39th Annual Student Design Competition

2021-2022 Request for Proposal (RFP)

eVTOL Air Taxi for Passengers with Reduced Mobility (PRM)

Sponsored by

August 2021

Contents

1.0 Basic Proposal Information

Bell extends greetings and invites you to participate in the 39th Annual Student Design Competition (SDC) of the *Vertical Flight Society* (VFS).

This Request for Proposal (RFP) is divided into two sections. Section 1 (this section) provides:

- General description of the competition
- Process for entering
- Rules (both general and proposal specific)
- Schedules
- Award description
- Contact information

Section 2 describes the specific challenge by Bell and VFS.

1.1 Rules

1.1.1 Who May Participate

All undergraduate and graduate students from any school (university or college) may participate in this competition, ***with the exception of countries or persons prohibited by the United States Government.*** A student may be full-time or part-time; their education level will be considered in the classification of their team (see 1.1.3).

1.1.2 Team Information: Roles, Size and Number of Teams

The formation of project teams is encouraged and must follow these rules:

- **ALL teams, regardless of size, MUST name at least one (1) faculty advisor in order to compete**
- **Maximum number of students on a single-university team is ten (10)**
- **Minimum team size is one (1), an individual**
- **Schools may form more than one team, and each team may submit a proposal, but each team is limited to a maximum of ten (10) students**
- **A student may be a member of one team only**
- **Teams are allowed to include up to two external (2) advisors e.g. from industry and/or government organizations to mentor/advise on the design. The advisors roles should be limited to providing feedback on existing ideas/designs. External advisors from the current sponsor of the RFP are NOT allowed.**

We look favorably upon the development of collaborative, multi-university teams for the added experience gained in education and project management. ***The maximum number of students for a multi-university team is twelve (12), distributed in any manner over the multi-university team*.**

The members of a team must be named in the Letter of Intent (LOI). The LOI is drafted by the team captain and emailed to the Vertical Flight Society contact by the date specified in section 1.3. Information in the Letter of Intent must include:

- **Name of the university or universities forming the team**
- **Name of the team**
- **Printed name of each student member of the team including**
  - **Email**
  - **Education Level (Undergraduate or Graduate)**
  - **Affiliation of each student in the case of multi-university team**
- **Printed name(s) and email address of the team captain and faculty advisor(s): the team captain and faculty advisor will be the point of contact for all SDC communication.**
- **Printed name, affiliation and email address of any other external advisors if applicable.**

1.1.3 Categories and Classifications

The competition has three categories, in addition to an optional bonus task, that are eligible for prizes, which are:

- Undergraduate Student Category (1st, 2nd, 3rd)
- Graduate Student Category (1st, 2nd, 3rd)
  NOTE: The classification of the team is determined by the highest educational level currently pursued by any member of the team.
- New Entrant Category: A new entrant is defined as any school (undergraduate or graduate) that has not participated in the last three competitions.

1.1.4 Language of Proposal

Regardless of the nationality of the teams, all submittals and communications to and from VFS will be in English.

1.1.5 Units Used in Proposal

All teams must submit using both **English and SI units**. The primary units are to be SI units, followed by the secondary units in parentheses. The use of units shall be consistent throughout the proposal. All engineering units should be expressed in the units of:

- Force: Newtons (pounds)
- Mass: Kilograms (pound-mass or slugs as appropriate)
- Time: Seconds, minutes or hours as appropriate
- Length: Meters (feet)
- Velocity: Kilometers per hour or meters per second (knots or feet per second)
- Power: kW (horsepower) – Note for electrical power, only metric units are necessary.

1.1.6 Proposal Format, Length and Medium

Two separate files comprise the Final Submittal and both must be present for a submission to be considered complete. The judges shall apply a penalty if either file is missing.

The two mandatory files are the Executive Summary and the Final Proposal. Each are described herein.

The first file is called the Final Proposal. It is the complete, self-contained proposal of the team and must be submitted in PDF readable with Adobe® Acrobat® software and follow these guidelines:

- Undergraduate category Final Proposals shall be no more than 50 pages
- Graduate category Final Proposals shall be no more than 100 pages
- All pages are to be numbered
- Page count includes all figures, diagrams, drawings, photographs and appendices
- Pages should measure 8½ x 11 inches
- Use of font size of at least 10 points and spacing that is legible
- If a submission exceeds the page limit for its category, the judges will apply a penalty equal to ¼ point per page over the limit.

In short, anything that can be read or viewed is considered a page and subject to the page count, with the following exceptions:

- Cover page
- Acknowledgement page
- Signature page (see Section 1.1.7)
- Posting permission page (see section 1.1.10)
- Table of contents
- List of figures
- List of tables
- Nomenclature
- Reference pages
- Executive Summary

The second file is called the Executive Summary. This is a self-contained "executive" briefing of the proposal and must be submitted in PDF readable with Adobe® Acrobat® software and follow these guidelines:

- Limited to twenty (20) pages for both undergraduate and graduate category and can adopt a presentation format
- No additional technical content should be introduced in the Executive Summary
- All pages are to be numbered
- Pages should measure 8½ x 11 inches
- Use of font size of at least 10 points and spacing that is legible
- If a submission exceeds the page limit, judges will apply the same page count penalty to the Executive Summary score as the Final Proposal
- The Executive Summary is not scored separately but contributes up to 10% of the total score of the complete submission

All submissions shall be made via e-mail to the VFS contact or by upload to VFS.

