mission. The flight/mission definition comprises the block (includes all operational phases ranging from start-up to shut-down), as well as all contingency and reserves allowances.

Release Fuel Weight: Amount of chemical fuel mass in order to complete a given flight/mission. The flight/mission definition could comprise the block (includes all operational phases ranging from start-up to shut-down), as well as all contingency and reserves allowances.

Release Ancillary Energy Source Weight: Amount of ancillary energy source mass in order to complete a given flight/mission. The flight/mission definition could comprise the block (includes all operational phases ranging from start-up to shut-down), as well as all contingency and reserves allowances.

Aircraft Sizing Parameters and Metrics

Wing Loading: Maximum all-up mass (Maximum Take-off Weight) divided by the reference wing area of an aircraft.

Reference Wing Area: The projected equivalent straight trapezoidal planform area bounded by the wing leading and trailing edges, and, the wingtips. The manner in which the reference wing area is defined is subject to a given convention, e.g. Boeing Wimpress, Airbus Gross, ESDU, Weighted MAC and Net.

Reference Wing Aspect Ratio: Non-dimensional parameter quantifying the ratio of the span to the mean chord of a given reference wing planform. Typically, the mean chord is defined according to the Mean Aerodynamic Chord convention.

Disc Loading: For Vertical Take-off and Landing (VTOL) vehicles, the maximum all-up mass (Maximum Take-off Weight) of an aircraft divided by the reference disc area of the rotor(s).

Reference Disc Area: An equivalent circular area representative of the rotor(s) area swept by the blades of rotor(s) utilized by a Vertical Take-off and Landing (VTOL) vehicle.

Number of Rotors and Number of Blades for Each Rotor: The number of rotors (collection of blades for a given propulsor device) and number of blades for each rotor.

Maximum Mechanical Speed: The corresponding maximum speed of the rotor device at the shaft.

MWE/MTOW: Non-dimensional mass efficiency metric that relates the Manufacturer's Weight Empty Green (MWE) to the Maximum Take-off Weight (MTOW).

OWE (BOW)/MTOW: Non-dimensional mass efficiency metric that relates the Operating Weight Empty (OWE) or Basic Operating Weight (BOW) to the Maximum Take-off Weight (MTOW).

OWE (BOW)/PAX: Mass efficiency metric that relates Operating Weight Empty (OWE) or Basic Operating Weight (BOW) to the number of passengers (PAX) corresponding to a standard passenger Layout of Passenger Arrangement (LOPA).

Release Energy Weight/MTOW: Non-dimensional mass efficiency metric that relates the total release energy mass to the Maximum Take-off Weight (MTOW) of the aircraft.

MLW/MTOW: Non-dimensional ratio of the Maximum Landing Weight (MLW) and the Maximum Take-off Weight

(MTOW).

Conditions Describing Total Maximum Thrust or Power: Information in this field provides a background, such as assumed ambient conditions (elevation or altitude, Outside Air Temperature), speed, engine/motor rating, level of derate, flat rating temperature, amongst other considerations. It serves to contextualize data presented in subsequent fields. It is highlighted that this field also should contain information that tends to offer a breakdown of thrust and power values for each artifact that comprises the complete hybridized propulsion system.

Total Maximum Thrust: The total amount of useful thrust collectively produced by the propulsor(s) for purposes of affording flight capability and/or maneuverability of the aircraft.

Total Maximum Shaft Power: The total amount of installed power (at the shaft) collectively servicing the propulsor(s) for purposes of affording flight capability and/or maneuverability of the aircraft.

All-Engines Operational Thrust-to-Weight: Non-dimensional parameter that relates the total maximum useful thrust during a normal mode of operation to the maximum all-up mass (Maximum Take-off Weight) of an aircraft.

One-Engine Inoperative Thrust-to-Weight: Non-dimensional parameter that relates the total maximum useful thrust during an abnormal mode of operation to the maximum all-up mass (Maximum Take-off Weight) of an aircraft.

AEO Maximum Power-to-Weight: The All-Engines Operational (AEO) gravimetric specific power for the complete aircraft. It is calculated by dividing the total maximum shaft power by the maximum all-up mass (Maximum Take-off Weight).

AEO Maximum Power Loading: The reciprocal of the All-Engines Operational (AEO) Maximum Power-to-Weight ratio.

OEI Maximum Power-to-Weight: The One-Engine Inoperative (OEI) gravimetric specific power for the complete aircraft. It is calculated by dividing the total maximum power by the maximum all-up mass (Maximum Take-off Weight).

OEI Maximum Power Loading: The reciprocal of the One-Engine Inoperative (OEI) Maximum Power-to-Weight ratio.

Anti-torque or Tail Rotor Power: Installed power (at the shaft) of any anti-torque device used to maintain controlled flight of an aircraft, typically rotary-wing vehicles.

Maximum Non-propulsive Power/Total Maximum Power: Non-dimensional ratio relating the maximum power required by the non-propulsive systems to the total maximum installed power (at the shaft) servicing the propulsor(s).

Total Thermal Management: The total power loading of the complete thermal regulation and control system incorporated within the aircraft.

Peak Thermal Load: The maximum total amount of thermal power that the thermal regulation and control system within the aircraft is required to service.

Operational Performance

Take-off Field Length, MTOW, ISA, SL: The total distance for an aircraft to take-off defined as the most limiting case when constraints attributable to runway length, initial (e.g. first and/or second segment) climb, climb for obstacle clearance, brake energy, tire speed, and airframe structural limits are considered. Generally, this quantity should not reflect a balanced take-off (distance to continue the take-off following recognition of engine failure equal to the distance required to stop if the take-off should be aborted). Ambient conditions are assumed to International Standard Atmosphere (ISA), sea level (SL), and, the aircraft is taken to be at Maximum Take-off Weight (MTOW) upon brakes release (b.r.).

TOFL: Special case Take-off Field Length (TOFL) according to a given set of ambient conditions and aircraft mass as defined in the four fields below.

Payload: The payload corresponding to the given special case Take-off Field Length (TOFL) and Take-off Gross Weight (TOGW).

Take-off Gross Weight: The Take-off Gross Weight (TOGW) corresponding to the stated special case Take-off Field Length (TOFL).

