FOOT-POUND

ADS-10D-SP
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AERONAUTICAL DESIGN STANDARD

STANDARD PRACTICE

AIR VEHICLE TECHNICAL DESCRIPTION

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AIR VEHICLE TECHNICAL DESCRIPTION

UNITED STATES ARMY AVIATION AND MISSILE COMMAND

AVIATION ENGINEERING DIRECTORATE

REDSTONE ARSENAL, ALABAMA

FUNCTIONAL DIVISION: Dr. Robert L. King
Chief, Aeromechanics Division

SUBMITTED BY: Dr. William D. Lewis
Director, Aviation Engineering Directorate

APPROVED BY: Patricia T. Martin
AMCOM and PEO AVIATION
Standards Executive

Certification Record

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Prepared by: Mr. Michael J. Cardamone

Rationale for Certification:

Decision:

General Type	Decision (√)	Certification
Specification		Performance
		Detail
Standard		Interface Standard
	√	Standard Practice
		Design Standard
		Test Method Standard
		Process Standard
Handbook		Handbook (non-mandatory use)
Alternative Action		

	Concur	Nonconcur	Date
Division Chief, Aeromechanics Division Dr. Robert L. King	X		25Aug08
AMCOM Standardization Branch Chief Mr. William J. Smith	X		8/18/2008
Director, Aviation Engineering Dr. William D. Lewis	X		8/29/2008
AMCOM and PEO, Aviation Standards Executive Ms. Patricia T. Martin	X		9/16/08

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AIR VEHICLE TECHNICAL DESCRIPTION

1. SCOPE

This standard practice Aeronautical Design Standard specifies the air vehicle technical data necessary to perform a detailed analysis of the performance, handling qualities, rotor dynamics, airframe dynamics, acoustics and engine/drive train response characteristics of proposed new development or derivative rotorcraft. The purpose of this standard is to provide a clear technical description of the proposed air vehicle and its components at a level of detail consistent with the current stage of its design. To this end, the data requirements are divided into topics and the topics are divided into three levels: Level I, Level II, and Level III. Level I (minimum) requires sufficient information to conduct a basic performance and stability and control analysis including the aerodynamic effects of the rotor system and the fuselage. Level II (intermediate) requires all of the data required for Level I plus additional data required for more detailed rotor and fuselage aerodynamics analyses, a basic dynamic analysis of the rotors and the fuselage and a basic analysis of engine/airframe response characteristics. Level III (detailed) is intended to allow a very detailed aerodynamic and dynamic analysis.

This standard practice Aeronautical Design Standard is a communications tool. It is intended to provide a standard nomenclature and format for providing a technical description of the design. This standard contains a set of requirements designed to be tailored for each contract by the contracting agency. The tailoring process intended for this standard is the deletion of non-applicable requirements.

2. APPLICABLE DOCUMENTS

2.1 General. The documents listed in this section are specified in sections 3, 4, or 5 of this standard. This section does not include documents cited in other sections of this standard or recommended for additional information or as examples. While every effort has been made to ensure the completeness of this list, document users are cautioned that they must meet all specified requirements of documents listed in sections 3, 4, or 5 of this standard, whether or not they are listed.

2.2 Government Documents

2.2.1 Specifications, standards and handbooks. The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

MIL-DTL-31000	Technical Data Packages

MIL-PRF-28000	Digital Representation for Communication of Product Data: IGES Application Subsets and IGES Application Protocols
MIL-STD-1840	Automated Interchange of Technical Information

(Copies of these documents are available online at http://assist.daps.dla.mil/quicksearch/ or http://dodssp.daps.dla.mil/ or from the Standadization Documents Order Desk, 700 Robbins Avenue, Building 4D, Philadelphia, PA 19111-5094.)

2.2.2 Other Government documents, drawings, and publications. The following other Government documents, drawings, and publications form a part of this document to the extenet specified herein. Unless otherwise specified, the issues of these documents are those cited in the solicitation or contract.

NACA Report 1351	Theory of Self-Excited Mechanical Oscillations of Helicopter Rotors with Hinged Blades
NASA TM-78627	Computer Program to Prepare Airfoil Characteristics Data for Use in Helicopter Performance Calculation

(Copies of these documents are available online at http://ntrs.nasa.gov/ or from the NASA Center for AeroSpace Information (CASI), 7115 Standard Drive, Hanover, MD 21076-1320.)

2.3 Non-Government Publications. The following documents form a part of this specification to the extent specified herein. Unless otherwise specified, the issues of the documents are those cited in the solicitation.

AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS

AIAA G-077-1998	Guide for the Verification and Validation of Computational Fluid Dynamics Simulations
AIAA S-071A-1999	Guide to Assessing Experimental Uncertainty - Supplement to S-071A-1999

(Copies of these documents are available from http://www.aiaa.org or from the AIAA Publications Customer Service, PO Box 960, Herndon, VA 20172-0960.)

AMERICAN NATIONAL STANDARDS INSTITUTE

ANSI S-071A-1999	Assessment of Experimental Uncertainty with Application to Wind Tunnel Testing

(Copies of these documents are available from http://www.ansi.org or from the American National Standards Institute, 1819 L St. NW Ste 600, Washington, DC 20036-3864.)

SOCIETY FOR AUTOMOTIVE ENGINEERS

SAE-AS681	Gas Turbine Engine Steady-State and Transient Performance Presentation for Digital Computer Programs

(Copies of these documents are available from http://www.sae.org or from the SAE Customer Service, 400 Commonwealth Drive, Warrendale, PA 15096-0001.)