1.1.7 Signature Page

All submittals must include a signature page as the second page, following immediately after the cover page. The signature page must include:

- Student name
- E-mail address
- Education level (undergraduate or graduate)
- Signature of each student
- In the case of a multi-university team, the page must also indicate the affiliation of each student

The submittals must be wholly the effort of the students, but Faculty advisors may provide guidance. **The signature page must also include the printed names, e-mail addresses and signatures of the Faculty Advisors and any External Advisors.**

Design projects for which a student receives academic credit must be identified by course name(s) and number(s) on the signature page.

1.1.8 Withdrawal

If a student team member withdraws from a team, or if a team withdraws their project, including the Bonus Task, from the competition, the team captain must notify the VFS SDC point of contact by email immediately.

1.1.9 Special Sponsor Rules

The Vertical Flight Society and the Student Design Competition Committee reserves the right to decline to make all of the awards in the listed categories if there are not a sufficient number of submissions that meet the expectations of the judges.

Proposals that do not, in the assessment of the judges, demonstrate an adequate understanding of the problem may be deemed ineligible for an award. In addition, any proposal that includes plagiarism or that copies substantial portions of prior proposals or publications will be disqualified.

1.1.10 Permission/Proposal Posting

VFS will post at least the Executive Summaries of each of the winning entries in the undergraduate and graduate categories on their web site. *Therefore, written permission MUST appear on a separate page immediately following the signature page* **–** this permission page will not count against the page count.

1.2 Awards

Bell is very pleased to sponsor the VFS Student Design Competition this year and will provide the funds for the awards and travel stipends as described below (all amounts in USD.) Submittals are judged in the following three (3) categories.

Undergraduate category:

- 1st place: $2,000
- 2nd place: $1,200
- 3rd place: $750

Graduate category:

- 1st place: $2,500
- 2nd place: $1,800
- 3rd place: $1,000

Best New Entrant (as defined in section 1.1.3):

- Undergraduate: $500
- Graduate: $750

Additional award information:

- Certificates of achievement will be presented to each member of the winning team and to their faculty advisors for display at their school.
- Student representatives from the first place graduate (up to two students) and undergraduate (up to two students) teams are expected to present a technical summary of their design at the Vertical Flight Society's 79th Annual Forum — planned for May 13-18, 2023 in West Palm Beach, Florida — during an Aircraft Design Technical Session.
- The students(s) presenting the winning design teams will receive complimentary registration to Forum 79.
- In addition, the first place graduate and undergraduate team's school will be provided a $1,000 stipend to help defray the cost of the team's Forum attendance – the additional travel stipend amount will be included in the first place award disbursement to the school(s).

1.3 Schedule

Schedule milestones and deadline dates for submission are as follows:

Milestone	Date
VFS Issues a Request For Proposal	August 2021
Teams Submit Letter of Intent (LOI) to Participate	No Later Than (NLT) Monday, **February 1, 2022**
Teams Submit Requests for Information (RFI)/Clarification **Note: questions/answers will <u>not</u> be communicated on a case-by-case basis. VFS will distribute ALL questions/answers collectively to all participating team captains by March 25, 2022.**	Continuously, but NLT **February 25, 2022**
Sponsor RFI Review	Feb. 25 to March 27, 2022
VFS Issues RFI/Questions Response to Teams	NLT Fri**. March 25, 2022**
Teams Submit Executive Summary and Final Proposal	NLT **May 31, 2022**
SDC Committee Reviews/Scores Final Proposals	June 1 to July 31, 2022
Sponsor notifies VFS of results	August 2022
VFS announces winners	August 2022
Winning Graduate and Undergraduate Teams present at VFS Forum 79 (2023)	Forum 79 May 13-18, 2023 West Palm Beach, FL

To reiterate:

- Letter of Intent (LOI) must be received by VFS no later than **February 1, 2022** and must include all of the information requested in section 1.1.2.
- All Requests for Information (RFI)/questions from teams must be submitted to VFS by **February 25, 2022**.
- VFS will distribute ALL of the questions and answers **<u>collectively to ALL entrant team captains</u> by March 25, 2022.**
- **Final proposals and executive summaries must be submitted by May 31, 2022** and must include all the information requested in Section 1.1.7.

1.4 Contacts

All correspondence should be directed to:

Julie M Gibbs, Technical Programs Director
VFS – *The Vertical Flight Society*
2700 Prosperity Ave., Ste. 275
Fairfax, Va. 22031
Phone: (703) 684-6777 x 103
E-mail: jmgibbs@vtol.org

1.5 Evaluation Criteria

The proposals shall be judged on four (4) primary categories with weighting factors specified below.

A. Technical Content (40 points)

The Technical Content of the proposal will be judged on the following criteria:

- Design meets the RFP technical requirements
- Assumptions are clearly stated and logical
- A thorough understanding of tools is evident
- All major technical issues are considered
- Appropriate trade studies are performed to direct/support the design process
- Well balanced and appropriate substantiation of complete aircraft and subsystems is present
- Technical drawings are clear, descriptive, and accurately represent a realistic design
- ***Emphasis this year is placed on accommodating Persons with Reduced Mobility***.

