11th ANNUAL
American Helicopter Society
Student Design
Competition

1994 RFP

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Boeing Defense & Space Group,
Helicopters Division

Eleventh Annual
American Helicopter Society
Rotary Wing Student Design Competition
1994

RFP for a VTOL System for Dual Use
(Civil Transport/Military Assault Aircraft)

Sponsored by
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Helicopters Division

1994 AHS Student Design Competition -- Contents

Appendices

1994 AHS Student Design Competition -- Symbols & Abreviations

APU	auxiliary power unit
BA	Baltimore
BO	Boston
C_L	coefficient of lift
COM	cost of money
C_P	coefficient of power
C_T	coefficient of thrust
δ	pressure ratio (with altitude)
dBA	decibels ("A" weighted)
D_e	effective drag
DOC	direct operating cost
DoD	Department of Defense
FAR	Federal Airworthiness Regulations
G&A	general and administrative (costs)
GSE	groung support equipment
HIGE	hover in ground effect
HOGE	hover out of ground effect
hp	horsepower
IAW	in accordance with
IFR	instrument flight rules
IHPTET	Integrated High Performance Turbine Engine Technoilogy Program
I_P	polar inertia
IRP	intermediate rated power
ISA	international standard atmosphere
θ	temperature ratio (with altitude)
KEAS	knots equivalent air speed
LHA	light helicopter amphibious (ship)
μ	advance ratio
MCP	maximum continuous power
MH	manhours (labor hous)
MMH	maintenance man (labor) hours
MOM	measure of merit
MTTR	mean time to repair
N_R	rotor speed (rpm)
NY	New York
OEI	one engine inoperative
ORD	operational requirements document
PH	Philadelphia
RAM	reliability, availability and maintainability
RFP	request for proposal
RI	Richmond
SDGW	structural design gross weight
σ	rotor solidity
SFC	specific fuel consumption
SHP	shaft horse power
SDGW	structural design gross weight = full crew+passengers+60% fuel
SL	sea level
SLS	sea level standard (atmospheric conditions)
TOP	takeoff power
V/STOL	vertical/short takeoff and landing
V_{BR}	speed for best range
V_{BROC}	speed for best rate of climb
V_{MCP}	speed for cruise at maximum continuous power
$V_{MIN\ DOC}$	speed for minimum direct operating cost
VROD	vertical rate of descent
VTO	vertical takeoff
VTOL	vertical takeoff and landing
w_a	gas mass flow
WA	Washington
w_F	fuel flow rate

OPERATIONAL REQUIREMENTS DOCUMENT (ORD)

FOR THE

DUAL USE CIVIL/MILITARY TRANSPORT

1.0 GENERAL DESCRIPTION OF OPERATIONAL CAPABILITY

This ORD presents design requirements for a dual use civil/military VTOL transport aircraft. The objective is to design an aircraft capable of satisfying two sets of design requirements. Maximum commonality of dynamic systems is required to minimize development and qualification/certification costs. Therefore, all dynamic components, the rotor system(s), transmission(s), and engine(s), must be common. Commonality of other systems are also desired, as practical.

1.1 Mission Areas

The Marine Corps has a long standing operational requirement to provide the capability to conduct assault support operations in support of national military strategy. As one of the six functions of Marine Aviation, the assault support mission area is defined as "the air transport of personnel, supplies, and equipment into or within the battle area." The Marine Corps' medium lift assault transport aircraft must provide combat assault transport of Marines.

Commercial flight in and around the Northeast United States transportation corridor between Washington, D.C. and Boston presents an opportunity for short-range transport, passenger service. Increased utilization of major airports by larger carriers will make alternative landing sites more valuable resources. Vertiport locations being considered will allow for VTOL operations closer to city centers thereby affording reduced ground travel time.

1.2 Type of System Required

The Marine Corps requires a dual-piloted, all-weather, day/night, medium lift vertical takeoff and landing (VTOL) aircraft that is capable of operating from ships. The aircraft shall incorporate high value technologies in airframe, propulsion, turreted gun weaponry, and aircraft human factors engineering. The new system will provide dramatic improvements in performance, and system commonality. The basic assault troop transport configuration of the aircraft will have a turreted gun capability and be mission configured for troop and internal/external cargo transport.

In its civil role, the aircraft must provide passenger service between Boston, New York, Philadelphia, Baltimore, Washington, and Richmond in IFR conditions. The aircraft must be designed in accordance with (IAW) FAR 29 or FAR XX, Interim Airworthiness Criteria for Powered-Lift Transport Category Aircraft, July 1988. It should satisfy postulated Northeast corridor passenger volume requirements at minimum fleet direct-operating-cost (DOC) to an operator. Assume that improvements will be made which provide unique terminal area procedures to V/STOL aircraft, and that vertical takeoff and landing sites will be developed near city centers.

2.0 MISSION PROFILES

2.1 Military

Several ships are envisioned to participate in an amphibious assault, with the size of an LHA complement of rotorcraft defined so as to deliver a minimum of 700 combat Marines in a 90 minute window to a landing zone 50 nm from the ship. The 90 minute time window starts counting when the first rotorcraft lands at the landing zone. The entire mission is at zero wind conditions, tropical day temperature profile.

1.* Warm-up: 5 minutes at Idle Power at SL
2. Takeoff: 1 minute HOGE at SL (maximum allowable power is 95% Takeoff Rated power)
3. Cruise outbound at V_{MCP} at SL to 50 nm required.
4. Maneuver/Land/VTO: 5 minutes HOGE at 3000 ft. (maximum allowable power is 95% Takeoff Rated power) Offload troops.
5. Cruise inbound at V_{MCP} at SL for 50 nm required.
6. Land: 1 minute HOGE at SL
7. Reserves: Greater of 10% initial fuel or 30 minutes at V_{BE} at SL.

*Add 15 minutes additional time for refueling, when appropriate.

2.2 Commercial

For this study, assume that a viable U.S. Northeast corridor commercial operator will require a fleet capable of flying 700,000 passenger-miles in a 16 hour day (6am to 10pm), at minimum direct operating cost (DOC). Considering the intercity ranges, and predominant New York-to-Washington, D.C. traffic volume, a design range of 197 nm is required. Fuel sizing for two legs should be considered. Mission performance with full passenger load is required, though an average load factor of 0.70 should be applied for passenger-mile estimation. The design performance mission, with IFR reserves, is described below. Cruise speed should be that for minimum DOC (V_{MCP} maximum). DOC calculations are provided in the data package.

The entire mission is at zero wind conditions, Standard Day temperature profile.

1.* Warm-up/taxi: 10 minutes at Idle Power at SL
2. Takeoff: 1 minute at HOGE at SL (maximum allowable power is 100% Takeoff Rated Power)
3. Climb on course at V_{BROC} at cruise power to cruise altitude. Max Speed is 250 KEAS below 10,000 ft.
4. Cruise outbound at $V_{MIN\ DOC}$ to desired range.
5. Descend to SL Max Speed is 250 KEAS below 10,000 ft.
6. Land: 1 minute at HOGE at SL (maximum allowable power is 100% Takeoff Rated Power)
7. Taxi: 5 minutes at Idle Power. Offload passengers.
8. Reserves: Cruise fuel for 25 nm to alternate vertiport, plus 30 minutes (rotor-bourne configurations) or 45 minutes (wing-bourne configurations).