Specified ISA Deviation: The International Standard Atmosphere (ISA) temperature deviation corresponding to the stated special case Take-off Field Length (TOFL).

Specified Airport Elevation, AGL: The airport elevation with reference to Above Ground Level (AGL) corresponding to the special case Take-off Field Length (TOFL).

Stall Speed and Flap Setting, MTOW, ISA, SL: The stall speed of the aircraft assuming Maximum Take-off Weight (MTOW) and International Standard Atmosphere (ISA), sea level (SL) ambient conditions. Where applicable, the field requires input as to the flap setting considered.

Reference Speed and Flap Setting, MLW, ISA, SL: The reference approach speed of the aircraft assuming Maximum Landing Weight (MLW) and International Standard Atmosphere (ISA), sea level (SL) ambient conditions. Where applicable, the field requires input as to the flap setting considered.

Landing Field Length, MLW, ISA, SL: The total distance for an aircraft to land defined as the most limiting case when constraints attributable to runway length (approach, landing), climb, brake energy, and airframe structural limits are considered. Ambient conditions are assumed to International Standard Atmosphere (ISA), sea level (SL), and, the aircraft is taken to be at Maximum Landing Weight (MLW).

ICAO Cumulative Noise Margin to Chapter 14: The margin arising from a comparison against the arithmetic sum of certification levels for sideline, flyover, and approach as defined in ICAO Annex 16 Environmental Protection, Volume I, Chapter 14.

ICAO NO_x-Emissions Level: The amount of NO_x-emissions in accordance with rules stipulated by ICAO Annex 16 Environmental Protection, Volume II.

LTO NO_x-Emissions: The amount of NO_x-emissions for a given Landing/Take-off (LTO) cycle, which includes all activities near the airport that take place below an altitude of 3000 ft.

ICAO Metric Value $MVCO_2$: The amount of CO_2-emissions in accordance with rules stipulated by ICAO Annex 16 Environmental Protection, Volume III.

Maximum Operating Altitude: The maximum altitude in which the aircraft can operate as defined by its flight envelope.

Maximum Hover Altitude: The maximum altitude in which the aircraft can operate in hover mode.

Glide Ratio: A value that captures the ratio of the forward speed to the rate of descent of an aircraft.

Maximum Endurance Speed: The speed at which an aircraft can loiter or hold at a given altitude for a maximum length of time. Both calibrated and true airspeeds are required as input.

Maximum Endurance Time: The maximum duration at which an aircraft can loiter or hold at a given altitude.

Climb Speed Schedule: The typical or recommended speed schedule for climb control comprising a fixed calibrated airspeed and a fixed Mach speed.

Maximum Rate-of-Climb, MTOW b.r., ISA, SL: Maximum attainable rate-of-climb of an aircraft with ambient conditions assumed to be International Standard Atmosphere (ISA), sea level (SL), and, the aircraft is at Maximum Take-Off Weight (MTOW) upon brakes release (b.r.).

Rate-of-Climb, MTOW b.r., ISA: The instantaneous rate-of-climb of an aircraft at a specified altitude assuming ambient conditions to be International Standard Atmosphere (ISA), and, the aircraft is at Maximum Take-off Weight (MTOW) upon brakes release (b.r.).

Specified Altitude: The specified altitude corresponding to the instantaneous rate-of-climb quoted in the "Rate-of-Climb, MTOW b.r., ISA" field.

Time-to-Climb to Initial Cruise Altitude: The total duration from take-off to the initial cruise altitude of the aircraft. Ambient conditions assumed to be International Standard Atmosphere (ISA), sea level (SL) at take-off, and, the aircraft is at Maximum Take-off Weight (MTOW) upon brakes release (b.r.).

Initial or Fixed Cruise Altitude, MTOW b.r., ISA: Initial cruise altitude or specified target cruise altitude of the aircraft. Ambient conditions assumed to be International Standard Atmosphere (ISA), sea level (SL) at take-off, and, the aircraft is at Maximum Take-off Weight (MTOW) upon brakes release (b.r.).

Typical Cruise Speed: The typical or standard cruise speed of the aircraft. Expressed both in terms of Mach number and true airspeed.

Typical Cruise Lift-to-Drag: The typical or standard lift-to-drag ratio of the aircraft. Ambient conditions assumed to be

International Standard Atmosphere (ISA).

Maximum PAX/Payload Design Range and Maximum PAX/Payload Off-design Stage Length

Range and PAX: The maximum distance flown corresponding to a nominated number of accommodated passengers (PAX). The PAX entry would be taken as blank if the payload entry does not entail passengers.

Payload: The amount of payload corresponding to the stated maximum range quoted.

Block Fuel: The amount of expended fuel for all phases of operation from propulsion start-up phase to shut-down after taxi-in. This quantity does not contain any reserves or contingency allowances.

CO_2-Emissions: The total equivalent CO_2-emissions reflecting the quoted block mission.

Block Fuel per PAX: The block fuel normalized by the number of passengers (PAX).

CO_2-Emissions per PAX: The total equivalent CO_2-emissions normalized by the number of passengers (PAX).

[Fuel] Specific Air Range: The overall performance efficiency of the aircraft with regards to expended chemical fuel. The fuel quantity reflects that of the block mission.

Block Energy: The total energy expended for the block mission of the aircraft.

Block Energy per PAX: The total energy expended for the block mission normalized by the number of passengers (PAX).

Degree-of-Hybridization for Block Energy: A non-dimensional quantity that expresses the amount of stored electrical energy divided by the total energy (chemical fuel plus stored electrical) utilized for the stated block mission.

Energy Specific Air Range: The overall performance efficiency of the aircraft with regards to the total expended energy. The energy quantity (chemical fuel plus stored electrical) reflects that of the block mission.

Mission Energy Index: A vehicular efficiency metric calculated by dividing the total expended energy of the block mission by the Maximum Take-off Weight (MTOW) and the maximum design range of the aircraft.

