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Abstract

Performance requirements usually drive the initial configuration selection for most aircraft. Vehicle design synthesis for aerospace systems is usually based on achieving a fuel balance between the fuel weight required to accomplish the mission(s) and the fuel weight available derived principally from the technology assumed in the empty weight expression. Power loading in the form of thrust to weight, T/W, or horsepower to weight, is determined from equating the thrust or horsepower available to the thrust or horsepower required. With the gross weight determined from the fuel balance, the installed thrust or power can be determined from the power loading to obtain a configuration solution. For rotorcraft and other Vertical Takeoff and Landing (VTOL) aircraft vehicle design synthesis can be achieved by following the flow diagram in Figure 1. As illustrated, requirements are broken out into Performance and Mission inputs and address hover, forward flight, maneuvering and agility considerations. For conventional helicopters of the past the hover requirements, in terms of altitude, temperature, and Vertical Rate of Climb (VROC), were often the driving considerations for vehicle design synthesis and configuration selection with the forward flight speed requirements often being a fall-out or off-design consideration. However, in recent years as rotorcraft have demonstrated their ability to perform a variety of military and commercial missions vehicle design synthesis and rotorcraft configuration selection must be based on the driving performance requirements. This paper will address the impact of performance requirements on rotorcraft configuration selection using the requirements identified in the 10th Annual American Helicopter Society (AHS) Student Design Competition.

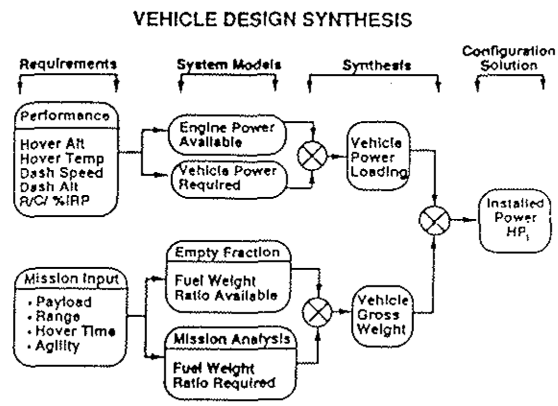

Fig. 1 Vehicle Design Synthesis

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Symbols and abbreviations

η	Velocity ratio
σ	Solidity
ρ	Atmospheric density
b	Number of blades
c	Chord
C_T	Rotor thrust coefficient
L_W	Wing lift
M_{Tip}	Rotor tip Mach number
R	Rotor Radius
V_T	Rotor tip speed
W	Vehicle weight
ABC	Advancing Blade Concept
AHS	American Helicopter Society
IRP	Intermediate Rated Power
GTPDP	Georgia Tech Preliminary Design and Performance code
HESCOMP	Helicopter sizing and performance computer program
HSHMR	High Speed and Highly Maneuverable Rotorcraft
LZ	Landing Zones
MMH/FH	Maintenance Man Hour per Flight Hour
MTBF	Mean Time Between Failure
MTTR	Mean Time To Repair
NOE	Nap-of-the-Earth
QFD	Quality Function Deployment
RPM	Revolution Per Minute
RFP	Request For Proposal
SMR	Single Main Rotor
T/W	Thrust to Weight
VECTR	VTOL Effectiveness in Combat/Tactical Regimes
VTOL	Vertical Take Off and Landing
VROC	Vertical Rate of Climb

1. Introduction

Recent regional conflicts around the world, such as in the Middle East and the Balkan states, demonstrated that the United States has to keep itself ready to intervene in world affairs to protect its security, economics, political, and humanitarian interests. As a result, the United States must have rapid intervention armed forces and equipment to achieve its goals and self-interests. Obviously, a need for high speed rotorcraft becomes a priority for Army weapon system acquisition in the near future.

In 1992, the American Helicopter Society (AHS) issued a student design competition Request for Proposal (RFP) for a preliminary design of a High Speed, Highly Maneuverable Rotorcraft (HSHMR) to satisfy the armed forces future needs. The HSHMR outlined in the RFP has to be affordable, rugged, reliable, and easily operated and maintained under austere conditions worldwide, including dusty, tropic, arctic, and marine environments.

A listing of the requirements in the AHS Request for Proposal for a high speed, highly maneuverable rotorcraft is provided in the RFP requirement matrix, Figure 2. As can be seen, stringent performance requirements at 4000 ft., 95 deg F are included, such as a forward speed of 200 knots at Intermediate Rated Power (IRP), Vertical Rate of Climb (VROC) of 800 feet per minute (fpm) at IRP, and a transient maneuver load factor of 4 g's at 160 knots.

In this conceptual design study, the sizing of five feasible candidate configurations was performed by using a "sensitivity" trade-off study. From this conceptual study, a particular design configuration was obtained and chosen. The chosen configuration was designed to meet the full mission requirements of the RFP through the use of the R_F (fuel ratio balance) graphical method which is used to size and select the optimum design parameters (Reference 1). The sizing procedure followed and the rationale behind the selection of the final configuration is the intent of this paper. Finally, the general layout and the performance of the chosen candidate are also presented .