*Add 15 minutes additional time for refueling, when appropriate.

3.0 SYSTEM CAPABILITIES REQUIRED

3.1 Military Considerations

The typical military mission scenario originates at night in low visibility or adverse weather from an LHA (Light Helicopter Assault ship). The LHA has 7 launch/landing locations, the equivalent of 19 spotting units available for parked aircraft ready to cycle onto the launch positions, and 12 hangar spotting units available for below-deck aircraft maintenance and storage. 15 minutes should be allocated for cycling from parked to flight ready, and 45 minutes from hangared to parked.

The aircraft must have the capability to provide suppressive fire. It is required to carry a turretted cannon, with +15 to -40 deg elevation and ±110 deg azimuth articulation ranges relative to the nose of the aircraft.

The aircraft must be structurally designed for +3 to -1g's normal load factor at SDGW. The aircraft must also have the structural capability to lift external loads of up to 10,000 pounds for dual point external hook operations. The aircraft must be capable of executing a transient 30° bank angle turn at cruise speeds, SL/103°F.

The aircraft must be capable of sustained level flight at SL for emergency single engine operations. The aircraft must also be capable of power off glide/autorotation to a survivable emergency landing.

A crew of three is required, with either pilot or co-pilot capable of flying the aircraft, and a crew chief in the cabin.

The aircraft will have a shipboard spot factor of not more than 1.4. Spotting factor is defined in the data package. Automatic blade folding is required for minimum spotting factor and shipboard handling considerations. Fuselage folding (tailboom, wing, etc.) may also be considered. The aircraft must be designed for shipboard elevator and hangar compatibility as defined in the data package.

The aircraft should be designed to DoD Military Specifications and Standards (reference SD24L for standard Navy design requirements).

The aircraft must have the capability to efficiently handle both personnel and cargo/vehicle loads with minimum reconfiguration requirements. Cargo handling system must be capable of loading Military Airlift Command Standard 463L half-pallets (54x88 inches floor space - variable heights to 48"). It must have crashworthy seating for combat equipped Marines that can be easily stowed for cargo load operations. Receiving loads from forklifts (at least the MC-4000) must be accomodated for in the design of the airframe and cargo handling system.

The static tipover angle shall not be less than 28 degrees.

Engine inlet particle separator and IR suppression devices are required. These typically reduce available engine power by a total of 3%.

Total military aircraft procurement quantities will be equivalent to 8 LHA complements sized to satisfy the troop lift requirement defined in Section 2.1.

3.2 Commercial Considerations

Commercial flight operations will originate from commercial or private prepared vertical takeoff and landing sites.

Ride comfort must be as good as competing modes of travel. Adequate seat pitch, head and shoulder room, and aisle width should be provided. Overhead storage capacity is 1.5 ft^3/passenger, and suitcase stowage average allocation is 2.5 cu. ft. per passenger at 10 lbs/ft^3.

Authorized flight envelope must be +2.5 g's to -1.0 g's normal load factor at SDGW and must be designed for a 1.5g jump takeoff. The aircraft must be capable of a transient turn capability at cruise equal to two times a standard rate turn.

For maximum takeoff and landing safety, the aircraft must provide an OEI HIGE capability (5' wheel height) for full fuel and payload gross weight, on Contingency Power. For scalable or developmental engines, consider contingency power to be 15% above takeoff Power rating.

A flight crew of two is required, with side-by-side pilot seating preferred. For vehicle designs of 19 or more passengers, one flight attendant is required. Two flight attendants are required for more than 39 passenger configurations. Cabin accomodations include a 6 sq ft galley, 4 sq ft oversize luggage closet, and a 9 sq ft lavatory.

If commercial service above 8000 ft pressure altitude is planned, cabin pressurization is required so that maximum internal pressure altitude does not exceed 8000 ft.

Total commercial aircraft production quantity will be equivalent to 8 fleets sized to satisfy the passenger transport requirement of Section 2.2.

3.3 Combined Considerations

To operate from remote sites, the aircraft must be capable of reliable unassisted self-starting and be capable of powering all electrical equipment without main propulsion systems operating. An auxilliary power unit (APU) is therefore required.

The aircraft must be designed to facilitate basic aircraft maintenance. The design must facilitate access for inspection and rapid repair/replacement of all aircraft components (engines, transmission(s), avionics, hydraulic/electrical/fuel/cooling systems, flight controls, etc.).

The design should incorporate the elements of good crashworthiness design: a good keel structure with antiplowing characteristics; landing gear struts should not penetrate the cabin area; high mass items (engine and transmissions), should have adequate crash protection to prevent entry into the cabin areas; crashworthy fuel tanks; and adequate seat stroke (at least 8 inches).

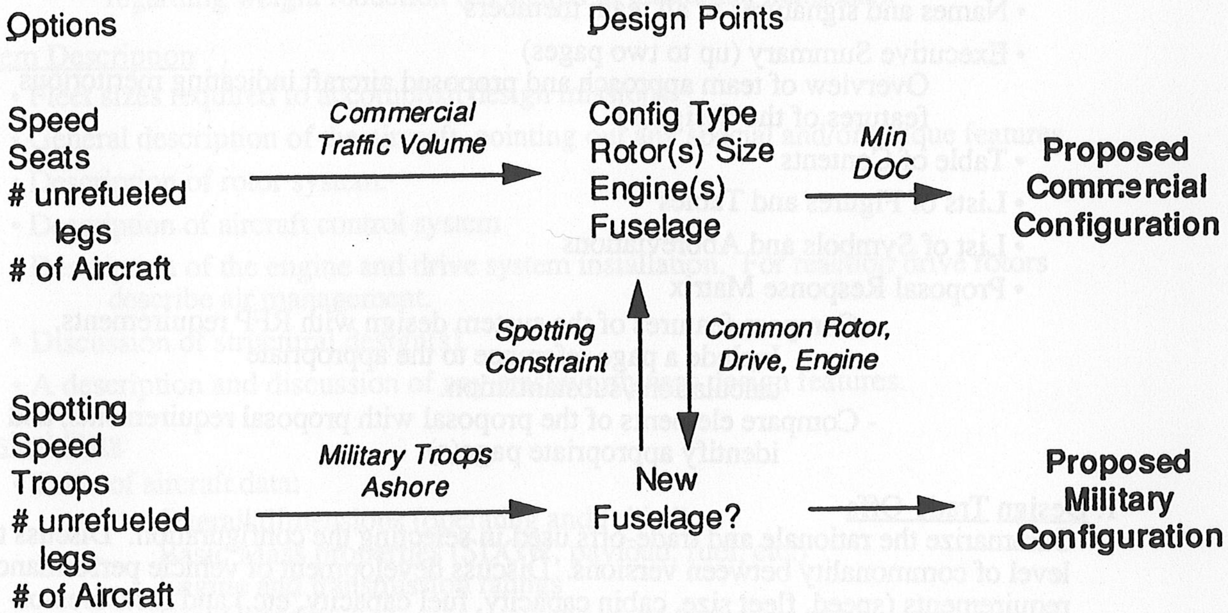
Designs for low noise are required to minimize external noise (threat detection and community impact) and internal noise (crew/troop fatigue and passenger comfort). Since rotor advancing tip Mach number is a significant noise source, it is suggested that advancing tip Mach number be limited to 0.87 for cruise conditions. In addition, 1% of the design takeoff gross weight should be allocated for internal noise reduction treatments for the commercial vehicle.