Operating Cost Assumptions: The underlying assumptions and methodology used to calculate cost of operation associated with the block mission. Typically, for initial technical assessments or pre-design/conceptual design activities, only Cash Operating Cost (COC) plus Additional Operating Cost (AOC) analysis is performed. The COC is defined to be a tally of expenditures related to fuel, crew, maintenance, airport, and en route charges. The AOC covers external noise, and, NO_x-emissions and CO_2-emissions related charges. For purposes of undertaking a Direct Operating Cost (DOC) analysis, Cost of Ownership (which includes depreciation, interest, and insurance costs) requires a suitably robust prediction of aircraft list/next available price reflecting the prognosticated value the aircraft will have in the targeted market segment.

Operating Cost: The operating cost for the given block mission. The currency units are in US Dollars (USD).

Operating Cost per PAX: The operating cost per passenger (PAX) for the given block mission. The currency units are in US Dollars (USD).

Properties/Attributes of Components and Sub-systems

		SI Units	SI Value	Imperial Units	Imperial Value	Max./Avg. Efficiency
Engine	Fuel Specific Energy and Type	kWh/kg [type]	xx.xx [xxxx]	BTU/lbm	xx.xx	
Engine	Engine Designation and Type	xxxxxx [xxxxx]				
Engine	Maximum Rated Thrust Maximum Rated Power	kN kW	xxxx xxxx	lbf hp	xxxx xxxx	
Engine	Core Specific Power	kW/kg	xxxx	hp/lbm	xxxx	xx.x%
Engine	Thrust Specific Fuel Consumption Brake Specific Fuel Consumption Thrust Power Speed Altitude	g/N.s g/W.s kN kW M ft	xxx xxx xxxxx xxxxx Mx.xx xxxxx	lbm/lbf.h lbm/hp.h lbf hp KCAS	xxx xxx xxxx xxxx xxx	xx.x%
Battery	Type and Chemistry	xxxxxxxxxx				
Battery	Cell-to-System Description	xxxxxxxxxx				
Battery	C-rate and E-rate Capacity	- A.h	xC and xE xxx			
Battery	Burst Rate and Duration	- [s]	xC [xx]			
Battery	System-Level Specific Energy	Wh/kg	xxx	BTU/lbm	xxx	
Battery	Cell-Level Specific Energy	Wh/kg	xxx	BTU/lbm	xxx	
Battery	Operating and Float Voltage	V (oper.) V (float)	xxx xxx			
Battery	Internal Resistance	Ω	xx			
Battery	System-Level Energy Density	Wh/L	xxx	BTU/gal	xxx	
Battery	Cycle Stability Criterion	cycles	xxxx			≥ xx% SOC
Battery	Cycle Stability Criterion	cycles	xxxx			≤ xx% SOC
Battery	Impedance Margin and Cycles	(-) [cycles]	xx.x% [xxxx]			
Battery	System-Level Specific Power	W/kg	xxx	hp/lbm	xxx	xx.x%
Battery	System-Level Power Density	W/L	xxx	hp/gal	xxx	
Battery	Total Thermal Management and Parasitic Power Safety Features Total: *itemize constituents as required*	kg/kW(th) [kW] kg/kW *kg/kW*	xxx [xxx] xxx *xxx*	lbm/hp(th) [hp] lbm/hp *lbm/hp*	xxx [xxx] xxx *xxx*	
Battery	Charger-Specific Power	kW/kg	xxx	hp/lbm	xxx	xx.x%
Battery	Charge Voltage and C-Rate	V [-]	xxx [xC]			
Capacitor	Specific Energy and Type	Wh/kg [type]	xxx [xxxxx]	BTU/lbm	xxx	
Capacitor	Specific Power	W/kg	xxx	hp/lbm	xxx	xx.x%
Capacitor	Charge Voltage and Cycles	V [cycles]	xxx [xxxx]			
Fuel Cell	Specific Power and Type [a]stack-level; [b]system-level	kW/kg kW/kg [type]	x.x[a] x.x[b] [xxxxx]	hp/lbm hp/lbm	x.x[a] x.x[b]	xx.x%[b]
Fuel Cell	Stack-to-System Description	xxxxxxxx				
Fuel Cell	System-Level Power Density	W/L	xxx	hp/gal	xxx	
Fuel Cell	Start-up Time	min.	xx			
Fuel Cell	Compressors or Pressurization System Power (pressurized air at altitude or O_2 at sea level)	kW/kg	xxx	hp/lbm	xxx	
Fuel Cell	Storage Energy Carrier Pressure Safety Features Total: *itemize constituents as required*	kWh/kg energy carrier bar kg/kW *kg/kW*	xxx xxxx xxx xxx *xxx*	BTU/lbm psi lbm/hp *lbm/hp*	xxx xxx xxx *xxx*	
Fuel Cell	Percentage Balance of Plant	-	xx.x%			

