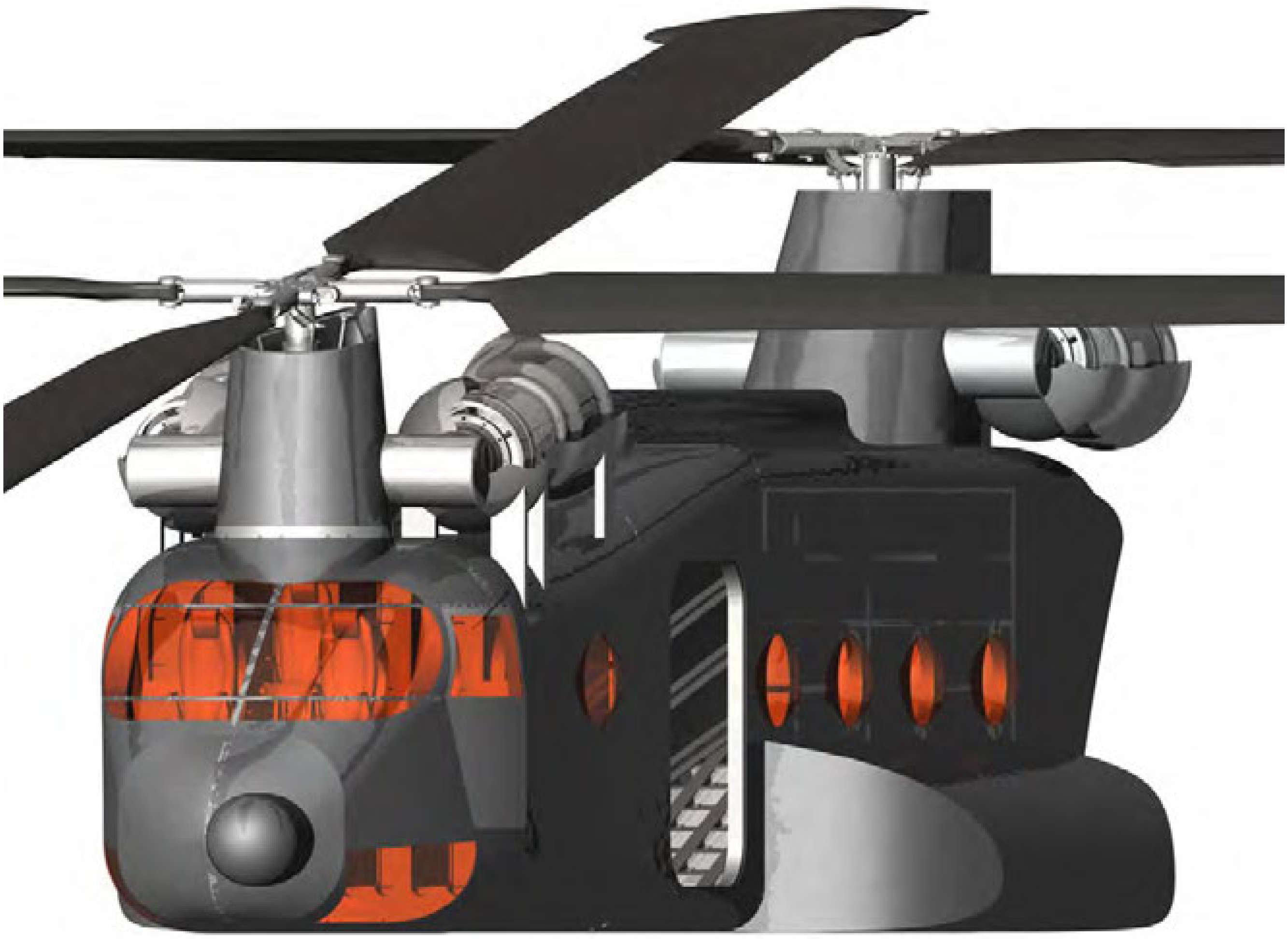
WYVER
Heavy Lift VTOL Aircraft



Rensselaer Polytechnic Institute

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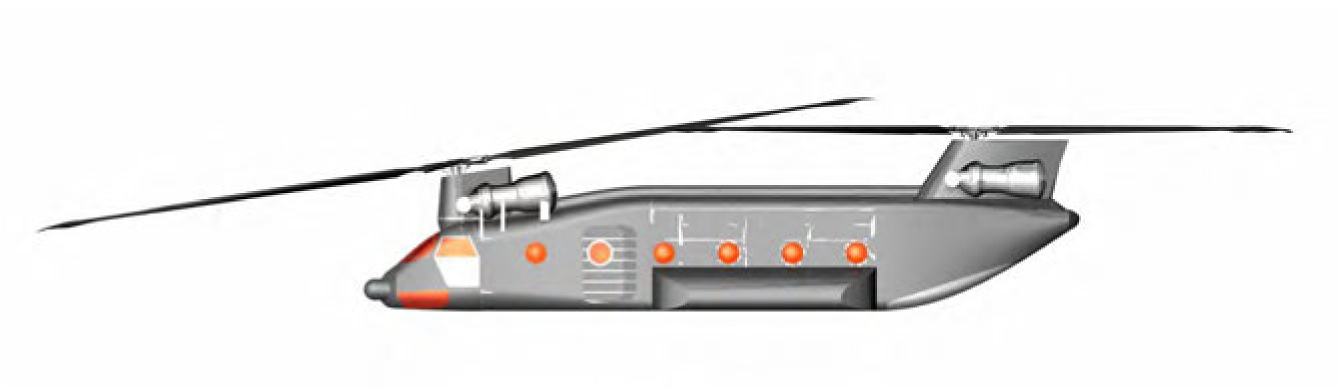
We would like to thank Professor Nikhil Koratkar for his help, guidance, and recommendations, both with the technical and aesthetic aspects of this proposal.



22ND ANNUAL AHS INTERNATIONAL STUDENT DESIGN COMPETITION

UNDERGRADUATE CATEGORY

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Executive Summary

This proposal presents a detailed design description of the Wyver, an aircraft designed in response to the 2005 AHS Design Competition. The main goals for the Wyver were to produce an extremely versatile rotorcraft while maintaining a commitment to reliability and cost effectiveness.

The Wyver is a multi-mission heavy lift cargo helicopter that pushes the limits of rotorcraft aviation while offering excellent safety characteristics and a low production cost. The Wyver is truly in a class of its own: mammoth in its lifting capabilities, swift in its cargo delivery, and compact for shipboard storage. The aircraft will be fully functional from an L-Class or CVN vessel and is capable of long-range intra-theater or short-range heavy-lift missions. Its primary design mission is to carry a twenty-ton Future Combat System (FCS) vehicle two hundred nautical miles from a naval vessel inland to a drop zone and return. To operate onboard an aircraft carrier or L-class assault ship, the Wyver is designed to be compact, utilizing a unique automated blade folding system to fit onto the ships' elevators. This design is an optimal choice for mass military production due to its adaptable design. Its similarities to the existing CH-47 allow for little or no additional training or procedural changes allowing for easy assimilation into existing fleets. Additionally, its reliable foundation of existing technology and exceptionally low cost to produce make it optimal for use as the multi-mission cargo helicopter of the future.

Key design highlights of the Wyver are summarized below:

Rotor Hub and Powered Blade Folding

An articulated rotor hub was selected to incorporate the automatic blade folding mechanism. Although mechanical hinges have a limited design life, they are cheap, easy to manufacture, and

replace/repair. Due to very high centrifugal and lifting forces, forged titanium is the choice of material for the hub because of its high strength to weight ratio.

One of the novel features in the Wyver is its blade folding mechanism. This unique design uses a lead-lag damper that doubles as an actuator. A bi-directional electro-hydraulic linear actuator is installed between the pitch and lead-lag hinges of the hub. The viscosity of the hydraulic fuild provides damping for in-plane movement of the blades. During folding, the actuator extends when a voltage is applied to the electric motor causing the blade to rotate about the lag hinge. Electrical connections can be made either manually or through a slip ring which would allow full control of the folding operation from within the cockpit. This original design offers a simple, reliable, and low cost method for automatic blade folding.

Engine and Transmission

The muscle behind the Wyver is four 6,150 peak horsepower Allison AE1107C turboshaft engines. The engines are locked through two main fore and aft integrated gearboxes that combine and transmit power to the two rotors with a combined reduction ratio of 77:1. The synchronizing shaft runs on top of the fuselage and is split into 13 segments coupled with Kaman Kaflex connectors to reduce torsional vibration and add flex points where needed. The pylons, engine nacelles, and shaft housing will have access panels/doors for easy access and maintenance. The engines will have the latest FADEC system for slowing the rotors at high speeds to mitigate transonic effects.

Airframe

The airframe was designed with compactness in mind. The fuselage is less than 20 feet wide and only 66 feet long. It can easily fit on an L-class elevator and it also weighs less than the elevator load capacity. The airframe is a very traditional semi-monocoque design because of its high longitudinal strength and low weight.

The airframe was designed to withstand the load of the FCS even with a 2.5G load factor, which is approximately 110,000 lbs. One key design factor was the high bending moment due to a heavy load in the center and two points of thrust. There are 3 bulkheads, 6 feet apart, in the cargo area and 3 bulkheads, 8 feet apart, in the cabin with extra reinforcements and longerons. The rest of the airframe is built adequately to support the weights of the aircraft on the ground as well as in air.

Retractable Landing Gear

The design of the landing gear was inspired by the need of landing stability in high wind conditions. The design allows for a small oleo stroke but a much larger wheel displacement. This ensures that the wheels are in contact with the surface even before the aircraft is fully on the ground. The landing gears are also designed to keep the fuselage only a few inches from the surface in order for the aircraft to meet the L-class elevator height requirement. The tires are also sized to be relatively big with low pressure so that the tire contours to the surface it lands on and does not pierce or sink into the surface.

Low Drag Features

To enable high speed flight, the fuselage of the Wyver is streamlined to minimize profile drag. All major components such as engines, transmission system and drive shafts that protrude out into the flow are enclosed within aerodynamically contoured fairings. Hub drag is also a major contributor to vehicle drag in forward flight. Since the Wyver has two hubs, special attention was paid to minimizing hub drag. This was accomplished by choosing a compact hub design with hub caps and encapsulating the entire swashplate mechanism and pitch links within well contoured fairings. A retractable landing gear design was also selected to minimize power in forward flight.

Shipboard Maintainability

The Wyver's design is simple yet functional. In order for the Wyver to be easily maintained and operated at sea the use of complex structures, mechanisms, and moving parts were kept to a minimum. Also, due to high corrosion at sea from salt water, the airframe and all other metallic components will be zinc sprayed for prolonged life.

The Wyver will be installed with standard hydraulic and electrical systems similar to the CH-53, which enables ease of maintenance and repair. The rotor hub assembly is made of titanium, which is corrosion resistant, and has a very high fatigue life. All of the components, such as bearings, hinges, and dampers were selected to be very simple, readily available, and easy to repair.

Mission Adaptability

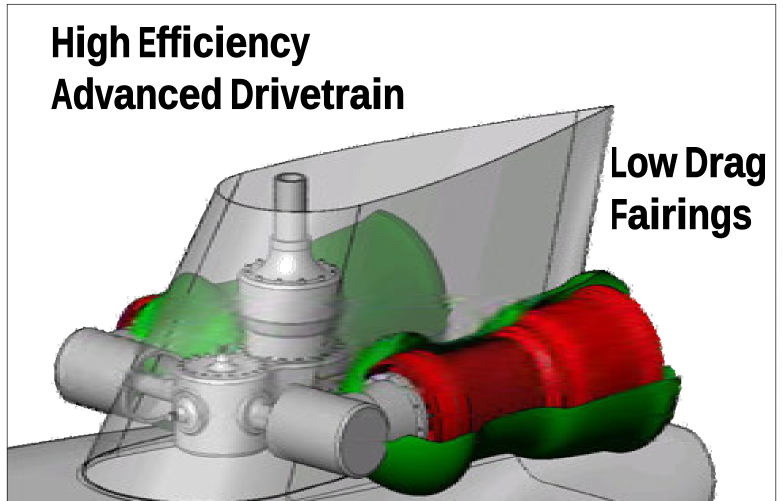
The Wyver's design is very versatile for multiple missions because of its payload and internal space capacity. With its excellent CG envelope (tandem configuration) and multistage tanks, the Wyver can counterbalance CG offsets and carry cargo with large eccentric loads.

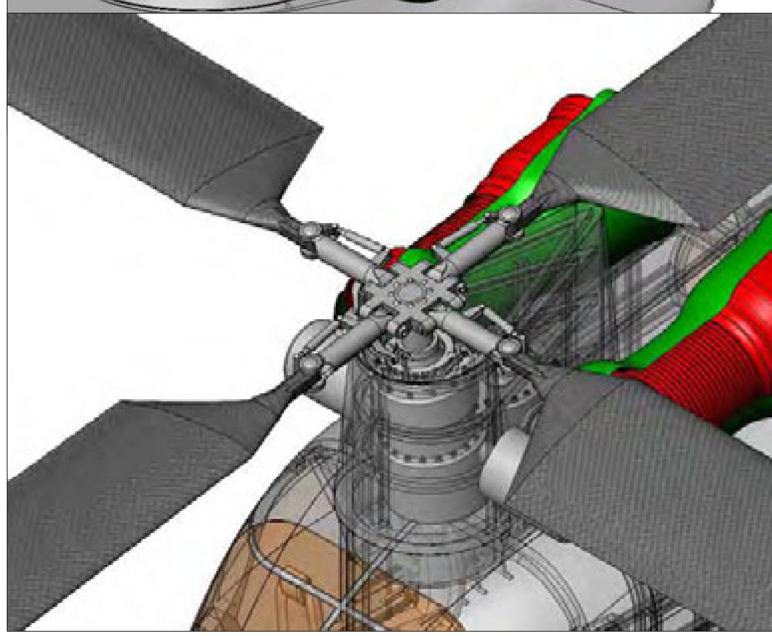
To expand on the Wyver's adaptability, cargo hooks are added to the airframe to carry external loads. As a result, the Wyver can be used as an air-crane or to carry odd shaped cargo that cannot fit inside the cargo bay. The three recessed cargo hooks are located at the CG, 10 feet fore, and 10 feet aft. These locations give the Wyver stability when carrying one, two, or three, external loads.

Aside from numerous military uses, the Wyver's relatively low cost and reduced operational complexity makes it suitable as a civilian VTOL transport aircraft. The 37 feet long cabin can be easily transformed to seat dozens of passengers and be used for transport to places without runways or remote exploratory locations.

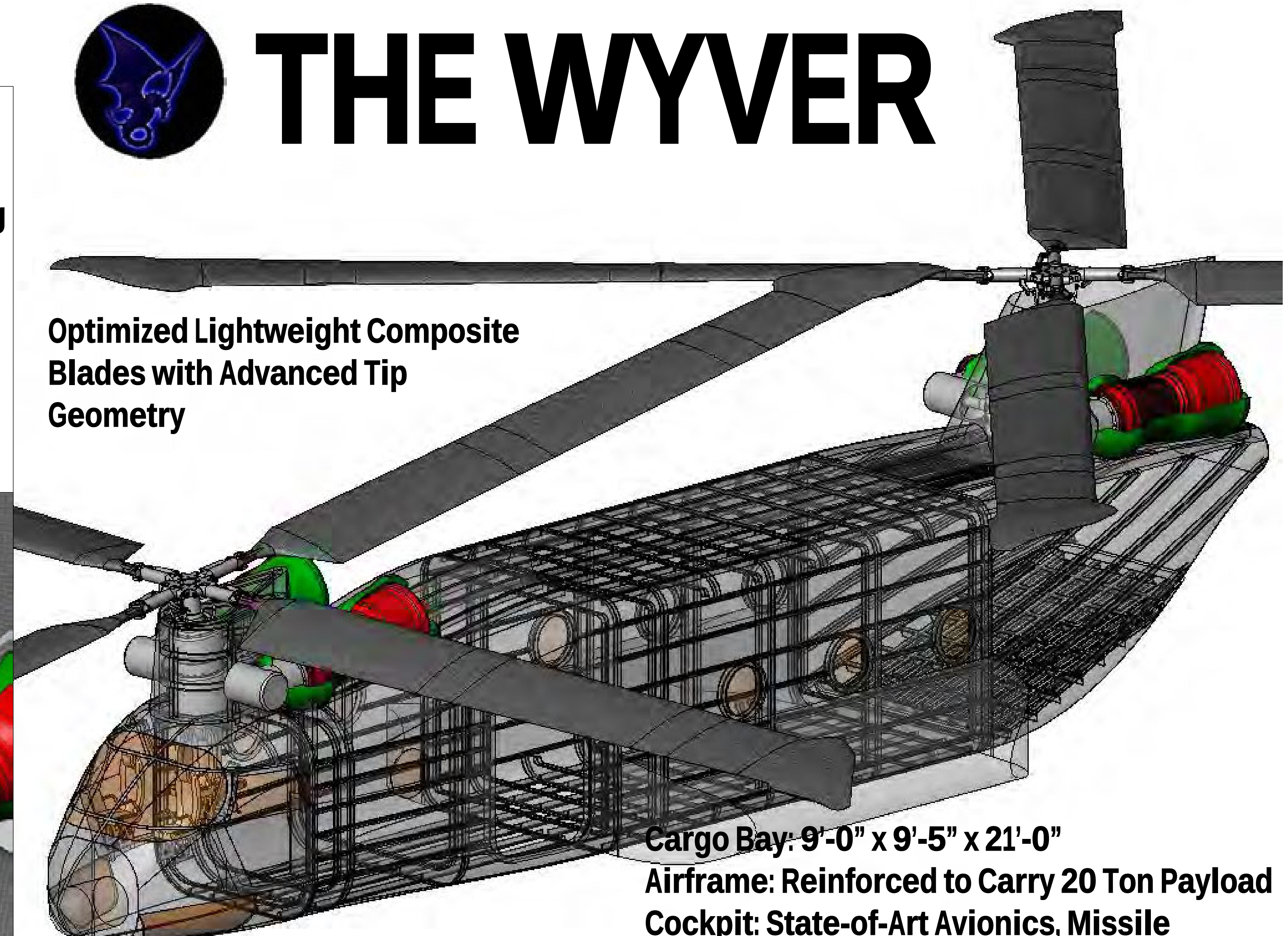
The main features of the Wyver are illustrated in the following fold-out.

THE WYVER





Compact, Fully Articulated Hub
Assembly with Automatic Blade
Folding Mechanism



Cargo Bay: 9'-0" x 9'-5" x 21'-0"
Airframe: Reinforced to Carry 20 Ton Payload
Cockpit: State-of-Art Avionics, Missile
Warning and Countermeasures Systems.

High Tire Displacement
for Landing Stability

Fully Retractable
Landing Gears

Low Pressure Tires for
Soft Terrain Landings

4 Allison AE1107C Turboshaft Engines
6150 Max. HP @ 12750 RPM
Locked Transmission for OEI Conditions

Parameter	Metric	English
PERFORMANCE		
Payload	20000 kg	44000 lbs
Range - Mission	740 km	400 Nm
- Intratheatre	1850 km	1000 Nm
V-max	320 km/h	173 kts
V-cruise	300 km/h	162 kts
POWERPLANT & TRANSMISSION		
Number of Engines	4	4
Allison AE1107C	6150 HP	4586 kW
Transmission reduction	77:1	77:1
WEIGHTS		
Max. Gross	47500 kg	104500 lbs
Empty	17850 kg	39270 lbs
Useful load	24000 kg	52800 lbs
Fuel	5560 kg	12230 lbs
DIMENSIONS		
tor Diameter	24.28 m	80' - 0"
Blade Chord	1.21 m	4' - 0"
Hub - to - Hub	14.63 m	48' - 0"
Fuselage - Length	20.12 m	66' - 0"
- Width	5.97 m	19' - 7"
- Height	5.72 m	18' - 9"
ROTOR SYSTEM		
Blades per Hub	4	
Blade construction	Fiberglass	
Tip Speed	220 m/s	722 ft/s
Disk area each	395 sq-m	4252 sq-ft
Disk area total	790 sq-m	8500 sq-ft
Blade folding	Automatic	

1. Introduction

This proposal presents a detailed design description of the Wyver, an original aircraft created in response to the 2005 AHS/Industry/NASA sponsored student design competition. The competition consisted of a request for proposal (RFP) provided by The Boeing Company, outlining several desired capabilities and mission characteristics. The Wyver was named after a mythical creature of medieval European origins: a dragon-like serpent with large powerful wings. The helicopter resembles its namesake with its massive stature and large rotors. The main design goals for the Wyver were to produce an extremely versatile rotorcraft while maintaining a commitment to reliability and cost effectiveness.

The Wyver is a multi-mission super heavy lift cargo helicopter that pushes the limits of rotorcraft aviation while offering excellent safety characteristics and a low production cost. By using pre-existing technologies and new enhancements all of the requirements outlined in the RFP are met. The aircraft will be fully functional from an L-Class or CVN vessel and is capable of long-range intra-theater or short-range heavy-lift missions. Its primary design mission is to carry a twenty-ton Future Combat System (FCS) vehicle two hundred nautical miles from a naval vessel inland to a drop zone and return. To operate onboard an aircraft carrier or L-class assault ship, the Wyver is designed to be compact, utilizing a unique automated blade folding system to fit onto the ships' elevators.