Existing turboshaft engines with improvements for IHPTET technologies (assume 25% SFC reduction and 40% power-to-weight improvement) are recommended for this aircraft. Other engine types may use similar factors on SFC and weight. If data are not available, use the scalable turboshaft data provided in the data package.

4.0 APPROACH

It is anticipated that the basic aircraft configuring and sizing will follow a logic path similar to that shown below to satisfy both military and commercial requirements. Options of speed, seats, and unrefueled legs will need to be compared against fleet size and various design points. Then, a selection based on minumum commercial DOC/seat-mile, with the military spotting constraint, will need to be made to provide the basis for further design work and analyses..

Sample Logic Path for Basic Aircraft Sizing



1994 AHS Student Design Competition -- Proposal Requirements

General

The proposal should communicate the system design and approach, and present and substantiate assumptions, input data used, and estimated/calculated data. Identify the methodologies used including assumptions, results and limitations.

The proposal is limited to 100 pages including double-spaced, typed text, drawings, graphs and tables. This limit excludes any appendices that contribute to, but are not required to describe the system design approach. Deliver five copies of the proposal, in a format compatible with a standard three-ring binder.

Data, drawings, and descriptions should be presented for both configurations, unless explicitly stated otherwise.

The following elements must be addressed.

Prologue (not numbered...not included in page limit)

- Cover, including school and judging category
- Names and signatures of all team members
- Executive Summary (up to two pages)
  Overview of team approach and proposed aircraft indicating meritorious features of the design(s).
- Table of Contents
- Lists of Figures and Tables
- List of Symbols and Abbreviations
- Proposal Response Matrix
  - Compare features of the system design with RFP requirements. Include a page reference to the appropriate calculations/substantiation.
  - Compare elements of the proposal with proposal requirements, and identify appropriate page(s).

1. Design Trade-Offs

Summarize the rationale and trade-offs used in selecting the configuration. Discuss the level of commonality between versions. Discuss development of vehicle performance requirements (speed, fleet size, cabin capacity, fuel capacity, etc.) and measures-of-merit (DOC). The discussion shall include a summary statement of key assumptions made and some consideration of the impact of differing assumptions.

2. Drawings

- General arrangement (external three-view) drawing of each configuration showing major dimensions, and illustrate the access locations, vision limits, landing gear, steps, handholds, and work platforms.
- Military configuration folded for shipboard handling with calculation of deck spotting factor.
- Inboard of either configuration (internal three-view) drawing showing major dynamic components, powerplant (engines, fuel system, ducting), structure, cabin and crewstation(s), avionics and any special features.

- Military configuration cabin layout with troop seating and access provisions.
- Civil configuration cabin layout showing passenger seating, galley, lavatory, and baggage provisions.
- For military configuration, layouts of 50th percentile maintainer at three man/machine interfaces:
  (1) accessing engine,
  (2) accessing transmission and
  (3) accessing primary avionics installation.
  Identify any special ground support equipment (GSE) required.

Additional drawings required for proposals in Graduate category:

- Schematic of drive system, with gearboxes, shaft directions and couplings identified. Include a listing of types and reduction ratios of gearsets and shaft speeds. For reaction drive, illustrate ducting, valves, nozzles, seals.
- A schematic drawing of (each) aircraft structure showing location of high-mass items, primary structure, and load path continuity. Identify crash safety features. Discuss materials used, with reference to any assumptions made regarding weight reduction (compared to traditional materials).

3. System Description

- Fleet sizes required to accomplish design missions.
- General description of the aircraft, pointing out any special and/or unique features.
- Description of rotor system.
- Description of aircraft control system
- Description of the engine and drive system installation. For reaction drive rotors describe air management.
- Discussion of structural design(s).
- A description and discussion of any crashworthiness design features.

4. Physical Data

- Table of aircraft data:
  Overall dimensions (operating and folded)
  Basic Mass properties (SDGW, payload, fuel, etc.)
  Engine and transmission ratings
  Fuel Capacity
  Cabin Size

- For each rotor:
  Rotor - Diameter
  - Solidity or activity factor
  - normal tip speed
  - polar inertia (I_P)
  Hub - type (incl. blade retention and motions)
  - number of blades
  - control ranges
  Blade - planform (radius, taper/chord distribution, tip)
  - cross-section (airfoil(s), twist)
  - autorotation index, Locke number

- For each aerodynamic surface (wing, canard, horizontal/vertical tail):
  Installation (sweep, incidence, control range if articulated)
  Planform (span, taper/chord distribution)
  Cross-section (airfoil(s), twist)
  Features (control surfaces, high-lift devices or download alleviation devices)

5. Weights (for each configuration)

- Explain methodology used. List all technology factors used in adjusting weight estimation equations with assumptions and/or basis of rationale.
- Provide a group weight statement similar to format provided.
- Calculate aircraft inertias about three major axes at SDGW. SDGW is defined as gross weight for full crew, full payload and 60% fuel capacity.
- Generate weight and balance diagram(s) showing center-of-gravity movement (weight vs. fuselage station) as a function of loading and fuel burn. Include forward and aft CG limits with justification.

6. Aerodynamic Data:

- Summary table of significant performance attributes.
- For each lifting rotor, provide graphs of isolated and installed HOGE Figure of Merit versus C_T/σ, and isolated and installed L/D_e versus μ at each SDGW configuration at SLS.
- For each rotor provide a graph of C_P vs. C_T for $\mu=0$, best endurance and maximum speeds
- For each aerodynamic surface provide C_L vs. α and C_L vs. C_D
- Calculations of performance factors, including transmission efficiency and accessory power, drag build-up, vertical drag, and ground proximity effect.

7. Engine Performance:

- Provide a graph of static power available (installed) per engine versus altitude for MCP, TOP, and contingency power ratings, for ISA and tropical day. For reaction drive rotors, provide installed engine exhaust temperature and pressure and mass flow versus altitude.
- Provide graph of installed engine fuel flow vs. horsepower, for SLS. For reaction drive, provide installed engine fuel flow versus 'referred' gas flow ($W_f/\delta\theta^{0.5}$ vs. $W_a\theta^{0.5}/\delta$).