2.4 Order of Precedence. In the event of a conflict between the text of this document and the references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

3. DEFINITIONS

3.1 Acronyms.

AFCS	Automatic Flight Control System
CAD	Computer Aided Design
CG	Center of gravity
IGES	International Graphics Exchange Standard
GW	Gross Weight
NACA	National Advisory Committee for Aeronautics
NASA	National Aeronautics and Space Administration
RPM	Revolutions per minute
SDGW	Structural Design Gross Weight
STEP	Standard for the Exchange of Product Model Data
TBD	To be determined
VTOL	Vertical Take Off and Landing
3-D	Three dimensional

3.2 Symbols.

Cd	Coefficient of drag
Cm	Coefficient of moment
Cl	Coefficient of lift
D/q	Equivalent parasite drag area
L/q	Equivalent parasite lift area
L/Q	Roll moment equivalent volume
M	Mach Number
M/q	Pitch moment equivalent volume
N/q	Yaw moment equivalent volume
Y/q	Equivalent parasite side force area
ψ	Yaw angle or rotor azimuth
δ	Small increment
α	Angle of attack
∂	Partial derivative
θ	Pitch angle

4. GENERAL REQUIREMENTS

4.1 Documentation. The report(s) prepared to satisfy the requirements of this standard shall be delivered in electronic format. Each report shall include a table of contents, a list of symbols, a list of figures, a list of tables, and a list of references and/or bibliography. The body of each report shall be organized in essentially the same format, sequence of topics, and numbering system which is used in this standard. The Level I air vehicle technical description shall consist of a single report. The Level II and Level III air vehicle technical descriptions shall each be divided into two distinct reports. The content of the two reports shall be as follows:

a. Information required by Paragraphs 5.0 through 5.7.

b. Information required by Paragraphs 5.8 through 5.11.

Each report for each level shall include the relevant data and substantiation as specified in Paragraph 4.6 below.

4.2 Graphs. The size and scale used for graphic presentations are a function of the data to be presented. Odd scales (such as 7, 2.5, and 3 units per division) shall not be used. The scale shall facilitate interpolation (i.e., there shall be sufficient scale increments to facilitate reading information directly off the graph).

4.3 Tables. Tables shall be provided in order to give more detail than can be presented in graphic presentations and, also, to provide certain types of computer inputs. As with graphic data, the exact format of the table is a function of the variables to be tabulated. For computer input tables, there shall be enough points tabulated to allow linear interpolation between points without introducing significant errors.

4.4 Drawings. Drawings shall be accurately scaled and the scale shall be called out on each drawing. The scales used shall be integer multiples of scales found on a conventional engineer's scale (10, 20, 30, 40, 50, and 60). Computer Aided Design (CAD) system format is desired, however if CAD format is not possible, a file translated from an original CAD database system into International Graphics Exchange Standard (IGES) format shall be provided.

4.5 Solid Models. Solid models shall be provided in accordance with (IAW) the Department of Defense interface standard MIL-STD-1840. The Government's preference for technical data exchange is the Standard for the Exchange of Product Model Data (STEP) Application Protocol AP203 (MIL-DTL-31000), followed by the Initial Graphics Exchange Specification (IGES) Class 7 (MIL-PRF-28000). Other formats may be acceptable upon agreement between the offeror and the Government.

4.6 Substantiation. All of the air vehicle technical description data shall be divided into two parts: basic description and derived data. The basic description shall consist of physical dimensions under the direct control of the designer or well-documented properties of standard materials (e.g., Young's Modulus for 2024-T6). Derived data shall consist of any properties of the proposed design which are the result of physical laws operating on the design (e.g., airfoil section data, aerodynamic coefficients, or the stiffness and damping of a complex structure). The basic description data shall require no substantiation. Derived data shall be substantiated for Levels II and III. Substantiation data derived from experiments shall include both qualitative and quantitative descriptions of the experimental uncertainty associated with the derived data (refer to ANSI S-071A-1999 and AIAA S-071A-1999). Substantiation data derived from modeling and simulation (computational fluid dynamics, computational structural mechanics, computational acoustics, etc.) shall include both qualitative and quantitative descriptions of the verification and validation of the derived data, as well as associated uncertainty (refer to AIAA G-077-1998). Substantiation documentation shall be complete and copies of any references (or the referenced portion(s) thereof) shall be appended.

5. DETAILED REQUIREMENTS

5.1 Air Vehicle Dimensional Data, Level I.

5.1.1 Drawings. A set of three-view, inboard profile and folded/stowed engineering drawings of the air vehicle shall be provided. Air vehicles which change configuration during normal operation (e.g., tilting rotors or wings, stopped rotors, stowed rotors) shall be shown in vertical take-off mode for the basic drawings, with supplemental drawings showing other modes (e.g., short takeoff, cruise, folded/stowed). These supplemental drawings shall emphasize overall dimensions, clearances, and operating parameters (e.g., rotor shaft angle).

5.1.1.1 Locations. The following stationline, buttline, and waterline locations (inches) shall be clearly labeled on the appropriate drawing(s):

a. The origin of the fuselage reference system.

b. Forward and aft ends of the fuselage.

c. Each rotor hub.

d. Aerodynamic center for each aerodynamic surface.

e. Rotor shaft tilt axis and the center of gravity of the tilting mass (if applicable).

f. The ground plane (landing gear unloaded; loaded at Structural Design Gross Weight (SDGW); and kneeled if applicable).

g. Each external store station.

h. The air vehicle center of gravity (cg) location(s) which are most critical for static turnover, tip-back and tip-forward.

5.1.1.2 Dimensions. The following dimensions (in inches or degrees) shall be documented on the appropriate drawing(s):

a. The radius of each unique rotor.

b. The angle of incidence (with respect to the fuselage reference waterline plane/centerline plane) of the aerodynamic reference line of each non-rotating aerodynamic surface.

c. The longitudinal and lateral shaft tilt angles or angular range (with respect to a vertical axis perpendicular to the reference waterline plane) of each unique rotor shall be indicated.

d. The static and dynamic (rotors turning) clearances of the most critical rotor blade(s) with respect to the rest of the air vehicle and/or the ground plane (landing gear loaded at SDGW).

e. The most critical static turnover, tip-back and tip-forward angles.

f. The air vehicle overall length, width and height (rotors on and off).

g. The maximum airframe width, landing gear retracted and extended (without aerodynamic surfaces).

h. The static and dynamic (limit sink speed landing) clearances of the most critical non-rotating components with respect to the ground or deck for the most critical operating condition(s) including slope landings and rolling decks.

i. Cargo compartment, door, and ramp dimensions.