No contemporary aircraft in production is capable of such mission requirements. The C-130 is an able fixed wing transport but is unable to operate without a full runway. The CH-47 "Chinook" cargo helicopter is the largest widely used tandem but is unable to carry such a large payload and has no blade folding capabilities. Also, the V-22 Osprey Tilt-rotor is capable of high-speed flight and carrier operation but is also limited by its cargo weight capacity. The Wyver is truly in a class of its own: mammoth in its lifting capabilities, swift in its cargo delivery, and compact for shipboard storage.

This design is an optimal choice for mass military production due to its adaptable design. Its similarities to the existing CH-47 allow for little or no additional training or procedural changes allowing for easy assimilation into existing fleets. Additionally, its reliable foundation of existing technology, good maintainability and cost effectiveness make it optimal for use as the multi-mission cargo helicopter of the future.

2. Design Philosophy

We believe that the most valuable knowledge base when developing a new design is the population of pre-existing designs that have been proven effective, or for that matter, ineffective. By drawing from the concepts used in other aircraft the designers can avoid "reinventing the wheel" and costly research costs. However, the mission requirements set forth in the Boeing RFP are very demanding and far beyond the capabilities of existing rotorcraft. Thus, we must not close our minds to more radical design concepts that could be a more proper match for the requirements.

The following sections will describe the RFP mission requirements and the aircraft configuration trade study that was performed.

2.1 Mission Requirements

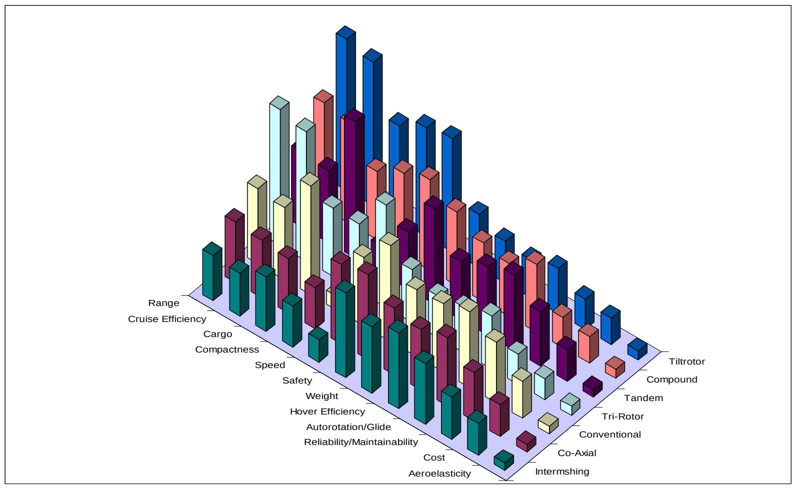
The three main requirements described in the RFP are range (400 nm), payload (20 tons), and compactness (50’ × 44’ × 19’ elevator size). There are in existence today rotorcraft that can meet some of these requirements, but not all of them. For example, the Comanche helicopter design, although not in use today is capable of flights in excess of 1,000 nautical miles. The MI-26 “Halo” can lift a payload in excess of 40,000 pounds. The V-22 Osprey is able to fold both the rotors and wings to fit easily onboard an attack ship or carrier. However, no single aircraft in existence today envelops all of these requirements. The main challenge of incorporating all three of the aforementioned qualifications is that they are trade-offs of each other. Increasing payload usually means increasing aircraft size and decreasing range. Increasing range corresponds to decreased maximum payload size. The design solution must be an optimum integration of these capacities to achieve the best possible outcome. After performing an extensive aircraft configuration trade-off study, we came to the conclusion that the Tandem helicopter is best suited for meeting the RFP requirements. Details of the trade study are provided below.

2.2 Aircraft Configuration Trade Study

We considered several configurations for the Wyver. These included conventional helicopter (single main-rotor tail-rotor), tandem, coaxial, tri-rotor, tilt-rotor, intermeshing rotor and compound helicopter configurations. A weighting matrix (Table 1) was used to qualitatively compare the different designs. The tandem, quad tilt-rotor and tri-rotor scored highly and were selected for further analysis.

	Intermeshing	Co-Axial	Conventional	Tri-Rotor	Tandem	Compound	Tiltrotor	Weighting Factor
TOTAL SCORE	**3805**	**4365**	**4950**	**5005**	**5015**	**5065**	**5660**	
Range	300	400	500	900	500	700	1000	100
Cruise Efficiency	285	380	475	855	475	665	950	95
Cargo	360	360	720	450	900	450	630	90
Compactness	270	270	90	450	180	540	720	90
Speed	150	525	450	675	375	600	750	75
Safety	560	560	630	350	630	490	350	70
Weight	440	440	440	275	385	385	275	55
Hover Efficiency	500	400	450	300	450	350	250	50
Autorotation/Glide	400	450	500	350	500	450	300	50
Reliability/Maintainability	280	320	400	200	360	200	200	40
Cost	210	210	245	140	210	175	175	35
Aeroelasticity	50	50	50	60	50	60	60	10

Table 1: Weighting matrix used to compare the competing designs. The information from the table is depicted pictorially in the adjoining diagram.



Performance, weights and rotor sizing computations for the tandem, quad tilt rotor and tri-rotor configurations were performed following the method outlined by Tischenko et al. (*AHS Journal*, Vol. 48, No. 2, April 2003. pp. 71-79). Details of this model are provided in the appendix.

2.2.1 Tandem Design Evaluation

The primary design variables in the Tischenko method are weight efficiency (Kwe), vehicle cruise lift/drag ratio (K) and the rotor disk loading (p) in hover. Weight efficiency (Kwe) is defined as the ratio of the empty weight by the gross take off weight. Lift to drag ratio is the total vehicle lift divided by the total vehicle drag (including fuselage drag). Given these inputs the Tischenko method calculates the aircraft sizing, detailed weight breakdown, hover and cruise power, and the fuel consumption. For the tandem configuration, we chose (based on historical data) Kwe=0.5 and K=3.5 (this is less than single main-rotor tail rotor aircraft that have K ~ 4.2). The disk loading (p) was varied in the 10 to 90 Kg/m^2 range. All computations assume a 4-bladed rotor.

Figure 1 shows the power and rotor diameter versus disk loading (10 to 90 kg/m^2 range). The results indicate that a disk loading between 50 and 70 kg/m^2 would require the smallest rotor diameter. We felt that compactness was very important and therefore we selected a disk loading of 60 kg/m^2 for the Wyver because this resulted in the smallest possible rotor diameter (25.58 meters or 84 ft.). For a disk loading of 60 Kg/m^2 the hover power (also installed power) is ~ 24,000 HP. The cruise power (for a cruise speed of ~ 160 kts) is about 23,000 HP.

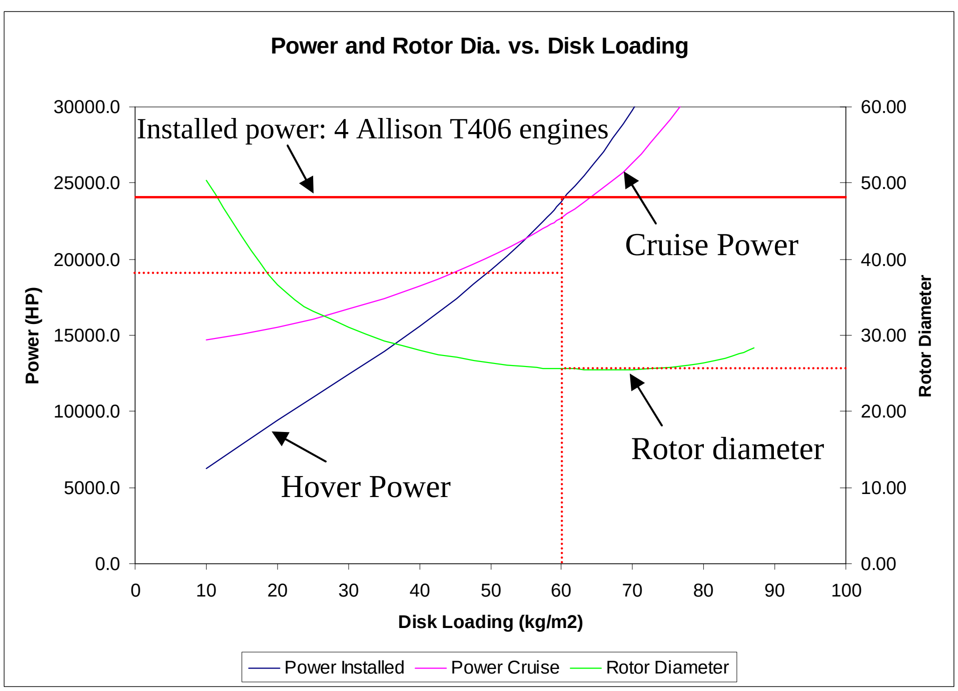


Figure 1 - Tandem – Power/Rotor Diameter vs. Disc Loading

To study the effect of cruise speed on performance, we plotted the power and weights versus cruise speed in the 100 to 350 km/hr range. The maximum power that can be delivered by four engines is ~ 24,000 HP. This is because the engine with the highest available power is the Allison T406 (6150 HP each). The maximum cruise speed can be found by locating the intersection point of the installed power and cruise power curves. This happens at around 320 km/h (172 knots). At this point the required hover power also matches the cruise power and the maximum available power of 24,000 HP. To prevent transonic effects, retreating blade stall and to provide some power reserve, a lower speed of about 160 knots appears appropriate for the tandem configuration.

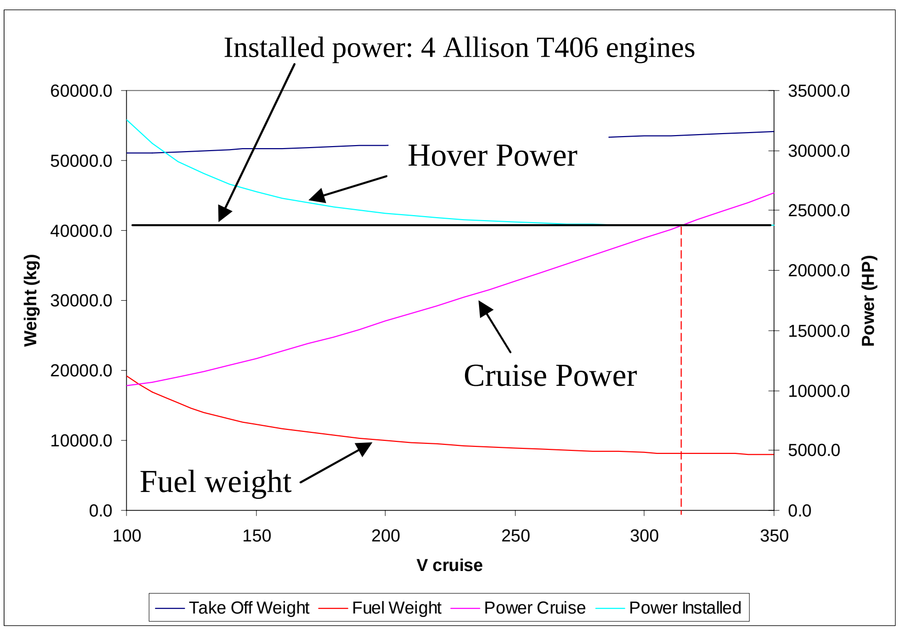


Figure 2 - Tandem - Weight/Power vs. Cruise Velocity in Km/hr (Range: 400 nm)

2.2.2 Tilt-Rotor Design Evaluation

The quad-tilt rotor appears more feasible than the conventional tilt rotor for the RFP and was therefore selected for detailed analysis. For this case, we selected a weight efficiency (Kwe)=0.3 and a vehicle cruise lift to drag ratio (K)= 8.71. For all calculations the aircraft is modeled as two twin tilt rotors with each tilt rotor carrying half the total aircraft weight. The rotors are assumed to be 3-bladed and a tip speed of 201.75m/s is chosen. A detailed parametric study is performed by varying the disk loading. The results are summarized in figure 3 for each tilt rotor pair. The power and weight for the quad configuration can be obtained by doubling the results shown in figure 3.

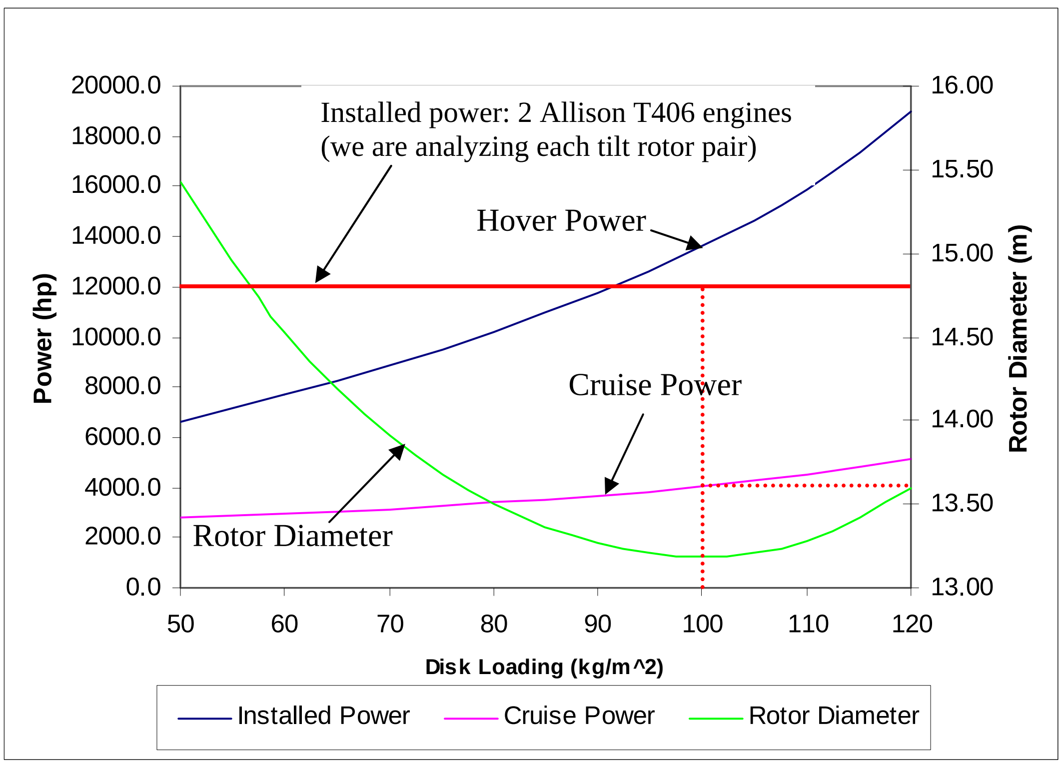


Figure 3 - Tilt-Rotor - Power/Diameter vs. Disk Loading

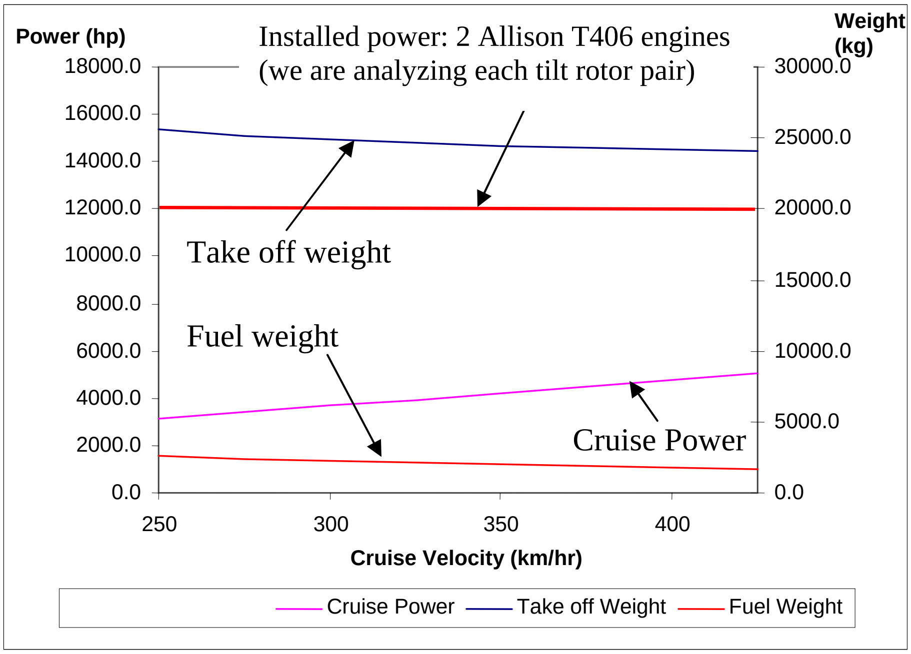


Figure 4 - Tilt-Rotor - Power/Weight vs. Cruise Velocity

From the relationship between disk loading and rotor diameter (figure 3), it is apparent that at a disk loading of approximately one hundred, the diameter reaches a minimum of about 13.2 meters. The minimum rotor diameter is chosen because a smaller rotor allows for more feasible operation, especially aboard a naval vessel. This is even more critical for a tilt-rotor due to the fact that the rotors must be able to shift from horizontal to vertical without striking the fuselage. However, a noticeable limitation arises in the engine technology currently available. The needed installed hover power reaches almost 7,000 horsepower per engine (figure 3) while the most powerful modern turboshaft is the Allison T406 with only 6,150 horsepower.

Figure 4 shows the relationship between aircraft cruise velocity, power, and weight. As can be seen the cruise power is much lower than the available installed power and therefore meeting cruise power requirements is feasible.

Figure 3 shows that with a disk loading of 100 Kg/m^2 the power requirements are slightly more than can be provided. Decreasing the disk loading below 100 results in excessively large rotors, which is generally not acceptable for a tilt-rotor. By choosing a disk loading of 100 a trade-off is made between the size of the rotor and the power/weight of the aircraft. The value decided upon is a reasonable compromise although a lower value would allow for power requirements to be better met.

In conclusion, after exploring the quad tilt-rotor design, numerically, it seems as though it does not fit well with the super heavy lift mission requirements. The rotors would have to be too large and the engines would need more power than can currently be provided.

2.2.3 Tri-Rotor Design Evaluation

This configuration includes a main rotor in the fore of the rotorcraft (with rotor diameter dimension comparable to a single rotor helicopter) and one tilt-rotor pair in the aft of the rotorcraft. This design was therefore modeled as a conventional helicopter for the fore main-rotor (where the tail-rotor was ignored) and as a tilt-rotor for the aft rotors.

In the analysis, we assumed that half of the total weight was carried by the fore main-rotor and the other half was carried by the aft tilt-rotor pair. For the fore main rotor we chose a Kwe=0.46 and K=4.2. For the aft tilt rotor pair we chose Kwe=0.3 and K=8.71. The analysis indicated that the optimal disk loading for the fore main rotor was about 65 kg/m^2. This gave a main-rotor diameter of 17.9 m (Figure 5).

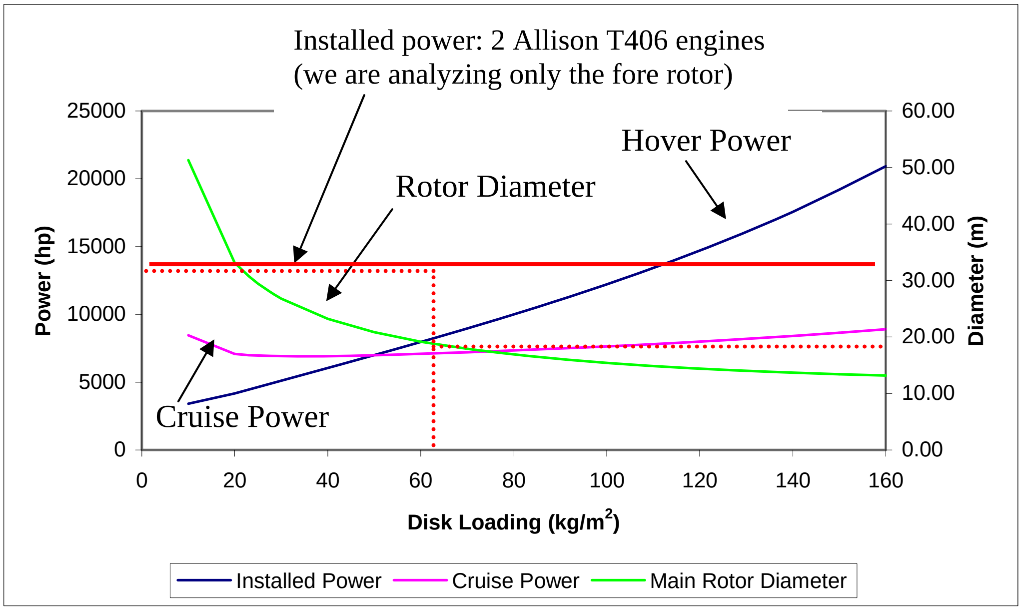


Figure 5 – Fore tri-rotor power and rotor diameter vs. disk loading

To determine the optimum cruise speed, the disk loading of 65 kg/m^2 was kept constant, and power in cruise and installed power were plotted against cruise speed. The results indicated that at a cruise speed of about of 400 km/hr (215 knots) the installed power was equal to the cruise power. However at a cruise speed of 215 kts, the rotor speed will have to be reduced substantially to avoid transonic effects. Note that the maximum power is limited by the two 6,150 hp engine that were considered to be used for this rotor. The other two engines on the aircraft will drive the aft tilt rotor pair.