8. Mission Performance/Envelope:

- Graph(s) of engine power required and specific range versus level flight forward speed at SDGWs and design cruise conditions. Show power available (MCP, TOP, contingency) and transmission limit.
- Graph of maximum gross weight for HOGE versus altitude, for ISA and tropical day at TOP, for military mission configuration.
- Graph of one-engine-inoperative (OEI) HIGE (at 5 ft landing gear height) gross weight versus altitude for ISA at contingency power, for civil configuration.
- Troops versus radius capability for the military configuration, and passenger versus range capability for the civil configuration.

- For military mission, graph of cumulative troops ashore versus time after first wave lands, and utilization of LHA launch spots versus time.
- For civil mission, scheduled operations and cumulative passenger seat-miles during the day.

9. Handling Qualities:
   - Aircraft trim attitude and control positions versus level flight speed at SDGWs and design cruise conditions.
   - Graph(s) of maximum transient and sustained load factor capability versus forward speed at SDGWs at SLS.
   - Graph of pitch, roll and yaw damping as a function of pitch, roll and yaw control sensitivity for low speed (hover) and cruise operations. This should be shown in relation to a Cooper-Harper pilot rating (PR) curve of 3.5.

10. Cost Analysis
    - Provide an estimate of the total manufacturing cost. Each production run (military and civil) is eight (8) times the number of aircraft required for the design missions. Assume a total average production rate of 8 aircraft per month. A production cost model is provided in the Appendix
    - Predict a direct operating cost (DOC) estimate in cents per available seat mile for civil aircraft. Assume 2000 hours of annual utilization. Assume other factors as shown in DOC discussion of Appendix.

11. Risk Assessment

    Provide a discussion of technical risks in the development of this system. Identify high risk components which would require specific risk reduction activities prior to aircraft design.

12. Detailed Analyses

    Undergraduate teams are required to submit two analyses from the following list; graduate teams are required to submit four analyses.

    Results of these analyses should be supported by a discussion of methodology (with correlating data) and assumptions made, especially advanced technology assumptions.

    - Analysis of engine air induction system airflow (inlet to exhaust) in support of engine installation loss factor. Identify losses in power and fuel flow used in aircraft sizing methodology, and any ram recovery expected. Include as part of the analysis a schematic of the air induction system, with area and shape distributions, and a description of the inlet and exhaust geometries.
    - Analysis of internal and external noise levels for civil configuration. Compare internal noise levels to a notional requirement of 90dBA (85dBA desired). Compare external noise level to certification requirements contained in FAR 36 Part H.
    - Description of main rotor blade structural design concept, and determine the rotating blade natural frequencies over a rotor speed range of at least ± 5% from normal operating speed. At 100% N_R, the frequency separation from significant integer multiples of the rotor speed should be greater than 0.3 cycles/rev. Present results in a fan diagram.

- Detail the shafting design for power transmission to one rotor. Provide analyses of shaft cross-section and critical speeds. Discuss trade-off between shaft design and number of unique parts. Address access to the drive system components for inspection and removal.
- Provide an estimate of unscheduled flight line MMH/FH for subsystems broken down to at least the major subsystem level (see Appendix to this RFP). Data provided in the appendix are for currently fielded tandem rotor helicopters. Provide rationale for values more optimistic than those shown in Appendix. Assume values of 4.0 for MMH/FH allotted to scheduled maintenance for the aircraft. Identify design changes to the aircraft which could achieve a twenty (20) percent improvement in MMH/FH.
- Predict aircraft open loop-stability derivatives and stability roots. Define feedback gains which provide desirable closed loop roots. Analysis should be conducted for at least two conditions (hover and cruise) for either configuration.
- Detailed structural analysis of any one of the main frames supporting a main landing gear. Design loads shall be based upon a hard landing, level attitude (0° pitch, 0° roll) on a level runway at 20 feet-per-second vertical rate of descent (VROD). Include a structural drawing of the frame being analyzed.

Note: other detailed anaylses may be acceptable, if request is formally submitted as a question, and approved by the customer (sponsor).

1994 AHS Student Design Competition -- Judging Criteria

The proposal is the means by which a customer evaluates each offeror's concept. Clear and concise descriptions are required, with appropriate use of illustrations. Data charts should include requirements, constraints or other data for reference. Spelling, grammar and neatness are important, but unnecessary or extravagant presentations are not required.

20%....... Creativity...Credit is given for innovative approaches to the design or integration of a component, a system, the aircraft or the fleet. Primary benefits and drawbacks (if any) should be identified.

20%....... Compliance with mission/system requirements, or thorough discussion of justification for deviations taken to the stated requirements.

20%....... Realism of the design(s).

20%....... Rigor of the design process, including appropriate application of technology, substantiation of assumptions, documentation of trades, and completeness of data presented.

20%....... Balanced approach, reflecting a consideration of all stated and implied requirements for design, fabrication and fielding of both civil and military fleets.

DATA PACKAGE

These data are provided as reliable estimates but should be afforded some level of scrutiny in any rigorous analysis. Changes are acceptable with supporting technical data.

Shipboard Considerations:

Simplified Spotting Factor = (maximum length x maximum width) / 680 sq. ft. in the parked/folded configuration (CH-46E ≡ 1.0)
Maximum ship hangar height is 18 ft 6 in.

Maximum ship elevator capacity is 40,000 lbs. Aircraft are transferred to and from the maintenance hanger fully fueled and folded.

Weights:

Fixed Equipment Weights (as required)

Avionics	1300 lb	(military)	650 lb	(commercial)
Armament (Cannon)	400 lb			
Cargo Handling	350 lb	(military)		

Fixed Useful Load Items (as required)

Expendables & Ammo	250 lb	(military)

Payload Characteristics

Crew	220 lb	Military	200 lb	Commercial
Troop	240 lb	(includes equipment)		
Passenger	210 lb	(includes baggage)		
Flight Attendant	200 lb			

463L half-pallet is 54 by 88 inches.

Scalable State-of-the-art Engine Characteristics:

Scalable turboshaft engine SFC haracteristics are provided here. Data are static, uninstalled. If existing engine data are used, assume a 25% reduction in SFC and a 40% improvement in power to weight ratios, representing IHPTET improvements.