5.1.2 Tabulated Dimensions and Areas.

5.1.2.1 Airframe. The dimensions required on the drawings shall be tabulated in a compact format for easy reference. All angles shall be in degrees and linear dimensions shall be converted into feet, except for clearances in inches. The following items (feet or $feet^2$) shall be added to this table:

a. Horizontal and/or vertical distance(s) between rotors.

b. Landing gear track and tread (feet) plus the stationline and buttline location of the center of each ground contact patch (inches).

c. Cargo compartment floor area.

d. Wetted areas of the following mutually exclusive components: fuselage, sponsons, nacelle(s), pylon(s), and spinner(s)/hub fairing(s).

5.1.2.2 Aerodynamic Surfaces. As a minimum, the data per Table I shall be tabulated for each aerodynamic surface (excluding rotor blades).

Table I. Aerodynamic Surfaces

ITEM	UNITS
Planform area (exposed and theoretical)	$feet^2$
Span	feet
Aspect ratio (theoretical)	---
Chord (tip and root)	feet
Sweep angle of quarter chord	degrees
Orientation w.r.t. fuselage reference system	degrees
Thickness (tip and root)	percent of chord
Airfoil section(s)	---
Control surface, flap or leading edge device area	$feet^2$
Control surface, flap or leading edge device span	percent of span
Control surface, flap or leading edge device chord	percent of chord

5.2 Air Vehicle Dimensional Data, Level II. The requirements of Level I shall be provided with the following additions.

5.2.1 Drawings. As a minimum, drawings shall include the following documentation:

a. Inboard profile drawings depicting the major air vehicle systems in sufficient detail to allow cross-section outlines to be drawn.

b. A set of line drawings of the air vehicle, including a cross-section for each station at which there is a major change in shape.

5.2.1.1 Locations and Dimensions. As a minimum, the following items shall be clearly documented on the appropriate drawing(s):

a. The centerline and center of gravity of the engine, transmission, fuel, internal armament, external stores, and major equipment.

b. Cross-section dimensions sufficient to define the configuration.

c. Landing gear dimensions and travel, including wheel and strut dimensions, under both loaded and unloaded conditions.

5.2.1.2 Mass Properties. Aircraft mass properties data shall be provided for the SDGW in the primary mission configuration. As shown in Table II, mass properties shall be provided with the rotor blades on and with the rotor blades off.

Table II. Mass Properties Data

Rotor Blades	GW (lbs)	CG (IN)			MOMENTS OF INERTIA (SLUGS-FT^2)					
		LONG	LAT	VERT	I_xx	I_yx	I_zz	I_xy	I_xz	I_yz
On										
Off										

5.2.2 Airfoil Drawings. Separate scale drawings of each airfoil section used on the air vehicle shall be provided. An expanded vertical scale, or "whale plot" shall be used. The reflex angle and/or tab deflection angle shall be indicated on each drawing, and the center of rotation shall be provided. The airfoil profile drawings shall be provided in IGES entity of 126. Otherwise, a table of coordinates shall be provided with each drawing. Not less than 50 points on both the upper and lower surfaces shall be included in the table; at least 20 of these points shall be within the first 20 percent of the airfoil chord. Separate drawings of each unique rotor blade shall be provided; each drawing shall show the value(s) of blade chord, tip sweep, tip anhedral, blade taper and the radial distribution of airfoil section. Both rotor and wing airfoil sections may be continuously varying with respect to radius or span. In this case, primary airfoil section drawings and the radial location of airfoils shall be provided.

5.2.3 Solid Models. Three-dimensional solid models of the complete air vehicle outer mold line shall be provided. Models should be of sufficient fidelity and water tightness for use in creating grids for viscous computational fluid dynamics (CFD) simulations.

5.3 Air Vehicle Dimensional Data, Level III. In addition to the Level II requirements, as a minimum, the following drawings shall also be documented.

5.3.1 Basic Drawings. Basic drawings shall contain both a three-view drawing which shall include the overall dimensions, and an inboard drawing profile.

5.3.2 Structure Drawings. Structure drawings shall contain direct and cross-sectional views (not isometric) accurately scaled. The drawings shall include the following information: general arrangement and locations, materials (e.g. aluminum, composites, etc.), material conditions (heat treatment, etc.) and dimensions (size and gage), and armament arrangement including internal and external stores. The scaled views shall include or be attached to the drawing, with details and dimensions that show the following:

a. Wing – Structural box including box chord and thickness along the span, typical cross sections showing flaps, slats, etc. engine location and centroids, dimensions and areas for flaps, slats, ailerons, spoilers, leading edge, trailing edge, major cutouts, etc., fold and production joints, materials used, critical temperature areas with design temperatures. Areas shall be shown in square feet and identified by cross hatching or other suitable means.

b. Tail – Drawings and information compatible with wing requirement where applicable.

c. Rotor – Hub and hinge, including method of rotor attachment, typical cross section including any balance weight, structural box, rotor chord and thickness along the span. Blade area shall be expressed in square feet and identified by cross hatching or suitable means.

d. Fuselage, hull, and booms – Primary and secondary structure including bulkheads, frames, longerons and stingers, major cutouts, flooring, major fittings and splices; pressurized area including volume, materials, and critical temperature areas with design temperatures indicated. Fuel tank areas shall be cross hatched and capacities indicated, where not shown on a separate fuel system drawing. Major cutouts, weapons bays, store provisions, engine, engine compartment, access doors, landing gear support and cutout shall be identified.

e. Nacelle – Primary and secondary structure. Details shall be compatible with wing and fuselage requirements, when applicable.

f. Air induction system – Details may be included on a separate drawing on the fuselage drawings or on the nacelle drawings. Inlet design, including spike, ramp, mechanisms, etc., shall be shown. Details of optional air filtration systems shall be provided.

g. Alighting gear – Main, nose, or tail, and auxiliary gear drawings shall detail the gear structure, rolling stock, retracting mechanism, attachment fittings, catapult and arrest structure. Sizes and dimensions shall be included for the rolling stock, oleo, travel, wheel travel (where different from oleo travel), and strut length from axle to centerline trunnion.