B. Application & Feasibility (25 points)

The proposals will be judged on how well current and anticipated technologies are applied to the problem, and on the feasibility of the solution. The proposals must:

- Justify and substantiate the technology levels that are used or anticipated
- Direct appropriate emphasis and discussion to critical technological issues
- Discuss how affordability considerations influenced the design process
- Discuss how reliability and maintainability features influenced the design process
- Discuss how manufacturing methods and materials were considered in the design process
- Show an appreciation for the operation of the aircraft

C. Originality (20 points)

The originality of the proposal shall be judged on:

- Innovation, simplicity, and elegance of the solution
- Imagination and ingenuity of the ideas investigated within the trade studies
- Vehicle/system aesthetics

- ***Additional points will be awarded this year to teams that address hidden disabilities in their design***

D. Organization & Presentation (15 points)

The organization and presentation of the proposal requires:

- Self-contained Executive Summary that contains all pertinent information and a compelling case as to why the proposal should win and must be a separate file.
- An introduction that clearly describes the major features of the proposed system
- A well-organized proposal with all information presented in a readily accessible and logical sequence
- Clear and uncluttered graphs, tables, drawings and other visual elements
- Complete citations of all previous relevant work (the State-of-the-Art)
- Professional quality and presentation
- The proposal meets all format and content requirements
- The RFP describes the proposal requirements (Section 1.6) and design objectives (Section 2)

1.6 Proposal Requirements

The Final Submittal needs to communicate a description of the design concepts and the associated performance criteria (or metrics) to substantiate the assumptions and data used and the resulting predicted performance, weight, and cost. Use the following as guidance while developing a response to this Request for Proposal (RFP):

A. Demonstrate a thorough understanding of the RFP requirements.
B. Describe how the proposed technical approach complies with the requirements specified in the RFP. Technical justification for the selection of materials and technologies is expected. Clarity and completeness of the technical approach will be a primary factor in evaluation of the proposals.
C. Identify and discuss critical technical problem areas in detail. Present descriptions, method of attack, system analysis, sketches, drawings and discussions of new approaches in sufficient detail in order to assist in the engineering evaluation of the submitted proposal. Identify and justify all exceptions to RFP technical requirements. Design decisions are important, but so is the process and substantiation.
D. Describe the results of trade-off studies performed to arrive at the final design. Include a description of each trade and a thorough list of assumptions. Provide a brief description of the tools and methods used to develop the design.

Section 1.1.6, titled "Proposal Format, Length and Medium" describes the data package that a team must provide in the Final Submittal. Specifically, the Final Submittal must contain the primary two files submitted via email or upload.

A. The first file is the ***Final Proposal***, which is the full length, complete and self-contained proposed solution to the RFP. By self-contained, we mean that the proposal does not refer to and does not require files other than itself.

B. The second file is an ***Executive Summary***, which presents a compelling story why the VFS evaluators should select your design concept. The Executive Summary should highlight critical requirements and the trade studies you conducted as well as summarize the rotorcraft concept design and capabilities.

2.0 System Objectives

2.1 Operating Concept

New electric propulsion technology is shaping a future for advanced air mobility (AAM) that could transform the way people and cargo are moved from Point A to Point B. **To live up to this vision, designers must begin to account for a broad spectrum of travellers that includes persons with disabilities of all types. This calls for an electric vertical take-off and landing (eVTOL) concept that factors the unique requirements for such passengers.**

2.2 Specific Objectives

The goal of this RFP is the design of an all-electric eVTOL aircraft that addresses passengers with reduced mobility (PRM). The effort comprises:

A. Conceptual Design of an eVTOL aircraft to execute the required mission while accommodating passengers with reduced mobility **(required of ALL teams)**

B. Detail Design and Analysis to substantiate the critical aspects of the results from Task 1. **(Graduate teams ONLY)**

2.2.1 Task 1 Conceptual Design

Student design teams shall develop an all-electric eVTOL aircraft with two primary design requirements.

- Firstly, the design of the cockpit, cabin and baggage compartment shall accommodate a single pilot and no less than two (2) passengers with disabilities.
    - Alternative seating of four (4) passengers with full mobility shall be provided.
- Secondly, an eVTOL aircraft that incorporates the cockpit, accessible cabin and baggage compartment shall be designed to accomplish a specified air taxi mission.

2.2.1.1 Cockpit, Accessible Cabin and Baggage Compartment

The cockpit, cabin and baggage compartment design requirements are as follows:

- All operations shall be conducted by a single pilot in the cockpit.
- The cabin interior shall be reconfigurable to accommodate:
    - A baseline configuration of four (4) adult passengers without disabilities; and, separately,
    - An alternative configuration with no less than two (2) adult passengers with disabilities.
- The cabin design shall focus on safety and simple ingress and egress.
    - Support equipment may be incorporated into the aircraft design and/or provided at the origin and destination sites at the discretion of the design team.
    - Personnel to assist with ingress and egress may be assumed to be provided at the origin and destination sites.
- The design shall conform to the applicable requirements of 14 CFR 29 — US Code of Federal Regulations (CFR) Title 14 (Aeronautics and Space) Airworthiness Standards: Transport Category Rotorcraft — paragraphs §29.771 through §29.833.

- Each passenger, whether disabled or not, shall be accompanied by the typical airline baggage load consisting of
    - One (1) piece of checked baggage: 158 cm (62 inches) total linear dimensions weighing up to 23 kg (50 lb) ;
    - One (1) piece of carry-on baggage: 56 x 36 x 23 cm (22 x 14 x 9 in) and weighing up to 10 kg (22 lb); and
    - One personal item: 45 x 35 x 20 cm (18 x 14 x 8 in) and weighing up to 5 kg (11 lb)
- Checked baggage shall be secured in the baggage compartment.
- Carry-on baggage and personal items may be secured in the baggage compartment or in the cabin at the discretion of the design team.
- For passengers with disabilities, the baggage compartment shall accommodate their required durable medical equipment (e.g., crutches, walker, wheelchair) in addition to their baggage.