		SI Units	SI Value	Imperial Units	Imperial Value	Max./Avg. Efficiency
	Total Thermal Management and Parasitic Power Safety Features Total: *itemize constituents as required*	kg/kW(th) [kW] kg/kW *kg/kW*	xxx [xxx] xxx *xxx*	lbm/hp(th) [hp] lbm/hp *lbm/hp*	xxx [xxx] xxx *xxx*	
	Technology Notes and Approach	xxxxxxx				
Motor/Generator	Maximum Power	kW (shaft) kW (useful)	xxxx xxxx	hp (shaft) hp (useful)	xxxx xxxx	
	Maximum Rated Motor Specific Power	kW/kg	x.x	hp/lbm	x.x	xx.x%
	Maximum Rated Motor Specific Torque	N.m/kg	xxxx	lbf.ft/lbm	xxxx	
	Rated Motor Power Rated Motor Torque Rated Motor Speed Maximum Speed at Constant Power Maximum Mechanical Speed	kW N.m RPM RPM RPM	xxxx xxxx xxxxx xxxxx xxxxx	hp lbf.ft	xxxx xxxx	xx.x%
	Motor Efficiency at 100% Load Motor Efficiency at 75% Load Motor Efficiency at 50% Load Motor Efficiency at 25% Load					xx.x% xx.x% xx.x% xx.x%
	Maximum Rated Motor Linear Speed Limit	m/s	xxx	ft/s	xxx	xx.x%
	Over-Speed Limit Over-Temperature Limits	%RPM °C	xxx% xxx	 °F	 xxx	
	Maximum Rated Generator Specific Power	kW/kg	x.x	hp/lbm	x.x	xx.x%
	Rated Generator Torque Rated Generator Speed	N.m RPM	xxxx xxxxx	lbf.ft	xxxx	
	Power Electronics Processed Power	%Rated	xx.x%			
	Total Thermal Manag. and Parasitic Power Safety Features Total: *itemize constituents as required*	kg/kW(th) [kW] kg/kW *kg/kW*	xxx [xxx] xxx *xxx*	lbm/hp(th) [hp] lbm/hp *lbm/hp*	xxx [xxx] xxx *xxx*	
Propulsive Device	Attributes of the Propulsive Device	xxxx				
	[Ducted Fan] Pressure Ratio	1.xx	1.xx			
	Prop./Fan Max. Corrected Tip Speed (Aero)	m/s	xxx	ft/s	xxx	
	Propeller/Rotor Specific Power and/or Fan Specific Power	kW/kg kW/kg	x.x x.x	hp/lbm hp/lbm	x.x x.x	xx.x% xx.x%
Trans-mission	Gearbox Specific Power and Gearing Ratio Total Thermal Manag. and Parasitic Power Safety Features Total: *itemize constituents as required*	kW/kg (-) kg/kW(th) [kW] kg/kW *kg/kW*	xxx (x:1) xxx [xxx] xxx *xxx*	hp/lbm lbm/hp(th) [hp] lbm/hp *lbm/hp*	xxx xxx [xxx] xxx *xxx*	xx.x%
Power Electronics	AC-DC Rectifier Specific Power Total Thermal Management and Parasitic Power Safety Features Total: *itemize constituents as required*	kW/kg kg/kW(th) [kW] kg/kW *kg/kW*	xxx xxx [xxx] xxx *xxx*	hp/lbm lbm/hp(th) [hp] lbm/hp *lbm/hp*	xxx xxx [xxx] xxx *xxx*	xx.x%
	DC-AC Inverter Specific Power Total Thermal Manag. and Parasitic Power Safety Features Total: *itemize constituents as required*	kW/kg kg/kW(th) [kW] kg/kW *kg/kW*	xxx xxx [xxx] xxx *xxx*	hp/lbm lbm/hp(th) [hp] lbm/hp *lbm/hp*	xxx xxx [xxx] xxx *xxx*	xx.x%
	DC-DC Converter Specific Power Total Thermal Manag. and Parasitic Power Safety Features Total: *itemize constituents as required*	kW/kg kg/kW(th) [kW] kg/kW *kg/kW*	xxx xxx [xxx] xxx *xxx*	hp/lbm lbm/hp(th) [hp] lbm/hp *lbm/hp*	xxx xxx [xxx] xxx *xxx*	xx.x%
	Controller and Type	kW/kg [type]	xxx [xxxxx]	hp/lbm	x.x	xx.x%
	Bus Voltage for Propulsion System and Type Maximum Operating Power	V [AC or DC] kW	xxx [xC] xxx	 hp	 xxx	
	Bus Voltage for Non-Prop. System and Type Maximum Operating Power	V [AC or DC] kW	xxx [xC] xxx	 hp	 xxx	
	Bus AC Grid Frequency	Hz	xxxx			

		SI Units	SI Value	Imperial Units	Imperial Value	Max./Avg. Efficiency
	Transmission	kg/m.kA	xxx	lbm/ft.kA	xxx	xx.x%
	Cross-Sectional Area and Wire Gauge	mm^2 (-)	xxx (xx)	sq.in	xxx	
	EMI/EMC Shielding	kg/m.kV	xxx	lbm/ft.kV	xxx	
	Active Cooling Measures	kg/m.kA	xxx	lbm/ft.kA	xxx	
	Wiring Total Length and No. of Contactors	m (-)	xx (xx)	ft	xx	xx.x%
Protec-tion	Specific Power and Types	kW/kg [types]	x.x [xxxx]	hp/lbm	x.x	xx.x%
	Fault Current	A	xx			

Glossary for Properties/Attributes of Components and Sub-systems

This section has been itemized and sequenced according to the classification shown in the first column of the **Properties/Attributes of Components and Sub-systems** table.

As advanced propulsion systems begin to comprise multiple energy sources, such as electrical or even alternative chemical fuels, in conjunction with traditional aviation fuels, it is necessary to offer a brief discussion about how one compares and contrasts various energy/power devices on a like-for-like basis. The two common comparison standards presented here are the [Gravimetric] Specific Energy and [Gravimetric] Specific Power.

Preamble

[Gravimetric] Specific Energy (Consumption)

For propulsion and power systems that utilize chemical fuels the metric Specific Fuel Consumption (SFC) represents the conversion efficiency of the fuel into power. SFC can be expressed in two ways: Thrust Specific Fuel Consumption (TSFC, g/N.s or lbm/lbf.h); or, Brake Specific Fuel Consumption (BSFC, kg/kW.h or lbm/BTU or lbm/hp.h). Neither consider system infrastructural aspects that are requisite to generating useful thrust or power. BSFC can be expressed as an equivalent Specific Energy with units kW.h/kg or BTU (hp.h) per lbm fuel, and when speed and efficiency are known, TSFC lbm fuel per lbf.h also can be calculated. Therefore, Specific Energy (also represented as BSFC) relates to the process of converting a quantity of fuel flow (in units kg/h or lbm/h) of an energy resource (taking into account the ideal latent heating value of a propellant) into mechanical shaft power, after considering conversion efficiencies. Below are a series of examples as to how a variety of energy conversion devices could be compared and contrasted on an equitable basis:

Battery: discharge of *xxx lbm* (weight retained) per BTU (or per hp.h) assumes efficiency losses across the drive-train (e.g. controllers, transmission lines, converters/inverters, motor, fan, Battery Management System [BMS]), and/or battery margins (e.g. 80% maximum State-of-Charge, and minimum 20% according to state-of-the-art, 20% impedance loss, etc.). BSFC (in this case) does not normally include the weight of the requisite sub-systems to supply the motor(s) with conditioned power, which are often lumped into the aircraft empty weight.