5.3.3 Propulsion System Drawings. Propulsion system drawings shall include the following:

a. Engine – Location and shape, mounts, access provisions, intake attachment station, etc, unless shown on the fuselage or nacelle structural drawings. Bleed or bypass ducts not shown on the basic air induction drawing.

b. Fuel system – Tank location, shapes, and capacities as well as location of the major distribution system components.

c. Transmission system – Gear boxes and supports, drive shafts and supports, from engine to final output drive points. Horsepower, torque, RPM, and gear ratios shall be shown for each stage. Change of drive angle within a gearbox should also be provided.

5.3.4 Equipment Drawings. Equipment drawings shall be scaled drawings to show major component locations and schematics to show the functional layout of the flight control, mission equipment avionics, hydraulic, pneumatic, electrical, air conditioning, and anti-icing groups. Isometric drawings may be substituted.

5.4 Description of the Rotor Systems. Data describing the rotor systems shall be divided into two categories: 1) Information that describes the total system, and 2) those properties that vary with rotor radius. The tabulation shall be compact and shall exclude any items not applicable to the type of rotor system proposed. Both graphic and tabular data shall be used in describing the radially-varying properties. The tabulation shall include not less than 20 nor more than 50 blade stations. If the property is piecewise linear, break points only shall be used. Blade stations should be selected to insure accurate interpolation. Radially-varying properties shall be documented from the center of rotation to the blade tip. Properties that vary with rotor blade collective pitch shall be documented for three values of collective pitch (minimum, middle and maximum). Properties that vary with operating mode (e.g., hover, cruise) shall be documented for each significant operating mode. The following data shall be documented for each unique rotor system and propeller, if applicable.

5.4.1 Level I. Level I data shall be as specified in 5.4.1.1 and 5.4.1.2.

5.4.1.1 Rotor Data. Rotor data shall consist of, as a minimum, the data required by Table III.

Table III. Rotor System Data (Level I)

ITEM	UNITS
A brief description of the rotor system including the hub type, arrangement and number of blades, direction of rotation, and the hinge, and bearing configuration	---
Radius	feet
Chord (specify effective value if chord is not constant)	inches
Geometric, thrust and torque weighted solidity	---
Thickness (effective if not constant)	percent of chord
Airfoil section (effective if not constant)	---
Twist angle of the aerodynamic reference line of the section, root to tip (positive nose up, ref. zero at zero radius; if blade twist is non-linear then specify its linear equivalent)	degrees
Blade mass per blade (outboard of physical or equivalent flapping hinge)	slugs
First mass moment of flapping inertia (about physical or equivalent flapping hinge)	slug-ft
Second mass moment of flapping inertia (about physical or equivalent flapping hinge)	slug-ft^2
Lock number (sea level, standard day conditions)	---
Flapping and lead-lag hinge offsets (articulated rotor)	percent of radius
Undersling (teetering or gimbaled rotor)	inches
Pitch bearing offset	percent of radius
Equivalent flapping and lead-lag hinge offsets (hingeless rotor)	percent of radius
First flap and lag natural frequencies	per rev
Direction of rotor rotation	---
Normal design RPM, power-on and power-off (a table of values shall be provided if design RPM is a function of mast tilt or flight condition).	RPM
Hub radius (distance from hub center to blade attachment point)	feet
Frontal area of exposed hub, shaft and control rods	feet^2
Equivalent parasite drag area of exposed hub, shaft, and control rods (omit if tilting mass drag provided below)	feet^2
Longitudinal mast tilt* (positive forward, show operating range if variable)	degrees
Lateral mass tilt* (positive starboard)	degrees
Mast length from tilt axis to rotor	inches
Location of mast: tilt axis (stationline, buttline, waterline)	inches
Distance from mast tilt axis to nacelle aerodynamic center	inches
Tilting mass center of gravity location (stationline, buttline, waterline)	inches
Tilting mass weight	pounds
Equivalent parasite drag area of tilting components VTOL mode Cruise mode	 feet^2 feet^2
Azimuthal relationship between rotors (ψ_2 when $\psi_1 = 0$, + counterclockwise)	degrees

*Lateral mast tilt may vary with longitudinal mast tilt due to conversion-axis or pylon dihedral or conversion-axis or wing sweep. Quantities associated with mast tilt shall be given in terms of a schedule of values as a function of tilt angle.

5.4.1.2 Radial Distribution of Blade Properties. Radial distribution of blade properties data shall consist of, as a minimum, the data required by Table IV. If the item is constant with radius, it may be omitted.

Table IV. Radial Distribution of Blade Properties (Level I)

ITEM	UNITS
Blade chord	inches
Blade twist (positive nose up, zero at zero radius)	degrees/airfoil section designation

5.4.2 Level II. In addition to the data required in Level I, the following items shall be documented.

5.4.2.1 Rotor System Data. Rotor system data shall consist of, as a minimum, the data required by Table V. Special care shall be taken to ensure that the rotor system data presented represents an accurate and consistent model of the design from a mathematical viewpoint.

Table V. Rotor System Data (Level II)

ITEM	UNITS
Flapping spring stiffness (articulated rotor)	foot-pound/degree
Hub spring stiffness (teetering or gimbaled rotor)	foot-pound/degree
Equivalent flapping and lead-lag spring stiffness (hingeless rotor)	foot-pound/degree
Pitch-flap coupling angle δ_3, (positive for up flap yielding nose down pitch)	degree
Precone, prelag, droop and sweep angles	degree
Swashplate/Control Phase angle	degree
Locations at which precone, prelag, droop and sweep start	percent of radius
Flapping and lead-lag damping (articulated or hingeless rotor)	foot-pound/radian/second
Longitudinal and lateral gimbal damping	foot-pound/radian/second
Control system stiffness (collective, cyclic, rotating)	foot-pound/degree
Control system damping (collective, cyclic, rotating)	foot-pound/radian/second

5.4.2.2 Rotor Hub Drawings. In the interest of maintaining as general a description of the rotor as possible, a list of additional specific data shall not be provided. Instead, a set of drawings of the rotor hub region from which all kinematics can be determined shall be documented. As a minimum, the following items shall be included on the drawings:

a. A vertical, longitudinal, and lateral reference axis system with respect to the fuselage.

b. The location of the axis of each hinge, and the angle between the hinge axis and the reference axes.

c. The location of the centerline of each control link above the swashplate, the length of each control link, and the angle between each control link and the reference axes.

d. The swashplate, shown perpendicular to the shaft.

e. The orientation of the blade's spanwise axis with respect to the reference axes (i.e., rotor blade droop, sweep, coning, pretwist, etc.)

f. The location and orientation of all spring and damper forces and moments.

g. The location of all mechanical coupling points and the line of action of all forces through them.

h. All rotor blade or hub mounted vibration reduction devices.