The results obtained for the aft tilt-rotor pair (for the tri-rotor configuration), were very similar to the previous tilt rotor analysis shown in figures 3-4. The optimal disk loading that minimizes rotor diameter was 90 kg/m^2. The corresponding dimension of the tilt-rotor diameter is 14.37 m. Since the cruise speed is limited to 400 Km/hr for the fore rotor, we computed the power requirements for the aft tilt rotor pair at this velocity. We determined that at 400 km/h the installed power (for the two engines attached to the aft tilt rotor pair) is greater than cruise power required by an extra 7700 HP. Therefore, 400 km/h is much less than the optimal speed for a tilt-rotor which is in excess of 500 Km/hr. The speed of 400 km/h is limited by the fore main-rotor which constrains the performance of the aft tilt rotor pair.

The main advantage of the compound tilt rotor helicopter over the tandem helicopter is that it is faster (400 km/h compared to 300 km/h). The downside is that it is a configuration that has never flown, and the flight mechanics and handling qualities of the aircraft may be very complex. In particular the transition between hover and forward flight is problematic because as the rear tilt rotor pair transitions into propeller mode, the torque of the fore rotor can no longer be balanced.

2.3 Trade Study Conclusions

Using the RFP's payload and range requirements as a basis, we evaluated the three design configurations in terms of sizing, power, weights etc. and also considered several other parameters such as cost, maintenance, safety, standard parts, manufacturability, complexity, etc.

It becomes apparent that the tri-rotor cannot compete with the quad tilt rotor. This is because for the tri-rotor the aft tilt rotor is not being used efficiently (cruise speed is constrained by the fore rotor) and hence it suffers in comparison to a quad tilt rotor. The advantage of the quad tilt rotor over the tandem is that it can achieve significantly high cruise speeds, which reduce mission time. However given the 200 nm range, this reduction is not as significant. A critical limitation for the quad tilt rotor is its excessive power requirement in hover. The needed installed hover power reaches almost 7,000 horsepower per engine (assuming four total engines). The most powerful modern turboshaft is the Allison T406 with only 6,150 horsepower. Therefore given the status of current engine technology it does not appear feasible to meet the quad tilt rotor requirements in hover.

The proven design of the tandem makes it a much more worthy choice because manufacturing and maintenance cost will be considerably lower than the other two designs since most of the components will be modular and can be manufactured on the same lines as the CH-47D Chinook. Neither the quad tilt-rotor nor the tri-rotor configurations have been developed or tested previously and proving these designs would require significant time and resources. Additionally, the tandem design requires less complex transmission configurations than the other designs. Lastly, the tandem design greatly out-distances the other configurations in safety. Tilt-rotors are notorious for their less than perfect safety record while the untested tri-rotor design falls victim to its complexity.

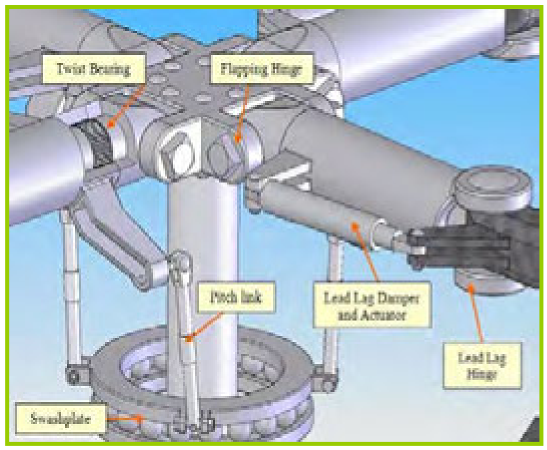
After assessing all these factors it was decided that the tandem configuration is the best suited design for the mission requirements with minimal trade-offs between cruise speed and complexity, cost, and manufacturability. The Wyver will be a Tandem!

3. The Wyver: Design Highlights

The detailed design of the Wyver is presented in the following chapter. In this chapter we would like to summarize some of its key design features and attributes.

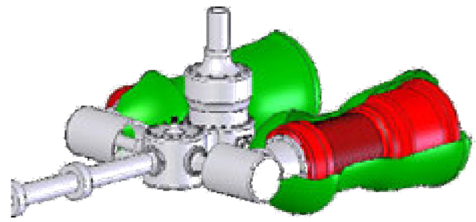
Rotor Hub and Powered Blade Folding

An articulated rotor hub was selected to incorporate the automatic blade folding mechanism. Although mechanical hinges have a limited design life, they are cheap, easy to manufacture, and replace/repair. Due to very high centrifugal and lifting forces, forged titanium is the choice of hub material because of its high strength to weight ratio.



One of the novel features in the Wyver is its blade folding mechanism. This unique design uses a lead-lag damper that doubles as an actuator. A bi-directional electro-hydraulic linear actuator is installed between the pitch and lead-lag hinges of the hub. The viscosity of the hydraulic fuild provides damping for in-plane movement of the blades. During folding, the actuator extends when a voltage is applied to the electric motor. Electrical connections can be made either manually or through a slip ring which would allow full control of the folding operation from within the cockpit. This original design offers a simple, reliable, and low cost method for automatic blade folding.

Engine and Transmission



The muscle behind the Wyver is the 4, 6150 peak horsepower Allison AE1107C turboshaft engines. The engines are locked through two main fore and aft integrated gearboxes that combine and transmit power to the two rotors with a combined reduction ratio of 77:1. The synchronizing shaft runs on top of the fuselage and is split into 13 segments coupled with Kaman Kaflex connectors to reduce torsional vibration and add flex points where needed. The pylons, engine nacelles, and shaft housing will have access panels/doors for easy access and maintenance.

Airframe

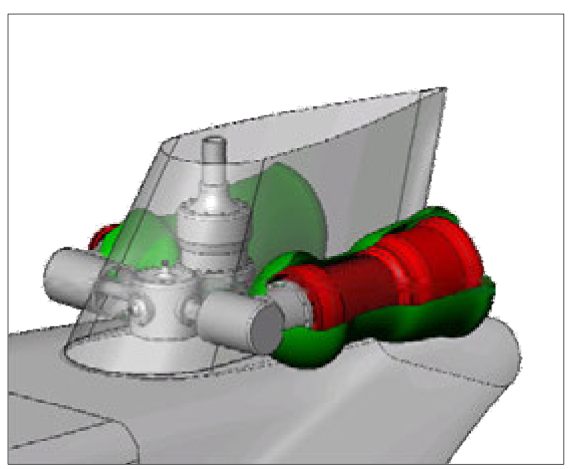
The airframe was designed with compactness in mind. The fuselage is less than 20 feet wide and only 66 feet long. It can easily fit on an L-class elevator and is also weighs less than the elevator load capacity. The airframe is a very traditional semi-monocoque design because of its high longitudinal strength and low weight.

The airframe was designed to withstand the load of the FCS even with a 2.5G load factor, which is approximately 110,000 lbs. One key design factor was the high bending moment due to a heavy load in the center and two points of thrust. There are 3 bulkheads, 6 feet apart, in the cargo area and 3 bulkheads, 8 feet apart, in the cabin with extra reinforcements and longerons. The rest of the airframe is built adequately to support the weights of the aircraft on the ground as well as in air.

Retractable Landing Gear

The design of the landing gear was inspired by the need of landing stability in high wind conditions. The design allows for a small oleo stroke but a much larger wheel displacement. This ensures that the wheels are in contact with the surface longer even before the aircraft is fully on the ground. The landing gears are also designed to keep the fuselage only a few inches from the surface in order for the aircraft to meet the L-class elevator height requirement. The tires are also sized to be relatively big with low pressure so that the tire contours to the surface and does not pierce or sink in it.

Low Drag Features



To enable high speed flight, the fuselage of the Wyver is streamlined to minimize profile drag. All major components such as engines, transmission system and drive shafts that protrude out into the flow are enclosed within aerodynamically contoured fairings. Hub drag is also a major contributor to vehicle drag in forward flight. Since the Wyver has two hubs, special attention was paid to minimizing hub drag. This was accomplished by choosing a compact hub design with hub caps and encapsulating the entire swashplate mechanism and pitch links within well contoured fairings. A retractable landing gear design was also selected to minimize power in forward flight.

Shipboard Maintainability

The Wyver's design is simple yet functional. In order for the Wyver to be easily maintained and operated at sea the use of complex structures, mechanisms, and moving parts were kept to a minimum. Also, due to high corrosion at sea from salt water, the airframe and all other metallic components will be zinc sprayed for prolonged life.

The Wyver will be installed with standard hydraulic and electrical systems similar to the CH-53, which enables ease of maintenance and repair. The rotor assembly is made of titanium, which is corrosion resistant, and has a very high fatigue life. All of the components, such as bearings, hinges, and dampers were selected to be very simple, readily available, and easy to repair.

Mission Adaptability

The Wyver's design is very versatile for multiple missions because of its payload and internal space capacity. With its excellent CG envelope (tandem configuration) and multistage tanks, the Wyver can counterbalance CG offsets and carry cargo with large eccentric loads.

To expand on the Wyver's adaptability, cargo hooks are added to the airframe to carry external loads. As a result, the Wyver can be used as an air-crane or to carry odd shaped cargo that cannot fit inside cargo bay. The three recessed cargo hooks are located at the CG, 10 feet fore, and 10 feet aft. These locations give the Wyver stability when carrying one, two, or three, external loads.

Aside from numerous military uses, the Wyver's relatively low cost and reduced operational complexity makes it suitable as a civilian VTOL transport aircraft. The 37 feet long cabin can be easily transformed to seat dozens of passengers and be used for transport to places without runways or remote exploratory locations.

Wyver: Mission Timeline

The mission timeline is based on a typical RFP mission of transporting an FCS from an aircraft carrier to a location 100 nm inland. The following spreadsheet breaks down the mission time into blocks of procedures and how long each segment is expected to take. This type of representation can be used to determine a flight plan for a prescribed mission.

The timeline starts from bringing the Wyver to the flight deck and ends with the delivery of 4 FCS. The estimated total mission time is 13 hours.

The Wyver Mission Timeline is illustrated in the following fold-out.

MISSION TIMELINE

	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315
PRE-LAUNCH	***PRE-MISSION : 45 min.***																				
TRANSPORT HELICOPTER FROM BELOW DECK	30 min																				
UNFOLD BLADES		15 min																			
LOAD CARGO (IF INTERNAL)																					
FUEL AIRCRAFT																					
BATTERY CHARGE																					
AVIONICS/ELECTRONICS CHECK																					
CREW BRIEFING																					
PRE-FLIGHT INSPECTIONS																					
MISSION (1FCS)			***MISSION TIME (1 FCS): 3.5 HRS***																		
MASTER ON			15 min																		
FUEL PUMP ON																					
APU ON																					
START ROTORS																					
START ENGINES																					
ENGAGE ENGINES																					
POWER UP (90% HOVER POWER)																					
WAIT FOR TOWER CLEARANCE																					
HOVER																					
ATTACH SLING LOADS																					
CLIMB			15 min																		
CLEAR DECK																					
DEPARTURE (200NM LZ)																					
ACCELERATE TO V-climb				15 min																	
CLIMB TO 3000 FT MSL				30 min																	
CRUISE AT V-cruise						45 min															
DESCEND TO 100 FT AGL									30 min												
HOVER											15 min										
DETACH SLING LOADS																					
DESCEND TO SURFACE																					
UNLOAD CARGO																					
LOAD CARGO												15 min									
ARRIVAL																					
CLIMB TO 3000 FT MSL													15 min								
CRUISE AT V-cruise													45 min								
DESCEND TO 100 FT MSL															15 min						
HOVER																15 min					
DETACH SLING LOADS																					
LAND ON DECK																					
MISSION (4 FCS)																	***MISSION TIME (4 FCS): 13 HRS***				
RE-FUEL																	15 min				
RE-LOAD																					
MISSION																		15 min			
DEPARTURE																			135 min		
ARRIVAL																				60 min	

4. The Wyver: Detailed Design

This section describes the detailed design of the main components of the Wyver.

4.1 Rotor System

The rotor system is a standard tandem configuration with counter-rotating rotors eliminating the need for a tail rotor. The design goal was to produce a simple, sturdy and reliable rotor system for the heavy lift mission. Mechanical hinges were chosen to keep the part design simple and also allow for automatic rotor folding for shipboard operations. Additionally, advanced airfoil shapes and techniques create a highly efficient and powerful lifting device for this massive aircraft.

4.1.1 Airfoil Selection and Configuration: (Please refer fold-out for figures)

A helicopter rotor encounters a range of dynamic conditions during the operation of the aircraft. During hover each location along the blade encounters a different airspeed. During horizontal maneuvers several phenomena occur which reduce the effectiveness of the rotor. On the retreating side near the root, reversed flow forms at higher airspeeds, greatly reducing lift. Dynamic stall and transonic effects reduce effectiveness near the tip of the blade. A majority of modern rotor designs incorporate several specialized airfoils sections along the length of the blade which perform well in these different environments. Due to pressure distributions a standard airfoil creates a strong nose-down pitching moment. Larger pitching moments results in increased pitch link loads which can result in failure. To reduce pitch link stresses, the Wyver incorporates a reflex airfoil (RAE 9468) within the 40% radial location. A reflex airfoil utilizes an upward curving tail or a vertical tab to create local high pressure which causes a counteractive nose-up moment.

At intermediate radial locations a medium thickness, mildly cambered airfoil is used to generate large lifting forces and further out a flatter, thinner airfoil is used out of necessity because of the high mach numbers. The desired performance characteristics for these sections are a high lift coefficient and a high drag divergence mach number, the latter especially for the outer section.

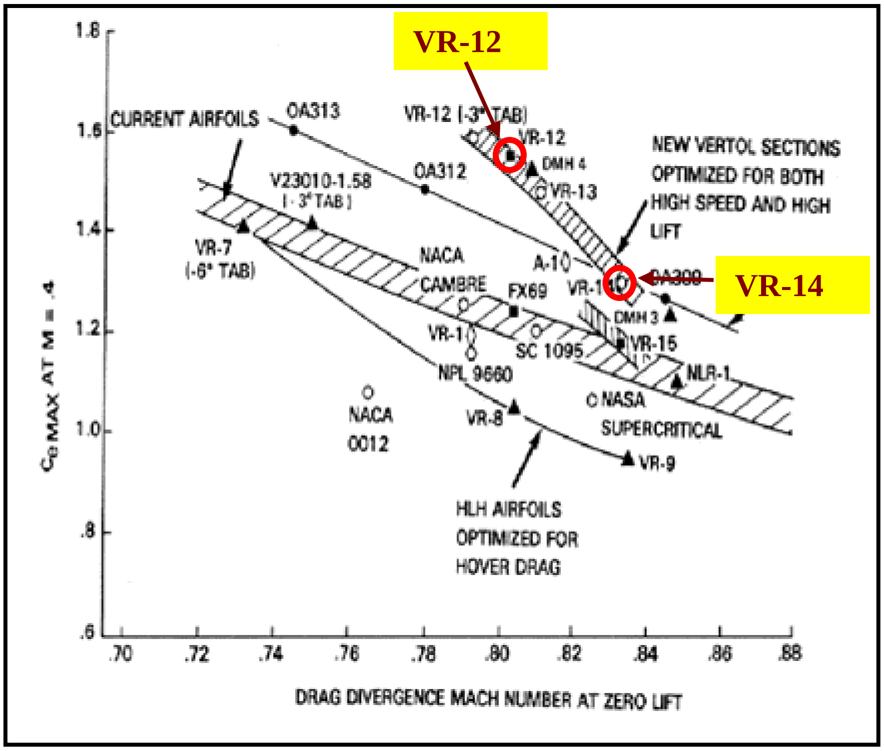


Figure 6 - Rotorcraft Airfoil Performance Comparison

Boeing VERTOL sections were chosen for these regions for their superior lift and drag characteristics. The VR-12 airfoil was used in the intermediate region and the thinner VR-14 airfoil was used near the tip. Performance characteristics of these airfoils are given in figure 6. These airfoils meet all the desired requirements for the design: (a) high lift coefficient (b) high drag divergence Mach number; especially near tip, (c) low drag, and (d) mild stall response. Another important feature of these airfoils is their performance near the stall region where the unsteady periodic conditions cause the airfoil to cycle in and out of stall. All airfoils chosen for this design have a gradual stall behavior which is important under such conditions.

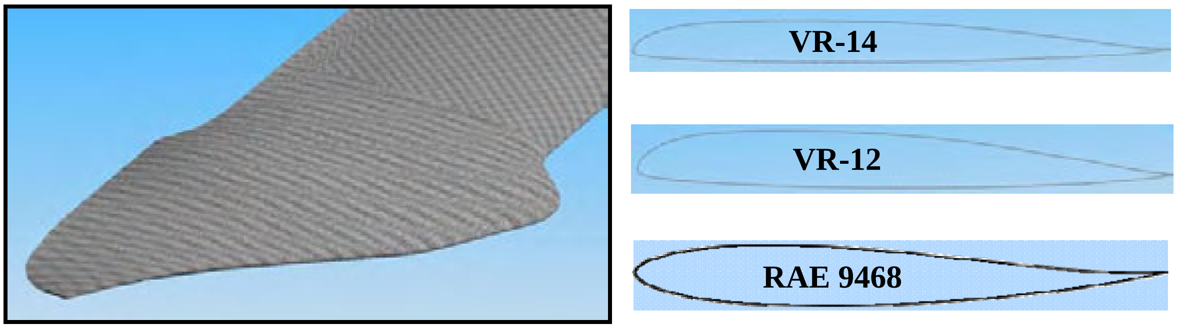


Figure 7 - Rotor Tip Geometry and Rotor Airfoils

Further optimization of the rotor was introduced by adding a 10˚ nose down linear twist and a complex geometry tip similar to the British Experimental Rotor Program (BERP) design developed by Westland. The design was used by the Lynx demonstrator model, which obtained the world absolute speed record for a helicopter in 1986. The BERP concept is important for us as we strive to achieve a high cruise speed of ~160 kts. This advanced concept replaces a traditional swept tip and assists in reducing BVI (Blade Vortex Interaction) noise. Contrary to traditional swept tips, the BERP tip keeps the center of gravity and aerodynamic nearer to the blade axis which eliminates unwanted inertial and aerodynamic effects. The BERP tips varying sweep angle reduces compressibility effects during high speed forward flight. Additionally the protruding geometry on the leading edge, called the notch, further reduces the compressibility effects. The notch geometry also creates a vortex which delays flow separation until very large angles of attack. Lastly, the anhedral angle releases the tip vortex below the plane of the rotor, which helps to mitigate blade vortex interaction noise.

4.1.2 Rotor Structure (Please refer fold out for figures)

The internal structure of the rotor blades has been adapted from standard designs currently in use including the CH-47. A solid composite spar will run the length of the blade, providing the bulk of strength and stiffness for the blade. Layers of composite skins are laid to provide strength and form the airfoil geometry. Lightweight honeycomb-structure foam fills in to provide additional strength to the trailing edge section. Nose weights are inserted in the leading edge cavity as needed for balance. A titanium nose cap delays corrosion effects from weather and solid particles in the air. This conventional layout can be strengthened or trimmed upon further analysis to create an optimal design for the aircraft.

4.1.3 Hub Design (Please refer fold out for figures)

The design trend of modern helicopters is to incorporate bearingless rotors with flex-beam and torque-tube technology. However the RFP specification of automated blade folding requires for a mechanical lead-lag hinge. With the presence of at least one mechanical hinge it was decided to design with all three to simplify the design and manufacturing process. The fold out at the end of this section displays the layout of the three hinges, damper and folding mechanism.

The hydraulic damper on the lead-lag hinge will also serve as an actuator to fold the rotor blades for shipboard stowage. Pitch control is accomplished through a traditional swashplate mechanism with pitch links and pitch bearings for each blade. Three actuators under the swashplate will control the angle of the plate for cyclic and collective pitch control. Centrifugal droop stop mechanisms similar to those installed on the Chinook will be included to prevent the blades from striking the fuselage during engine start-up and shut-down. These mechanisms use the centrifugal force from rotation to shift and allow downward flapping during flight but remain fixed to support blades at rotational speeds less than approximately 70 RPM.

By placing the pitch hinges outboard of the flapping hinges, potential control issues could occur. As the blade flaps upwards, the pitch link will pull the nose of the blade down causing the blade to flap downward and visa versa. This occurs naturally in most tail rotor designs but not often in main rotor designs. However, since the pitch link arm was placed as near to the flapping hinge as possible this effect should be minimized. A simple analysis should confirm this. From the mass properties of the blades and aircraft, the maximum coning angle can be found to be 9.4˚. With the pitch link arm located only 12.7 centimeters from the flapping hinge, the vertical distance induced is approximately 0.381 centimeters, a small value due to the angled design of the arm. With a pitch link arm length of 24 centimeters, positioned 45 degrees from the horizontal, and the angular change is 0.64 degrees. Since this offset would be constant, it is easily counteracted by further increasing the collective pitch. However, in forward flight when the flapping angle is no longer constant the cyclic blade flapping response can be affected. However, the cyclic flapping angle as the blade travels its circular path will be less than the coning angle used for the previous calculations. Thus the difference in angle of attack induced will most likely be only a few tenths of a degree, too small to make a significant difference in control.