Fuel Cell: *xxx lbm* of, for example, hydrogen, is consumed per BTU or per hp.h (including efficiency losses, of fuel cell, controls, etc.). BSFC (in this case) should relate to the fuel rate/weight, and efficiency losses (e.g. Proton-Exchange Membrane or PEM cell, etc.); but again, not the infrastructure (covered later).

Turbo-shaft: *xxx lbm* of propellant is consumed per BTU or per hp.h (including efficiency losses, such as 45% thermal conversion of fuel to power, or hot-and-high lapse). BSFC (in this case) again relates to the fuel rate/weight, and efficiency losses (e.g. cycle, recovery, nozzle efficiencies, bleed, high-pressure extraction, etc.), but again, not the infrastructure (covered later).

Hydrate: *xxx lbm* of hydrate is consumed per BTU or per hp.h (including efficiency losses, such as xx% volumetric capacity, or conversion efficiency to electricity (e.g. PEM, etc.). BSFC (in this case) again should relate to the fuel rate/weight, and efficiency losses (e.g. catalyst reactor, PEM, etc.); but again, not the infrastructure (covered later).

[Gravimetric] Specific Power (or Thrust)

Specific power (or thrust) is essentially a representation of power (or thrust) to weight ratio for engines or motors, and is expressed as kW/kg or hp/lbm. It describes a ratio between supplied (gross) power (thrust) or useful (net output) power (thrust), and, the overall power plant weight. The difference between supplied (gross) power and useful (net) power relies on account of efficiency for a given speed and ambient conditions. Ideal (gross) power is often uninstalled, while net power is installed. Typically, manufacturers quote ideal (gross) power-to-weight because variances in installations will dramatically (adversely) affect net power-to-weight ratio. Specific power (like thrust-to-weight ratio) refers to the power plant, not the fuel, and not to ancillary supporting infrastructures. In the context of thermal engines (turboshaft, turboprop/jet/fan), specific power can be thought of as a metric that captures the efficiency of a power plant to convert an energy resource (e.g. fuel) into power. Below are a series of examples as to how a variety of power conversion devices could be compared and contrasted on an equitable basis:

Battery: For a given amount of power produced there would be a summation of system element(s) necessary to arrive at the (as of yet) uninstalled power-to-weight ratio of the power plant hp/lbm. System weights might include items that are directly in power production path (e.g. controllers, transmission lines, AC/DC or DC/DC converters, battery reserves, etc.); whereas, ancillary sub-systems that predominantly support installation will later be accounted for under the aircraft empty weight installation fraction (discussed later). Examples might include the Environmental Control System (ECS), heating/cooling, heat exchangers, inlets/ducts/exhausts, vents, armor/safety systems, BMS, and if thrust-to-weight, then motors and fans.

Fuel Cell: For a given amount of power produced, there would be a base amount of systems, for which weights would be summed, to arrive at power (or thrust) to weight ratio. This might include a fuel cell, or air compressors/oxygen generators for operation at altitude, etc. Additional mission specific items will be captured under aircraft empty weight installation fraction (discussed next). Examples of this might be hydrogen conformal tanks (sized to fit vehicle volume), as opposed to an ideal "sphere" or compressors to maintain liquid state.

Turbo-shaft: In this case the main item necessary to create power is essentially the engine (nozzle included usually). If electric power is desired, then additional "operational" items such as generators, gearboxes, transmissions, etc. will be captured under the aircraft empty weight installation fraction (discussed next).

Hydrate: In this case the main items necessary to create power are a reactor, catalyst system, plumbing, and (usually) a PEM fuel cell to generate electrical power. Any and all other ancillary or "operational" items that are necessary for sustained operation would be captured under aircraft empty weight installation fraction (discussed next).

[Gravimetric] Mission Specific Installation Weight Fraction

Specific energy and power described above explicitly referred to the fuel and power plant (respectively). These are general terms used in the industry that typically address uninstalled systems. Installation considerations are often left unstated because the general nature of the installation is not known until the energy/power system is applied to a given mission. Thus, for a given mission, all ancillary systems required to meet the objective operational envelope should be documented, at least within reason, as these form the initial basis for an Interface Control Documentation (ICD) process. The purpose of stating features necessary, even if quantities are estimates, serves as a placeholder that will later be reviewed and refined for better fidelity. Therefore, unlike before where the fuel or power plant were the subject of the metric, here, the requisite systems installation are the focus. To set this metric apart from specific energy/power, perhaps a energy/power loading type metric, i.e. lbm/BTU (or lbm/hp.h) or lbm/hp, should be considered. For example:

Battery: In addition to the batteries, there are many installation features that often go unstated, but these can add up and significantly (adversely) affect the overall installation. Installation features accounted for here are those not captured under specific energy/power discussed above. Examples might include weights of: controllers, transmission lines, converters/inverters, motors, fans, BMS, fire suppression systems, armor bays/cells, vents (as well as inlets/exhausts, or pressurization), racks and rollers (for R&R, namely, removing and replacing), heating/cooling systems, robust connectors, secured mounting, etc. If known, these can be broken out individually, or in the case of conceptual design, lumped together and estimated as best as possible (knowing these will be better quantified at later date). Again, these can either be summed into one (or more) weight sheet categories ranging from something very generic (e.g. battery installations) to very detailed (e.g. battery cooling fluid), but all get rolled up under vehicle empty weight.

Fuel Cell: Ancillary equipment necessary for proper operation might include weight of conformal tanks, e.g. for liquid hydrogen.

Turbo-shaft: Ancillary equipment can include the inlet, exhaust, gearbox or Airframe Mounted Accessory Drives (AMADs), bleed lines, etc. that are necessary to sustain proper flight operations. The lbm/hp or lbm/BTU (or lbm/hp.h) conditions also can be stated (e.g. for take-off at sea level, or cruise at given altitude).

Hydrate: Items such as tanks, air compressors, and any other systems, not included in the specific energy/power figures, would be identified, reported, and summed here.

Given all three parameters, a better view of what the final installed system will actually represent can be obtained for more meaningful comparisons. Again, even if the explicit values are not known, specifying what "anticipated" systems are required for proper realization of projected performance levels begins the process of forming a coherent ICD, and serves as a basis for tracking increasingly higher fidelity figures.