Design Parameter	Requirements
General Requirements	
Army Attack Rotorcraft	
High Speed	
Highly Maneuverable	
Performance Requirements (4000 feet, 95 deg. F)	
Range	430 km
Reserve	30 min
Speed	200 knots at IRP
Vertical Rate of Climb	800 fpm at IRP
Payload	Primary 1274 lbs
Sustained Maneuver Load Factor	2.0 g at Vmin Pwr
Transient Maneuver Load Factor	4.0 g at 160 knots
Ferry Range	1260 nm
Ferry Reserve	100 nm
Design Requirement (400 feet, 95 deg. F)	
Engine Operates on Current Fuel	JP-4, JP-5, JP-8
Multiple Engines	at least 2
Onboard APU	
Disc Loading	<15.0 lbs/ft^2
Main Rotor Normal Operating Tip Speed	never exceed 752 fps
Antitorque Normal Operating Tip Speed	never exceed 650 fps
Autorotation t/K index	0.8 sec or greater
Minimum Structural Design Envelope	RFP
Crew	2
Cannon	30 mm
Handling Qualities	MIL-H-8501A
Minimize Aircraft Vibration Levels	fan plot
Rotor Start Up/Shut Down	in winds to 60knots
Transportability	C-141B
Crashworthiness	42 fps vertical
Maintainability	7.5 MMH/FH or less
Cost	low

Fig. 2 10th Annual American Helicopter Society Student Design Competition Request For Proposal Matrix

2. Rationale for Configuration Selected

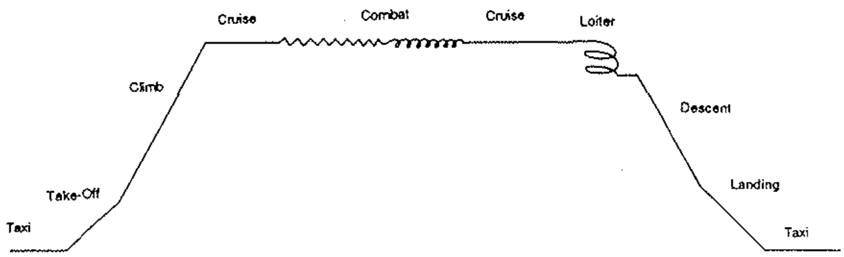
To offer the best choice of a configuration, a wide range of rotorcraft had to be modeled, analyzed, and compared. These concepts included tiltrotors, which offer good range and speed characteristics, to single main rotor (SMR) helicopters, which offer better hover performance. Also, previously studied rotorcraft were examined as feasible candidates. The preliminary trade-off study was based on an extension of the R_F method, a graphical fuel-balance optimization approach, to VTOL aircraft. This method provides an easily understood approach to configuration synthesis.

For configuration trade-off studies, the R_F method requires a priori knowledge of the empty-to-gross weight ratio, figure of merit, disk loading, hover efficiency, rotor download, propulsive efficiency, and lift to drag ratio for forward flight. Baseline values for this data were found in the VECTR (Reference 2) database. An initial premise that the hover specification dictates the amount of power required is assumed.

The initial Trade-off study between configurations included: SMR, SMR compound, coaxial, coaxial compound, and tiltrotor. The Army's Helicopter Preliminary Design Handbook (Reference 6) defines a compound helicopter as one that has auxiliary propulsion for forward flight. The study was based on the stringent requirements and constraints given in the Request for Proposal (RFP, Reference 3). These included: 200 knots dash speed, 800 fpm vertical rate of climb, moderate payload, 232 nautical mile range, and a disk loading constraint of 15 lbs/ft^2, all at an altitude of 4000 feet and a temperature of 95° F. A mission profile was assumed for a sensitivity study of the potential configurations (Figure 3). Graphs of each configuration for range versus payload (Figure 4) and range versus hover time (Figure 5, Figure 6) were produced to provide a comparison of hover and forward performance capabilities. Also, graphs of installed power, rotor diameter, power loading, and gross weight plus fuel weight for each configuration were produced (Figure 7). The tiltrotor was eliminated because it had the lowest hovering capability, highest gross weight, and highest installed power. In addition, it would be more difficult to locate the RFP required radome on a tiltrotor configuration. Furthermore, the SMR could not reach the required velocity for the given payload and disk loading constraint, and therefore was also eliminated. The other three feasible configurations were kept for further study using more sophisticated techniques.