Plots and tables of the spring forces and moments versus angular displacements for various velocities and the damper forces and moments versus angular velocity shall be documented. The angular location of the blade stops shall be indicated on the graphs. The displacement of all springs and dampers as a function of rotor blade angular displacement shall be documented. Data defining stiffness, mass, and damping for blade-mounted vibration reduction devices shall be documented. The stiffness and damping of control system components shall be documented.

5.4.2.3 Radial Distribution of Rotor Blade Properties. Plan-view drawing(s) of the blade shall be documented showing the radial variation of cg, aerodynamic reference point, shear center, tension center, pitch axis, and elastic axis, and shall be defined IAW Table VI. All parameters shall be measured with respect to the blade axis system defined by the offeror.

Table VI. Radial Distribution of Rotor Blade Properties (Level II)

ITEM	UNITS
Airfoil section designation	---
Blade thickness	percent of chord
Blade running weight	pound/inch
Flapwise and chordwise bending stiffness	pound/inch^2
Torsional stiffness	pound/inch^2
Flapwise and chordwise mass moment of inertia	inch-pound-second^2/inch
Flapwise and chordwise shear center offset	inch
Flapwise and chordwise c.g. offset	inch
Aerodynamic center offset	inch
Center of gravity offset (aft of elastic axis)	inch
Flapwise and chordwise Principal axes (based on mass) offset	inch
Section polar radius of gyration (mass)	inch
Moment of inertia about elastic axis	slug-feet^2
Section cross-section area	inch^2
Flapwise and chordwise pitch axis offset	inch
Tension center flapwise and chordwise offsets	inch

5.4.3 Level III. Level II data shall be documented for Level III.

5.5 Rotor Airfoil Section Data.

5.5.1 Level I. A simple description of the level of airfoil technology proposed shall be documented. This may be done by reference to a well known and documented airfoil section. For example: maximum lift (at M = 0.6) 10% higher than VR-7, C_d (at $C_l = 0.4$ and M = 0.6) 10% lower than SC-1095.

5.5.2 Level II. A set of algebraic equations describing the aerodynamic characteristics of each airfoil section shall be documented. As a minimum, the equations should include the following variations:

a. C_l vs α for $M = 0$ to M_{max}

b. C_d vs α for $M = 0$ to M_{max}

c. C_m vs. α for $M = 0$ to M_{max}

d. C_d vs. C_l for $M = 0$ to M_{max}

e. C_m vs. C_l for $M = 0$ to M_{max}

The maximum Mach number (M_{max}) for each airfoil section shall be determined by considering the specific application proposed (e.g., rotor blade tip vs. blade root vs. wing). The angle of attack (α) variation shall be -180° to +180° for low Mach numbers and –20° to +20° for high Mach numbers. Pitching moments shall be referenced to the airfoil quarter chord. A discussion of the source(s) of the data shall be documented or referenced, including details of any corrections made from the test data. Justification of the form of the equations used to represent the data shall be included. The data shall be presented graphically and, included on these graphs, shall be the available experimental data for which the equations are intended to represent.

5.5.3 Level III. The following specific data, describing each of the airfoil sections used, shall be documented. Airfoil section data shall be representative of two-dimensional flow conditions at full-scale Reynolds Numbers. In the case of a surface with multiple airfoil sections, data shall be provided at an adequate number of positions along the span to allow accurate linear interpolation of airfoil properties (C_l, C_d, C_m). Airfoil section data shall be documented electronically, graphically and in tabular formats (tables IAW Paragraph 4.3). The range of data shall include angle of attack (α) -180° to +180° and Mach Number (M) from 0 to M_{max}. At a minimum, the following specific graphs shall be documented:

a. C_l vs. α for selected Mach number

b. C_d vs. α for selected Mach number

c. C_m (about the quarter chord) vs. α for selected Mach numbers

d. C_l vs. M for selected angles of attack

e. C_d vs. M for selected angles of attack

f. C_m (about the quarter chord) vs. M for selected angles of attack

g. C_d vs. C_l for selected Mach numbers

h. C_m vs. C_l for selected Mach numbers

A complete description of the source of the data, including a description of any corrections made, shall be documented (refer to Paragraph 6.1) The final data shall be representative of airfoil force coefficients resulting from those measured in two-dimensional flow at full scale Reynolds Numbers. The computer program described in NASA TM-78627 may be used to generate the computer deck of the airfoil data.

5.6 Airframe Aerodynamic Data. The following specific aerodynamic data describing the rotorcraft airframe shall be provided for all normal modes of flight as determined by the mission requirements. The data shall be documented in the wind-axis system. The location of the point at which the forces and moments are defined to be acting (the aerodynamic reference point) shall be identified. The forces and moments shall be normalized by dynamic pressure such that the units are $feet^2$ and $feet^3$.

5.6.1 Level I.

5.6.1.1 Aerodynamics of the Fuselage. For the purposes of this paragraph, the fuselage shall be defined in such a way as to exclude all items in Paragraphs 5.4 (rotor system) and 5.9 (aerodynamic surfaces). Fuselage aerodynamics data shall be documented IAW Table VII. (NOTE: θ_W = pitch angle, wind axis; ψ_W = yaw angle, wind axis; use a unit reference area.)