Students are encouraged to consider the wider societal challenges faced by people with disabilities of all types – including hidden disabilities* – and then consider how their eVTOL design might alleviate some of the challenges, remove barriers and create an enabling environment. [*Additional originality points will be awarded to teams that address hidden disabilities in their design.]

Recommended sources for relevant information are as follows:

- **World Report on Disability**
  https://www.who.int/disabilities/world_report/2011/report.pdf
  Although this is a lengthy and detailed document, the introductory sections provide background in the context of global disability and the challenges faced, including some real-world examples. The section "Enabling environments", beginning on p. 167, and the discussion "What are the disabling barriers?", beginning on p. 262, are particularly relevant.
- **ADA Accessibility Guidelines for Transportation Vehicles**
  https://www.access-board.gov/ada/vehicles/
  Subpart B – Buses, Vans and Systems – provides specific regulations for vehicles to comply with the Americans with Disabilities Act (ADA).
- **Guidance: Rights of disabled passengers on transport** (based on the UK Equality Act 2010)
  https://www.gov.uk/guidance/rights-of-disabled-passengers-on-transport
  The section on Taxi and Private Hire Vehicle (PHV) provides more relevant guidance for vehicles in the target size class than the section on aviation.
- **General Government Policy** DPTAC position statement on non-visible disabilities - GOV.UK (www.gov.uk)
- **Advice to Airports** New CAA guidelines: Making air travel more accessible for passengers with hidden disabilities | UK Civil Aviation Authority

- **Advice to Airlines** Airlines given guidance on assisting passengers with hidden disabilities | UK Civil Aviation Authority (caa.co.uk)
- **CAA Publication Advice to Airlines on Passengers with Hidden Disabilities** CAP1603: Guidance for airlines on assisting people with hidden disabilities (caa.co.uk)
    - Chapters 1 & 3 are relevant.
- Aircraft Cabin Design for Disabled Passengers | [AT] connects (atconnects.com)
    - Mostly about visible disabilities but there is reference to hidden disabilities and the use of technology where appropriate i.e. visual and auditory disabilities.

Based on their research, each design team shall define their accessible cabin design requirements and provide a brief rationale for their choices. Design teams shall establish weights for the pilot, passengers, baggage and support equipment that can be stored in the baggage compartment (e.g., crutches, walkers, wheelchairs, etc.) and/or which must remain in the cabin with the passenger (e.g., oxygen systems, prostheses, etc.).

The design team could also include provisions to accommodate small children, such as child car seats/booster seats that are approved for aviation use, as well as strollers/prams.

Each design team shall create separate dimensioned three-views of their proposed cockpit, cabin and baggage compartment layouts:

- A single-pilot cockpit layout
- Cabin layouts of the baseline four-passenger configuration and the alternative interior that accommodates passengers with disabilities
- The baggage compartment layout shall demonstrate that the enclosed volume accommodates all combinations of allowed baggage and durable medical equipment.

Regardless of cabin configuration, the dimensions of the cabin, cockpit, and baggage area remain the same.

Methods of ingress and egress shall be described in figures and text, including the required support equipment, whether built-in or external.

A compliance checklist shall combine the applicable (as determined by the design team) requirements from 14 CFR 29 specified earlier with the accessible cabin requirements developed by the design team. The checklist shall explain how each cabin configuration meets or has provisions to meet the requirements.

Each cabin configuration shall be described by a list containing items that are included in that configuration, including fixed equipment (seats, seat rails, storage bins, etc.), passengers and their personal and carry-on items, if applicable. Fixed equipment weights shall be substantiated using published information. Movable equipment that is carried in the aircraft and used to facilitate ingress and egress must be accounted for and secured in either the cabin or baggage compartment. Baggage compartment contents associated with each configuration and the corresponding weights shall also be listed.

The cockpit is to be common to all cabin internal configurations, and its contents and weights shall also be listed.

The configuration with four passengers without disabilities and the associated baggage weight shall define the maximum gross weight configuration for the aircraft.

2.2.1.2 Air Vehicle

The design teams shall develop an air vehicle that accommodates their cockpit, cabin and baggage compartments and accomplishes the following mission in the most efficient manner. In accordance with the operating concept, the mission is to transport adult passengers between an urban, suburban or rural hub and an airport, separated by 100 miles (161 km). For the purpose of sizing the air vehicle, the mission is defined by the following segments:

Mission Segment	Segment Characteristics(1)
1. Normal vertical takeoff to IGE hover	0(2) sec
2. IGE hover	10 sec
3. Vertical climb to 30.48 m (100 ft) AGL	Rate of climb (ROC) = 48.77m/s (160 ft/min) OGE(3)
4. OGE hover at 30.48 m (100 ft) AGL	10 sec
6. Steady climb to 609.6 m (2000 ft) AGL at V_{CLIMB}(4)	Climb gradient = 1:6 (9.46 deg angle of climb)
6. Cruise at 609.6 m (2000 ft) AGL	V_{CRUISE} = TBD(4)
7. Steady descent to 30.48 m (100 ft) AGL	Angle of descent = 4 deg; $V_{DESCENT}$ = TBD(4)
8. OGE hover at 30.48 m (100 ft) AGL	10 sec
9. Vertical descent to IGE hover	Rate of descent = TBD(4)
10. IGE hover	10 sec
10. Normal vertical landing from IGE hover	0(2) sec

Notes:

1. Parameters required to determine time (and energy consumption) in steady-state conditions
2. Energy consumption and distance travelled during transitions between steady-state flight conditions are to be neglected for the purpose of the trade study.
3. Power required for vertical climb and descent shall not include the benefit of ground effect.
4. Parameters to be determined (with rationale) by the design team
5. Ground elevation is 609.6 m (2000 ft) above sea level at both mission origin and destination.
6. Atmospheric conditions are ISA + 20°C at all mission points.