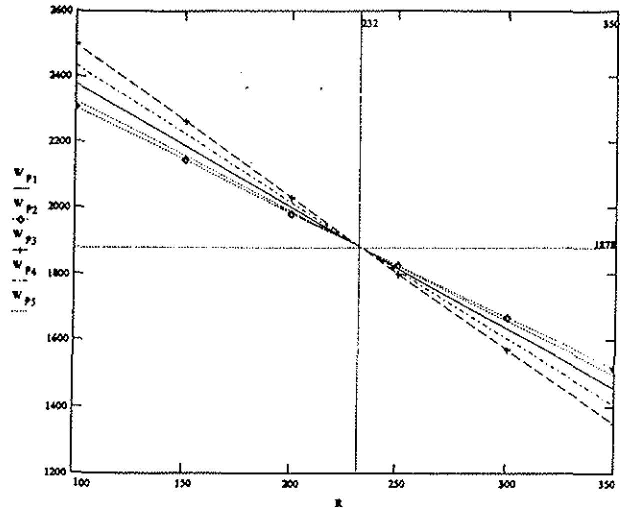
Continuing with, the SMR compound, the coaxial, and the coaxial compound, it was decided to conduct a more in-depth parameter study of the configurations with minor changes. An in-house developed code GTPDP, Georgia Tech Preliminary Design and Performance program (GTPDP, Reference 4) and the program "Helicopter Sizing & Performance Computer Program" (HESCOMP, Reference 8) were used in this analysis. For the SMR compound concept, it was decided to analyze two variants, one with an open propeller and one with a shrouded propeller. These were added to provide auxiliary propulsion, needed for high speed, in order to reduce the weight of the main rotor system. The same variations were true for the coaxial compound as well. While using the computer program, it was noted that the driving requirements in computing installed power required was the 800 fpm vertical rate of climb (VROC) and the 200 knots dash speed, both at IRP and 4000 ft and 95^{o} F. The most important factor for rotor/wing design was driven by the 4 g transient maneuver load factor requirement at 160 kts.

Using the RFP and Designing Defense Systems (Reference 5), vehicle requirements were compared to the five configurations studied in HESCOMP and the two configurations that were eliminated by the R_F method. The early eliminated rotorcraft were analyzed to prove that they should not be considered as candidates. An objective decision of the best rotorcraft was made by using a Quality Function Deployment (QFD) matrix. This allowed



Time	3 min.	2.5 min.	4 min.		10 min.	10 min.		30 min.	4 min.	2.5 min.	3 min.
Distance			12 nm	232 nm (430 km)				75 nm	12 nm		
Weight	PMGW	PMGW	PMGW	PMGW	Payload expanded						
Altitude	SL	SL	4000 Ft	4000 Ft	4000 Ft	4000 Ft	4000 Ft	4000 Ft			SL
Power		IRP	IRP		IRP	MRP				IRP	
Temperature	STD + 50.26										
Speed		80 Kts	180 Kts		200 Kts	0 Kts	180 Kts	150 Kts		180 Kts	

Fig. 3 Mission Profile



W_{P1} : Single Main Rotor Helicopter
W_{P2} : Coaxial Helicopter
W_{P3} : Single Main Rotor Compound Helicopter
W_{P4} : Coaxial Compound Helicopter
W_{P5} : Tilt Rotor Aircraft

Fig. 4 Payload versus Range

4000 ft hovering

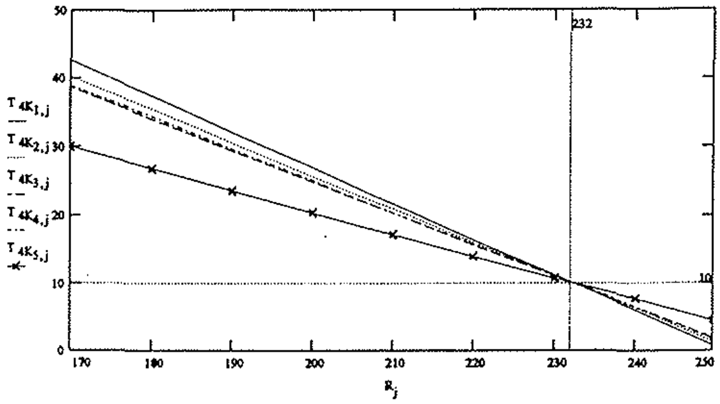
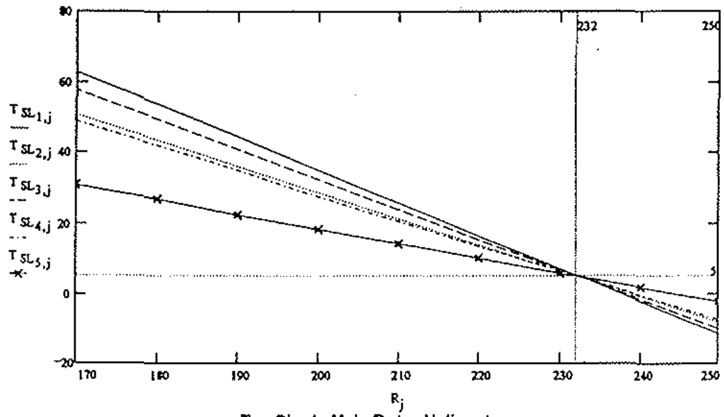


