NASA Contractor Report 185222
PW FR-20668

Assessment of High Temperature Superconducting (HTS) Electric Motors for Rotorcraft Propulsion

Jay Doernbach
United Technologies Corporation
Pratt & Whitney
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Prepared for
Lewis Research Center
Under Contract NAS3-25117 (Task 009)

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ABSTRACT

The successful development of high temperature superconductors (HTS) could have a major impact on future aeronautical propulsion and aeronautical flight vehicle systems. A preliminary examination of the potential application of HTS for aeronautics indicates that significant benefits may be realized through the development and implementation of these newly discovered materials.

Applications of high temperature superconductors have been envisioned for several classes of aeronautical systems, including subsonic and supersonic transports, hypersonic aircraft, V/STOL aircraft, rotorcraft, and solar, microwave and laser powered aircraft. This study examines the potential application and benefits of applying HTS to helicopter drive trains.

Three existing helicopters were chosen to determine the feasibility of using HTS motors and generators to replace their conventional mechanical power drive systems. Helicopter selection was made to cover the range of applications from small to very large to be sure all size categories would be considered including the 500 and 3000 HP applications specified in the contract requirements. Motor/generator designs were created and cooling systems to keep them at cryogenic temperatures were sized. The helicopter's gas turbine power turbines were customized to drive the electrical generators at acceptable speeds while the existing helicopter rotor speeds were used as the design speed requirements for the electrical motors. Mission studies using the chosen helicopters were then done using a helicopter sizing computer program (HESCOMP) developed for NASA by Boeing Vertol Co. HESCOMP was used to determine the impact of the HTS weight and power changes on helicopter takeoff gross weight (TOGW). The TOGW impacts showed which applications would be good choices for HTS motors and generators to replace the mechanical transmissions.

PREFACE

This report documents a contracted study to investigate conceptual HTS power train systems for a helicopter with a Technology Availability Date (TAD) year of 2000.

System weights as well as TOGWs were generated for helicopters with gas turbines rated in the 500 through 13000 HP range having missions designed using the HESCOMP computer code. This study was conducted by Pratt & Whitney for NASA during the time period from February 1989 through July 1989.

The NASA project manager for this study was George Turney, NASA Lewis Research Center, Cleveland, Ohio. Roger Luidens of NASA Lewis was the technical consultant. George Champagne was program manager at Pratt & Whitney. Key technical contributions came from Osman Mawardi, President of Collaborative Planners Inc. in Cleveland, Ohio; Frank Biancardi of United Technologies Research Center in East Hartford, Connecticut; Marv Glickstein, Bill Grunske and Bruce Trembly of Pratt & Whitney at West Palm Beach, Florida. Jay Doernbach of Pratt & Whitney at West Palm Beach coordinated the efforts, provided technical contributions and wrote the final report.

1.0 - Introduction

The recent discovery of high temperature superconductors (HTS) has created a major stir of excitement in the scientific community. The potential benefits which may be provided through application of these newly discovered superconducting materials are now being explored by investigators. Studies have been initiated to assess the potential advantage of HTS in a number of areas including electrical power transmission and storage, communications, computer systems, medical diagnostic equipment, and ground transportation systems (magnetically levitated high speed trains).

Despite the claims and projections made for these newly discovered superconducting materials, it is generally agreed that a significant effort will be required before these materials can be developed to a state where they can be successfully used in practical applications. Nevertheless, the feeling of many researchers seems to be that most or all of the currently recognized problems with HTS can be resolved through applied research efforts. Based on this premise, HTS will, in time, find it's way into applications of aeronautical systems.

With successful demonstration of superconductivity at a temperature of 95K, which is in excess of the liquid nitrogen boiling point (77K), potential applications for aeropropulsion systems appear feasible. As the technology for HTS develops, extending the critical temperatures to higher levels, the potential benefits of such applications appear more interesting. With evidence of potential superconducting material exhibiting critical temperatures approaching room temperature (300K), a variety of potential aerosystem applications can be envisioned, one of which is helicopter drive system motors and generators to replace the mechanical drive train. The objective of this task was to define the characteristics of high temperature superconducting motors and generators and to assess their benefits in helicopter main lift systems. This study looked at three existing helicopter systems; namely, the small Bell Jet Ranger, the medium Sikorsky Black Hawk and the large Sikorsky Super Stallion.