The steady-state mission segments are illustrated in Figure 1.

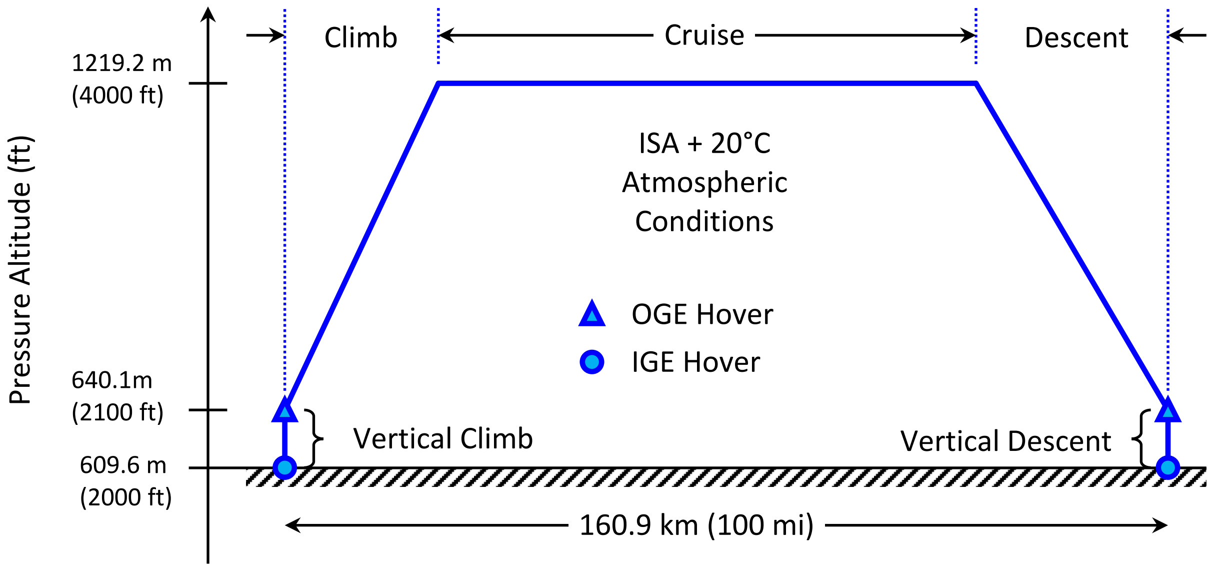

Figure 1: Mission Profile

The air vehicle design is to be constrained as follows:

- The aircraft length and width (with rotors turning) must each be no greater than 15.24 m (50 ft).
- Electric power is provided by an idealized battery with an energy density of 400 W-hr/kg.
  - All battery energy will be considered usable during the mission with the exception of the reserve energy requirement below. No limitations on available energy due to charge/recharge or other real-world battery characteristics are to be considered.
  - The battery shall be assumed to have no limitations on the demanded power level until fully depleted.
  - The battery shall be assumed to generate no heat.
  - The battery reserve energy shall be equal to 20 minutes of continuous draw at the power level determined for the cruise segment of the design mission.
  - The spatial volume that the battery pack(s) occupy shall be based on a mass density consistent with current battery technology. Design teams shall provide a reference to a currently available battery to establish their mass density.
- No additional power sources are available during flight.
- The aircraft shall be capable of continued safe flight following any single failure of the electrical power distribution system (motor, motor controller, wiring harness, etc.). The remaining systems shall be capable of controlling the aircraft, and the drive system shall be able to provide the steady-state power and torque required for IGE hover at the point of origin, destination or alternative landing site at ground level.

Design teams shall conduct trade studies to down select and justify the appropriate vehicle configuration.

The trade space shall be fully defined for all aircraft configurations considered.

- Powered-Lift and Propulsive Elements (rotors, propellers, proprotors, ducted fans, etc.)
    - *All thrusting devices are referred to collectively as "rotors" for the balance of this RFP.*
    - For simplicity, the rotor design parameters to be traded are limited to radius (R), solidity (σ), tip speed (ΩR) and twist rate. Twist shall be assumed to be linear.
    - Tip speeds shall not exceed 600 ft/s.
    - Design teams are encouraged to select the ¾ radius position to assess their rotor configurations. Teams should present the corresponding ¾ radius two-dimensional aerodynamic coefficients (C_ℓ and C_d versus angle of attack α) for a single Reynolds number that is representative of the average of their trade space. Students should provide a brief discussion (not analysis) of their recommended blade configuration that may include planform shape, root and tip airfoil selection, and twist. The purpose of these simplifications is to afford students the opportunity to demonstrate their understanding of rotor design fundamentals.
    - Thrust coefficient versus torque (power) coefficient shall be plotted for each rotor configuration being considered in the trade study. Students may continue to use the ¾ radius for this analysis. Data ranges shall be consistent with the trade spaces defined by the design team. The data shall indicate various combinations of the traded parameters — e.g., twist rate, axial flow ratio [$\lambda=V_{Axial}/(\Omega R)$] and tangential flow ratio [$\mu=V_{Tan}/(\Omega R)$] — that the design team deems sufficient to characterize the aerodynamic performance of their rotors in each mission segment.
    - For design teams that choose to include ducted fans in their trade spaces, duct augmentation levels must be substantiated. Similarly, ducted fan performance must be penalized in flight regimes where the duct is detrimental to performance.
    - Design teams shall provide discussions of the positive and negative aspects of each rotor configuration in their trade space, referring to their thrust-power relationships, to demonstrate comprehension.
- Define electric motor and drive system characteristics:
    - Motor rotational speeds, powers, torques and efficiencies
    - Motor control units
    - Drive type (direct, multiple, geared, interconnected, etc.)
- Define lifting surfaces (wings, stabilizers, etc.)
    - Lift and drag characteristics of lifting surfaces shall be presented. For any lifting surface that stalls within the operational envelope, the design team shall explain how the stall effects will be mitigated.
- Define electric power consumed by avionics, flight controls, air conditioning, etc. and losses.