Engine Rating Ratios		Duration	$SFC/\delta\theta^{0.5}$ (lb/hr/hp)
1.150	(OEI, Contingency)	2 min	0.302
1.000	(Takeoff or MAX)	10 min	0.305
0.924	(IRP)	30 min	0.309
0.791	(Cruise or MCP)	Continuous	0.328
0.5	(partial power)	-----	0.400
0.2	(Idle)	-----	1.000

Engine Weight, lb = 160+ 0.05539 * (Design SHP)
Engine Diameter, ft = 0.017 * $(\text{Design SHP})^{0.5}$
Fuel Density, lb/gal = 6.75 (Jet A)

U.S. Northeast Corridor:Intercity Distances

Commercial Great Circle Distances (nautical miles, no reserves)

		BO	NY	PH	BA	WA	RI
Boston	(BO)	---	162	242	321	358	467
New York	(NY)		---	80	159	197	292
Philadelphia	(PH)			---	79	117	210
Baltimore	(BA)				---	38	134
Washington	(WA)					---	99
Richmond	(RI)						---

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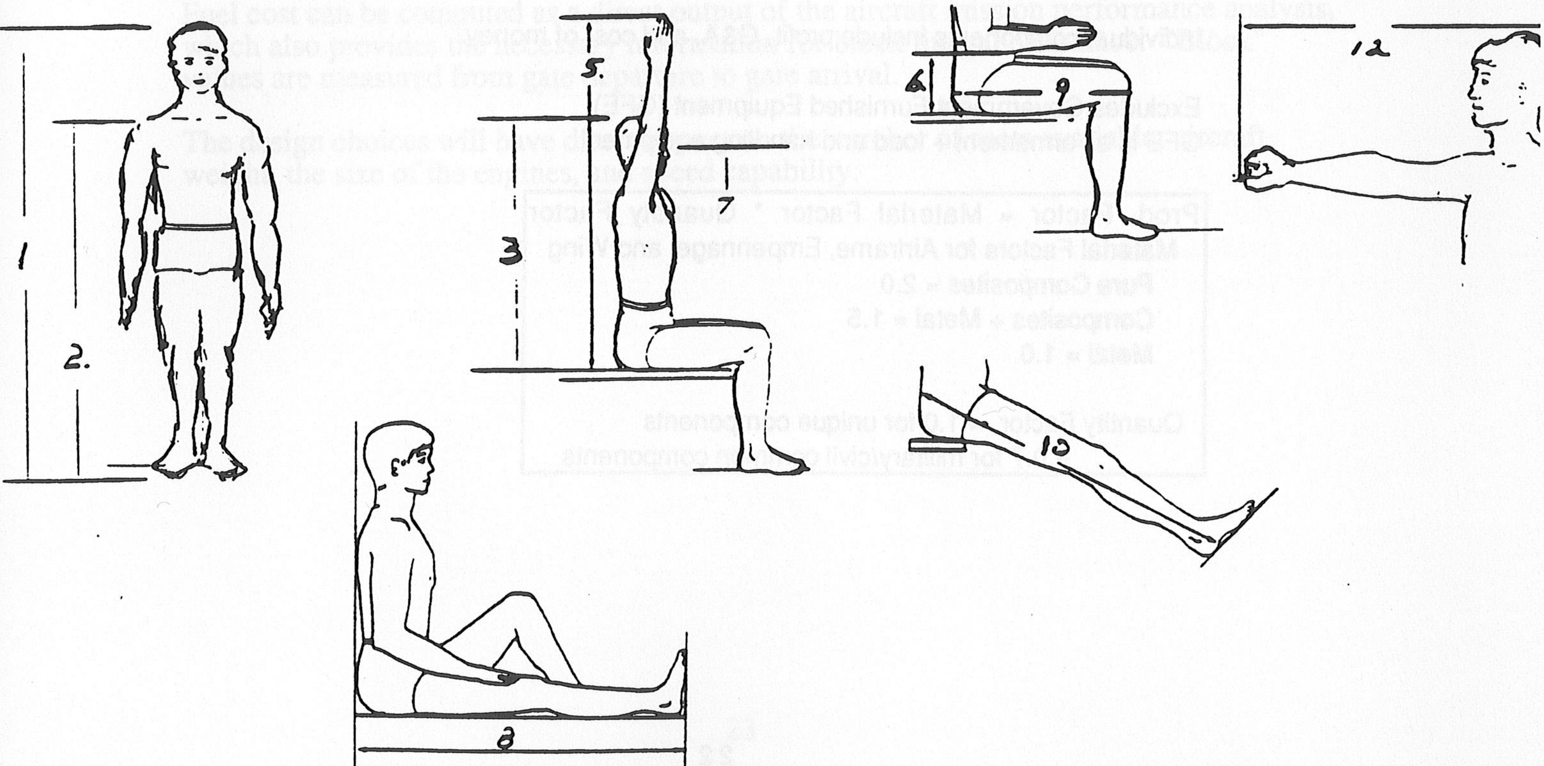
Appendix 1 -- Army Aviator Anthropometric Data (1970)

	5Th	25th	50th	95th
1. Standing Height	64.5	67.0	68.7	73.1
2. Shoulder "	52.5	54.7	56.3	60.2
3. Sitting "	33.3	34.7	35.7	38.1
4. Knee Height Sitting	19.3	20.2	20.8	22.6
5. Vertical Reach Sitting	52.8	54.9	56.5	60.4
6. Elbow Height Sitting	7.4	8.4	9.1	10.8
7. Eye Height Sitting	29.0	30.2	31.0	33.1
8. Buttock-Heel Length	42.1	43.8	44.9	47.6
9. Buttock-knee "	22.1	23.1	23.8	25.8
10. Functional Leg Length	40.9	42.8	44.2	47.4
11. Hip Breadth	13.2	14.1	14.8	16.7
12. Thumb Tip Reach	28.8	30.1	31.1	34.2
13. Hand Length	7.0	7.3	7.6	8.1
14. Shoulder Elbow Length	13.3	14.0	14.4	15.6



Appendix 2 -- V/STOL Aircraft Purchase Price Model

Subsystem	$/lb	Prod. Factor	Weight (lbs)	Cost ($K)
Airframe+Engine Sect+Air Induction	300	1.5	2500	1,125
Empennage	400	1.5	500	300
Wing	500	1.5	300	225
Rotors/Props/Fans	250	0.7	4000	700
Landing Gear	250	1	1000	250
Propulsion (incl engines)	1000	0.7	2000	1,400
Drive System	350	0.7	3000	735
Fuel System	300	1	1500	450
Flight Controls	250	1	1000	250
Hydraulics + Pneumatics	300	1	150	45
Instruments	500	1	170	85
Electrical	300	1	600	180
APU	500	1	200	100
Avionics	1500	1	650	975
Furnishings	200	1	1000	200
ECS/Anti-Ice	600	1	300	180
Subtotal of Weighed Components				7,200
Assembly+Integration	4	1	18870	75
Subtotal of Manufactured Components				7,275
Non-Recurring Amortization	0.19	* Manuf. Comp. $		1,382
Total Purchase Price				8,658

DOC Inputs	Seats	24	$K/Seat	361

Individual components include profit, G&A, and cost of money

Excludes Government Furnished Equipment (GFE)
GFE is all armament + load and handling equipment

Prod. Factor = Material Factor * Quantity Factor
Material Factors for Airframe, Empennage, and Wing
Pure Composites = 2.0
Composites + Metal = 1.5
Metal = 1.0

Quantity Factor = 1.0 for unique components
= 0.7 for military/civil common components

APPENDIX 3: DIRECT OPERATING COST DISCUSSION

For commercial operations, direct operating costs (DOCs) are a complex measure of the true operational impact of a wide range of cost drivers. One can evaluate the relative impact of key design variables at a conceptual design level. The key drivers in any operating cost analysis are aircraft purchase price, maintenance, crew and fuel costs.

The following provides the description of a methodology to compute DOCs given the necessary data to determine these key drivers. Sample output from a spreadsheet, Figure 1, is provided to aide in the discussion.