Fig. 5 Hovering Time vs. Range (Sea Level Standard)

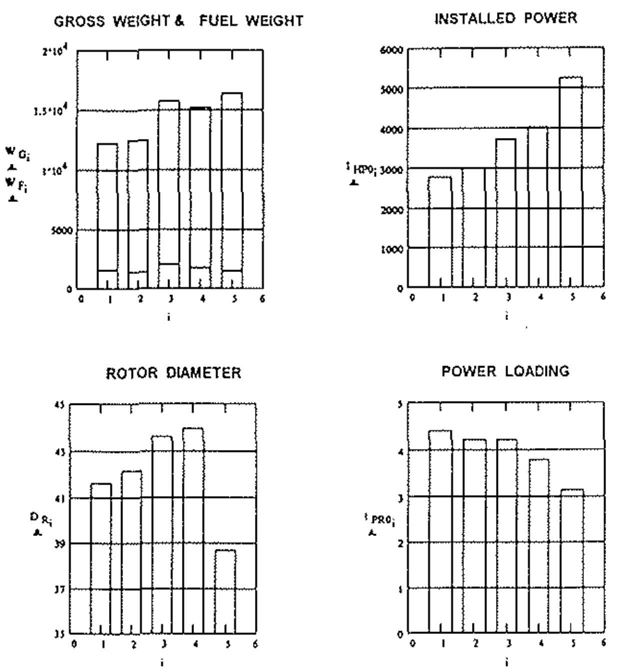


T_1 : Single Main Rotor Helicopter
T_2 : Coaxial Helicopter
T_3 : Single Main Rotor Compound Helicopter
T_4 : Coaxial Compound Helicopter
T_5 : Tilt Rotor Aircraft

Fig. 6 Hovering Time vs. Range (4000 ft/90 deg.)

an unbiased decision to be made while addressing all pertinent qualifications for a high speed, highly maneuverable rotorcraft. Following is a discussion of some of the more important "Whats" of the QFD matrix (Figure 8).

Maintainability Trade-off studies were researched to see if previous work had been done in this area that addressed the various configurations considered for this study. A reliability and maintainability trade-off study done early in the LHX study was found to be an excellent source of information. This study compared SMR compounds, coaxials, coaxial compounds, and tiltrotors against Mean Time To Repair (MTTR), Maintenance Man Hours per Flight Hour (MMH/FH), and Mean Time Between Failure (MTBF). For comparison purposes, the SMR was assumed to have the same characteristics as the SMR compounds.



1. Single Main Rotor Helicoper
2. Coaxial Helicopter
3. Single Main Rotor Compound Helicopter.
4. Coaxial Compound Helicopter
5. Tilt Rotor Aircraft

Fig. 7 Results of Sensitivity Study

Personnel safety in this report is mainly considered as the possibility of rotor strike to ground personnel. Therefore, the coaxial has the best trait for this category since it does not have a tail rotor. The other configurations all have a tail rotor or prop which can become a hazard to ground personnel, except for the tiltrotor. However, the tiltrotor may create the possibility of a greater hazard than the coaxial since its blades cover a much greater area, namely almost twice the area, which could be critical in tight Landing Zones (LZ's), confined areas, or Nap-Of-the-Earth (NOE) flight.

Transportability is how well the vehicle can be transported by the C-141B cargo plane. The complication in transportability is mainly size limitations. Size calculations of an SMR compound with a shrouded propeller, an SMR compound with an open propeller, a coaxial, a coaxial compound with a shrouded propeller, and a coaxial compound with an open propeller were all conducted using HESCOMP (Table 1). The coaxial, not having the smallest overall dimensions, but the simplest dismantling procedure, was considered the best candidate for this requirement. The coaxial compound represented the configuration with the smallest overall dimensions. The SMR configurations were the least desirable due to the long length of the fuselage required to meet the performance requirements. This was due mainly to the long rotor blades needed for high speed. The problem arising with the tiltrotor was the wings that carry the rotors. This can cause high unloading and loading times which are not desirable.

In this paper, it was assumed that all the configurations presented in the above table would be able to meet any specified requirements for any mission frequency, whether in peacetime or conflict.