The material chosen for the hub assembly parts is titanium alloy. The advantage of using high strength titanium alloys is that the weight of the hub can be lowered without decreasing the factor of safety. Even stronger alloys are in existence however the price and elasticity of these materials is outside the desirable range. Another consideration is that titanium is naturally corrosion-resistant, which is important for ship-borne operations. For additional protection of exposed parts a zinc spray will also be applied.

By choosing simple mechanical hinge designs several advantages are attained. First, the parts can be made from a single material, usually either steel or titanium. Combined with the relatively simple geometry and manufacturing, the results are low acquisition and replacement costs. Also, by using an uncomplicated design, the reliability and maintainability will be superior to more complex configurations.

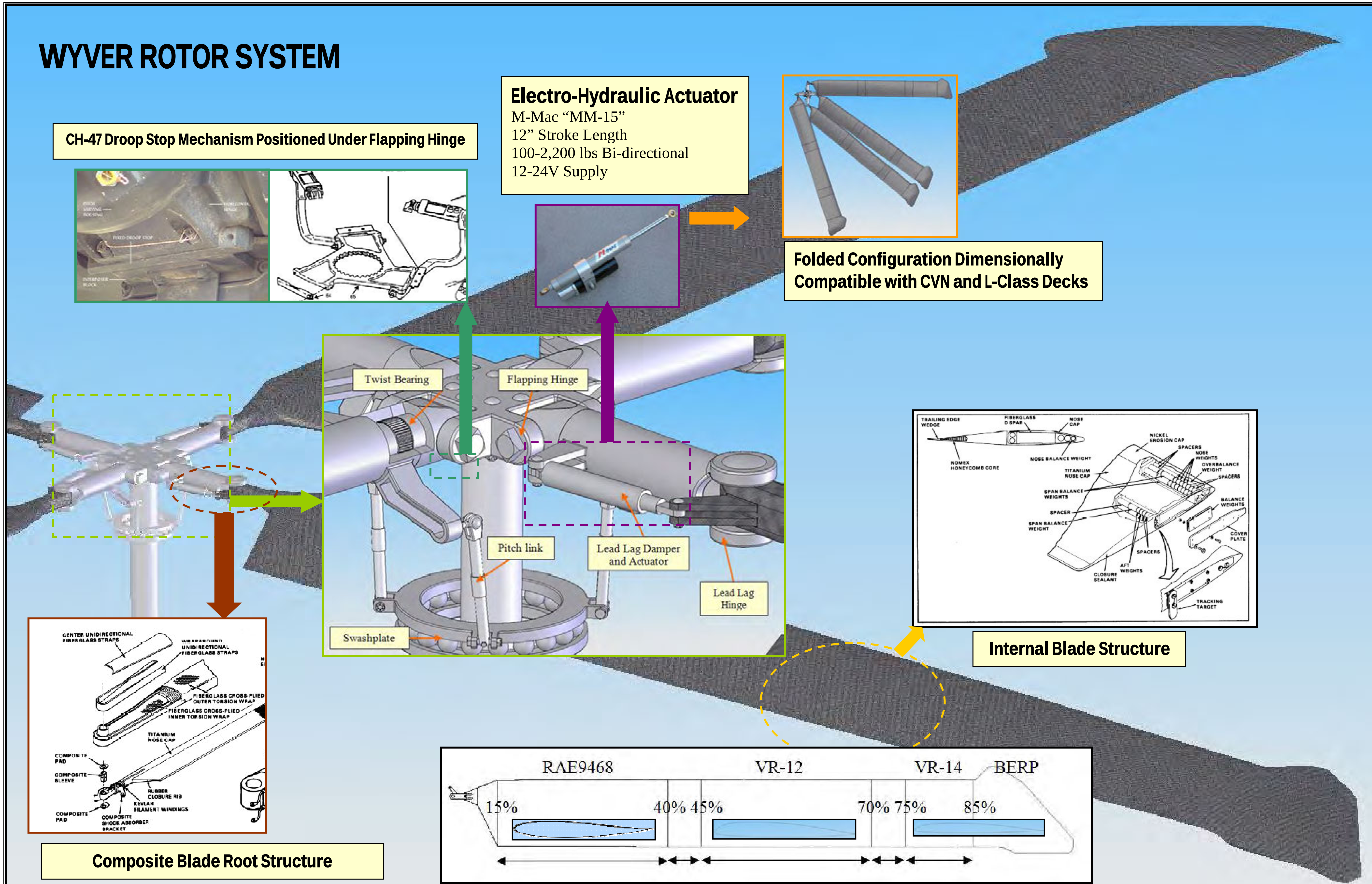
4.1.4 Blade Folding (Please refer fold-out for figures)

An important requirement of the RFP is automated rotor blade folding. Both electric and hydraulic systems were researched and the decision was made to use both systems in the form of an electro-hydraulic linear actuator. By using this, the actuator can also be manipulated as a lead-lag damper. The slight compressibility of the hydraulic chamber will allow small in-plane movements of the blade and the viscosity of the hydraulic fluid will provide damping in the in-plane mode. Power connections could be made through the hub and shaft via a slip-ring however this is complicated and often requires frequent surveillance and maintenance. A much easier method is to make connections to the power supply manually when on the ship deck. This can be accomplished in a matter of a few minutes by a crewmember or technician. If it is determined at a later date, however, that fully automatic folding is desired the slip ring technology can be added to the design, allowing control from within the cockpit.

There are many various models available that can meet the requirements of this design. To sufficiently fold the rotor blades a stroke length of approximately 12 inches is needed with a force of perhaps less than 100 pounds, although the drag forces in flight may greatly exceed the folding force. A good example of a design that fits the design is manufactured by M-mac Actuators, Inc. The MM15 model is a bi-directional actuator with a closed hydraulic system, 12 inch stroke length, and a maximum force of 2,200 pounds. It operates of a nominal voltage supply of 12-24 Volts. The model is available in chromed stainless steel for corrosion resistance in marine applications

During the folding operation, the rotors are aligned at 45 degrees to the fuselage. The inner two blades on each rotor are folded nearly parallel to the fuselage. The outer two blades must remain at a significant angle to the fuselage due to space restrictions. One foreseen problem with the rotor folding design is that the pitch links come under high tensile or compressive forces when the rotors are folded. To keep the pitch link mechanisms from failing during folding, the twisting hinge must be restrained from rotating (e.g. by another support mechanism). One possibility is to have automated opening of the pylon and extending a support structure to hold the blades.

The Wyver's Rotor System is illustrated in the following fold-out.


WYVER ROTOR SYSTEM
CH-47 Droop Stop Mechanism Positioned Under Flapping Hinge
Electro-Hydraulic Actuator
M-Mac “MM-15”
12” Stroke Length
100-2,200 lbs Bi-directional
12-24V Supply
Folded Configuration Dimensionally Compatible with CVN and L-Class Decks
Twist Bearing
Flapping Hinge
Pitch link
Lead Lag Damper and Actuator
Lead Lag Hinge
Swashplate
TRAILING EDGE WEDGE
FIBERGLASS D SPAR
NOSE CAP
NOMEX HONEYCOMB CORE
NOSE BALANCE WEIGHT
TITANIUM NOSE CAP
NICKEL EROSION CAP
SPACERS
NOSE WEIGHTS
OVERBALANCE WEIGHT
SPAN BALANCE WEIGHTS
SPACER
SPAN BALANCE WEIGHT
BALANCE WEIGHTS
COVER PLATE
AFT WEIGHTS
CLOSURE SEALANT
TRACKING TARGET
Internal Blade Structure
CENTER UNIDIRECTIONAL FIBERGLASS STRAPS
WRAPAROUND UNIDIRECTIONAL FIBERGLASS STRAPS
FIBERGLASS CROSS-PLIED OUTER TORSION WRAP
FIBERGLASS CROSS-PLIED INNER TORSION WRAP
TITANIUM NOSE CAP
COMPOSITE PAD
COMPOSITE SLEEVE
RUBBER CLOSURE RIB
KEVLAR FILAMENT WINDINGS
COMPOSITE PAD
COMPOSITE SHOCK ABSORBER BRACKET
Composite Blade Root Structure
RAE9468
VR-12
VR-14
BERP
15%
40% 45%
70% 75%
85%

4.2 Fuselage

4.2.1 Fuselage Structure

The structure of the Wyver is designed in a rather unique way due to a high concentrated mass at the center of the aircraft. The cargo structure has 3 bulkheads (I-beam) with additional braces (I-beam) between the bulk heads. There are also two longerons (Square Channels) for each corner and two main longerons (Rectangular Channels) on the top and bottom surface. The rest of the structure is designed to be a support structure for all other weights. Stringer and runners are added wherever necessary to support the skin (see figure 8 for details).

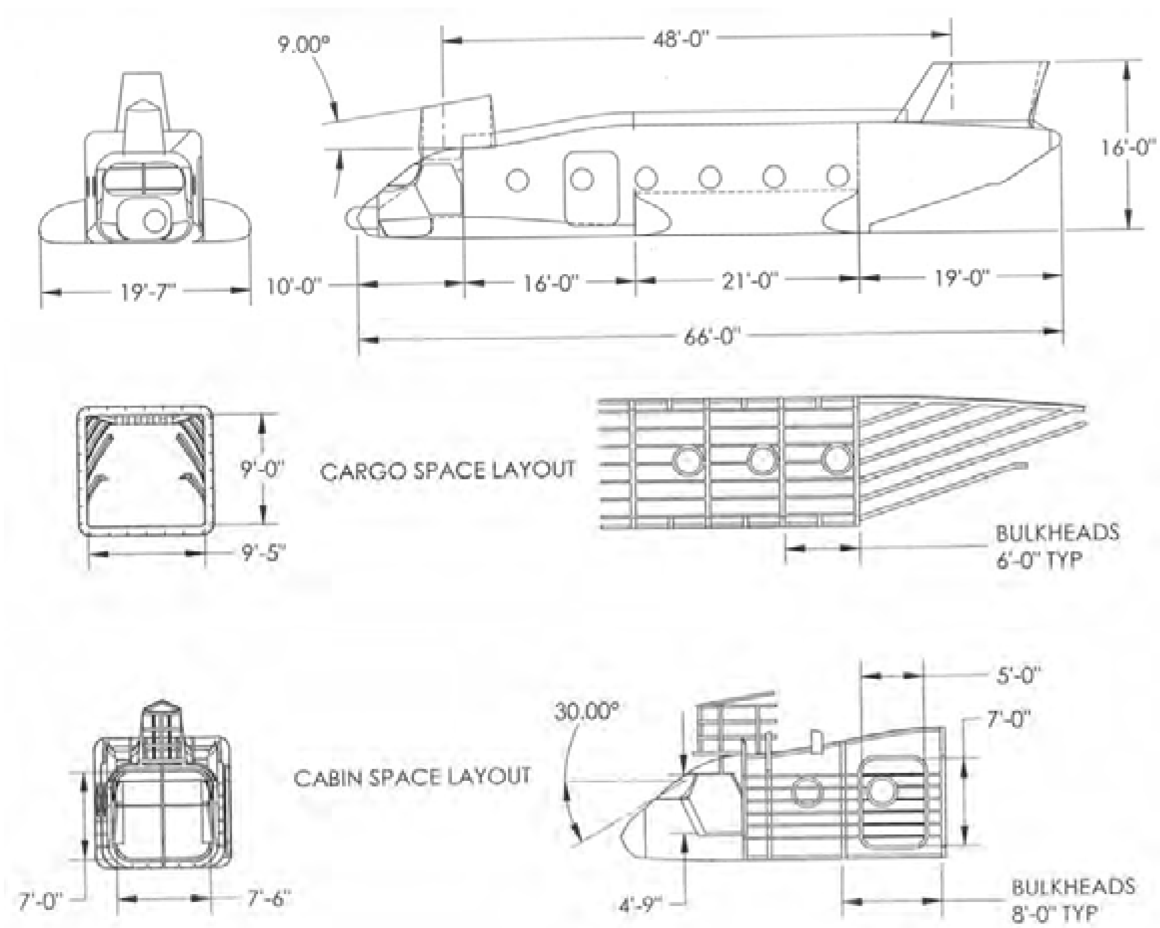


Figure 8 – Fuselage Internal Structure

The longerons will transfer the load from the landing gears or rotors to the entire fuselage. The bulk heads are placed at evenly spaced locations to provide an even load distribution and also to keep the CG centered. The braces are required to strengthen the midsection of the aircraft, cargo, because of the high bending moments experienced in flight. The stringers transfer torsional loads to the skin, which is attached to all bulkheads, stringers and runners. Figure 9 shows the cabin layout and cockpit seating arrangement.

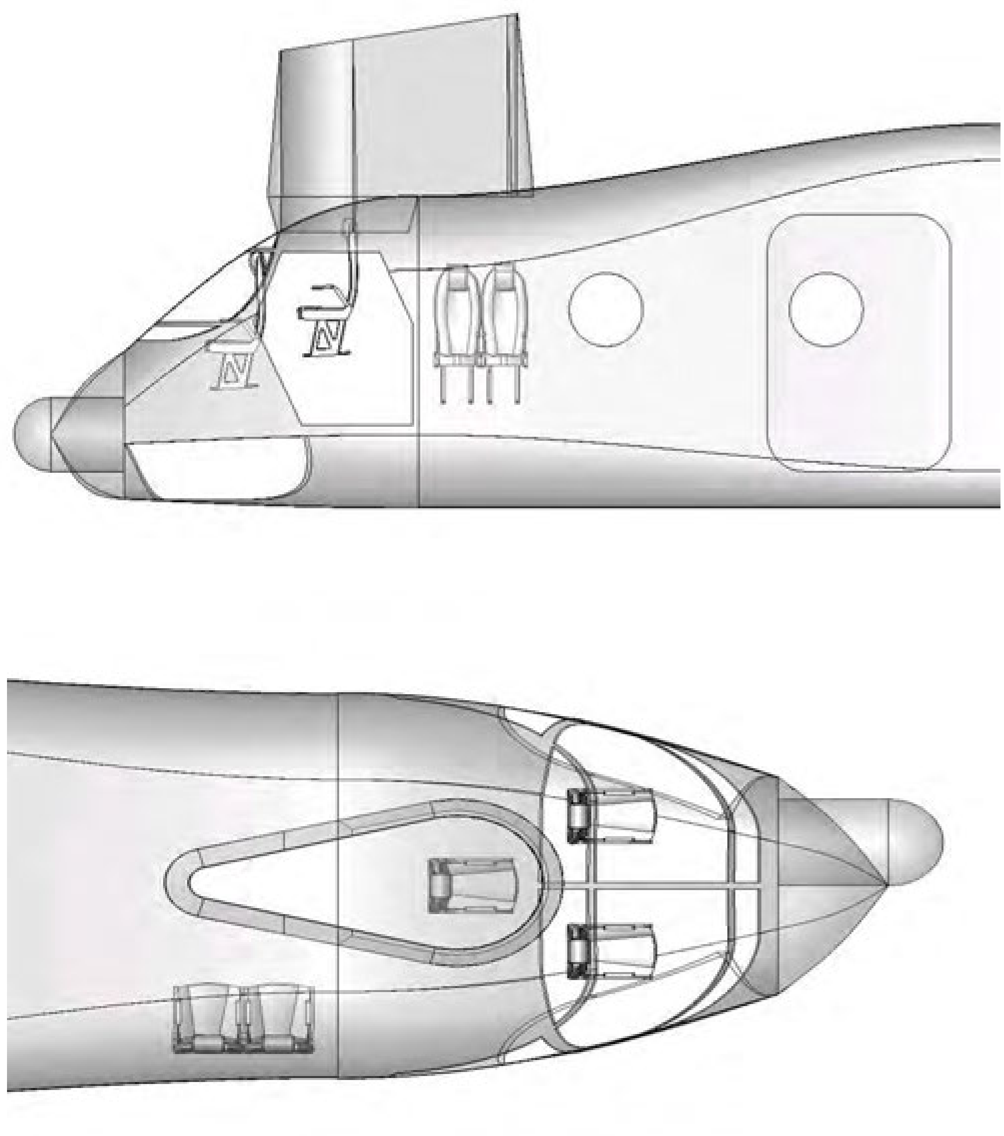


Figure 9a – Cabin Layout

The structure of the pylons will carry the load of the rotors to the longerons and bulkheads by using a thrust bearing (bevel roller bearings) mounted between the transmission and swashplate. This will increase transmission life and efficiency.

Cargo loading/unloading will be done through the rear of the aircraft. The ramp and cargo area floor will be equipped with rollers for ease of loading pallets, or other flat objects. The frame will open in two pieces: (a) Top flap, (b) Ramp. The Ramp is made of I-beams running laterally and longitudinally to ensure integrity while loading the 20 ton FCS. The top flap is opened so that the cargo can be loaded with ease and also to avoid cargo height restrictions. For extreme emergencies or parachute-deployment, if jettisoning the FCS is necessary, the top flap and ramp can be opened to drop the load in mid air.

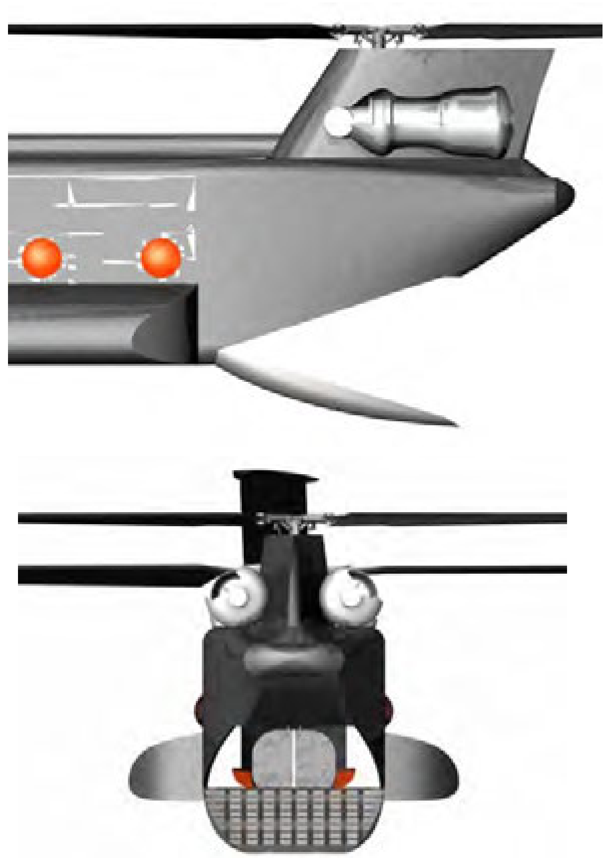


Figure 9b– Wyver's unloading ramp

External cargo will be attached at the three anchor points of the airframe. These points are at the intersection of the main longeron and a bulkhead, giving it strength to lift heavy loads. Care should be taken to lift a 20 ton payload on one hook, because the airframe was not designed with point load analysis. Modal analysis will have to be performed on the complete airframe in order to determine the natural frequencies and nodes, and place bulkheads/braces accordingly. Structural integrity will also have to be optimized for 2.5G load rating and fatigue due to vibrations.

4.2.2 Fuel System

The fuel tanks on the Wyver are outside of the main fuselage structure. They are separated by steel panels as a mode of fire/explosion prevention. They are shrouded with self-sealing material under a forged steel skin. The fuel tanks are split into three interconnected segments on each side, with high output pumps connecting them. The Stability system uses this feature to balance the CG or assist the pilot in trimming the aircraft. The tanks are also pressurized in order to keep constant fuel flow to the engine at all times, especially in negative G dives. The fuel lines travel through the bulkheads and engine mounts into the engines.

4.2.3 Landing Gear

The Helicopter will have four retractable twin-wheel landing gears, located out on the sides of the fuselage. Because of the weight of the helicopter, a tricycle styled landing gear was deemed insufficient to support the aircraft. The quad configuration will provide extra support and stability needed with the large payload that must be loaded onto the helicopter. The wheels must be retractable to reduce drag during the 200nm trip that is detailed in the RFP as a mission profile requirement. The wheel type landing gear will allow for maneuverability on an aircraft carrier or on land.

The landing gears will be able to settle slightly retracted when the aircraft is at rest so that the bottom of the fuselage sits closer to the ground. This partial retraction will be accomplished through the oleo stroke length as a function of load. The landing gear will include hydraulic pistons for full retraction.