Purchase Price

Purchase price is dependent on many factors including system complexity, production quantity (learning curve and absorption of development costs), avionics, and engine power and quantity. The production cost model assesses cost through a simple estimate of cost per pound for various systems, and accounts for quantity through compensation for common components.

Maintenance Costs

Maintenance can be broken down into fixed and dynamic components, then the maintenance costs can more truely reflect the design in terms of aircraft weight empty (excluding engine and drive) and installed power.

Personnel Costs

Crew costs are primarily affected by the design in terms of the number of passengers served by cabin crew and the flight time. Commercial aircraft of the size needed for the aircraft will always require at least two cockpit crew.

Other Costs

Fuel cost can be computed as a direct output of the aircraft mission performance analysis, which also provides the necessary information for block time and distance. "Block" values are measured from gate departure to gate arrival.

The design choices will have direct impact on the number of seats available, aircraft weight, the size of the engines, and speed capability.

Direct Operating Cost (DOC) Methodology

DOC ($/revenue-seat-mile)		$0.56	= X/B/E
DOC ($/available-seat-mile)		$0.40	= X/A/E
DOC per flight per aircraft	X	$1,873	

Cost Elements		
Flight Crew	$428	= N*D*M
Fuel	$225	= C*P
Insurance	$65	= K*I/L*D*1000000
Airframe Maintenance	$216	= Q*F*D
Engine/Drive System Maintenance	$225	= R*G*D*O
Depreciation & Financing	$714	= J/L*D*I*1000000

Inputs			
No. of seats	A	24	
No. of Passengers	B	17	
Block Fuel, lbs	C	1500	
Block Time, hrs	D	1.5	
Block Distance, nm	E	197	
Aircraft Weight Empty (excl. engines/drive)	F	14420	lbs
Engine Size	G	3000	Hp/engine
Purchase Price Factor	H	361	$K/seat
Purchase Price	I	8.66	$M = H*A/1000
Depreciation & Financing Factor	J	0.11	$/year/$ price
Insurance	K	0.01	% of purchase price/year
Expected Utilization	L	2000	flight hours/year
Number of Crew and Attendants	M	3	
Crew, Attendant Cost	N	95	$ per block hour per person
Maintenance Cost		50	$ per maint. manhour
No. of Engines	O	2	
Fuel Cost	P	0.15	$/lb
Airframe Maintenance	Q	0.01	$/lb/flight hour
Engine Maintenance	R	0.025	$/hp/flight hour

Appendix 4 -- Maintainability Definitions & Data

(MIL-STD-721C)

Mean-time-to-repair (MTTR): A basic measure of maintainability: The sum of corrective maintenance times at any specific level of repair divided by the total number of failures within an item repaired at that level, during a particular interval under stated conditions.

Corrective maintenance: All actions performed as a result of failure, to restore an item to a specified condition. Corrective maintenance can include any or all of the following steps:

Localization
Isolation
Disassembly
Interchange
Reasssembly
Alignment
Checkout

MMH - Maintenance manhours

MMHTR - Maintenance manhours to repair

- Is the average number of manhours spent on a repair event.
- This is a number intimately associated with maintenance crew size (MCS) and MTTR:

  MMHTR = MCS * MTTR

- Be aware - when you estimate MTTR and MCS, they must be consistent.

MMH/FH - Maintenance manhours per flight hour - is the average labor hours spent for each flight hour.

MMH/FH = MMHTR/MTBM = MCS * MTTR / MTBM

MTBM - Mean time between maintenance - is the average number of maintenance-free flight hours between the need for any kind of maintenance; includes scheduled and unscheduled maintenance:

$$\frac{1}{MTBM} = \frac{1}{MTBUM} + \frac{1}{MTBSM}$$

MTBSM - Mean time between scheduled maintenance - is the average number of flight hours before (at least a piece of) the aircraft is examined for a failure mode or an unsafe condition. The event occurs at a predetermined time: either number of flight hours or calendar hours.

MAINTAINABILITY DEFINITIONS (continued)

MTBUM - Mean time between unscheduled maintenance - is the average number of flight hours of trouble-free operation of an item between any occurrences of the need for maintenance caused by either inherent failures or induced causes.

Inherent failure represents the need for maintenance caused by the failure of an item due to its design.

Induced cause represents the need for maintenance caused by mechanic error, pilot error, the environment etc.

MMH/FH may also refer to component or subsystem removal:

$$MMH/FH = MMHTR/MTBR$$

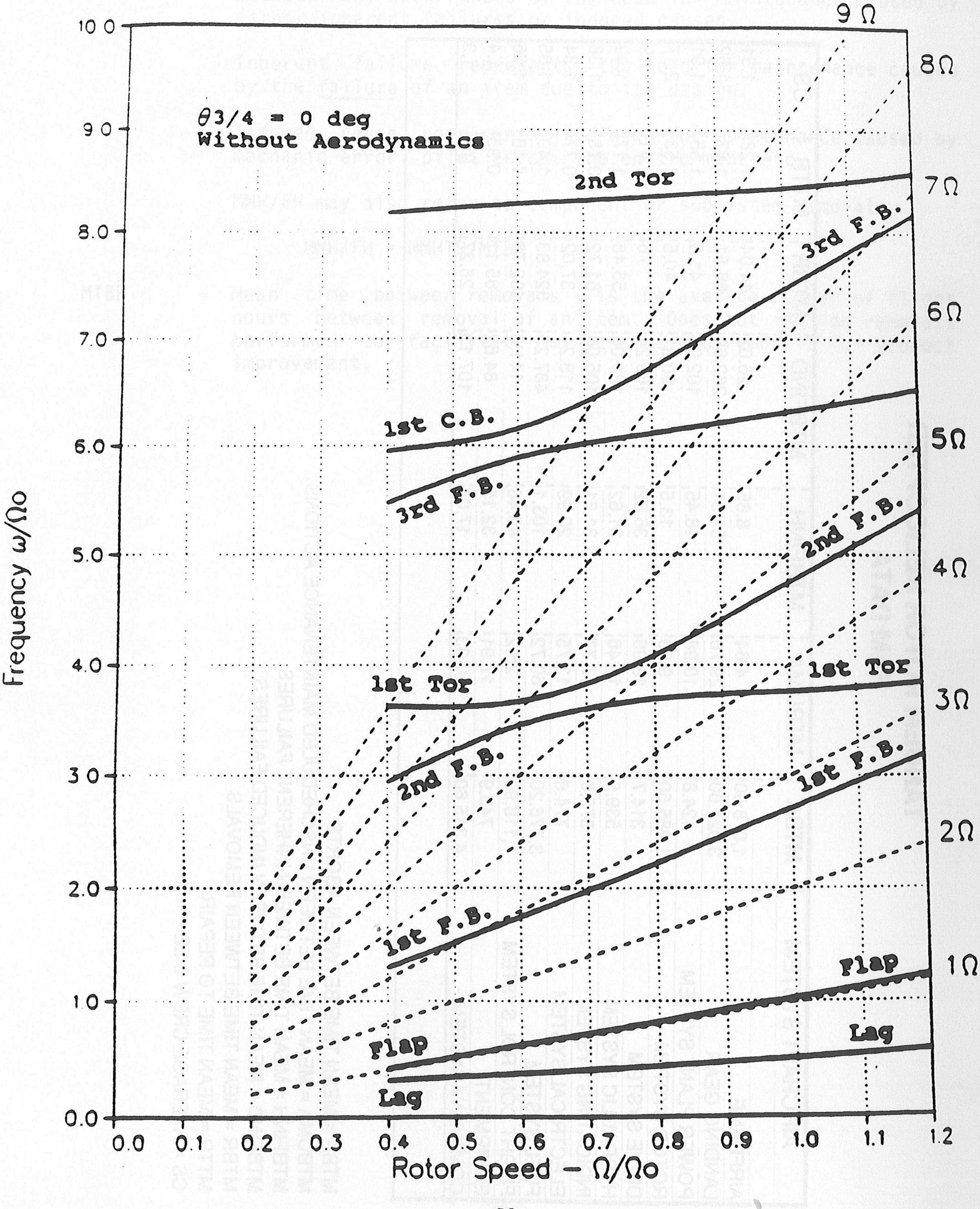
MTBR - Mean time between removals - is the average number of flight hours between removal of an item. Does not include removals performed to facilitate maintenance and removals for product improvement.