Table VII. Fuselage Aerodynamic Data

ITEM	UNITS
Equivalent parasite lift area (L/q) @ $\theta_W = \psi_W = 0$	$feet^2$
$\partial(L/q)/\partial\theta_{W,}\ \psi_W = 0$	$feet^2$ / degree
θ_W at which (L/q) = 0, $\psi_W = 0$	degree
Equivalent parasite drag area (D/q), $\theta_W = \psi_W = 0$	$feet^2$
$\partial(D/q)/\partial\theta_{W,}\ \psi_W = 0$	$feet^2$ / degree
$\partial^2 (D/q)/\partial\theta_W^2,\ \psi_W = 0$	$feet^2$ / $degree^2$
θ_W at which (D/q) is minimum, $\psi_W = 0$	degree
Equivalent pitching moment volume: (M/q), $\theta_W = \psi_W = 0$	$feet^3$
$\partial (M/q)/\partial\theta_{W,}\ \psi_W = 0$ (static longitudinal stability)	$feet^3$ / degree
θ_W at which (M/q) = 0, $\psi_W = 0$	degree
Equivalent parasite side force area (Y/q), $\theta_W = \psi_W = 0$	$feet^2$
$\partial(Y/q)/\ \partial\psi_W = 0$	$feet^2$ / degree
ψ_W at which (Y/q) = 0, $\theta_W = 0$	degree
(D/q), at $\theta_W = -90^o$, $\psi_W = 0$ (download drag area)	$feet^2$
Equivalent yawing moment volume (N/q), $\theta_W = \psi_W = 0$	$feet^3$
$\partial(N/q)/\partial\psi_W\ \theta_W$, = 0 (static directional stability)	$feet^3$ / degree
ψ_W at which (N/q) = 0, $\theta_W = 0$	degree
Equivalent rolling moment volume (**L** /q), $\theta_W = \psi_W = 0$	$feet^3$
$\partial(L/q)/\partial\psi_W,\ \theta_W = 0$	$feet^2$ / degree
ψ_W at which (L /q) = 0, $\theta_W = 0$	degree
Stationline, buttline and waterline of fuselage aerodynamic data reference point	inches

5.6.1.2 Drag Buildup. Analysis of the drag of each component of the airframe from both the vertical direction (for download calculations) and from the forward and lateral directions shall be documented for yaw angles of 0°. For purposes of this paragraph, a component shall be any item on the air vehicle which contributes more than two percent of the total drag or that cannot be conveniently combined with another item. The effects of roughness, leakage and interference shall be included as separate items. A table shall be provided which includes a list of the drag items, their horizontal and vertical drag coefficients (C_d), an equivalent flat-plate drag area, and an indication of the source of the drag estimate.

5.6.1.3 Stability and Control Derivatives. Tables of stability and control derivatives for hover and cruise for SDGW in primary mission configuration shall be provided. A description of the method used to obtain the derivatives shall be included.

5.6.2 Level II. In addition to all Level I items, the following specific data shall be documented.

5.6.2.1 Airframe Aerodynamics. The aerodynamic forces and moments (normalized to free stream dynamic pressure) generated by the entire airframe (including aerodynamic surfaces) shall be documented in graphic and tabular form. The forces shall be documented as a function of yaw angles which vary from -20° to +20° at a zero pitch angle and as a function of pitch angles which vary from -20° to +20° at a zero yaw angle. The forces and moments generated at yaw angles of +90°, -90°, and 180° at zero pitch angle and pitch angles of -90° and +90°, at zero yaw angle shall also be documented.

5.6.2.2 Stability and Control Derivatives. In addition to the Level I requirements of Section 5.6.1.3, tables of stability and control derivatives shall be documented to assess the effects of altitude, center-of-gravity position and gross weight variations.

5.6.3 Level III. The following data shall be provided in addition to the data required by Paragraph 5.6.2.

5.6.3.1 Component Aerodynamics. The airframe aerodynamic forces and moments (normalized to free stream dynamic pressure) generated with each of the major components removed separately, shall be documented in graphic form. The forces shall be presented as a function of yaw angles which vary from -20° to +20° and as a function of pitch angles which vary from -20° to +20° (matrix of forces and moments). The aerodynamic forces and moments generated with and without the empennage at yaw angles of +90°, -90°, and 180° shall also be documented. (Refer to Paragraph 6.2 for further information.)

5.7 Rotor Structural Dynamics Data.

5.7.1 Level I. No data required.

5.7.2 Level II.

5.7.2.1 Blade Mode Shapes. Rotor blade mode data shall be documented in graphic and tabular form. As a minimum, the following specific items shall be provided:

a. Southwell (fan) plot of the rotor natural frequencies for fully-coupled modes showing at least the first 2N/rev frequencies, including the effect of collective pitch. (N = number of rotor blades)

b. Plots of the mode shapes at design and power-on RPM for the modes identified in Paragraph 5.7.2.1(a).

c. Plots of the mode shapes at minimum and maximum power-on and power-off RPM for the modes identified in Paragraph 5.7.2.1(a).

The mode shape plots shall include separate plots of the edgewise, flapwise, and torsional displacements of each mode shape. A complete description of the method used, including the hub boundary conditions assumed in calculating these mode shapes, shall be documented.

5.7.2.2 Data for Ground Resonance Model. The following data shall be documented IAW Table VIII for the entire range of potential operating conditions including vehicle inertia, main rotor speed, and from 0 percent to 100 percent airborne in increments of 20 percent. Definitions and discussion of these data shall be per NACA Report 1351. Blade damper properties shall be provided for the entire range of temperatures, frequencies and amplitudes as specified in the operating conditions above. Effective hub parameters shall be provided for the critical body modes.