Engine

Fuel Specific Energy and Type: Gravimetric specific energy of the chemical fuel only, and the corresponding designation. Chemical fuel is taken to be one which facilitates deflagration/combustion.

Engine Designation and Type: Name of the engine (generic designation or industrial product moniker) and the thermodynamic cycle it utilizes.

Maximum Rated Thrust: Maximum rated thrust generated by the engine. Typically quoted assuming static conditions and at International Standard Atmosphere (ISA), sea level standard (SL).

Maximum Rated Power: Maximum rated shaft power generated by the engine. Typically quoted assuming International Standard Atmosphere (ISA), sea level standard (SL).

Core Specific Power: The combined gravimetric specific power of the core system, quoted assuming installed (shaft) power. Also known as power-to-weight ratio.

Thrust Specific Fuel Consumption: Thrust Specific Fuel Consumption is a metric describing the extent of fuel efficiency of an engine with respect to thrust output.

Brake Specific Fuel Consumption: The Brake Specific Fuel Consumption is a metric describing the extent of fuel efficiency of an engine with respect to rotational or shaft power.

Thrust: The corresponding thrust coinciding with the quoted Thrust Specific Fuel Consumption given previously.

Power: The corresponding installed (shaft) power coinciding with the quoted Brake Specific Fuel Consumption given previously.

Speed: The freestream Mach number and Calibrated Airspeed coinciding with the quoted Thrust Specific Fuel Consumption or Brake Specific Fuel Consumption given previously.

Altitude: The altitude coinciding with the quoted Thrust Specific Fuel Consumption or Brake Specific Fuel Consumption given previously.

Battery

Definitions (not presented as fields within the table)

Battery Management System (BMS): The hardware and software used to monitor the state of the cells comprising the battery system and to regulate rates of charge and discharge.

Characteristic Thermal Threshold (CTT): A temperature beyond which a rechargeable battery cell will exhibit permanent deterioration of its critical performance parameters.

Energy Storage System (ESS): A complete energy storage device consisting of one or more energy storage cells arranged into one or more packs, with ancillary subsystems for physical support and enclosure, thermal management, and electronic control. Typical energy storage cells include but are not limited to batteries or capacitors.

State of Health (SOH): The drop-in capacity of a battery on repeated use, when compared with the capacity of a healthy battery.

Thermal Runaway: Denotes a condition where the internal heat generation exceeds the rate at which heat can be dissipated from the battery system, leading to a rapid self-sustained heating of a cell which is accompanied by exothermic cell material chemical reactions.

Venting: The release of excessive internal pressure from a cell or pack in a manner intended by design to preclude rupture or explosion.

Fields Presented Within the Table

Type and Chemistry: A battery is a device composed of electro-chemical cells used to convert chemical energy to electrical energy. A battery type is typically the name of the battery (generic designation or industrial product moniker) and a description of the corresponding chemistry utilized by the voltaic cells (also recommend identifying elements used for the anode and cathode). A general classification should also be stated in this field, i.e. whether "high-power," "high-energy," or "high-durability."

Cell-to-System Description: Itemization of what peripherals are needed in order to configure the fully integrated battery device. Considerations could include provision for packaging, cycle stability with corresponding design life, aging effects, minimum State-Of-Charge (SOC), thermal management, safety features, and sensing requirements, amongst others.

C-rate and E-rate: Maximum steady-state current (amps) at which the battery cell or pack may be discharged without having pack temperature exceed the Characteristic Thermal Threshold (CTT) of its constituent cell(s) or result in a reduction in cell life. C-rate is expressed as a multiple of the cell or pack capacity. 1C rate infers current will discharge the entire battery in one hour. For a battery with a capacity of 100 Ah, this equates to a discharge current of 100 A. 5C rate for this battery would be 500 A, and a C/2 rate would be 50 A. E-rate describes the discharge power. A 1E rate is the discharge power to discharge the entire battery in one hour.

Capacity: The Coulometric capacity expressed in Amp-hours. It is calculated by multiplying the discharge current by the discharge time (in hours) at the specified C-rate from 100 percent State-Of-Charge (SOC) to the cut-off voltage.

Burst Rate and Duration: A measure of the maximum current that can be drawn for an extremely short period of time (typically assumes 30 s) before damage sets in. Duration of the discharge also needs to be specified.

System-Level Specific Energy: The gravimetric specific energy content of the battery device.

Cell-Level Specific Energy: The gravimetric specific energy content of a given cell.

Operating and Float Voltage: The reference or nominal voltage of a battery device is referred to as the operating voltage. The float voltage is one that maintains the battery at full capacity, thereby countering any self-discharge tendencies (internal chemical reactions tend to reduce the stored charge of a battery).

Internal Resistance: Maximum resistance of an operating/discharging battery. Does not necessarily reflect charging internal resistance.

System-Level Energy Density: The volumetric specific energy of the battery device.

Cycle Stability Criterion (option 1): The number of discharge-charge cycles the battery device can experience before it fails to meet specified performance criteria. This particular field input corresponds an inequality constraint defined as operation assuming always greater than a given State-Of-Charge (SOC) value. For example, 1500 cycles if the state-of-charge during operation > 20%.

Cycle Stability Criterion (option 2): The number of discharge-charge cycles the battery device can experience before it fails to meet specified performance criteria. This particular field input corresponds to an inequality constraint defined as operation assuming less than a given State-Of-Charge (SOC) value.

Impedance Margin and Cycles: This particular field requires an input capturing the amount of relative impedance increase (internal resistance tends to increase with aging) a battery device will tolerate before failing to meet specified performance criteria. For example, a range of typical impedance margin is +30% to +100%. The corresponding number of discharge-charge cycles according to this definition of battery device life is also expected as an input.

System-Level Specific Power: The gravimetric specific power of the battery device. Also known as power-to-weight ratio.

System-Level Power Density: The volumetric specific power of the battery device.

Total Thermal Management and Parasitic Power: Total power loading of the complete thermal regulation and control system incorporated within the battery device. Additionally, total amount of power to operate thermal regulation and control system is requested.

Safety Features Total: The power loading of each itemized artifact that constitutes the complete thermal regulation and control system incorporated within the battery device.