TANDEM ROTOR HELICOPTER
RAM DATA

AIRCRAFT SYSTEM	MTBA	MTBUMA	MTBFINH	MTBFIND	MTBR	MTTR	CS
AIRFRAME	1,078.90	4.64	8.65	26.02	44.04	1.28	1.51
LANDING GEAR	3,021.00	29.76	51.51	262.69	86.81	1.22	1.62
POWER PLANT SYSTEM	124.8	10.98	18.45	102.06	41.9	1.55	1.91
ROTOR SYSTEM	1,285.50	9.03	13.5	90.31	40.5	1.53	2.17
DRIVE SYSTEM	314.7	18.96	36.82	169.24	76	1.41	1.9
HYDRAULIC SYSTEM	539.5	19.46	31.62	121.08	55.48	1.17	1.49
INDICATING SYSTEM	875.6	17.77	31.31	105.08	61.72	0.78	1.38
ELECTRICAL SYSTEM	774.6	13.75	20.99	118.24	37.02	0.77	1.34
FUEL SYSTEM	3,776.20	60.72	103.1	487.25	324.83	1.49	1.85
FLIGHT CONTROL SYSTEM	1,118.90	26.2	49.48	141.5	102.75	1.48	1.66
EQUIPMENT	745.9	17.91	32.15	84.62	65.11	0.95	1.4
COMM/NAV SYSTEM	4,315.60	10.33	17.04	107.13	28.27	0.7	1.3

MTBA = MEAN TIME BETWEEN ABORTS
MTBUMA = MEAN TIME BETWEEN UNSCHEDULED MAINTENANCE ACTIONS
MTBFINH = MEAN TIME BETWEEN INHERENT FAILURES
MTBFIND = MEAN TIME BETWEEN INDUCED FAILURES
MTBR = MEAN TIME BETWEEN REMOVALS
MTTR = MEAN TIME TO REPAIR
CS = AVERAGE CREW SIZE