- A suitable landing gear must be considered in the trade study. Retractable and non-retractable landing gear should be considered with the corresponding impact of weight and drag.
- Component weights and the weights estimation methodology shall be presented and substantiated.
- A drag estimation methodology shall be presented and substantiated.
- Download in hover due to wake impingement on aircraft components must be included in computing the required thrust from each lifting rotor.

A minimum of three (3) air vehicle configurations shall be included in the trade study. The design teams shall utilize the data compiled within their trade spaces to synthesize their design. Each air vehicle shall incorporate the cockpit, cabin and baggage compartments and weights for the four-passenger baseline configuration developed in 2.2.1.1.

Total energy consumption for the mission and the battery reserve energy shall determine the battery size and weight. A summary table shall be developed to include the following information for each converged air vehicle design:

- Configuration description, e.g., “Compound Quadrotor”, “Single Main Rotor Helicopter,” etc.
- Isometric external view
- Gross weight
- Cruising speed
- Total equivalent drag area in cruise
- Time to complete mission
- For each rotor, provide the following:
  - Rotor(s) description; e.g., “Left and Right, Forward Rotors”
  - Radius
  - Solidity
  - Linear twist
  - Tip speed for each mission segment, if variable
  - Figure of Merit, out of ground effect (OGE) hover, all systems operating
  - Figure of Merit, in ground effect (IGE) hover, under worst-case single-system failure
- Power required (kW) and energy consumed (kW-hr) for each mission segment — total for all rotors and other energy absorbers
- Total energy consumed per mission
- Reserve energy
- Total battery weight
- Drive system maximum continuous power and torque ratings

Based on the trade study results, the design team shall provide a discussion of the advantages and disadvantages presented by each air vehicle configuration and select a configuration that represents the best overall value. For the selected vehicle, the following information shall be presented:

- Dimensioned external three-view of the aircraft:
    - Hover configuration
    - Cruise configuration if different from the hover configuration
- Views of major components and systems:
    - Fuselage:
        - Cockpit, cabin and baggage compartment volumes shall be shown without contents. (This three-view shall focus on the air vehicle.)
        - Show systems and items contained in the fuselage, but outside of the cockpit, cabin and baggage compartment (e.g., batteries, avionics, flight control computers, environmental controls, system routing).
        - Show primary structure in the three-view.
    - Show each rotor and drive system.
    - Show the control system.
    - For features that change orientation between hover and cruise flight, show the conversion system.
    - Show landing gear in the extended and retracted positions as applicable.
- Weight breakdown (according to Military Standard MIL-STD-1374, SAWE RP-A7 or RP-8 or similar format)
- Center of Gravity analysis for hover and cruise configurations:
    - Teams shall verify that the distribution of thrust among the powered elements combined with lifting surfaces and airframe aerodynamic forces can be placed in equilibrium about the center of gravity (cg).

2.2.2 Task 2: Air Vehicle Detailed Design (Graduate Teams ONLY)

For the graduate category, a deeper technical substantiation of the capability of the aircraft to perform its mission is required. This will require the development of suitable operating and design envelopes.

- The control system shall be sized to meet certain threshold requirements, and the aircraft shall be shown to be capable of recovering from critical maneuvering conditions.
- Aerodynamic properties of the aircraft shall be generated to enable the required analyses. Loads associated with the critical flight maneuvering conditions shall be defined and used for structural analysis.
- Landing gear energy absorption characteristics shall be defined, and loads associated with limit landing conditions shall be incorporated in the structural analysis.
- The operating envelope shall be defined such that the aircraft can generate revenue in its role as an air taxi.
- An envelope of aircraft gross weight versus longitudinal center of gravity position shall be developed considering all combinations of allowable passenger and baggage configurations for the various cabin configurations presented in 2.2.1.1. Those

combinations shall span the extremes from a single pilot (with no passengers or baggage) up to a single pilot, with maximum passenger and baggage loading.
  - For an aircraft that changes its configuration, envelopes for both the hover and cruise configuration shall be generated.
  - For aircraft with retractable landing gear, the hover envelope shall have the landing gear extended, and the cruise envelope shall have the landing gear retracted.
- The intrinsic performance of the aircraft shall be established:
  - Provide the maximum takeoff altitudes plotted versus the range of gross weights, based on the maximum continuous power available from the drive system being equal to the power required for OGE hover at those altitudes.
  - Provide the maximum operating altitudes versus the range of gross weights, based on the maximum continuous power available from the drive system being equal to the power required to maintain a climb rate of 30.48 m/min (100 ft/min) at the forward speed for minimum power in the cruise configuration.
  - Provide the maximum takeoff and operating altitudes expressed as density altitude; i.e., standard atmospheric conditions are to be assumed.
- A design maximum operating speed V_{MO} shall be established that is no less than the cruising speed established for the design mission and no greater than the maximum level flight speed with the drive system providing maximum continuous power.
- For aircraft that operate in different configurations in hover and cruise conditions, the upper and lower operating speed limits throughout the range of conversion shall be defined (i.e., provide the conversion corridor).