WHATs			HOWs	IMPORTANCE	Configurations: SMR – SMR	SMR – SMR Comp, Shrouded Prop	SMR – SMR Comp, Open Prop	Coaxial – Pure Coaxial	Coaxial – Coaxial Comp, Shrouded Prop	Coaxial – Coaxial Comp, Open Prop	Tiltrotor – Tiltrotor
System Effectiveness	Availability & Dependability	Manning Levels	Operator Crew Size	7	○	○	○	○	○	○	○
			MCS	7	⊙	○	○	○	△	△	○
		Habitability	Cockpit Cooling	6	○	○	○	○	○	○	○
		Maintainability	MTTR	9	⊙	⊙	⊙	○	○	○	△
			MMH/FH	9	⊙	⊙	⊙	○	○	○	△
		Personnel Safety	Personnel Safety	6	△	△	△	⊙	○	○	○
		Reliability	Endurance	8	△	○	○	○	⊙	⊙	⊙
			Transportability	7	△	△	△	⊙	○	○	△
			MTBF	9	△	○	○	⊙	○	○	○
		Mission Frequency	Peacetime	6	○	○	○	○	○	○	○
			Conflict	7	○	○	○	○	○	○	○
		System Safety	Autorotation	7	⊙	⊙	⊙	○	○	○	△
			Blade Frequencies	7	△	△	△	⊙	⊙	⊙	○
			Start Up/Shut Down	7	△	△	△	⊙	⊙	⊙	○
			Crashworthiness	9	△	△	△	⊙	○	○	○
		Vulnerability	Tip Speed	9	△	○	○	⊙	⊙	⊙	△
			Size	7	△	△	△	⊙	○	○	△
		Survivability	Ballistic Hardening	9	○	○	○	○	○	○	○
	Capability	Work Load	Pilot Work Load	9	△	○	○	⊙	⊙	⊙	△
			Handling Qualities	8	△	○	○	⊙	⊙	⊙	○
		Performance	200 kt Dash Speed	10	△	○	○	△	○	○	⊙
			Cruise Speed	8	△	○	○	△	○	○	⊙
			VROC (800 fpm)	8	○	△	△	⊙	⊙	⊙	△
			4g Transient Load	10	△	△	△	○	⊙	⊙	○
			2g Sustained Load	8	△	△	△	○	⊙	⊙	○
			430 km Range	8	△	○	○	△	○	○	⊙
		Environment	<15 Disk Loading	9	△	○	○	⊙	⊙	⊙	△
Cost Effectiveness	Production	Non-Recurring	Process	7	⊙	⊙	⊙	○	○	○	○
			Fabrication	7	⊙	△	○	△	⊙	⊙	△
			Assembly	7	⊙	△	△	△	○	⊙	△
		Recurring	Material Type	8	○	○	○	○	○	○	○
			Weight	8	△	△	△	○	○	⊙	△
	Operating	DOC	Reserves	9	○	△	○	△	○	⊙	○
			Maintainance	9	○	△	○	○	⊙	⊙	○
			POL	9	○	△	○	△	○	⊙	△
ORGANIZATIONAL DIFFICULTY					1	2	2	3	4	4	3
ABSOLUTE IMPORTANCE					858	790	858	1288	1414	1612	828
RELATIVE IMPORTANCE					11%	10%	11%	16%	18%	21%	10%

MATRIX	WEIGHTS	ARROWS
Strong ⊙	9	Maximize ↑
Medium ○	3	Minimize ↓
Weak △	1	Nominal ○

Fig. 8 Rotorcraft Configuration Trade-off Functional Deployment Quality Matrix

	Gross Weight	Empty Weight	Fuel Weight	Length	Widith	Wing Area
	lbs	lbs	lbs	ft	ft	ft^2
Compound w/Prop	22438	16196	4449	60.2	7.8	200.1
Compound w/Shroud	23370	16763	4813	61	7.8	208.4
Coaxial	21882	15279	4809	38.8	8.3	65.8
Coaxial w/Prop	19133	13578	3761	37.1	8.3	65.8
Coaxial w/Shroud	19888	14019	4076	37.6	8.3	65.8
	Rotor Dia.	Rotor Chord	Disk Loading	He. Cost	Static Power	Product. Index
	ft	ft	lbs/ft^2	$	HP	Knots
Compound w/Prop	51	4.73	0.236	$5,602,093	7210	12.34
Compound w/Shroud	52	4.8	0.236	$6,002,848	7862	11.81
Coaxial	50.1	2.58	0.196	$6,602,391	9643	12.63
Coaxial w/Prop	47.1	2.11	0.171	$4,858,144	6616	14.7
Coaxial w/Shroud	48	2.46	0.196	$5,248,118	7301	14.08

Table 1: HSHMR Configuration Comparison

SMR configurations generally employ stiff blades that are not as stiff as the ones used by coaxial configurations. The RFP requirement for start up and shut down in high winds up to 60 knots can be translated to a requirement of what range is acceptable for the blades to flap. Since the Advancing Blade Concept (ABC) coaxial rotor system was designed to have very rigid blades, the ABC can be considered as the most suitable configuration to satisfy this requirement (Reference 7). Furthermore, it appears to be more suitable also with respect to the tiltrotor concept that uses a gimbal teetering rotor that is also not very stiff since there is no concern about the rotors interfering with each other.