Charger Specific Power: The gravimetric specific power delivered when the battery device is in charging mode. Also known as power-to-weight ratio.

Charge Voltage and C-Rate: The amount of constant voltage when the battery device is charged to full capacity. Charging schemes generally consist of a constant current (noting the corresponding C-Rate) charging until the charge voltage is reached, thereafter, allowing the charge current to taper until it is very small.

CAPACITOR

Specific Energy and Type: A capacitor is a passive electrical device consisting of a pair of conductors separated by a dielectric (insulator). When a potential difference (voltage) exists across the conductors, an electric field, which stores energy, is present in the dielectric. The gravimetric specific energy as well as the capacitor type is the required input. Type infers the category in which the capacitor is classified, e.g. super-capacitor, electrolytic.

Specific Power: The gravimetric specific power of the capacitor. Also known as power-to-weight ratio.

Charge Voltage and Cycles: Voltage needed to charge the capacitor device to full capacity. Additional expected information is the number of discharge-charge cycles the capacitor device can experience before it fails to meet specified performance criteria.

FUEL CELL

Specific Power and Type: Describes the gravimetric specific power of the complete fuel cell device. A component with a maximum rated power of 2 MW and a specific power of 2 kW/kg will be associated with a weight of 1000 kg. Also known as power-to-weight ratio. Scope is given in this field to present information at stack-level or system-level. The type of fuel cell can also be input.

Stack-to-System Description: Itemization of what peripherals are needed in order to configure the fully integrated fuel cell system – a notion of what constitutes the balance-of-plant of the fuel cell device. A fuel cell stack is an array of individual fuel cells connected in series to produce increased voltage, relative to a single fuel cell in isolation. Individual fuel cells typically provide DC supplies of less than 1 V, so combining multiple cells in series is often required in practice to meet the requirements of the electrical load. A fuel cell system is the full combination of a fuel cell stack and the additional components required for operation of a fuel cell. Typical fuel cell system components include the fuel cell stack, fuel conditioning systems, humidifiers, air compressors and conditioning systems, power conditioning systems, and pumps.

System-Level Power Density: Describes the ratio of rated power to total displaced volume of the fuel cell device. A fuel cell device with a maximum rated power of 2 MW and a power density of 25 kW/L would occupy a volume of 80 L. Also known as volume specific power or volume power density.

Start-up Time: Duration to achieve the optimal operating temperature, thereby providing the nominal power delivered by the fuel cell device. The process of introducing fuel into the anode of the fuel cell, with air or oxygen supply to the cathode, to begin the generation of electric current. After being shut down for extended periods of time, air typically permeates into the anode side of the fuel cell, which is purged by the inflow of fuel during startup. Typical start-up times vary depending on the type of fuel cell being used and are typically as short as 1 s or as long as 10 mins, or longer.

Compressors or Pressurization System Power (pressurized air at altitude or O_2 at sea level): The collective gravimetric specific power of the charging system comprising any compressor(s) or pressurization system(s), thus providing necessary pressurized air or O_2 to the fuel cell device.

Storage: The gravimetric specific energy of the complete storage system supporting the fuel cell device.

Energy Carrier: Substance used to contain/store energy, which can be converted into other forms of energy. Examples include Jet-A1 fuel and hydrogen (which can be converted into mechanical or electrical energy for aircraft propulsion and power).

Pressure: The level of pressure required to store the stated energy carrier.

Safety Features Total: The power loading of each itemized artifact that constitutes the complete thermal regulation and control system incorporated within the energy carrier storage artifact.

Percentage Balance-of-Plant: The components of a fuel cell system that exclude the fuel cell stack. Components included in the balance-of-plant may include, for example, air compressors, heat exchangers, pumps, transformers, inverters, and humidifiers. This value quotes the percentage of mass increase based upon the fuel cell stack mass.

Total Thermal Management and Parasitic Power: The total power loading of the complete thermal regulation and control system incorporated within the fuel cell device. In addition, the total amount of power to operate the thermal regulation and control system is requested. The power required by the balance-of-plant to operate a fuel cell system. This parasitic power requirement reduces the effective power production of the fuel cell below the power output directly produced from the fuel cell stack. Parasitic power can be drawn from the fuel cell stack power output directly or drawn from a separate power system.

Safety Features Total: The power loading of each itemized artifact that constitutes the complete thermal regulation and control system incorporated within the battery device. Components and considerations developed for fuel cell systems to ensure safe operation. These features will typically comprise systems used to prevent concerns introduced by volatile energy carrier media, such as risk of storage rupture, ignition, and leaking fumes.

Technology Notes and Approach: Provides an opportunity to describe various important facts about the electrical machine, power electronics, and power management and distribution artifacts. For instance, delineating what electrical machine or power electronics components or wiring are normal conducting or employ High-Temperature Super-Conducting (HTS) materials. Opportunity is also given to record any instances where synergies occur in a given architectural arrangement.

Motor/Generator

Maximum Power: Maximum installed (shaft) power of the motor and the maximum useful power of the propulsor device.

Maximum Rated Motor Specific Power: Rated maximum shaft power of the motor per unit of motor mass.

Maximum Rated Motor Specific Torque: Rated maximum torque of the motor per unit of motor mass.

Rated Motor Power: Specified rated power of the motor at the shaft.

Rated Motor Torque: Specified shaft torque of the motor.

Rated Motor Speed: Specified rotational speed of the motor.

Maximum Speed at Constant Power: Maximum attainable rotational speed of the motor assuming constant power at the shaft.

Maximum Mechanical Speed: Maximum attainable rotational speed of the motor assuming no load.

Motor Efficiency at 100% Load: Efficiency of the motor assuming 100% load.

Motor Efficiency at 75% Load: Efficiency of the motor assuming 75% load.

Motor Efficiency at 50% Load: Efficiency of the motor assuming 50% load.

Motor Efficiency at 25% Load: Efficiency of the motor assuming 25% load.

Maximum Rated Motor Linear Speed Limit: Maximum rated tangential speed of the motor.

Over-Speed Limits: Maximum short duration rotational speed the motor can attain without incurring catastrophic damage.

Over-Temperature Limit: Maximum short duration temperature the motor can attain without incurring significant damage.