Table VIII. Data for Ground Resonance Model

ITEM	UNITS
Effective blade lag damper viscous damping rate	foot-pound-second/degree
Effective blade lag damper spring rate	foot-pound/degree
Effective hub viscous damping in the longitudinal direction	pound-second/feet
Effective hub viscous damping in the lateral direction	pound-second/feet
Effective hub stiffness in the longitudinal direction	pound/feet
Effective hub stiffness in the lateral direction	pound/feet
Effective hub mass in the longitudinal direction	slugs
Effective hub mass in the lateral direction	slugs
Lag hinge offset	feet
First mass moment of blade about lag hinge	slug-feet
Second mass moment of blade about lag hinge	slug-feet^2
Blade mass (outboard of lag hinge)	slugs

In addition, plots of tire/oleo stiffness and damping versus load shall be documented.

5.7.3 Level III. Level II data shall be documented.

5.8 Airframe Structural Dynamics Data. The following data shall be documented to describe the airframe structure. The operational configuration, weight and loading shall be defined IAW the System Specification against which this standard is being applied.

5.8.1 Level I. No data required.

5.8.2 Level II. A description of a stick model approximation to the helicopter airframe shall be documented. As a minimum, the model shall include the following items:

a. A sketch of the stick model including elements representing the fuselage, wing structure, stores, support pylons, rotor pylons and empennage, as appropriate.

b. Definition of stationline, buttline, and waterline data for each node of each model element.

c. Definition of Euler angle orientations of each model element.

d. Definition of elastic and inertial properties of each model element.

5.8.3 Level III. A detailed finite element model of the airframe and any information necessary to reproduce the modal data requested below shall be documented.

5.8.3.1 Airframe Modal Data. As a minimum, the following modal data shall be documented.

a. The generalized masses, frequencies, and damping of each airframe mode up to 4N/rev (N = number of rotor blades for primary lift rotor(s)).

b. Modal displacements at each rotor hub employing six degrees of freedom at each mode (x, y, z translations and three corresponding rotations).

c. Modal displacements at the following locations on the airframe.

   1) Pilot and co-pilot positions

   2) Points at which stores are attached.

   3) Points at which wing stabilizing surfaces and stores support pylons are attached.

   4) Selected points at which specified forces may act (for example, forces to be used to simulate shake test or for other known excitations).

   5) Points at which vibration absorbers and isolation devices are attached.

6) Points at which visionic packages are attached.

5.8.3.2 Description of Airframe-mounted Absorbers and Isolators. As a minimum, the following data shall be documented for the airframe-mounted absorbers and isolators:

a. The stiffness, mass, and damping properties for vibration devices such as airframe-mounted absorbers, isolators and hub-mounted absorbers. Define the stationline, buttline, and waterline coordinates for points connection of such components to the airframe.

b. An engineering drawing that clearly defines the specific configuration and installation of all vibration absorption and isolation devices.

5.9 Aerodynamic Surface Data. The following data shall be documented for each non-rotating aerodynamic surface.

5.9.1 Level I. No data required.

5.9.2 Level II.

5.9.2.1 Surface 3-Dimensional Force and Moment Data. The three-dimensional lift, drag, and pitching moment coefficients (as a function of angle of attack and control surface position) of each of the aerodynamic surfaces shall be documented to include stall and any reasonable area of negative angle of attack operation of the surface (e.g., download in hover). Also, documentation shall include the items in Table IX.

Table IX. Aerodynamic Surface 3-D Force and Moment Data

ITEM	UNITS
Surface lift curve slope at zero lift (3-D)	per degree
Surface drag coefficient at zero lift (3-D)	-
Surface pitching moment coefficient at zero lift	-

5.9.3 Level III. Level III data shall be documented per 5.9.3.1.

5.9.3.1 Rotor Wake Aerodynamic Interference. As a minimum, the wake model shall consist of coefficients which multiply the baseline wake-induced velocities as a function of flight conditions, or the wake-induced velocities as a function of flight conditions at various points on the airframe. In either case, it shall either be a mathematical function suitable for rapid calculation on a digital computer, or a set of tables and graphs. (Refer to additional information in Paragraph 6.3.)

5.10 Control System Data.

5.10.1 Level I. A general description of the control system concept shall be documented. As a minimum, the description of stability augmentation (e.g., electronic, fluidic, hybrid), shall include the type of system (e.g. fly-by-wire, fly-by-light, mechanical), type of augmentation (e.g. fluidic, electronic, etc.), augmentation modes, anticipated redundancy, control authority limits, sensors, servos, and control surface implementation.

5.10.2 Level II. The following data shall be documented for each rotor as applicable.

5.10.2.1 Control Travel. Control travel and sign convention shall be documented IAW Table X. (NOTE: The rotor blade feathering angle is $\theta_f = \theta_0 - \theta_{1c} \cos \psi - \theta_{1s} \sin \psi$ measured at the theoretical root of the blade.)

Table X. Control Travel Data

ITEM	UNITS
Minimum and maximum root collective pitch (θ_0) blade angle	degree
Minimum and maximum longitudinal cyclic pitch (θ_{1c}) blade angle (w.r.t. θ_0)	degree
Minimum and maximum lateral cyclic pitch (θ_{1s}) blade angle	degree
Maximum collective stick position (+ up: 0 = full down)	inches
Minimum and maximum longitudinal cyclic stick position (+ forward) *	inches
Minimum and maximum lateral cyclic stick position (+right)*	inches
Minimum and maximum pedal position (+ right) *	inches
Minimum and maximum boost/AFCS servo input and output position	inches

*Reference control position is in middle of range. If the longitudinal and lateral cyclic swashplate deflections are not symmetric about the reference control position, the offset shall be provided.