At high rotor advance ratios an increase in installed power is usually required to account for compressibility and stall effects. A coaxial configuration can alleviate the importance of these two effects through the use of the ABC coaxial rotor system (which eliminates the stall regions and thus power increases due to stall) by using advanced airfoils (like the VR8 which has a high drag divergence Mach number) and a tip Mach number schedule (which by reducing the rotor RPM keeps the $M_{Tip} <$ .85) to suppress any compressibility drag rises. Finally, the very stringent 4g transient maneuver requirement at 160 knots does not directly affect the power installed but drives the rotor system design. Special consideration had to be given in addressing this issue which guided the down select process. More specifically, the combination of high speed (160 kts) and large transient maneuver load factor (4 g's) drove our decision to select a stiff in-plane coaxial bearingless system. This decision was based on the results of an effort involving the study of maximum allowable transient load factors of compounds and coaxials and their importance in selecting a rotor blade with a reasonable blade chord. A study of the chord length for the SMR compound using GTPDP (Table 2) was carried out comparing the effects of transient maneuver loads due to the rotor and the wing for various disk loading settings. The most obvious conclusion from this trade-off study was the fact that for a SMR compound rotorcraft, none of the selected combinations of disk loading and wing lift relief led to a rotor blade design with a chord less than 4.26 feet (result obtained for a wing area of 198.9 ft^2 which corresponds to the rotor lifting 3.5 g's while the wing carries the remaining .5 g's). This value for the chord is completely unrealistic and as such the SMR concept was eliminated and further consideration was given to alternate configurations. As it will be shown next a solution was obtained when the coaxial rotor was considered.

		* G (ROTOR) 4 g transient at 160 knots		
ω		3.5	3	2.5
15	GW	23452	27074	34967
	S	209.1	482.8	935.4
	DIAMETER	44.6	47.9	54.5
	σ	0.322	0.322	0.322
	CHORD	5.64	6.06	6.89
13	GW	22985	26126	33046
	S	204.9	465.9	884
	DIAMETER	47.4	50.6	56.9
	σ	0.279	0.279	0.279
	CHORD	5.19	5.54	6.23
11	GW	22438	25335	31362
	S	200.1	451.8	838.9
	DIAMETER	51	54.2	60.3
	σ	0.236	0.236	0.236
	CHORD	4.73	5.02	5.59
9	GW	22310	25000	29888
	S	198.9	445.8	799.5
	DIAMETER	56.2	59.5	65
	σ	0.193	0.193	0.193
	CHORD	4.26	4.51	4.93

* Rotor load factor contribution to the 4 g requirement.
It is assumed the wing, and hence the area, would contribute the remaining load factor capability

Table 2 SMR Compound Parametric Study of Chord

In this investigation an attempt was made to understand the mathematical relationship that ties together the chord sizing to the rotor blade loading, C_T/σ, and the lift provided by the wing, L_W. In doing so we arrived at the following expression for the rotor chord:

$$c = \frac{(4W - L_w)}{(\frac{C_T}{\sigma})\rho R V_T^2 b}$$

where ρ is the atmosphere density, W is the gross weight, L_W is the wing lift, and C_T/σ is the blade loading. Inspection of this equation shows immediately that in order for the chord to take a reasonable value, when sized for the most stringent blade loading candidate (which for this case is the transient maneuver load factor of 4 g's) a rotor system offering the highest possible value of C_T/σ (for the transient maneuver) must be obtained. Furthermore, since the density, ρ, is fixed and the rotor radius and tip speed are selected based on disk loading requirements (downwash considerations) the only other parameters that can be altered are the number of blades (solidity) and the amount of lift provided by the wing (proportional to wing surface area, incidence angle, etc.).

As far as the maximum C_T/σ is concerned, the coaxial rotor, as can be seen in Figure 9 (obtained from Reference 7), can provide, according to the XH-59A flight test data, a maximum sustained C_T/σ of 0.21 at 180 knots and an assumed (very conservative) transient C_T/σ of 0.25. This selected value is justified based on typical transient load behaviors when compared to the sustained loads as can be seen in Figure 9 for the helicopter configurations.

Furthermore, it is worth noting that the maximum expected transient C_T/σ for a helicopter rotor is on the order of 0.18. Based on a C_T/σ maximum transient value of 0.25, and a range of wing lift values (trade-off based on varying the wing surface) and a range of tip speeds and disk loadings it was found that the coaxial rotor system with its 6 blades (two rotors) and its superior (C_T/σ)max. capability (a practically unstallable rotor) can drive the rotor blade chord down to a reasonable range between 1.5 and 2.5 feet depending on the conditions. It was also the conclusion of this study that a SMR helicopter could never achieve a 4 g transient load factor even if it employed a large number of rotor blades without using an extremely large wing underneath its rotor. This alternative was also dismissed due to high profile drag penalties and decreased hover and vertical flight performance where the wing produced large downloads. The hover VROC requirement of 800 fpm at 4000 feet altitude and 95° F made a large wing completely impractical.