Each gear will have two oleo shock absorbers, used because of their simplicity and robustness, including a low resistance oleo and a high resistance oleo. The stroke lengths on the oleos will be 1.5 and 3.0 inches, respectively, with one inch of that added to each oleo for a safety factor. The diameter of the oleos will be 0.68 and 1.25 inches respectively. The oleo specifications are:

Table 2 – Oleo Characteristics

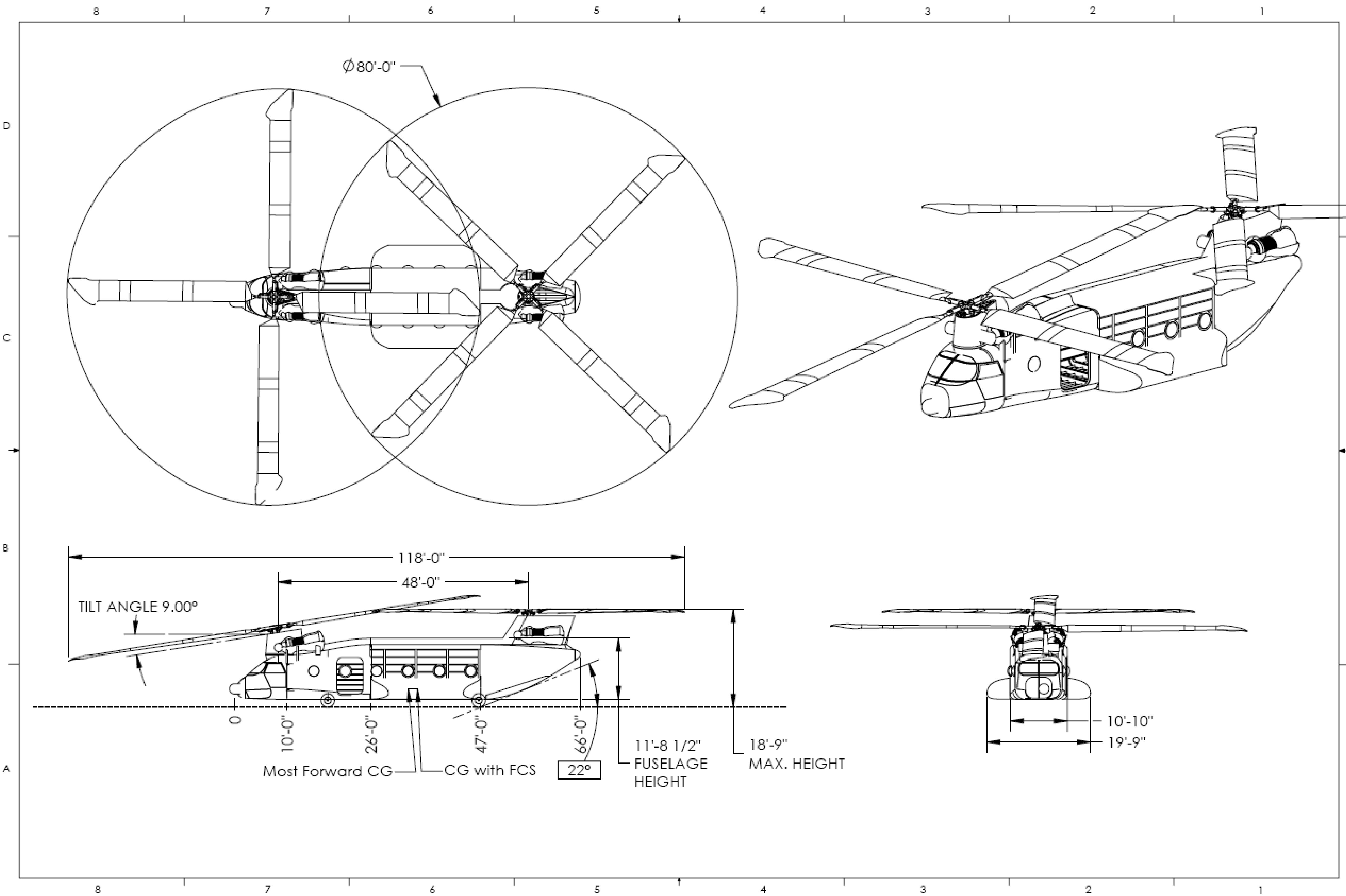
Oleo Characteristics		
	High Resistance	Low Resistance
Stroke	3.0”	1.5”
Max Load	4000 lbs	250 lbs
Length	8.37”	3.93”
Diameter	1.75”	0.68”

The oleos are sized according to a 12" drop test with a full payload, which exceeds FAR regulations that specify that height for a reserve energy absorption test. Since oleo efficiency was not factored into the drop test calculations, the tire deflection was not assumed for these landing gears, thereby creating additional safety factor for the landing gears. The limit for the oleos for energy absorbed per hour was not considered in the design considerations because of the function of use.

The tires used will be eight 31x13.0-12" (diameter, width, rim). Low pressure tires have been selected in order to allow the helicopter to land on variable surfaces throughout its missions. Because of the extreme weight of the helicopter, these tires also prevent the aircraft from sinking into soft surfaces such as asphalt or grass fields. The recommended pressure in the tires is 155 psi. Each tire must support an eighth of the aircraft’s total weight, or around 16,250 lbs gross weight. Hence tires with a rated load of 17,200 lbs static each have been selected. The weight of each tire is 68 lbs for a total weight of 544 lbs. The tire specifications are listed below.

Table 3 – Tire Characteristics

Tire Characteristics	
Diameter	31"
Width	13"
Rim	12"
Ply Rating	20
Rated Load	17200 lbs
Rated Inflation	155 psi



Ø80'-0"
118'-0"
48'-0"
TILT ANGLE 9.00°
0
10'-0"
26'-0"
47'-0"
66'-0"
Most Forward CG
CG with FCS
22°
11'-8 1/2"
FUSELAGE
HEIGHT
18'-9"
MAX. HEIGHT
10'-10"
19'-9"

4.3 Transmission System

4.3.1 Shaft (Please refer fold-out for figures)

Power is transmitted from the engine transmission to the rotors via connecting shafts. Since the shaft assembly has to accommodate any flexing and bending of the fuselage and be able to damp out vibrations, the design consists of multiple smaller shafts 36.9 (in) each with an 8 (in) outer diameter, and thickness of 0.25 (in) ; constructed of ASTM 4340 steel alloy. Connecting these are couplings that are specifically designed to provide axial movement and pivoting. Each section is joined at each end by a Kaman KAflex flexible coupling and supported by bearing blocks. Connecting the engine and combining transmissions is one of these sections. The hub transmissions are connected via a synchronizing shaft consisting of thirteen sections with a total length of 40 feet.

4.3.2 Engine configuration (Please refer fold-out for figures)

The Wyver is designed with four engines, which are mounted above the fuselage. Two of which are situated in the front, side by side, of the pylon feeding into the front combining transmission connected by horizontal Kaman KAflex shafts; two in the back with similar layout feeding into the rear combining transmission. The design of the Wyver necessitated very powerful engines. The available engine that met this requirement is the Allison T-406 turbo shaft rated at 6,150 max peak shp @ 15,000 rpm, and 4,362 max continuous shp @ 12,750 rpm. Specific fuel consumption (SFC) at max continuous power is (0.42 lb/hr/shp). The engine length is 77.0 in, and 26.4 in width, at 971 lb. dry.

4.3.3 Engine control system

These engines are controlled by the FADEC (full authority digital engine control) system. The FADEC is integrated into the flight control system and oversees the overall engine settings and functions in addition to OEI flight conditions. This system provides added safety in practically every area, but important to this design is the over-speed protection and accurate torque matching.

4.3.4 Engine oil system

The oil system is perhaps the most vital part where reliability and safety is of concern. It consists of a pump, tank, cooler, redundant filtration, particle detector and separator (monitored by the FADEC system) for each individual engine. The oil capacity is kept at 4 gallons per engine because of the high output and type of mission this helicopter is subjected to. The oil coolers for the engines are located above the combining transmissions that are cooled by fans driven off a vertical shaft that extract the heat.

4.3.5 Safety

The engines on the Wyver are designed to be safe and reliable. For added safety the engines are mounted in such a way that in a catastrophic failure, they do not penetrate into the fuselage. The engines are mounted directly onto the bulkheads ensuring a strong and solid support. In addition, shields are to be placed wherever there is a rotating high velocity mass. The engines have accessibility for inspection and rapid replacement of all related engine subsystems.

4.3.6 Transmission design and configuration (Please refer fold-out for figures)

The Wyver has a large transmission system that is somewhat complex because of the many separate components through which torque is transmitted. The components involved are the engine transmission x(4), combining transmission x(2), hub transmission x(2), synchronizing shaft sections x(13), sprag clutch x(4);the latter will disengage the engine for autorotation purposes. The combining and hub transmissions are contained within the same housing for compactness and decreased weight. An advantage to this configuration is the inclusion of parts and components that make use of commonality for maintainability and cost purposes. These combined transmissions provide the drive for oil pumps, fans, and electric generators. The components are arranged symmetrically which aids to balance the aircraft. For weight saving the housing are cast out of Al and for strength the gears made out of high strength ASTM 4340 steel.

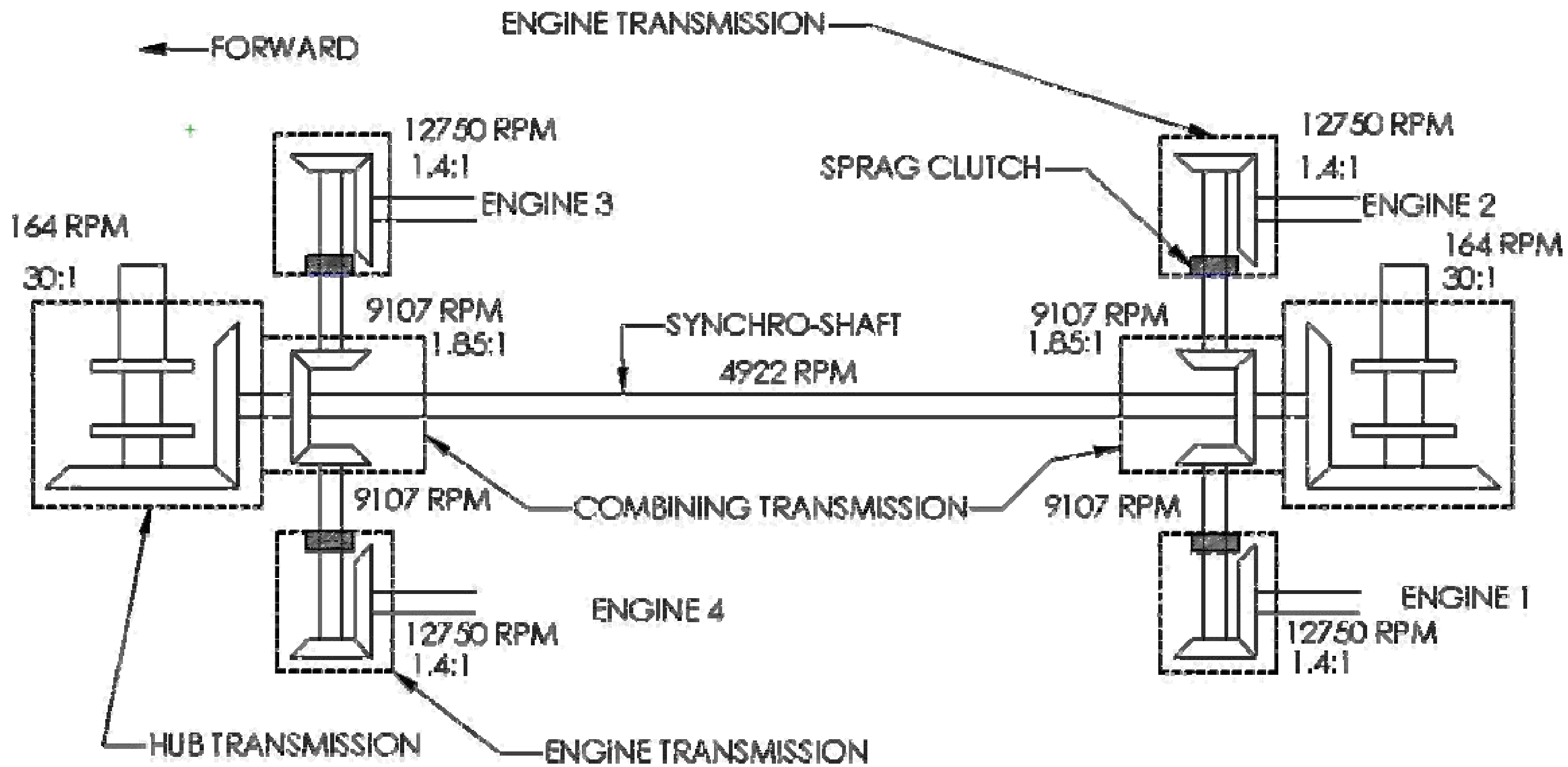
The first component to transmit torque in the system is the engine transmission which is coupled directly to the engine; there is a reduction of 1.4:1 within this unit. It then redirects the torque 90 degrees horizontally; where the sprag clutch is in line. Thus, the torque continues to the combining transmission through a section of shaft coupled with two Kaman KAflex couplings. The combining transmission receives the torque from both engine transmissions and distributes this torque to the hub transmission, this happens in the front and aft. The torque from both engines is combined within this unit by means two spiral bevel input pinion gears and a single spiral bevel gear. A reduction of 1.85:1 occurs at this point. The torque is then transferred to the spiral bevel input pinion gear, which meshes with a spiral bevel gear. At this point the direction of torque is changed from a horizontal to a vertical plane. The ring gear is attached to the first stage sun gear. The sun gear, in turn, drives the first stage planet gears which mesh with a stationary ring gear. The non-rotating ring gear causes the planet gears to revolve around the sun gear. The planet gears are attached to the first stage carrier which also revolves around the sun gear. The upper portion of the first stage carrier forms the second stage sun gear and it drives the second stage planet gears. These are attached to a second stage carrier and revolve in the same manner as the first stage gears and carrier. The second stage carrier is an integral part of the rotor shaft, which is externally splined at the top to receive the hub head. Three stages of speed reduction take place during this sequence and the overall reduction ratio is 30:1.

4.3.7 Oil system

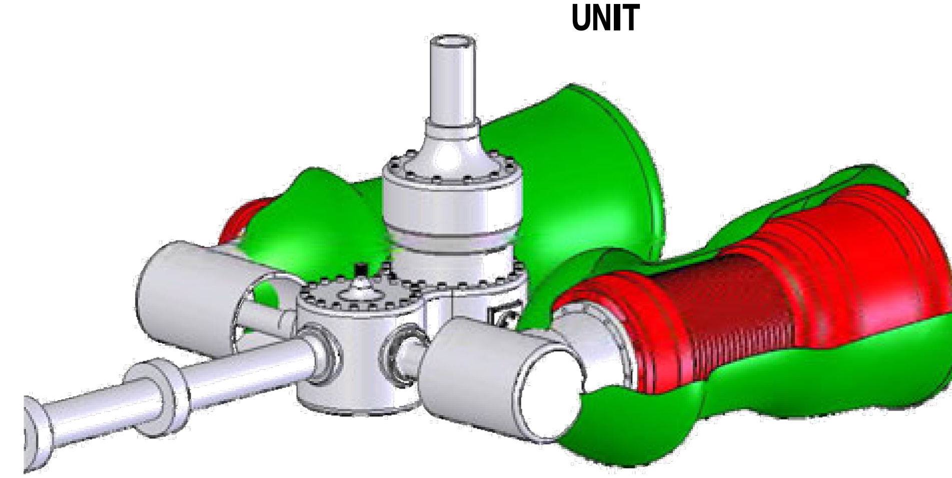
For the transmissions the oil system has a maximum operating temperature of 284 $^{\circ}$F and consists of filtration, pump, cooler, fan, and particle magnet. The engine transmission has an oil capacity of 25 quarts, while the combining- hub transmission has an oil capacity of 80 quarts.

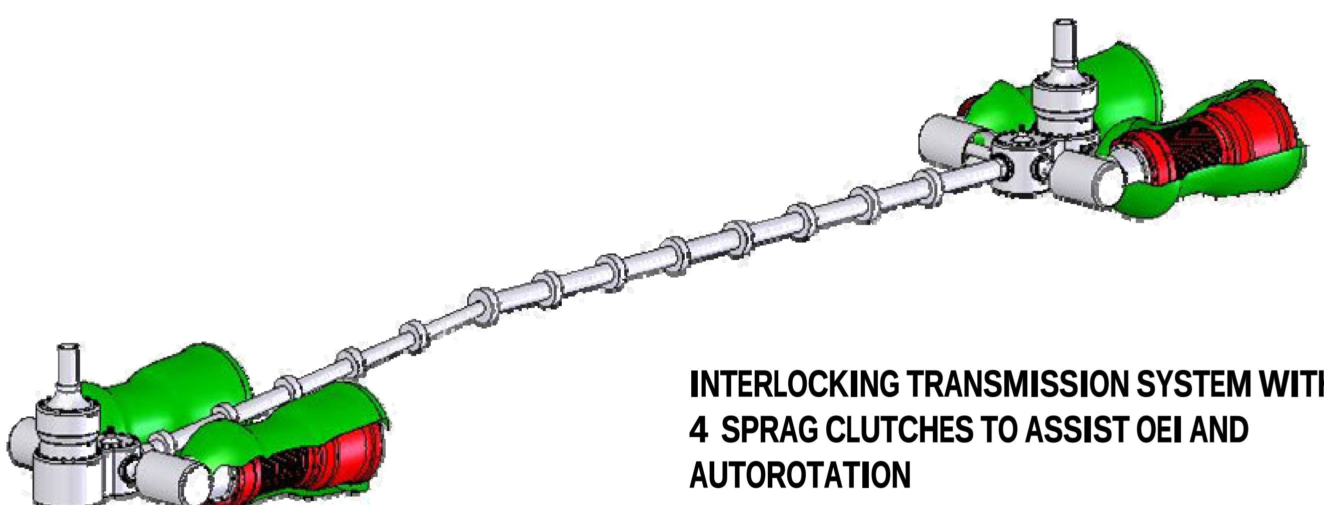
The following fold out summarizes the transmission system of the Wyver.

The WYVER Transmission



INGENUOUS COMPACT COMBINING AND HUB TRANSMISSION IN ONE UNIT





INTERLOCKING TRANSMISSION SYSTEM WITH 4 SPRAG CLUTCHES TO ASSIST OEI AND AUTOROTATION

KAMAN KAFLEX RELIABLE SHAFT COUPLING

4.4 Safety

4.4.1 Flight Procedure and Special Instructions

<u>Full Payload Mission</u>

To fly a typical mission, the helicopter must be prepared in advance and checked for maintenance problems. Keeping the aircraft fueled will also save time and personnel during launch. All preflight check up can be done during cargo loading therefore reducing launch time.

In order to overcome the cruise speed limitation, the pilot must initiate climb with maximum power at V-cruise. Since cruise requires less power than hover, a better rate of climb can be achieved. Upon reaching the mission altitude, the pilot must fly the aircraft at the necessary power setting to achieve best range. If the mission requires faster deployment, the pilot must use all available power to V-max. To maximize V-max while avoiding Mach effects on the advancing blades, the pilot will use the FADEC to slow down the rotors sufficiently. Although there will be additional drag, it is a small price to pay for a high priority mission. Descend to LZ will also be done at V-cruise to maintain high speeds as long as possible.

During cargo deployment, pilot will have to do a landing gear touch down while hovering because the weight of the aircraft might cuase the landing gears to sink into soft surfaces. With very low loads on the landing gear, the stroke of the landing gears will provide lateral and longitudinal stability for the deployment period. Upon delivery of the FCS or other cargo, the Wyver will return at 99% power with slowed rotors to ship deck and load the next FCS while being refueled.

<u>Intra-theatre Mission</u>

Intra-theatre mission is relatively easy for the Wyver because the 20-ton payload is removed for this mission. Our calculations indicate that no additional fuel beyond the Wyver's normal fuel capacity is necessary to complete the 1000 nm intra-theator deployment.

4.4.2 OEI and Emergency Procedures

The Wyver's onboard computer will be used as a backbone for a catastrophic event such as losing one engine or even two. The computer will calculate if it can still complete the mission based on total weight, altitude, airspeed, and decide on the best course of action. The computer will also assist on other factors such as displaying what airspeed, descent rate, heading, and attitude to maintain.

Computer calculated OEI procedures:

1. Maintain heading and velocity if LZ is near and moderate payload.
2. Maintain heading and start slow descent if LZ is near but heavy payload.
3. Abort mission and reverse course to base if it is less than 50% of the leg away.
4. If above options are not possible: Abort mission, and the navigation system will direct the pilot to the nearest suitable emergency landing area.

For other catastrophic failures, where emergency landing is a must and fuel is of no use, fuel will be jettisoned by the pumps using an external port and the aircraft will autorotate safely to the ground. Depending on the situation, if jettisoning the FCS or cargo will save the Wyver and its crew from imminent danger, The FCS will be ejected out through the rear.