Maximum Rated Generator Specific Power: Maximum electrical power generation of the generator per unit of generator mass.

Rated Generator Torque: Maximum shaft torque input to the generator per unit of generator mass.

Rated Generator Speed: Maximum rated rotational speed of the generator.

Power Electronics Processed Power: The necessary amount of power in operating requisite power electronics to operate the motor or generator. Expressed as a percentage of the rating, e.g. 0% for asynchronous machines or synchronous machines with wild frequency, 30 –40% for doubly fed machines, and 100% for variable frequency drives.

Total Thermal Management and Parasitic Power: The total power loading of the complete thermal regulation and control system incorporated within the motor/generator device. In addition, the total amount of power to operate the thermal regulation and control system is requested. Additional mass (reported as mass per unit of thermal power as kg/kW(th) or lbm/hp(th) or mass per unit of parasitic power as kg/kW or lbm/hp) and/or parasitic power (kW or hp) associated with the motor/generator thermal management and safety management systems. For those devices utilizing High-Temperature Super-Conducting (HTS) technologies additional information related to heat load (in units kW or hp) as well as operating temperature (in units of K) also is expected.

Safety Features Total: The power loading of each itemized artifact that constitutes the complete thermal regulation and control system incorporated within the motor/generator device.

Propulsive Device

Attributes of the Propulsive Device: This field provides an opportunity to describe important aspects of the propulsive device. For example, whether the propulsor is unducted/ducted, or, the scope of geometric variability (variable pitch blades, variable nozzle area).

[Ducted Fan] Pressure Ratio: For ducted rotor arrangements, the ratio of the fan discharge pressure to the fan inlet pressure.

Propeller/Fan Maximum Corrected Tip Speed, Aerodynamic: The equivalent maximum tip speed of a propeller or fan blade corresponding to International Standard Atmosphere (ISA), sea level standard (SL) ambient conditions.

Propeller/Rotor Specific Power and/or Fan Specific Power: The gravimetric specific power of the propeller/rotor or fan of the propulsor device. The definition is based upon useful power.

Transmission

Gearbox Specific Power and Gearing Ratio: Rated maximum power of the gearbox per unit of gearbox mass. Ratio of rotational speeds between gearbox pinion (fast) and gear (slow) shafts.

Total Thermal Management and Parasitic Power: The total power loading of the complete thermal regulation and control system incorporated within the gearbox device. In addition, the total amount of power to operate the thermal regulation and control system is requested. Additional mass (reported as mass per unit of thermal power as kg/kW(th) or lbm/hp(th) or mass per unit of parasitic power as kg/kW or lbm/hp) and/or parasitic power (kW or hp) associated with the gearbox's thermal management and safety management systems.

Safety Features Total: The power loading of each itemized artifact that constitutes the complete thermal regulation and control system incorporated within the gearbox device.

Power Electronics

AC-DC Rectifier Specific Power: Rated maximum power of the rectifier per unit of rectifier mass.

Total Thermal Management and Parasitic Power: The total power loading of the complete thermal regulation and control system incorporated within the rectifier device. In addition, the total amount of power to operate the thermal regulation and control system is requested. Additional mass (reported as mass per unit of thermal power as kg/kW(th) or lbm/hp(th) or mass per unit of parasitic power as kg/kW or lbm/hp) and/or parasitic power (kW or hp) associated with the rectifier's thermal management and safety management systems.

Safety Features Total: The power loading of each itemized artifact that constitutes the complete thermal regulation and control system incorporated within the rectifier device.

DC-AC Inverter Specific Power: Rated maximum power of the inverter per unit of inverter mass.

Total Thermal Management and Parasitic Power: The total power loading of the complete thermal regulation and control system incorporated within the inverter device. In addition, the total amount of power to operate the thermal regulation and control system is requested. Additional mass (reported as mass per unit of thermal power as kg/kW(th) or lbm/hp(th) or mass per unit of parasitic power as kg/kW or lbm/hp) and/or parasitic power (kW or hp) associated with the inverter's thermal management and safety management systems.

Safety Features Total: The power loading of each itemized artifact that constitutes the complete thermal regulation and control system incorporated within the inverter device.

DC-DC Converter Specific Power: Rated maximum power of the converter per unit of converter mass.

Total Thermal Management and Parasitic Power: The total power loading of the complete thermal regulation and control system incorporated within the converter device. In addition, the total amount of power to operate the thermal regulation and control system is requested. Additional mass (reported as mass per unit of thermal power as kg/kW(th) or lbm/hp(th) or mass per unit of parasitic power as kg/kW or lbm/hp) and/or parasitic power (kW or hp) associated with the converter's thermal management and safety management systems.

Safety Features Total: The power loading of each itemized artifact that constitutes the complete thermal regulation and control system incorporated within the converter device.

Controller and Type: Rated maximum power of the controller per unit of controller mass. Controller topological description is also expected.

Bus Voltage for Propulsion System and Type: Nominal voltage range of propulsion system bus [AC or DC].

Maximum Operating Power: Maximum operating power limit of the propulsion system bus.

Bus Voltage for Non-propulsive System and Type: Nominal voltage range of bus used for non-propulsive power needs [AC or DC].

Maximum Operating Power: Maximum operating power limit of the bus used for non-propulsive power needs.

Bus AC Grid Frequency: Operating frequency of the alternating current of the bus.

Transmission: Mass of electrical transmission cables per unit mass and rated ampacity.

Cross-Sectional Area and Wire Gauge: Cross-sectional area of transmission cable conductor and standardized gauge number.

EMI/EMC Shielding: Weight of transmission cable Electro-magnetic Interference (EMI) and/or Electro-magnetic Compatibility shielding per unit of distance and rate voltage.

Active Cooling Measures: Weight of active cooling hardware per unit of length and rated ampacity.

Wiring Total Length and Number of Contactors: The cumulative length of wiring together with the quantity of contactors (electrically controlled switches) incorporated in a given architectural layout.

PROTECTION

Specific Power and Types: Power management capability of protection hardware per unit of protection hardware mass. List of protection hardware types utilized is expected.

Fault Current: Amperage which triggers the protection hardware to enter a fault state.