Besides the tip speed or noise constraints, the size of the rotorcraft also figures into vulnerability. This configuration attribute was addressed under the transportability requirement. Since the compound configurations have auxiliary propulsive devices, they were considered more vulnerable due to the extra noise and heat that might be generated.

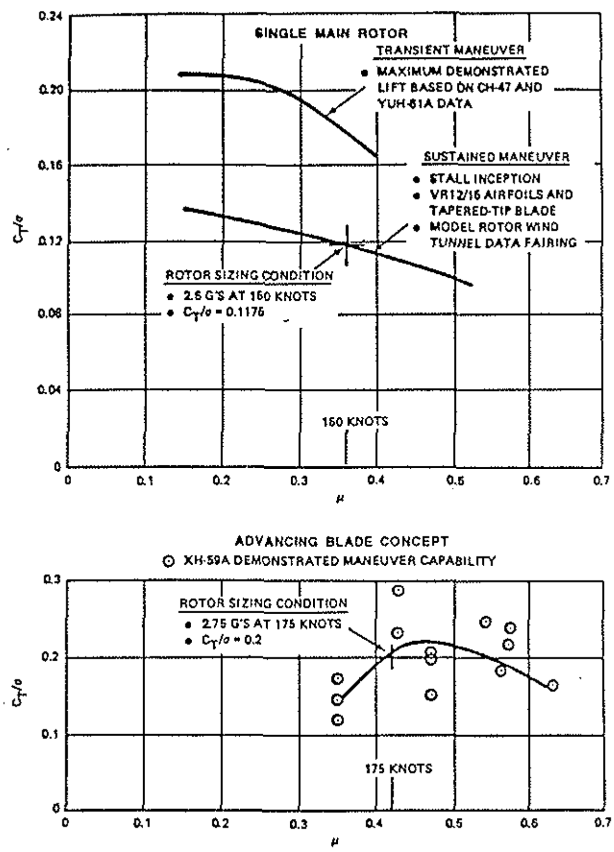


Fig. 9 Maneuver Rotor Lift Boundaries

The high speed requirement of 200 knots can obviously be easily reached by the tiltrotor configuration. The other configurations with some type of auxiliary propulsion also have a good chance of attaining high speed. The SMR and coaxial configuration might attain high speed with large engines, but this is doubtful and would not result in an optimum design. Generally, the SMR is limited to a forward speed of 200 knots or less due to compressibility effects of the advancing blade and stall on the retreating blade. The same reasoning can be applied to requirements for the cruise speed and range. The tiltrotor of cause can easily out-run and out-distance any of the other configurations, but as mentioned it was eliminated from further consideration for the reasons discussed.

Due to the lower disk loading, higher figure of merit, small or no wing, offered by the coaxial configurations, they become the primary choices for any high speed transient load factor capability coupled with stringent vertical rate of climb (VROC) and low disk loading requirements.

Coaxial configurations generally have better handling qualities than other configurations since they make use of very stiff hingeless rotor systems. Since they are smaller and have greater speed and acceleration capability than the SMR configurations, they can out-maneuver all other vehicle considerations.

As mentioned previously, GTPDP was used to size the different configurations for a preliminary selection process. Also embedded in the program is the capability of calculating production and operating costs. Therefore the results in the QFD matrix are entirely based on results from GTPDP.

This concludes the discussion of the "Whats" in the QFD matrix, but the production difficulty of the different configurations deserves an explanation. Single main rotor helicopters have been built for years and are considered the least risky. SMR compound prototypes have been built since the late 1960's and are considered only slightly more risky. Coaxials are in production in the former Soviet Union, but use an articulated rotor. Tiltrotor prototypes, such as the XV-15 and V-22, have been developed by NASA and the armed services. A coaxial prototype with hingeless rotors

(ABC), with auxiliary propulsion has been developed (XH-59A) and demonstrated in the 1970's. However, it is still considered to present the most risk.

It was obvious from the QFD matrix that the two top configurations were the coaxial compound with a shrouded propeller and the coaxial compound with the open propeller. Although the QFD matrix showed that the coaxial compound with the open propeller was the better choice, it was decided to examine the different qualities of the shrouded propeller and the open propeller.