The aircraft control system shall enable the aircraft to achieve the following minimum measures of agility:
- In OGE hover with a wind of 31.48 km/hr (17 knots) from the critical direction, there shall be sufficient control power to generate aircraft angular rate responses within 1.5 seconds of at least 15 deg/sec in pitch, roll, and yaw.
- In OGE hover there shall be sufficient vertical agility to accelerate from 1.0g to no less than 1.25g in 1.5 seconds.
- In cruise, there shall be sufficient control power to achieve attitude changes from trim of 10-deg pitch, 10 deg roll, and 6 deg heading within 1.5 seconds.
- Each of these measures of agility shall be achievable in the most adverse operating condition as defined by the gross weight — center-of-gravity envelope and design mission profile. Hover conditions shall be analyzed at 640.1 m (2100 ft) pressure altitude, and cruise conditions shall be analyzed at 1219.2 m (4000 ft) pressure altitude, both at ISA + 20°C.
- Design teams shall demonstrate these agility requirements by showing that the aircraft can produce the required forces/moments at each critical condition. For rotors, the required blade pitch and rpm ranges shall be established, and the drive system powers and torques required shall be determined. If the drive system maximum continuous power as defined by the trade study is insufficient to achieve the measures of agility,

reduced agilities shall be defined by the design team. For control surfaces, the required deflection ranges shall be established.

The design envelope shall have limit airspeeds of no less than $V_{MO}/0.9$ in forward flight and no less than 9.71 m/s (17/0.9 kts =18.88 kts) at any azimuth. For configurations that derive no lift from the rotors in cruise, the limit forward flight speed shall be no less than $V_{MO}/0.8$ in the cruise configuration only.

Design limit maneuvering load factors shall be defined in accordance with 14 CFR 29, paragraph §29.337. For configurations that derive no lift from the rotors in cruise, the limit maneuvering load factors shall be defined in accordance with 14 CFR 25, paragraph §25.337, in the cruise configuration only. The aircraft total vertical force produced by the rotors and lifting elements shall be determined at sea level ISA.

The design team shall present the limit maneuvering envelopes in the following forms:
- Limit maneuvering load factors versus gross weight
- Limit maneuvering load factors versus airspeed at maximum gross weight

Loads analyses shall be limited to the maximum gross weight configuration (four passengers without disabilities and their baggage) and the corresponding center(s) of gravity. Up to two specific weight configurations that shall be summarized as follows:

Configuration	Gross Weight (units)	Center of Gravity (units)			Mass Moments of Inertia (units)					
		x	y	z	I_{XX}	I_{YY}	I_{ZZ}	I_{XY}	I_{XZ}	I_{YZ}
Cruise										
Hover										

The cruise configuration shall have the landing gear retracted if applicable. The hover configuration shall have the landing gear extended. If both configurations are the same (i.e., the aircraft has fixed landing gear and no convertible thrusting and/or lifting elements), only one need be presented.

All design limit loading conditions shall be determined at sea level ISA atmospheric conditions.

Limit maneuvering loads shall be developed for the following conditions:
- In the cruise configuration at V_{MO}:
    - Symmetrical pull-up. Design teams shall apply appropriate loads to the aircraft to simultaneously achieve the limit positive maneuvering load factor and the nose-down pitch acceleration defined by the minimum measures of agility defined above in cruise flight. Rolling and yawing moments about the center of gravity shall be zero.
    - Symmetrical pushover. Design teams shall apply appropriate loads to the aircraft to simultaneously achieve the limit negative maneuvering load factor and the

nose-up pitch acceleration defined by the minimum measures of agility defined above in cruise flight. Rolling and yawing moments about the center of gravity shall be zero.

- Symmetrical pull-up in the hover configuration. Design teams shall apply appropriate loads to the aircraft to achieve the limit positive maneuvering load factor at the condition associated with maximum vertical thrust. All moments about the center of gravity shall be zero.
- For the purpose of analysis, angular velocities shall be assumed equal to zero for all maneuvering conditions.

Limit vertical gust load factors shall be defined in accordance with 14 CFR 29, paragraph §29.341. For configurations that derive no lift from the rotors in cruise, the vertical gust load factors shall be defined in accordance with 14 CFR 25, paragraph §25.341 at amendment 25-72, in the cruise configuration only.

All lifting elements of the aircraft shall be included in the computation of gust load factors. This historical regulation can be viewed at:
https://rgl.faa.gov/Regulatory_and_Guidance_Library/rgFAR.nsf/0/D60119A72A57DF4585256672004EBDDA?OpenDocument

Design teams shall apply loads to the aircraft to achieve the limit vertical gust loads in the cruise configuration at V_{MO}.

- Loads associated with both the positive and negative limit gust load factors shall be developed.
- Total rolling, pitching and yawing moments about the center of gravity shall be zero.
- Angular velocities shall be assumed equal to zero.

The landing gear shall be designed to absorb the energy associated with a rate of sink equal to 2 m/s (6.55 ft/s) at initial ground contact. To complete this section, the design teams shall determine the required load-stroke characteristics of the landing gear.