4.4.3 Engine Failure

The Wyver will be capable of flight in the One Engine Inoperable (OEI) state. The power requirements to remain airborne can be met with only three of the four Allison engines; this is demonstrated in the Chapter on Performance. However, it is also critical for a rotorcraft to be capable of safe descent and landing through autorotation. The standard Sikorsky equation for Autorotative Index (AI) was used in the calculations (figure 10-11) for the Wyver. Industry standards generally accept multi-engine rotorcraft with an AI index of 10 or greater as "safe." However with full payload and fuel this value is only just reached. Depending on the preference of the operator, fuel may be jettisoned to increase the AI index to a safer level. If the helicopter is no longer carrying the FCS, the Wyver can easily accomplish the autorotation maneuver.

$$M_{RotorBlade} = 689lb$$
$$M_{Rotor} = 817lb$$
$$I_R = n * M * z_{cg}^{\;2} = 2{,}998{,}466.80 lb \cdot ft^2$$
$$\Omega = 2.84783 \sec^{-1}$$
$$DL_{empty} = 4.82 \frac{lb}{ft^2}$$
$$DL_{payloadl} = 9.24 \frac{lb}{ft^2}$$
$$DL_{payload+fuel} = 10.47 \frac{lb}{ft^2}$$
$$AI_{no-payload} = 52.42$$
$$AI_{payload} = 14.28$$
$$AI_{payload+fuel} = 11.13$$

Figure 10 – Autorotative Index (AI) Calculation (DL stands for disk loading)

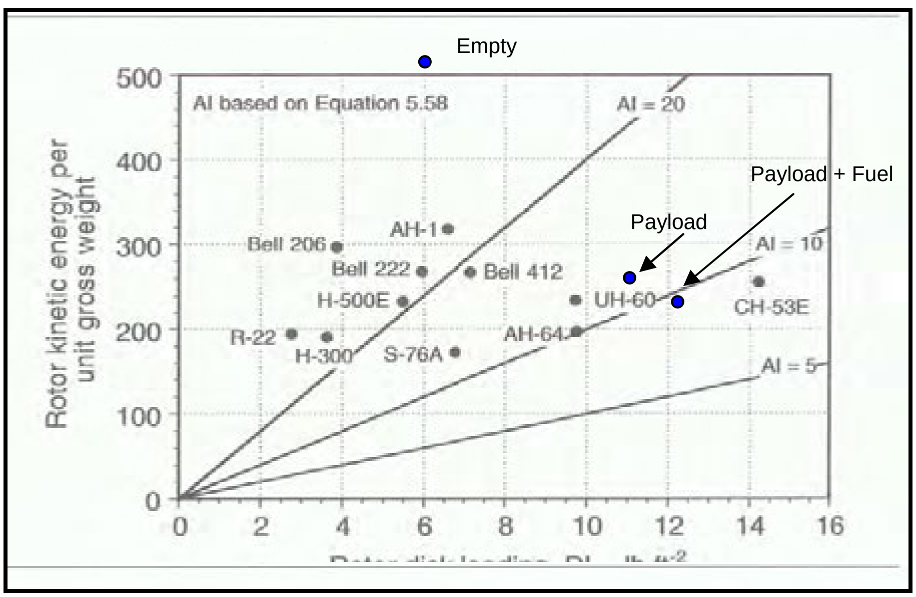


Figure 11 – Autorotative Properties of Existing Rotorcraft and the Wyver

4.5 Vibration and Noise

Because reduced noise levels are not specified for mission requirements in the RFP, noise and vibration control are geared toward the interests of structural integrity and pilot and passenger fatigue. Although proper blade balancing, both static and dynamic, and maintenance will help with reducing noise and vibration levels, both passive and active controls can be integrated into the system to help reduce pilot and structural fatigue.

Most lower frequency vibration is caused by sources that can be attributed to the rotors. Low frequency vibration (1/rev) can be caused by imbalances in the rotor (tracking problems), whose properties can shift after exposure to weather and operating conditions. Such problems can be overcome with proper manufacture, assembly, and maintenance. The more prominent vibrations, particularly in an N-bladed rotor system, are N/rev vibrations. The causes of these vibrations are the unsteady aerodynamic forces and the aeroelastic response of the flexible rotor blades. Since the Wyver has two rotors these vibrations can be significant particularly in transition and high speed forward flight.

To minimize the N/rev loads the structural frequencies of the Wyver's blades will be placed as far away from the rotor harmonics as possible on the Fan diagram. This will help to minimize the vibratory response of the rotor blades. In addition passive isolators and absorbers will be mounted on the Wyver. These can be tuned for the appropriate speed, more particularly cruise speed, since the majority of aircraft's mission is spent in cruise. Tuned mass absorbers and isolators can be placed on the airframe, nose, or cabin. Lag dampers are placed on the rotors for aeroelastic stability and reduced vibration. Active vibration control is proposed in the fuselage to minimize the impact of the vibration in the fixed frame. This can be achieved using an Active Control of Structural Response (ACSR) system featuring integrated arrays of actuators and sensors. The actuators can be piezoelectric stacks or inertial (flywheel type) actuators.

4.6 Operation and Controls

4.6.1 Controls

Since the Wyver and the CH-47D Chinook have the same rotor configuration, the control system will be based on the Chinook. Because of the two-rotor system, the control is a little more complex but the cyclic controls are generated by onboard computers based on pilot input. On the positive side, the complexity in the system gives the pilot more authority over the type of maneuver. For example, the pilot can yaw the Wyver in three ways: (a) Yaw the tail - cockpit stationary, (b) Yaw the cockpit - tail stationary, or (c) Yaw about the CG. Similarly, pitching and banking can also be done in several ways.

4.6.2 Computer Aided Stability

The Wyver will also be equipped with a computer aided stability program to maintain its fuel tank levels. The stability system will constantly monitor gyroscopic attitude and pilot input to determine the balance assistance required. The multi-stage tanks will be interconnected through high output pumps that will transfer fuel as necessary. This system will be most robust when 50% of its fuel has been consumed, which coincidentally occurs at about 75% of its mission leg. This adds to the maneuverability and survivability of the aircraft until it reaches the LZ.

4.6.3 Avionics

The pilot will have access to a state of the art glass cockpit, with onboard navigation and missile warning systems with both flares and chaff countermeasures. The back up power unit will provide power to control systems and avionics in case of emergency. There will be a backup set of gauges and navigation in case of any malfunction or component failure.

4.7 Center of Gravity

The cg travel for the Wyver is shown in figure 12. The cg location of the major components of the Wyver is marked out in the figure. The cg of the Wyver shifts from 166.875 inches to 145.25 inches (with respect to the origin marked in figure 12) from zero payload condition to full payload. This corresponds to only 2.72% travel with respect to the fuselage length. Given the tandem configuration of the Wyver it will be relatively easy to maintain stability for this cg travel.

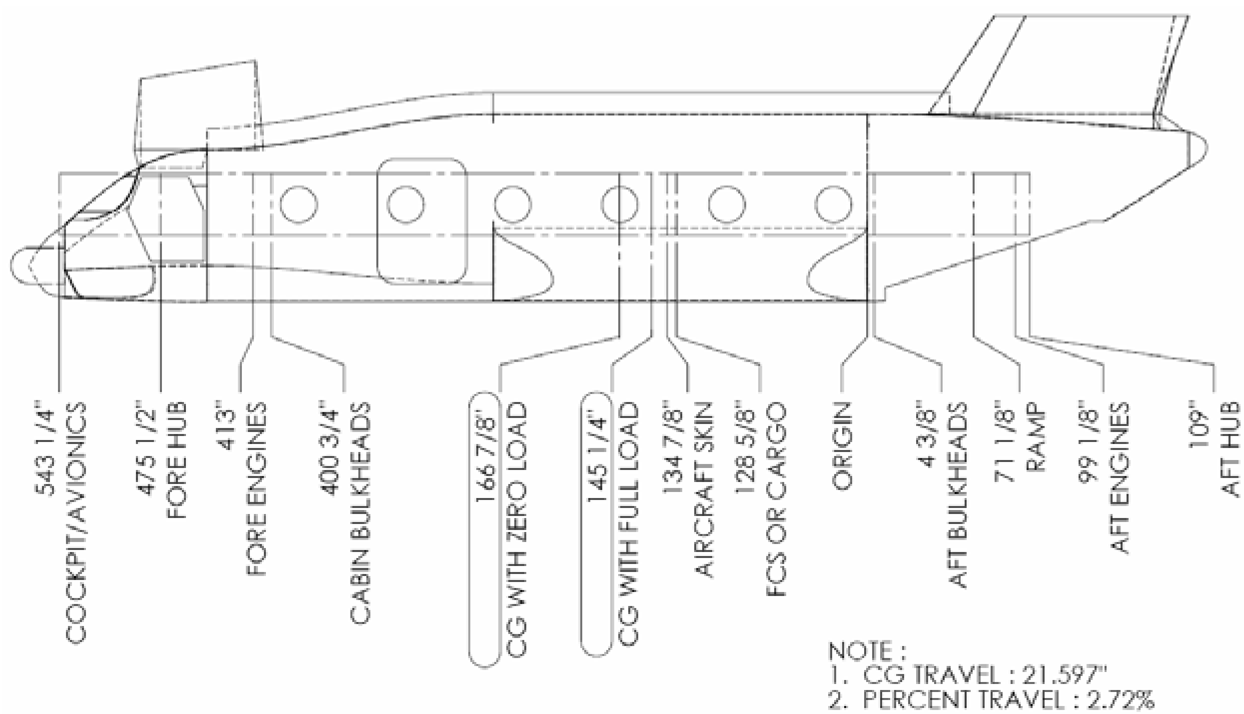


Figure 12 – Center of Gravity Travel

5. Manufacturing

In order to save weight yet maintain rigidity and strength the aircraft will have a semimonocoque fuselage, with internal braces and the skin both carrying the stresses. In terms of manufacturing this will require the construction of both rigid framework and strong skin to preserve the structural integrity of the aircraft. Because the fuselage and rotors are much greater in length than in width or height, unidirectional materials will be used to sustain the strength of the members while maintaining weight efficiency.

There will be four jigs used in the manufacture of the Wyver: one each for the cockpit, cabin, cargo, and tail. There will be two sub-jigs used for each of the pylons. All references will be made to a master tool.

5.1 Framework

The bulkheads will be made from machined aluminum. Standard aluminum is easy to form, resists corrosion, and is inexpensive relative to other materials. In addition the longitudinal framework components, the longerons and stringers, will be made from extruded aluminum stock.

5.2 Composite Panels

Structural composites are valuable in aircraft design because of their low density and high mechanical properties. However, they pose a problem in terms of complexity, time, and cost in terms of manufacture. Molds are needed and composites require strict controls in process and climate of manufacture. In order to reduce the negatives associated with composite manufacturing, the manufacturing process will take advantage of Resin Transfer Molding (RTM) technologies. In this method performs are used to convey resin and catalyst through the mold to quickly create consistent and accurate products of even the most complex shapes. RTM was used with great success on the F-22 as both cost and number of assembly reinforcements were reduced.

5.3 Rotor Blades

The rotor blades will be made according to the industry standard. The materials used will be Nomex honeycomb, which has an excellent strength to weight ratio, foam, carbon-fiber composites, and titanium for the leading edge. The rotor blade mold to be used for blade fabrication is shown in figure 13.

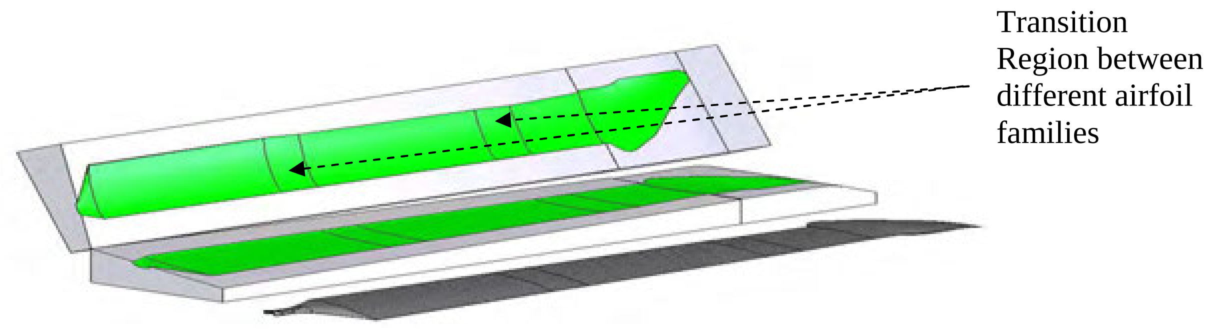


Figure 13 – Rotor Blade Mold

5.4 Rotor Hub

The rotor hub is to be a forged titanium assembly. Although titanium is approximately three times as dense as aluminum, it is also three times as strong, so will be used for high load bearing applications. Its use is also limited because of its high cost: up to ten times that of aluminum alloys.

6. The Wyver: Performance Estimation

Performance, weights and rotor sizing computations for the Wyver were performed following the method outlined by Tishchenko et al. (AHS Journal, Vol. 48, No. 2, April 2003. pp. 71-79). The equations used in the model are based on blade element momentum theory and are presented in the Appendix.

Table 4 – Preliminary parameters required by the model

Ce_1	Engine specific fuel consumption (kg/hp/h)	z_{MRBL}	Number of main rotor blades
Ce_2	Engine specific fuel consumption (kg/hp/h)	z_{TRBL}	Number of tail rotor blades
$(CT / \sigma)_{MR0}$	Main rotor thrust coefficient	z_{ENG}	Number of engines
$(CT / \sigma)_{TR0}$	Tail rotor thrust coefficient	η_{PR}	Main rotor propulsive efficiency
C_{POW}	Nominal engine power factor	ρ_0	Air density at sea level at standard temp.
FM_{MR}	FM of main rotor	ρ_{HOGE}	Air density at 8000 ft and standard temp.
FM_{TR}	FM of tail rotor	$(\omega R)_{MR}$	Main rotor tip speed (m/sec)
f_{SH}	Overloading factor	$(\omega R)_{TR}$	Tail rotor tip speed (m/sec)
K	Lift-to-Drag ratio	ξ_{CR} (1rotor)	Cruise power conversion efficiency
L	Given Range (km)	ξ_{MR} (1rotor)	Main rotor power conversion efficiency
n_{MTR}	Ratio of main rotor to tail rotor diameter	ξ_{TR}	Tail rotor power conversion efficiency
n_{SH}	Tail rotor shaft RPM	W_{PL}	Payload weight (kg)
p	Disk loading (kg/m2)	W_{FURN}	Weight of additional furnishing (kg)
P_{DC}	Power consumption of pump and other (hp)	k_{WE}	Weight efficiency coefficient
T_{RES}	Given time reserve (h)	Ce_{CR}	Engine specific fuel consumption (kg/hp/h)
t_{MR}	main rotor thrust losses	$\lambda_{MRBL.MIN}$	Minimum of main rotor aspect ratio
t_{TR}	tail rotor thrust losses	$\lambda_{TRBL.MIN}$	Minimum of tail rotor aspect ratio
V_{CR}	Cruise speed (Km/h)		

Table 5 – Main performance and geometrical dimensions calculated by the model

$W_{TO\ initial}$	Take off weight, initial (kg)	$P_{ENG.NOM}$	Nominal power (hp)
$W_{TO\ calculated}$	Take off Weight, calculated (kg)	P_{CR}	Cruise rotor power (hp)
D_{MR}	Main rotor diameter (m)	$P_{CR} / P_{ENG.NOM}$	
σ_{MR}	Main rotor solidity	Ce_{KR}	Engine specific fuel consumption (kg/hp/h)
z_{MRBL}	Number of main rotor blades	$W_{TO\ calculated}$ 1	Take off weight, calculated 1 (kg)
λ_{MRBL}	Main rotor aspect ratio	q_{CR}	fuel required per kilometer (kg/km)
b_{07MR}	Main rotor chord	W_{FUEL}	Fuel weight (kg)
$P_{ENG}\ z_{ENG\ preliminary}$	Engine power required	M_{TTR}	Tail rotor shaft torque moment (kgm)
M_{MRT}	Main rotor shaft torque moment	M_{TSH}	Shaft torque moment
D_{TR}	Tail rotor diameter (m)	σ_{TR}	Tail rotor solidity
T_{TR}	Tail rotor thrust (kg)	z_{TRBL}	Number of tail rotor blades
P_{TR}	Tail rotor power (hp)	λ_{TRBL}	Tail rotor inflow ratio
ξ_{HOV}	Hover power conversion efficiency	b_{07TR}	Tail rotor chord (m)
$P_{ENG}\ z_{ENG\ adjusted}$	Adjusted engine power required (hp)		

The initial parameters that need to be set by the designer are summarized in Table 4. Among the parameters in Table 4, the most significant ones are the weight efficiency (Kwe), vehicle cruise lift/drag ratio (K) and the rotor disk loading (p) in hover. Weight efficiency (Kwe) is defined as the ratio of the empty weight by the gross take off weight. Lift to drag ratio is the total vehicle lift divided by the total vehicle drag (including fuselage drag). Given these inputs the Tishchenko method calculates the aircraft sizing, detailed weight breakdown, hover and cruise power, and the fuel consumption. The main performance, weight and geometrical dimensions calculated by the Tishchenko model are summarized in Table 5.

For the tandem configuration, we chose (based on historical data) Kwe=0.5 and K=3.5 (this is less than single main-rotor tail-rotor helicopters that have K ~ 4.2). To verify the accuracy of the simulation code and of the assumed initial parameters, the code was used to model the CH-47 Chinook tandem helicopter. **The simulation was able to predict the take-off weight of the Chinook (22,686 Kg) within 2.5%, empty weight (10,618 Kg) within 1.8%, installed power (7500 HP) within 1.2% and the rotor diameter (18.28 m) within 1.5%.** This gave us confidence in the validity of our simulation model.

Next the simulation code was applied to the mission profile specified in the RFP. The equations used and the spreadsheet results for the analysis of the Wyver are presented in the appendix of this manuscript. In this section we will summarize the key results.

6.1 Selection of Disk Loading and Rotor Diameter

The disk loading (p) was varied in the 10 to 100 Kg/m^2 range. Figures 14-15 show the rotor diameter, hover power and gross weight plotted as a function of disk loading. A 4-bladed rotor is assumed in the computations. The results indicate that as disk loading increases, the rotor diameter decreases and the power and weight increases. These trends are expected based on momentum theory. The results also indicate that above about p=60 Kg/m^2, the reduction in rotor diameter levels off, indicating that substantial reduction in rotor diameter is not possible with further increase in disk loading. In contrast, the gross weight and hover power (or nominal power) continue to increase sharply above p=60. Hence it appears that a disk loading of about 60 Kg/m^2 appears to be optimal. For this value, the hover power is ~ 18,000 HP. The rotor diameter for p=60 Kg/m^2 is 24.3 m (79.6 ft). The relatively large disk loading of the Wyver, generates a powerful rotor downwash, and also results in a large induced power requirement. However choosing a lower disk loading would have resulted in significantly higher rotor diameter, which would not allow the Wyver to fit on the elevator of an L-class ship. For these reasons we chose a disk loading of 60 Kg/m^2 for the Wyver.

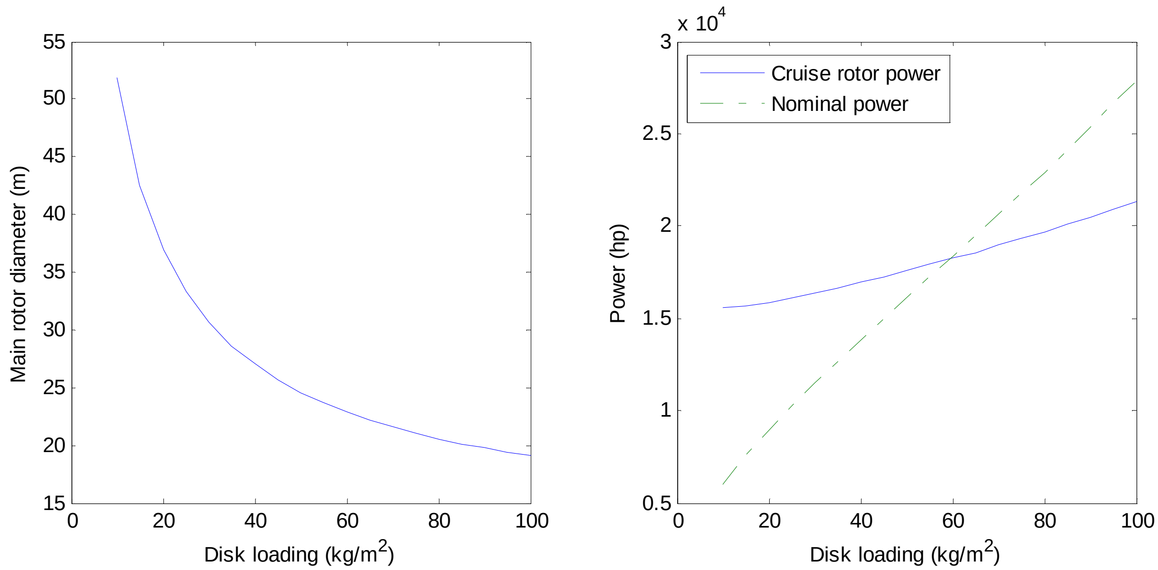


Figure 14 – Rotor diameter and power vs. disk loading (assuming 4-bladed rotors)

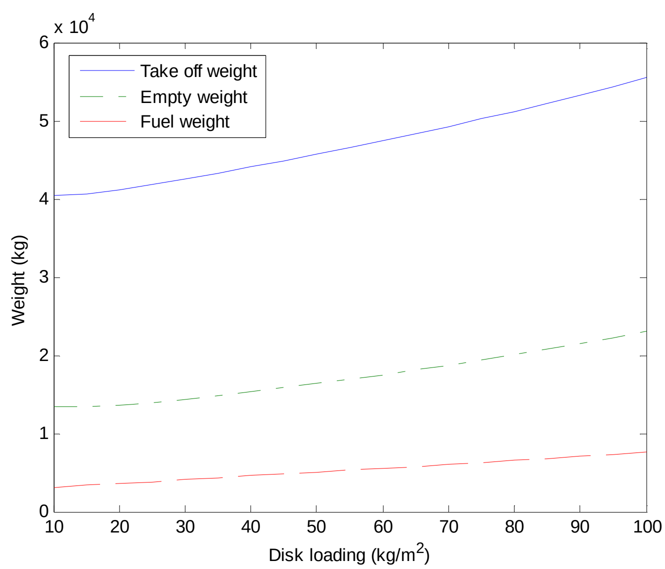


Figure 15 – Gross take off, empty and fuel weights vs. disk loading (assuming 4-bladed rotors)

Figure 15 also shows the variation of empty weight and fuel weight with increasing disk loading. For the disk loading of 60 kg/m^2, the gross take off weight including the 20-ton payload was almost 48,000 kg, with the fuel required to cover 250 nm of 5,500 kg (1,800 gal).