5.10.2.2 General Description. A general description of the total control system shall be documented. As a minimum, the topics to be addressed shall include the following:

a. Type of system: Linkage description (e.g., mechanical, electronic, hybrid), boost system, trim system, backup control system(s), level of augmentation, unique or nonstandard features (e.g., control mixing, non-linearities, limits).

b. Augmentation system: Axes augmented, type of hardware (mechanical, electronic, fluidic, hybrid), type of augmentation (e.g., rate command, attitude command, use of feed forward and feedback loops), actuator functional installation (e.g., parallel, series), actuator type (e.g., electrical, electro-hydraulic), augmentation modes and the methodology used for activating and/or selecting (switching) modes, authority limits, sensors.

c. Cockpit controls: Configuration (e.g., conventional, side-arm), control travels, pilot station arrangement (e.g., side-by-side, tandem, staggered).

d. Swashplate: Method of mechanization (e.g., rise-and-fall, collective sleeve).

e. For applicable configurations, a description of the coupling between longitudinal mast tilt and rotor control inputs shall be provided.

f. Descriptions of any rotor-to-rotor control couplings shall be provided. (i.e. differential cyclic, main rotor collective to tail rotor collective, etc.)

g. An algebraic/kinematic model shall be provided for the relationship between the cockpit controls and any non-rotating aerodynamic surfaces linked to them, along with a brief description of any augmentation systems.

5.10.2.3 Cockpit to Swashplate Linkages. The control linkages between the cockpit and the swashplate shall be documented in each of the following formats:

a. Block diagram(s): Including such items as cockpit controls, boost/AFCS servos; control mixing; bungee springs and/or force feel system (break-out forces and gradients) pylon coupling; swashplate; sensors which drive servos, swashplates, or aerodynamic surfaces; control system stiffness, and linkage to aerodynamic surfaces.

b. Algebraic representation of items in the block diagram(s): in particular, transfer functions for sensors, stabilization or control augmentation loops, and servos; control linkages; control mixing.

5.10.2.4 Swashplate to Blade Linkages. The control of linkages between the swashplate and the rotor blades shall be documented in each of the following formats:

a. Block diagram(s): Including swashplate, control inputs from augmentation systems above the swashplate (e.g., stabilizer bar, control gyro), non-unity gearing in the control linkage servos, blade feathering angle, angular travel of swashplate and resulting blade feathering.

b. Algebraic representation of items in the block diagram(s): In particular, transfer functions for augmentation systems, non-unity gearing.

5.10.2.5 AFCS Control Loops and Interface Definition. A graphical representation of the automatic flight control system shall be provided in MATLAB/Simulink™ (or equivalent) electronic format. In addition to the control system model file, the following information and data shall be included:

a. AFCS Interface Definition: A listing of all AFCS input and output parameters, with a description of each parameter’s function, variable type and engineering units.

b. AFCS Data Files: Files with initialization parameters, gains, and time constants that are accessed by the control system model.

5.10.3 Level III. In addition to the data required in Level II, the following shall be provided:

a. A detailed algebraic representation of the mechanical control system dynamics, to include mass and stiffness properties and nonlinear effects such as friction and hysteresis.

b. Timing delays due to sensor nonlinearities, management and transfer of sensor data to/from the AFCS, and AFCS computational processing.

5.11 Propulsion and Drive System Data.

5.11.1 Level I. A summary of all propulsion and drive system losses assumed for flight performance estimates shall be documented. All losses that affect the power available at the engine output shaft(s) shall be labeled "engine installation losses." All other losses or power requirements occurring between the engine output shaft(s) and the main rotor(s) shall be labeled "accessory losses," "drive system losses," or "anti-torque losses," as appropriate. Any variation of losses with air vehicle operating condition which is assumed for flight performance estimates shall be fully described.

5.11.2 Level II. In addition to the data required for Level I, the following shall be documented.

5.11.2.1 Engine and Drive Train Dynamics. A block diagram of the engine(s) and drive train components shall be provided, along with an algebraic representation (rotating moment of inertia, stiffness and output shaft speed) of each component of the block diagram.

5.11.2.2 Engine Thermodynamic Description. The following data shall be provided to describe the engine thermodynamics and dynamic response.

a. A block diagram of the engine components (inlet, duct, compressor, combustor, turbine stages and exhaust), along with an algebraic representation for each component of the block diagram. One-dimensional thermodynamic equations, tables, or maps used to quantify the quasi-steady flow, pressure, temperature, or power (as appropriate) for each system component shall be documented.

b. Transfer functions that approximate the lag in dynamic response of key engine parameters, such as gas generator speed, power turbine speed and power turbine output shaft torque, to fuel flow.

5.11.2.3 Engine Fuel Control Description. The following data shall be provided to describe the operation of the engine fuel control system.

a. A block diagram of the engine fuel control system, along with an algebraic representation of each component of the system.

b. Definition of partial- or full-authority electronic fuel control shall include a description of input and output interface parameters, control loops (including speed control, feed-forward compensation and torque output limiting), gains, and time constants.

5.11.3 Level III. In addition to the data required for Level II, the following data shall be provided:

a. An engine cycle model that satisfies the requirements of SAE-AS681.

b. A model of the engine electronic fuel controller in electronic format, including input files of gains, time constants and initialization parameters that are accessed by the model, and a listing of all input and output parameters, with a description of each parameter's function, variable type and engineering units.

c. A description of engine instrumentation, including measurements of temperature, pressure, flow and vibration.

6. NOTES

6.1 Airfoil Level III Data. Corrections are defined as, but are not limited to, wind tunnel wall corrections, adjustments to the measured data to account for any other known wind tunnel inadequacies, and adjustments to data to account for "surface roughness." If no wind tunnel test data exist for an airfoil section or the data are insufficient, then the procedure by which the data are estimated will be completely explained. Data derived from experiment should include both qualitative and quantitative descriptions of the experimental uncertainty associated with the data (refer to ANSI S-071A-1999 and AIAA S-071A-1999). Data derived from computational fluid dynamics analyses should include both qualitative and quantitative descriptions of the verification and validation of the data, including associated uncertainty (refer to AIAA G-077-1998).

6.2 Component Aerodynamics. The definition of a "major component" is left to the discretion of the offeror; those items usually tested in a component buildup (e.g., fuselage, wings, stores, landing gear and stabilizing surfaces) should be sufficient.

6.3 Rotor Wake Aerodynamic Interference. Rotor wakes may impinge upon various parts of the airframe causing significant aerodynamic interference. The baseline model for these wakes is a uniform-inflow, momentum theory wake whose trajectory is determined by the wake induced velocity and the freestream. A more sophisticated wake model may be provided for interference calculations, if necessary to accurately model the proposed design.