- The combined work done by the landing gear and the aircraft lift (equal to 2/3 of the maximum gross weight) shall completely arrest the rate of sink.
- Design teams shall explain their choice of gear stroke versus limit landing load factor.
- The aircraft gross weight and center of gravity shall be as defined by the maximum gross weight with four passengers without disabilities.
- For purposes of generating landing gear load-stroke curves, the combined forces due to lift must be balanced about the cg.
- Separately, the combined landing gear vertical reactions shall also be balanced about the cg. This approach places the aircraft in pitch/roll equilibrium during the landing sequence.

The following landing load conditions shall be developed:

- Vertical landing max load – landing gear vertical loads shall be equal to the maximum loads from the load-stroke curves
- Vertical landing with drag load – vertical loads from the vertical landing condition shall be combined with drag loads equal to 50% of the vertical loads acting aft in the ground plane.
- Both load conditions shall have, in addition to the landing gear loads, a lift equal to 2/3 of the maximum gross weight. That lift (possibly from multiple rotors) shall be distributed such that there are no moments due to lift about the center of gravity.
- The aircraft gross weight and center of gravity shall be as defined by the maximum gross weight with four passengers without disabilities.
- Landing gear loads shall be assumed to act at the center of the ground contact area of each landing gear.
- Angular velocities shall be assumed equal to zero.
- For landing with drag, any unbalanced moments about the center of gravity shall be reacted by aircraft inertia.

Shear and moment diagrams shall be made for the fuselage. It is preferable that each shear and moment diagram contains all seven limit load conditions (three flight, two gust, two landing), allowing critical conditions along the length of the structure to be identified.

Based on the shears, moments and structural layouts, the design team shall select critical fuselage section(s) for structural analysis

- For each section, the design team shall present the structural properties for the materials chosen and identify the most critically stressed point.
- The structural properties shall be sufficient for the stress to cause no permanent deformation under the action of the limit loads and not fail under the action of the limit loads multiplied by a factor of safety of 1.5.

The design team shall also perform a fatigue analysis of the most critically loaded, rotating element of the drive system. This will likely be the most highly loaded rotor mast (drive shaft) at the first bearing location as seen in Figure 2.

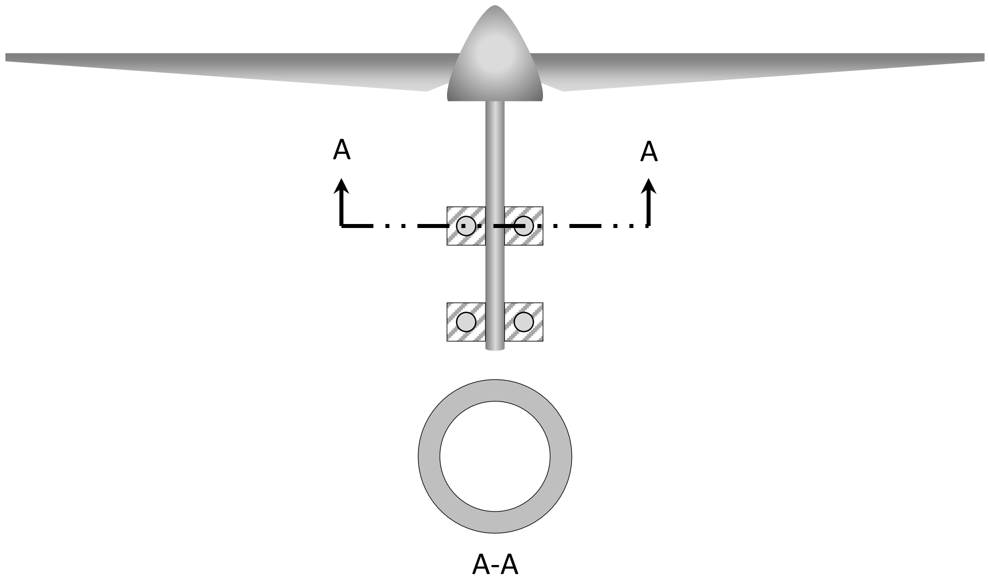

Figure 2. Critical Mast Section

The fatigue loading spectrum shall be defined by the design mission profile.

- The required fatigue life shall be 10,000 round trips or 20,000 missions.
- The loads corresponding to each segment of the mission shall be identified.
- For ground conditions, rotors off, component loads shall be equal to the weight supported by the selected component.
- Design teams shall report stresses at the critical point of the section for each loading.

The design team shall select a standard material and provide the associated S-N curve(s) necessary to determine the fatigue damage accumulated during each mission segment and from the overall mission. Scatter and/or reduction factors as described in FAA Advisory Circular AC 27-1B, MG 11, shall be applied. Any testing required to meet the required fatigue life shall be discussed.

3. Glossary

- AAM Advanced Air Mobility
- AC Advisory Circular
- ADA Americans with Disabilities Act (US)
- AGL Above Ground Level
- CFR Code of Federal Regulations (US)
- cg Center of Gravity
- eVTOL electric vertical takeoff and landing
- FAA Federal Aviation Administration (US)
- FAR Federal Aviation Regulations (US)
- IGE In Ground Effect

- ISA International Standard Atmosphere
- LOI Letter of Intent
- NLT No Later Than
- OGE Out of Ground Effect
- PDF Portable Document Format
- PRM Passenger (or persons) with Reduced Mobility
- RFI Request for Information
- RFP Request for Proposals
- ROC Rate of Climb
- SAWE Society of Allied Weight Engineers
- SDC Student Design Competition
- SI Système Internationale
- TBD To be determined
- UK United Kingdom
- US United States
- USD United States Dollar
- VFS Vertical Flight Society
- WHO World Health Organization