Collaborative Planners,Inc of Cleveland Heights,Ohio did the HTS electric motor/generator design work and specified the cooling requirements for all three sizes of applications investigated.

Two electrical motor constructions, called SROC and SRASC, are mentioned frequently in this study and some explanation here will be helpful. The superconducting rotor only construction (SROC) is used for the motors and generators having superconductors only in the rotors with the resulting electrical efficiencies of near 99%. The superconducting rotor and stator construction (SRASC) is used for the motors and generators having superconductors in both the rotors and stators with the resulting electrical efficiencies greater than 99%.

United Technologies Research Center of East Hartford, Connecticut sized the cryocoolers needed to meet the cooling requirements specified for various sizes of applications investigated.

Pratt & Whitney of West Palm Beach performed the helicopter trade factor studies using the HESCOMP code developed by Boeing Vertol Co. Pratt & Whitney of West Palm Beach, sized the expendable cooling equipment needed to meet the cooling requirements specified for the various sizes of applications investigated, and also coordinated the entire study and compiled and wrote the final report.

2.0 - Technical Requirements

The main technical requirement of this contract was to investigate HTS motor/generator characteristics consisting of power output, speed, size, efficiency and system weight and to apply these to the main lift system of helicopters designed with TAD's in the year 2000. The HTS operating temperatures of 95K and 300K were to be used for 500 & 3000 HP applications with an individual component efficiency of at least 97 to 98%. The cryogenic cooling systems to be considered were closed loop refrigeration and expendable liquid nitrogen systems. Cooling systems are necessary to keep the superconductors at operating temperatures consistent with the electrical superconductivity which makes the motors and generators much smaller than present state of the art equipment and thus provides a weight benefit for flight weight equipment.

Weight and performance characteristics of conventional and HTS drive systems were to be compared for each application. Missions and airframe performance and weight models were to be developed to assess the HTS and conventional systems' performances.

3.0 - Summary of Results

This study showed that larger helicopters provide the best potential for application of the HTS motor/generator drive systems. Figure 3-1 is a schematic of the mechanical drive system that is used to power the large MH-53E helicopter. The mechanical drive system shown in figure 3-1 is very similar to that of the CH-53E helicopter which was one of the systems investigated in this study.