The main purpose for using a propeller is to provide forward propulsion during cruise. Therefore the propeller should use a minimum of power during hover condition when it is not in use. This leads to choosing a propulsive device that has the greatest efficiency, thereby using the least power during hover. The ideal propulsive efficiency is defined as $1/(1 + \eta/2)$ where η is $(U-V)/V$. U is the effective exhaust jet velocity and V is the free stream velocity. Since the effective exhaust velocities decrease from the turbojet, turbofan, shrouded propeller, and down to the open propeller, the ideal propulsive efficiency increases in the same order. Therefore, the open propeller has the highest ideal propulsive efficiency. Although a shrouded propeller has good characteristics when flying at low speeds or static conditions, it loses efficiency at higher speeds because of the drag of the shroud. Because a high speed vehicle is required and it is desired to have the maximum efficiency at hover, the open propeller was chosen instead of the shrouded propeller. The Army's Helicopter Preliminary Design Handbook (Reference 6) is an excellent resource for addressing this topic.

In conclusion, using the R_F method as applied to rotorcraft, the Quality Function Deployment matrix, and the Army's Helicopter Preliminary Design Handbook, it was finally decided to select the coaxial compound rotorcraft with an open propeller for auxiliary propulsion. A description of the physical parameters of the selected configuration is provided in Table 3. A three view layout is provided in Figure 10.

Table 3 Physical Parameters of a Coaxial Compound HSHMR Candidate

<u>Main Rotor</u>	
Radius	20.45 ft
Disc Area	1318.82 ft^2
Number of Blades	3 per rotor
Airfoil Section	VR-7/VR-8
Blade Chord	2.1415 ft
Solidity Ratio	.200
Normal Operating Tip Speed	725 ft/sec
Mass Moment of Inertia	3149.16 slug/ft^2
Effective Twist	-9 deg
Main Rotor Blade Lock Number	8.2
Collective Pitch Range	+1° to +19°
Lateral Cyclic Pitch Range	-10.5° to +7°
Longitudinal Cyclic Pitch Range	-10 to +20°
<u>Auxiliary Thrust Device</u>	
Diameter	10 ft
Number of Blades	3
Normal RPM	1718.87
Activity Factor	140 per blade
Integrated Design Lift Coefficient	.411
<u>Wing</u>	
Span	14.6 ft
Area	65.8 ft^2
Root Chord	5 ft
Tip Chord	4 ft
Aspect Ratio	3.23

Taper Ratio	.8
Airfoil Section	NACA 4415

Horizontal Stabilizer

Span	4.35 ft
Root Chord	3.573 ft
Tip Chord	2.058 ft
Aspect Ratio	3.68
Area	29 ft^2
Airfoil Section	NACA 0012
Incidence Angle	0°.

Elevator Characteristics

Span	10.3 ft
Chord	2.8 ft
Controllable Angle Range	-15° to + 15°.

Vertical Tail

Height	4.88 ft
Root Chord	2.9 ft
Tip Chord	2 ft
Aspect Ratio	1.59
Area (each)	14.95 ft^2
Total Area	29.9 ft^2
Airfoil	NACA 0018
Incidence Angel	0 °

Rudder Characteristics

Span	2.18 ft
Chord	1 ft
Controllable Angle Range	-20° to +20°

4. Conclusions

Due to the forward speed and the transient load factor requirements the conventional single main rotor helicopter was not a viable candidate. This is due to the loss in the ratio of thrust coefficient to rotor solidity (C_T/σ) above approximately 130 knots for the single rotor conventional helicopter. Therefore, viable candidate configurations to meet these requirements were compound helicopters (both single main rotor with a wing and propeller and coaxial with a propeller but without a wing) and tilt rotor aircraft. The disk loading constraint of less than 15 lbs/ft^2 eliminated other VTOL aircraft configurations such as tilt wing aircraft.

While the winged rotorcraft could provide the high speed lift for the transient maneuver requirement and, in conjunction with a propeller, easily meet the forward speed requirement. A severe hover download penalty requirement is paid to meet the stringent hover VROC requirement of 800 fpm at IRP, 4000 ft 95° F. Therefore, the coaxial compound helicopter was selected based on considerable tradeoffs which provided a clear understanding of the impact of performance requirements on rotorcraft configuration selection.

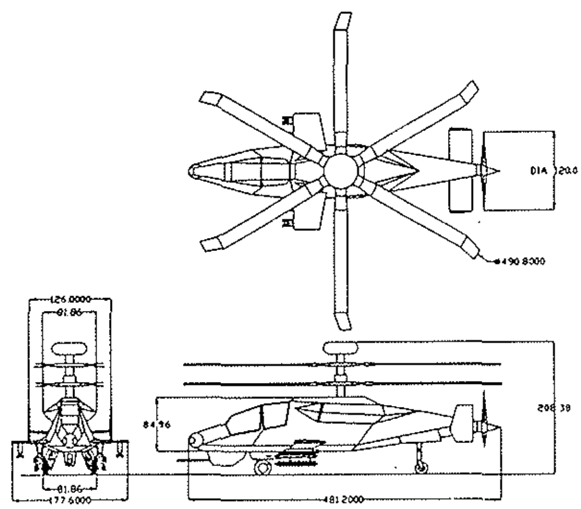


Fig. 10 A Coaxial Compound HSHMR 3 View Drawings

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