6.2 Selection of Cruise speed

We varied cruise speed in the 100 to 350 Km/hr range. Figure 16 indicates that the fuel weight decreases slightly as cruise speed increases since the mission time is reduced. This also affects the gross take off weight as shown in the figure. The cruise power increases with increasing cruise speed due to increase in the rotor profile power and increased fuselage drag. To obtain the maximum cruise speed, we note the point where the hover power (or nominal power) and cruise power curves intersects (right plot of Figure 16). This occurs at around 320 km/h (170 knots). In practice due to retreating blade stall, transonic effects on advancing blade tips, and vibration/noise limits it is unlikely that cruise speeds as high as 170 knots are possible. Thus, in the analysis, an approximate cruise speed of 300 km/h (~160 knots) was selected. This enables high speed delivery of FCS as well as some reserve power margin for high speed dash and maneuvers.

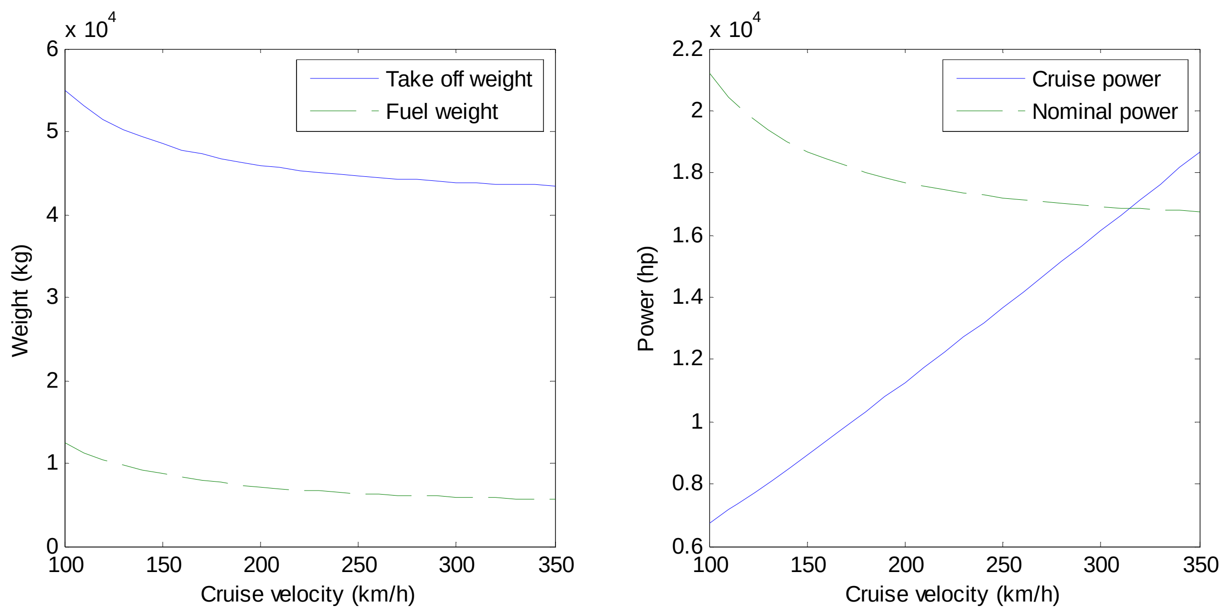


Figure 16 – Take off and fuel weight & power vs. cruise velocity (assuming 4-bladed rotors)

6.3 Selection of Number of Blades per Rotor

A study was performed to determine the effect of number of blades per rotor on power required, rotor diameter and total weight for a disk loading of 60 kg/m^2, 20 ton of payload and 4 engines. The results are presented in Figure 17.

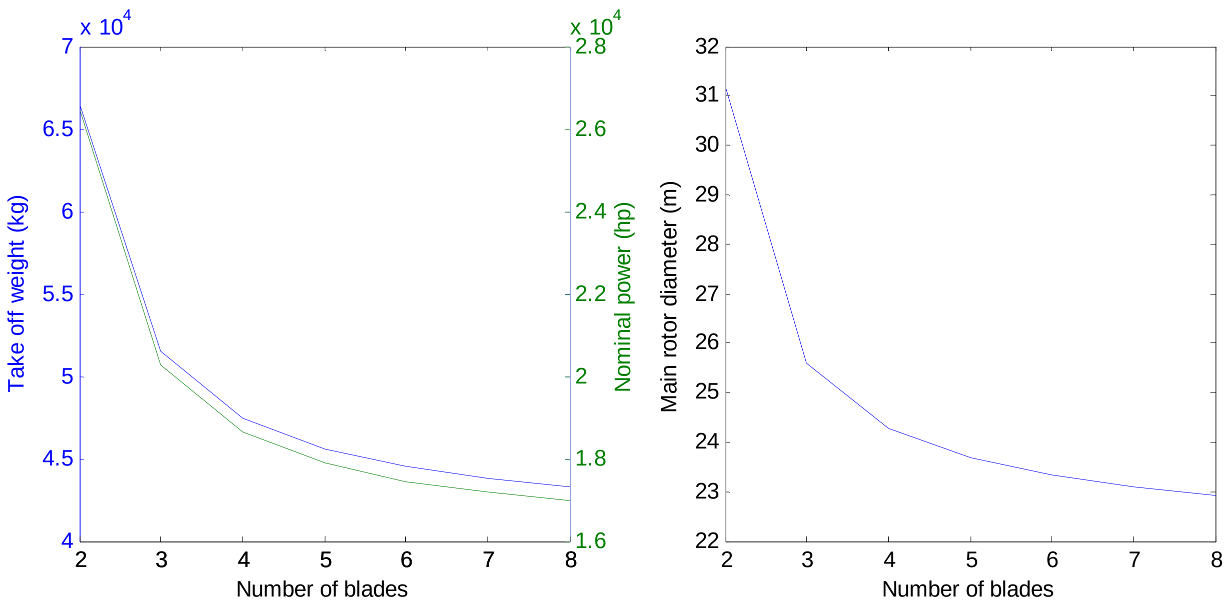


Figure 17 – Gross take off weight, power and rotor diameter vs. number of blades

The results indicate that there is significant decrease in take-off weight and installed power as the number of blades is increased. This trend cannot be explained by blade element momentum theory. The reason for the observed effect is that with increasing number of blades the stresses on each blade are reduced (reduced blade loads). This allows the blades to be designed lighter; this results in a corresponding reduction in the hub weight. Reduced weight of the helicopter causes a corresponding reduction in power. All these higher order effects are accurately predicted by the Tishchenko model that we are using. Figure 17 also indicates that with increasing number of blades, as the gross weight decreases, the rotor diameter also decreases (since disk loading is constant= 60 Kg/m^2). The results shown in figure 17 indicate that increasing the number of blades is advantageous. However having more than four blades will make blade folding too cumbersome and will increase the complexity and cost of the swashplate and hub mechanism. Hence for this design 4 blades were considered to be optimal. Vibration and noise are also decreased for a 4-bladed rotor compared to a 3-bladed one. This is important for us as we strive to achieve relatively high cruise speeds of ~160 kts.

6.5 Selection of Number of Engines

The number of engines to be mounted was determined by the power required to hover and the currently available engines capable of producing this amount of power. From figure 16, it was determined that using four engines, a total power of 18,000 hp was required. It was found that four AE1107C Rolls-Royce Allison rated at 6,150 hp would give the Wyver the necessary installed power. Take off and landing safety played an important role in the selection of this engine. With the Allison engines the Wyver is capable of a one engine inoperative (OEI) hover-out-of-ground-effect at full payload capacity as three operative engines can provide the 18,000 hp required to hover.

Furthermore, the RFP required the helicopter to be capable to sustain turn rates at cruise speed of at least twice the standard rate turn (3deg/sec). A traditional load factor equation is shown below and was used to calculate the power increase needed for a turn twice the standard rate. The calculation indicates that an additional 10% power increase is needed to maintain speed and altitude at this turn rate. The power capabilities of the Wyver (~ 24,000 HP installed) can easily fulfill this additional need.

$$n = \sqrt{1+\left(\frac{v\omega}{2g}\right)^2} = 1.0946$$

6.6 Weight Breakdown

In the calculation of empty weight of the aircraft, each weight of the individual major parts of the helicopter as well as the subsystems is estimated. This is achieved in the Tischenko model that we used by using historical data for existing helicopter fleets. Most of the aircraft structure materials used in the analysis are assumed to be steel and aluminum alloys. The rotor blades were assumed to be made of composite materials. To provide an additional safety margin a 5% reserve fuel weight was added to the empty weight. A detailed weight breakdown for the Wyver is provided in the MIL-STD-1374 Table provided at the end of this report.

7. Wyver: Cost Analysis

Equations based on historic data were used to determine an estimate of the cost of the aircraft. The overall cost depends on the weight of each individual system, materials used, production rate and quantity of the aircraft. The equations used to calculate the component costs are listed in the appendix (Koratkar, 1999). To reach the production quantity of 200 aircrafts over a fifteen-year manufacturing period as specified in the RFP, the production rate was approximated to 14 aircrafts per year. Table 6 shows the estimated cost of the aircraft broken into its components.

Table 6 – Aircraft cost breakdown

Component	Cost (in USD)
Rotor System	8,100
Fuselage	7,166,100
Landing Gear	2,575,200
Nacelle Group	265,300
Air Induction Group	400,200
Engine Installation	8,954,600
Drive System	2,391,500
Flight Controls	235,000
Instrumentation	364,800
Hydraulics	167,900
Electrical Systems	56,700

Avionics Systems	700,400
Furnishing and Equipment	1,247,600
Final Assembly	30,925,100
TOTAL	55,458,600

8. Summary and Conclusions

The extreme requirements of the RFP had a strong influence on the configuration selection, design, and performance analysis. Range, payload, shipboard operation, and elevator size constraints played a major role in the design process. Trade study for various existing, experimental, and theoretical configurations were studied to determine the best match for the unusually heavy payload and size restrictions.

The Wyver is a high performance tandem heavy lift VTOL helicopter. Its features are modern in appearance compared to existing aging designs. The most prominent of its capabilities is the payload that the Wyver can carry and still achieve the mission range without refueling. The tandem configuration of the Wyver employs two rotors, each of which has four blades that are locked and synchronized via a central shaft. The blades utilize the latest in design in terms of advanced geometry and composite materials that permits such a high level of lift with a reasonable disk loading. Streamlined fuselage and compact hub, aerodynamic fairings, retractable landing gear etc. all help to lower drag, allowing for a relatively fast cruise speed of about 160 kts. Automatic blade folding is part of the RFP requirements, and this is accomplished using a dual-purpose damper, which also serve as an actuator. The Wyver is powered by four powerful, FADEC governed, engines of 6150 peak HP each that feed power into an innovative and compact transmission design. Fully loaded, there is sufficient power to perform a one engine inoperative (OEI) and hover out of ground effect (HOGE) in ISA+20 °C conditions. In cruise the engines operate with 85% power at 12750 rpm.

In closing this aircraft was designed in mind to be reliable, fast, efficient, and cost effective. An attribute that permits all of the aforementioned is that the Wyver was designed with maintainability in mind; access for inspection and rapid repair is provided for parts leading to and from all major components. In conclusion, the Wyver is truly in a class of its own: mammoth in its lifting capabilities, swift in its cargo delivery, and compact for shipboard storage. Additionally, its reliable foundation of existing technology, good maintainability and cost effectiveness make it optimal for use as the multi-mission cargo helicopter of the future.

MIL-STD-1374 PART I - TAB

NAME UMD MODEL WYVER

DATE MAY 6 2005 REPORT

GROUP WEIGHT STATEMENT

AIRCRAFT

(INCLUDING ROTORCRAFT)

ESTIMATED - CALCULATED – ACTUAL

(CROSS OUT THOSE NOT APPLICABLE)

CONTRACT NO.	N/A
AIRCRAFT, GOVERNMENT NO.	N/A
AIRCRAFT, CONTRACTOR NO.	N/A
MANUFACTURED BY	N/A

	MAIN	AUX
ENGINE QUANTITY	4	
ENGINE MANUFACTURED BY	ROLLS-ROYCE / ALLISON	
ENGINE MODEL	AE1107C	
ENGINE TYPE	TURBOSHAFT	
PROPELLER QUANTITY	N/A	
PROPELLER MANUFACTURED BY	N/A	
PROPELLER MODEL	N/A	

PAGES REMOVED	NONE

MIL-STD-1374 PART I - TAB 2 **GROUP WEIGHT STATEMENT (KG)** PAGE

NAME UMD WYVER **WEIGHT EMPTY** MODEL

DATE MAY 6 2005 REPORT

1	WING GROUP			WINGLETS	GLOVE/LEX	WING	
2	TOTAL						
3	BASIC STRUCTURE						
4	INTERMEDIATE PANEL						
5	OUTER PANEL						
6	SECONDARY STRUCTURE						
7	AILERONS/ELEVONS						
8	SPOILERS						
9	FLAPS - TRAILING EDGE						
10	- LEADING EDGE						
11	SLATS						
12							
13							
14							
15	ROTOR GROUP						3943.04
16	BLADE ASSEMBLY					2205.34	
17	HUB & HINGE					1737.7	
18							
19	EMPENNAGE GROUP	CANARD	HORIZ. STAB.	VERTICAL FIN	VENTRAL FIN	TAIL ROTOR	
20	TOTAL						94.88
21	BASICS STRUCTURE						
22	SECONDARY STRUCTURE						
23	CONTROL SURFACES						
24	(INCL. BALANCE WEIGHTS)						
25	BLADES						
26	HUB & HINGE						
27	ROTOR/FAN DUCT & ROTOR SUPTS						
28							
29							
30	FUSELAGE GROUP				FUS. / HULL	BOOMS	
31	TOTAL						5821.68
32	BASIC STRUCTURE						
33	SECONDARY STRUCTURE						
34	ENCLOSURES, FLOORIN, ETC.						
35	DOORS, RAMPS, PANELS & MISC.						
36							
37							
38	ALIGHTING GEAR GROUP* QUADRICYCLE	FRONT	BACK		ARR. GEAR	CAT. GEAR	
39	TOTAL	592.925	592.925				1185.85
40	RUNNING GEAR / FLOATS / SKIS						
41	STRUCTURE						
42	CONTROLS						
43							
44							
45	ENGINE SECTION OR NACELLE GROUP	AUXILIARY ENGINES			MAIN ENGINES		
46	LOCATION **						
47	TOTAL - EACH LOCATION						
48							
49							
50							
51	AIR INDUCTION GROUP						
52	LOCATION **						
53	TOTAL - EACH LOCATION						
54	INLETS						
55	DUCTS, ETC.						
56							
57	TOTAL STRUCTURE						

* LANDING GEAR "TYPE": INSERT "TRICYCLE", "TAIL WHEEL", "BICYCLE", "QUADRICYCLE", OR SIMILAR DESCRIPTIVE NOMENCLATURE.
** WING, FUSELAGE, ETC.

MIL-STD-1374 PART I - TAB 3 **GROUP WEIGHT STATEMENT (KG)** PAGE

NAME UMD <u>WYVER</u> **WEIGHT EMPTY** MODEL

DATE MAY 6 2005 REPORT

58	PROPULSION GROUP		AUXILIARY		MAIN		5506.35
59	ENGINE					1762.83	
60	ENGINE INSTALLATION					264.43	
61	ACCESSORY GEAR BOXES & DRIVE					2932.58	
62	EXHAUST SYSTEM						
63	ENGINE COOLING						
64	WATER INJECTION						
65	ENGINE CONTROLS					150	
66	STARTING SYSTEM						
67	PROPELLER / FAN INSTALLATION					174.15	
68	LUBRICATIONG SYSTEM						
69	FUEL SYSTEM					222.36	
70	TANKS - PROTECTED						
71	- UNPROTECTED						
72	PLUMBING, ETC.						
73							
74	DRIVE SYSTEM						
75	GEAR BOXES, LUB SYS & RTR BRK						
76	TRANSMISSION DRIVE						
77	ROTOR SHAFTS						
78	GAS DRIVE						
79							
80	FLIGHT CONTROLS GROUP						
81	COCKPIT CONTROLS						
82	AUTOMATIC FLIGHT CONTROL SYSTEM						
83	SYSTEM CONTROLS						
84	AUXILIARY POWER GROUP					149.75	
85	INSTRUMENTS GROUP						
86	HYDRAULIC GROUP						
87	PNEUMATIC GROUP						
88	ELECTRICAL GROUP					93.43	
89	AVIONICS GROUP					544.31	
90	EQUIPMENT						
91	INSTALLATION						
92	ARMAMENT GROUP						
93	FURNISHINGS & EQUIPMENT GROUP						
94	ACCOMODATION FOR PERSONNEL						
95	MISCELLANEOUS EQUIPMENT				1000		
96	FURNISHINGS				2240		
97	EMERGENCY EQUIPMENT						
98	AIR CONDITIONING GROUP						
99	ANTI-ICING GROUP						
100	PHOTOGRAPHIC GROUP						
101	LOAD & HANDLING GROUP						
102	AIRCRAFT HANDLING						
103	LOAD HANDLING						
104							
105	TOTAL SYSTEM AND EQUIP. (LINES 80-104)						787.49
106	BALLAST GROUP						
107	MANUFACTURING VARIATION						
108	CONTINGENCY						
109							
110	TOTAL CONTRACTOR CONTROLLED						
111	TOTAL GOVERNMENT FURNISHED EQUIP.						
112	TOTAL CONTRACTOR - RESPONSIBLE						
113	TOTAL GOVERNMENT - RESPONSIBLE						
114	TOTAL WEIGHT EMPTY PG. 2-3						17339.29

MIL-STD-1374 PART I - TAB 2 **GROUP WEIGHT STATEMENT (KG)** PAGE

NAME UMD WYVER **WEIGHT EMPTY** MODEL

DATE MAY 6 2005 REPORT

115	LOAD CONDITION						PRIMARY
116							
117	WEIGHT EMPTY						17339.29
118	CREW (QTY 2)				90.72	90.72	181.44
119	UNUSABLE FUEL						
120	OIL						
121	TRAPPED						
122	ENGINE						
123	TRANSMISSION						
124	AUX. FUEL TANKS QTY						
125	INTERNAL						
126	EXTERNAL						
127							
128	WATER INJECTION FLUID						
129	BAGGAGE						
130	GUN INSTALLATIONS						
131	GUNS LOC FIX.OR FLEX. QTY CAL						
132							
133							
134	SUPPORTS*						
135	WEAPONS PROVISIONS**						
136							
137							
138							
139							
140	CHAFF (QTY____)						
141	FLARES (QTY____)						
142							
143							
144	SURVIVAL KITS						
145	LIFE RAFTS						
146	OXYGEN						
147							
148							
149							
150	OPERATING WEIGHT						
151	PASSENGERS				99.79	99.79	199.58
152							
153	CARGO					20000	
154							
155	AMMUNITION QTY. CAL.						
156							
157							
158	WEAPONS**						
159							
160							
161							
162							
163							
164	ZERO FUEL WEIGHT						
165	USABLE FUEL TYPE LOC GALS						5558.97
166	INTERNAL						
167							
168	EXTERNAL						
169							
170	TOTAL USEFUL LOAD						23279.28
171	GROSS WEIGHT						40618.57

* IF REMOVABLE AND SPECIFIED AS USEFUL LOAD.
** LIST STORES, MISSILES, SONOBUOYS, ETC. AND PYLONS, RACKS, LAUNCHERS, CHUTES, ETC. THAT ARE NOT PART OF WEIGHT EMPTY. LIST NOMENCLATURE, LOCATION, AND QUANTITY FOR ALL ITEMS SHOWN INCLUDING INSTALLATION.

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Appendix A

Design Code – adopted from Tishchenko et al., Journal of the American Helicopter Society, Vol. 48, No. 2, April 2003. Pages 71-79.