Appendix 5 -- Typical Rotor Modes Shapes

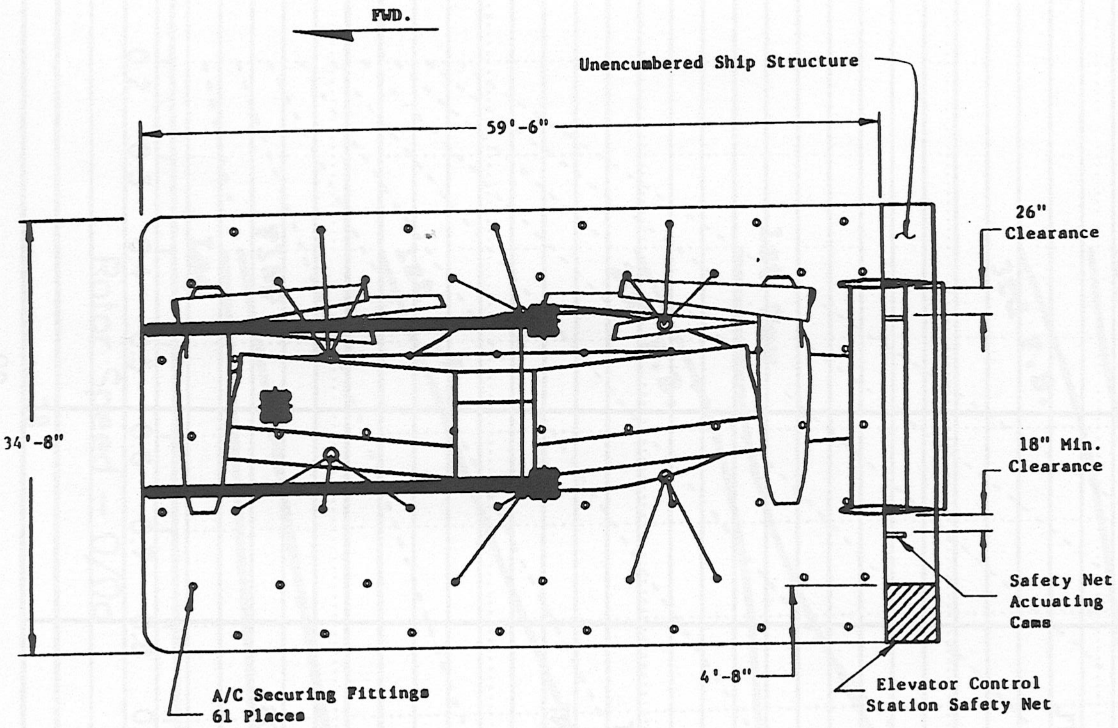


Appendix 6 -- Weight Summary, Preliminary Design Format

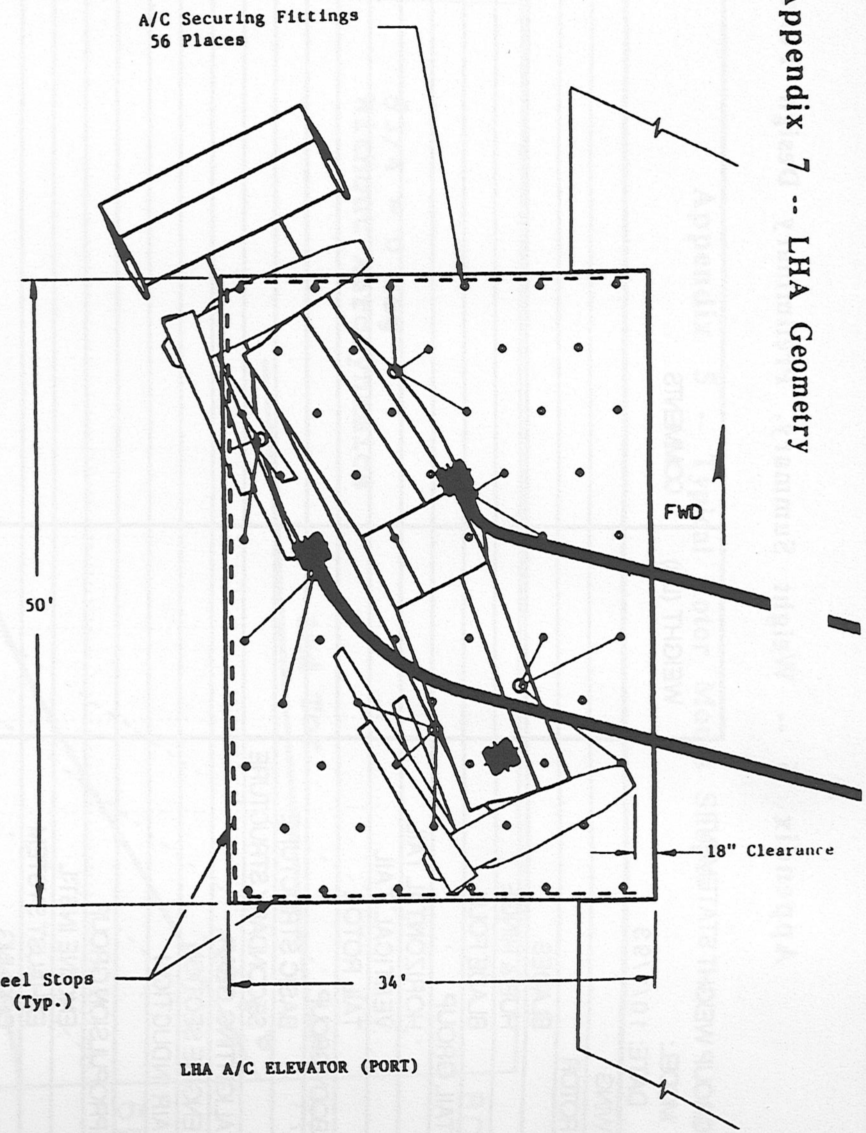
GROUP WEIGHT STATEMENT MODEL: DATE: 10/1/93	WEIGHT (LB)	COMMENTS
WING		
ROTOR		
BLADES		
HUB & HINGE		
BLADE FOLD		
TAIL GROUP		
HORIZONTAL TAIL		
VERTICAL TAIL		
TAIL ROTOR		
BODY GROUP		
BASIC STRUCTURE		
SECONDARY STRUCTURE		
ALIGHTING GEAR		
ENGINE SECTION		
AIR INDUCTION		
PROPULSION GROUP		
ENGINE INST'L		
EXHAUST SYSTEM		
COOLING		
CONTROLS		
STARTING		
PROPELLER INST'L		
LUBRICATING		
FUEL SYSTEM		
DRIVE SYSTEM		
FLIGHT CONTROLS		
AUX POWER PLANT		
INSTRUMENTS		
HYDR & PNEUMATIC		
ELECTRICAL GROUP		
AVIONICS		
ARAMENT GROUP		
FURN & EQUIP GROUP		
PERSON. ACCOM.		
MISC EQUIPMENT		
FURNISHINGS		
EMERG EQUIPMENT		
AIR CONDITIONING		
ANTI-ICE		
LOAD & HANDLING		
MISC		
WEIGHT EMPTY		
FIXED USEFUL LOAD		
CREW		
TRAPPED LIQUIDS		
ENGINE OIL		
PAYLOAD		
FUEL		
GROSS WEIGHT		

Bell-Boeing V-22 Osprey

Folded Configuration on LHA Elevators



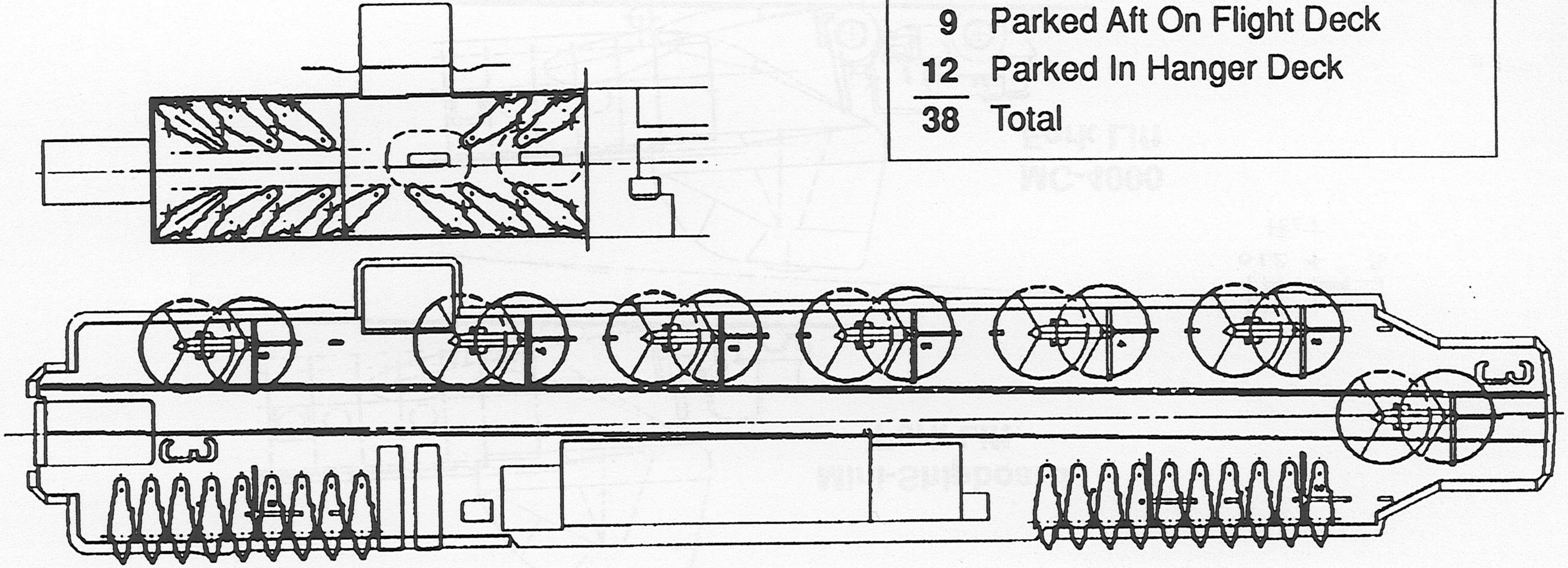
LHA A/C ELEVATOR (AFT)



LHA A/C ELEVATOR (PORT)

CH-46E Operational Spotting On LHA

7	Launch Spots
10	Parked Forward On Flight Deck
9	Parked Aft On Flight Deck
12	Parked In Hanger Deck
38	Total



CH-46 Cargo Loading Using Fork Lifts