Sequence of main performance and geometrical dimension calculations

$$W_{TO,initial} = \frac{W_{PL} + W_{FURN}}{k_{WE} - \left[\dfrac{\left(L + T_{RES}V_{CR}\right)Ce_{CR}}{270K\eta_{PR}\xi_{CR}}\right] - 0.005}$$

$$W_{TO,calculated} = \begin{cases} W_{TO,initial}\left(IF\ \text{TOW}_{\text{new}} = 0\right) \\ \text{TOW}_{\text{new}}\left(IF\ \text{TOW}_{\text{new}} \neq 0\right) \end{cases}$$

$$D_{MR} = \sqrt{\frac{4\left(W_{TO,calculated}/2\right)}{\pi P}}$$

$$\sigma_{MR} = \frac{\left(W_{TO,calculated}/2\right)}{\left(C_T/\sigma\right)_{MR0}\rho_0\pi\left(D_{MR}/2\right)^2\left(\omega R\right)_{MR}^2}$$

$$b_{07MR} = \frac{D_{MR}}{2\lambda_{MRBL}}$$

$$P_{ENG}Z_{ENG,pre} = \frac{\left[\left(W_{TO,calculated}/2\right)t_{MR}\right]^{3/2}}{33.25FM_{MR}\xi_{\text{MR}}\sqrt{\left(\rho_{HOGE}/\rho_0\right)}D_{MR}}$$

$$M_{MRT} = \frac{716.2\left(P_{ENG}Z_{ENG}/2\right)\pi\left(D_{MR}/2\right)\xi_{MR}}{30\left(\omega R\right)_{MR}}$$

$$D_{TR} = \frac{D_{MR}}{n_{MTR}}$$

$$T_{TR} = \frac{2M_{MRT}}{\left(D_{MR} + D_{TR} + 0.3\right)}$$

$$P_{TR} = \frac{\left(T_{TR}t_{TR}\right)^{3/2}}{33.25FM_{TR}\xi_{TR}\sqrt{\left(\rho_{HOGE}/\rho_0\right)}D_{TR}}$$

$$\xi_{HOV} = \frac{P_{ENG}z_{ENG,pre} - P_{TR} - P_{DC}}{P_{ENG}Z_{ENG,pre}}$$

$$P_{ENG}Z_{ENG,adj} = \frac{\left[\left(W_{TO,calculated}/2\right)t_{MR}\right]^{3/2}}{33.25FM_{MR}\xi_{HOV}\sqrt{\left(\rho_{HOGE}/\rho_0\right)}D_{MR}}$$

$$P_{ENG.NOM} = P_{ENG}Z_{ENG,adj}C_{POW}$$

$$P_{CR} = \frac{W_{TO,calculated} V_{CR}}{270 K \xi_{CR} \eta_{PR}}$$

$$Ce_{KR} = \frac{Ce_1 P_{ENG.NOM}}{P_{CR}} + Ce_2$$

$$W_{TO,calculated1} = \frac{W_{PL} + W_{FURN}}{k_{WE} - \left[\frac{\left(L + T_{RES} V_{CR}\right) Ce_{CR}}{270 K \eta_{PR} \xi_{CR}} \right] - 0.005}$$

$$q_{CR} = \frac{W_{TO,calculated1} Ce_{KR}}{270 K \xi_{CR} \eta_{PR}}$$

$$W_{FUEL} = W_{TO,calculated} \left\{ \left[\frac{\left(L + T_{RES} V_{CR}\right) Ce_{KR}}{270 K \eta_{PR} \xi_{CR}} \right] - 0.005 \right\}$$

$$M_{TTR} = \frac{716.2 P_{TR} \pi \left(D_{TR} / 2\right) \xi_{TR}}{30 \left(\omega R\right)_{TR}}$$

$$M_{TSH} = \frac{716.2 P_{TR} f_{SH}}{\eta_{SH}}$$

$$\sigma_{TR} = \frac{T_{TR}}{\left(C_T / \sigma\right)_{TR0} \rho_0 \pi \left(D_{TR} / 2\right)^2 \left(\omega R\right)_{TR}^2}$$

$$\lambda_{TRBL} = \frac{Z_{TRBL}}{\pi \sigma_{TR}}$$

$$b_{07TR} = \frac{D_{TR}}{2 \lambda_{TRBL}}$$

Sequence of weight calculations

$$FC_{MRBL} = \frac{W_{MRBL}}{Z_{MRBL} g} \left[\frac{2 \left(\omega R\right)_{MR}}{D_{MR}} \right]^2 \frac{D_{MR}}{2 \cdot 1000} Rr_{MRBLCG}$$

$$f_{ZMRBL} = \begin{cases} 1 & \left(IF \quad Z_{MRBL} \le 4\right) \\ 1 + \left(Z_{MRBL} - 4\right) 0.05 & \left(IF \quad Z_{MRBL} > 4\right) \end{cases}$$

$$FC_{TRBL} = \frac{W_{TRBL}}{Z_{TRBL} g} \left[\frac{2 \left(\omega R\right)_{TR}}{D_{TR}} \right]^2 \frac{D_{TR}}{2 \cdot 1000} Rr_{TRBLCG}$$

$$f_{ZMRBL} = \begin{cases} 1 & \left(IF \quad Z_{TRBL} \le 4\right) \\ 1 + \left(Z_{TRBL} - 4\right) 0.05 & \left(IF \quad Z_{TRBL} > 4\right) \end{cases}$$

$$W_{MRBL} = \frac{1.5 k_{MRBL}^{*} \sigma_{MR} \left(D_{MR} / 2\right)^{2.7}}{\left(\lambda_{MRBL} / 18\right)^{0.7}}$$

$$W_{MRH} = k_{MRHUB} f_{ZMRBL} {FC_{MRBL}}^{1.35} Z_{MRBL}$$

$$W_{SP} = k_{1SP}\left(\frac{D_{MR}}{2}\right)b_{07MR}{}^{2}\left(\frac{V_{CR}}{3.6(\omega R)_{MR}}\right) + k_{2SP}$$

$$W_{BCS} = k_{1BCS}\left(\frac{D_{MR}}{2}\right)b_{07MR}{}^{2}\left(\frac{V_{CR}}{3.6(\omega R)_{MR}}\right) + k_{2BCS}$$

$$W_{TRBL} = \frac{k^{*}_{TRBL}\sigma_{TR}\left(D_{TR}/2\right)^{2.7}}{\left(\lambda_{TRBL}/18\right)^{0.7}}$$

$$W_{TRH} = k_{TRHUB} f_{ZTRBL} FC_{TRBL}{}^{1.35} Z_{TRBL}$$

$$W_{MGB} = 2k_{MGB} M_{MRT}{}^{0.8}$$

$$W_{TRGB} = k_{TGB} M_{TTR}{}^{0.8}$$

$$W_{IGB} = k_{IGB} M_{TSH}{}^{0.8}$$

$$W_{SH} = k_{SH} M_{SH}{}^{0.8}\left[0.5\left(D_{MR} + \frac{D_{TR}}{0.7} + 0.3\right)\right]$$

$$W_{ENG} = k_{1ENG} P_{ENG.NOM} + k_{2ENG}$$

$$W_{PIS} = k_{PIS} W_{ENG}$$

$$W_{APU} = k_{1APU} P_{ENG.NOM} + k_{2APU}$$

$$W_{FS} = k_{FS} W_{FUEL}$$

$$W_{LG} = k_{LG} W_{TO,calculated}$$

$$W_{FUS} = k_{1FUS} W_{TO,calculated} + k_{2FUS} W_{PL} + k_{3FUS} W_{TO,calculated}\left(\frac{D_{MR}}{20} - 1\right)$$

$$W_{SLE} = k_{SLE} W_{PL}$$

$$\begin{aligned} W_{EMPT} = {} & W_{MRBL} + W_{MRH} + W_{SP} + W_{BCS} + W_{PBC} + W_{TRBL} + W_{TRH} + W_{MGB} + W_{TRGB} + W_{IGB} + W_{SH} + W_{ENG} \\ & + W_{PIS} + W_{APU} + W_{FS} + W_{EMPEN} + W_{ELSYS} + W_{AVSYS} + W_{SLE} + W_{M} + W_{M} + W_{M} + W_{M} + W_{M} + W_{M} + W_{M} \end{aligned}$$

$$reserve\ (5\%) = 1.05 W_{EMPT}$$

$$TOW_{NEW} = reserve\ (5\%) + W_{FUEL} + W_{PL} + W_{FURN}$$

$$k_{WE} = \frac{TOW_{NEW} - reserve(5\%)}{TOW_{NEW}}$$

Design Code with full weights, sizing and performance calculations

Preliminary and initial data

Ce_1	0.08	n_{MTR}	5.50	η_{PR}	0.98
Ce_2	0.09	n_{SH}	4000.00	ρ_0	0.125
$(CT/\sigma)_{MR0}$	0.075	p	35 - 55	ρ_{HOGE}	0.097
$(CT/\sigma)_{TR0}$	0.08	P_{DC}	0.00	$(\omega R)_{MR}$	220
C_{POW}	1.15	T_{RES}	0.33	$(\omega R)_{TR}$	220
F_{MMR}	0.72	t_{MR}	1.02	ξ_{CR} (1rotor)	0.88
F_{MTR}	0.67	t_{TR}	1.06	ξ_{CR} (2rotors)	0.94
f_{SH}	1.80	V_{CR}	300.00	ξ_{MR} (1rotor)	0.82
K	3.50	z_{MRBL}	3.00	ξ_{MR} (2rotors)	0.94

L	460.00	z_{TRBL}	6.00	ξ_{TR}	0.975
		z_{ENG}	4		

Main parameters

W_{PL}	20000
W_{FURN}	2240

Main performance and geometrical dimensions calculation

p	10	20	30	40	50	60
$W_{TO\ initial}$	48728.3	48728.3	48728.3	48728.3	48728.3	48728.3
$W_{TO\ calculated}$	41242.3	41848.4	43054.4	44422.5	45885.9	47433.9
D_{MR}	51.24	36.50	30.23	26.59	24.17	22.43
σ_{MR}	0.0220	0.0441	0.0661	0.0882	0.1102	0.1322
z_{MRBL}	4	4	4	4	4	4
λ_{MRBL}	57.77	28.89	19.26	14.44	11.55	9.63
b_{07MR}	0.4435	0.6317	0.7848	0.9205	1.0459	1.1649
$P_{ENG}\ z_{ENG\ preliminary}$	6885.25	9880.31	12449.58	14832.36	17129.36	19397.32
M_{MRT}	24656.19	25201.67	26298.89	27562.37	28935.47	30412.03
D_{TR}	9.32	6.64	5.50	4.83	4.39	4.08
T_{TR}	810.30	1160.47	1460.15	1737.63	2004.83	2268.45
P_{TR}	141.21	339.79	579.07	854.57	1165.05	1510.79
ξ_{HOV}	1.000	1.000	1.000	1.000	1.000	1.000
$P_{ENG}\ z_{ENG\ adjusted}$	5645.9	8101.9	10208.7	12162.5	14046.1	15905.8
$P_{ENG.NOM}$	6492.8	9317.1	11740.0	13986.9	16153.0	18291.7
P_{CR}	15181.8	15404.9	15848.9	16352.5	16891.2	17461.0
$P_{CR} / P_{ENG.NOM}$	2.3383	1.6534	1.3500	1.1691	1.0457	0.9546
Ce_{KR}	0.1171	0.1304	0.1406	0.1492	0.1567	0.1636
$W_{TO\ calculated}$ 1	50011.7	51058.0	51891.0	52614.7	53269.3	53875.2
q_{CR}	7.184	8.167	8.950	9.629	10.244	10.813
W_{FUEL}	3518.13	3951.19	4366.13	4766.75	5162.09	5558.97
M_{TTR}	218.65	374.74	528.89	686.61	850.92	1024.16
M_{TSH}	45.51	109.51	186.63	275.42	375.48	486.91
σ_{TR}	0.0246	0.0693	0.1272	0.1956	0.2731	0.3587
z_{TRBL}	6	6	6	6	6	6
λ_{TRBL}	77.765	27.549	15.017	9.765	6.994	5.325
b_{07TR}	0.060	0.120	0.183	0.248	0.314	0.383

Main weight coefficients and part weights

k^*_{MRBL}	**10.5**	*main rotor blade weight coefficient, kg / m$^{2.7}$*
k^*_{TRBL}	**14**	*tail rotor blade weight coefficient, kg / m$^{2.7}$*
k_{1APU}	**0.006**	*first APU weight coefficient, kg/hp*
k_{2APU}	**40**	*second APU weight coefficient, kg*
k_{1BCS}	**25**	*first booster system weight coefficient, kg*
k_{2BCS}	**30**	*second booster system weight coefficient, kg.*
k_{1ENG}	**0.092**	*first engine weight coefficient, kg/hp*
k_{2ENG}	**80**	*second engine weight coefficient, kg*
k_{1FUS}	**0.095**	*first fuselage weight coefficient*
k_{2FUS}	**0.06**	*second fuselage weight coefficient*
k_{3FUS}	**0.02**	*third fuselage weight coefficient, kg / m*
k_{1SP}	**46**	*first swash plate weight coefficient, kg / m3*
k_{2SP}	**54**	*second swash plate weight coefficient, kg*
k_{ELSYS}	**1.9**	*electrical system weight coefficient, kg / kW*
k_{EMP}	**12**	*empennage weight coefficient, kg/m^2*
k_{FS}	**0.04**	*fuel system weight coefficient*
k_{IGB}	**0.6**	*intermediate gearbox weight coefficient, kg / kg m*
k_{LG}	**0.025**	*landing gear weight coefficient*
k_{MGB}	**0.38**	*main gearbox weight coefficient, kg / kg m*
k_{MRHUB}	**0.95**	*main rotor hub weight coefficient, kg / mt1.35*
k_{PIS}	**0.15**	*power plant installation weight coefficient*
k_{SH}	**0.05**	*transmission shaft weight coefficient, kg / kg m^2*

k_{SLE}	**0.05**	*special load equipment weight coefficient*
k_{TGB}	**0.5**	*tail gearbox weight coefficient, kg / kg m*
k_{TRHUB}	**0.5**	*tail rotor hub weight coefficient, kg / mt1.35*
W_{AVSYS}	**55**	*avionics system weight, kg*
W_{PBC}	**150**	*pre-booster electronic system weight coefficient.*

p	10	20	30	40	50	60	
W_{MRBL} , kg	975.25	1267.74	1518.16	1751.41	1978.38	2205.34	*Main rotor blade weight*
W_{MRH}, kg	140.14	315.68	519.37	748.92	1004.13	1285.84	*Main rotor hub weight*
W_{SP}, kg	185.69	244.35	297.28	348.41	399.56	451.86	*Swash plate weight*
W_{BCS}, kg	77.71	98.97	118.15	136.67	155.20	174.15	*Booster system weight*
W_{PBC}	150	150	150	150	150	150	*Pre-booster electronic system weight*
W_{TRBL} , kg	0.00	0.00	0.00	0.00	0.00	0.00	*Tail rotor blade weight*
W_{TRH}, kg	0.00	0.00	0.00	0.00	0.00	0.00	*tail rotor hub weight*
W_{MGB} ,kg	2479.44	2523.23	2610.74	2710.61	2818.11	2932.58	*Main gearbox weight*
W_{TRGB} ,kg	0.00	0.00	0.00	0.00	0.00	0.00	*Tail gearbox weight*
W_{IGB}	0.00	0.00	0.00	0.00	0.00	0.00	*Intermediate gearbox weight*
W_{SH}	0.00	0.00	0.00	0.00	0.00	0.00	*Intermediate shaft weight*
W_{ENG}	677.34	937.18	1160.08	1366.80	1566.08	1762.83	*Engine weight*
W_{PIS}	101.60	140.58	174.01	205.02	234.91	264.43	*Power plant installation weight*
W_{APU}	78.96	95.90	110.44	123.92	136.92	149.75	*APU weight*
W_{FS}	140.73	158.05	174.65	190.67	206.48	222.36	*Fuel system weight*
W_{LG}	1031.06	1046.21	1076.36	1110.56	1147.15	1185.85	*Landing gear weight*
W_{FUS}	6406.44	5865.99	5730.46	5712.87	5750.55	5821.68	*Fuselage weight*
W_{EMPEN}	494.97	251.12	172.24	133.28	110.14	94.88	*Empennage weight*
W_{ELSYS}	82.22	83.80	86.02	88.40	90.86	93.43	*Electrical system weight*
W_{AVSYS}	55.00	55.00	55.00	55.00	55.00	55.00	*Avionics system weight*
W_{SLE}	1000.00	1000.00	1000.00	1000.00	1000.00	1000.00	*Special load equipment weight*
W_{EMPT}	14076.53	14233.80	14952.95	15832.54	16803.47	17849.98	*Empty weight*
Reserv 5%	15484.18	15657.18	16448.25	17415.79	18483.82	19634.98	*Empty weight 5% reserve*
TOW new	41242.31	41848.37	43054.37	44422.54	45885.91	47433.95	*Total weight*
k_{WE}	0.6246	0.6259	0.6180	0.6080	0.5972	0.5861	*weight efficiency*

Appendix B

Cost Estimate Calculation:

Formulae are taken from handout provided by Bell Helicopters as part of the 1999 AHS/Industry/NASA Student Design Competition.

```
% Rotor System Group
weight=4100;                % in kg
kyokmat=2.3;                % Titanium yoke
bldno=8;                    % Total # of blades
kbldmat=1.6;                        % Compsite blade
kappl=1.1;                  % Tandem
prodq=200;                  % Total production quantity
prodr=14;                   % Production rate per year
Avg_rotor_sys = 2*1500*weight^.7*kyokmat*bldno^.2*kbldmat*kappl*(prodq*prodr)^(-.8);

% Body Group
weight=6000;                % in kg
kmat=2;                     % Composite and metallic
Avg_fues = 10000*weight^.8*kmat*(prodq*prodr)^(-.13);

% Landing Gear Group
weight=1000;                % in kg
klgtyp=2;                           % Retractable Landing Gear
Avg_land_gear = 5000*weight*.5*klgtyp*(prodq*prodr)^(-.08);

% Nacelle Group
weight=1/5*1763;            % in kg
noeng=6;                            %Number of engines
Avg_nacl = 5000*weight^.8*kappl*noeng^.1*(prodq*prodr)^(-.12);

% Air induction group
weight=1/10*1763;           % in kg
Avg_air_in = 5000*weight^.8*kappl*noeng^.5*(prodq*prodr)^(-.09);

% Propulsion Group
weight=1763;                % in kg
engine_cost=8000000;                % in USD
Avg_eng_instl = 2000*weight^.7*noeng^.8*(prodq*prodr)^(-.06) + engine_cost;
Avg_drive_sys = 2500*weight^.9*noeng^.4*(prodq*prodr)^(-.07);

% Flight Contorl Group
weight=414;                 % in kg
kcontyp = 1;                % Flight control type factor
Avg_flt_cntrl_sys = 300*weight*bldno^.5*kcontyp*kappl*(prodq*prodr)^(-.06);
```

```
% Instrument Group
weight = 100;                          % in kg
ktype=4;                                      % instrument type factor
Avg_inst_sys = 1500*weight*ktype*(prodq*prodr)^(-.06);

% Hydraulics Group
weight = 300;                                 % in kg
Avg_hydr_sys = 1000*weight*(prodq*prodr)^(-.07);

% Electrical Group
weight=93;                             % in kg
Avg_elect_sys = 2000*weight^.9*kappl*(prodq*prodr)^(-.1);

% Avionics Group
weight=544;                            % in kg
Avg_Avio_sys = 2500*weight*(prodq*prodr)^(-.08);

% Furninshings and Equipment Group
weight=2240;                          % in kg
Avg_Furn_sys = 500*weight^1.1*(prodq*prodr)^(-.08);

% Final Assembly
weight = 27000;                               % Empty weight
kfusmat = 1;
Avg_final_ass = 30000*weight^.4*noeng^.9*kfusmat*(prodq*prodr)^(.15);



% Total Cost                           % Sum of all costs
total=Avg_final_ass+Avg_Furn_sys+Avg_Avio_sys+Avg_elect_sys+Avg_hydr_sys+Avg_inst_
sys+Avg_flt_cntrl_sys+Avg_drive_sys+Avg_eng_instl+Avg_air_in+Avg_nacl+Avg_land_gear+
Avg_fues+Avg_rotor_sys
```

Compliance to RFP Requirements Matrix

Vertical Take off and Landing	Yes
Payload : 20 Ton FCS	Yes
2 463L Pallets	Yes
Internally carry FCS (102" h x 107" w x 240" l)	Yes
Shipboard Compatibility : fits on CVN elevator (85' x 52')	Yes
fits on L-class elevator (50' x 44')	Yes
Elevator height clearance: CVN (25' max. folded height)	Yes
L-class (19' max. folded height)	Yes
Elevator weight limit: CVN (130,000 lbs.)	Yes
L-class (75,000 lbs.)	Yes
Range : Mission (100 nm inland)	Yes
Intra-theatre (1000 nm)	Yes
Autorotation	Yes
Powered rotor blade folding	Yes
Structural integrity (-0.5g - +2.5g)	Yes
Turn rate capability (2x standard rate turn)	Yes
HOGE with OEI, full payload, and 60% fuel	Yes
FCS Crew Accommodations	Yes
Missile Warning Systems and countermeasures	Yes
Mission equipment suite	Yes
Crashworthiness	Yes
Basic Maintenance	Yes
Dual Piloted	Yes