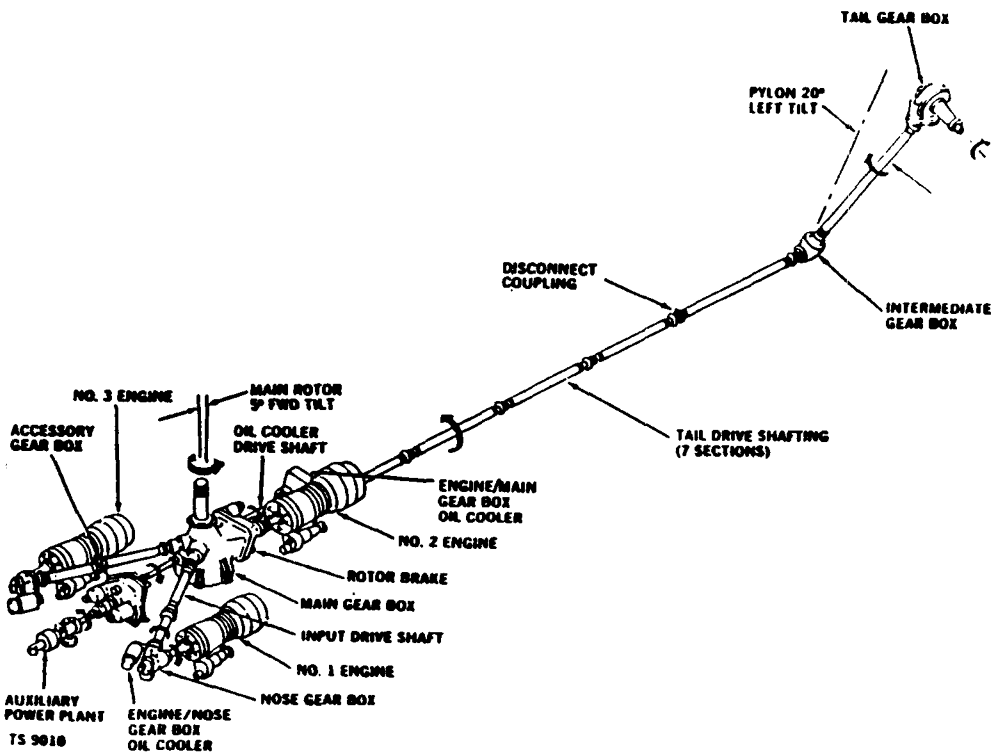

Figure 3-1. Mechanical Power Train for The MH-53E Helicopter

Figure 3-2 again shows the same MH-53 drive train with modifications to include the HTS motor and generator for main rotor power. The three gas turbines have been replaced with two having the power of three and the electrical generator is attached to the power turbine shaft of each. The large three engine gearbox has been eliminated but an accessory/tail rotor gearbox is still needed. The motor, generator and cryocooler shown are only conceptual.

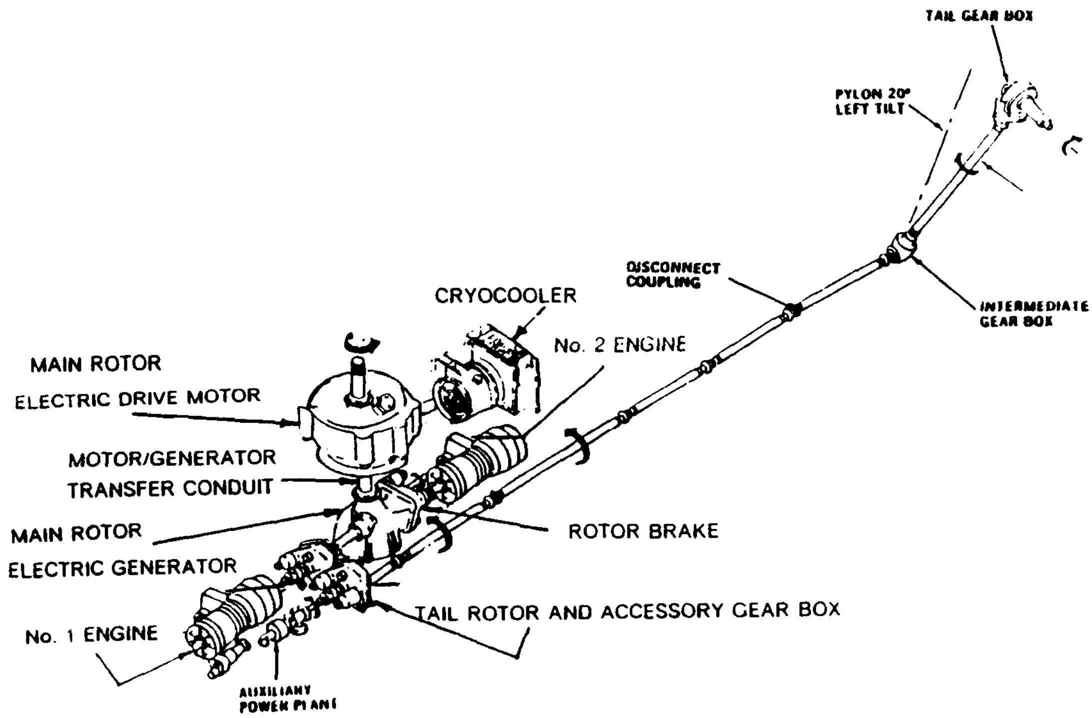

Figure 3-2. Conceptual HTS Power Train for the CH-53E Helicopter.

Table 3-1 includes the key study items consisting of cooling loads, system weights, power requirements and, electrical efficiencies used in this study and provides the system comparisons including drive train specific power (HP/LB) and aircraft takeoff gross weight (TOGW) changes.

Table 3-1 - HTS Key Items Summary

	Helicopter Power Plant : Gas Turbine Maximum HP Rating at Sea Level					
KEY ITEMS	502 HP	3606 HP SROC Motor/Generator	13407 HP	502 HP	3606 HP SRASC Motor/Generator	13407 HP
HTS ELECTRICAL SYSTEM SUMMARY						
Cooling Loads						
Refrigeration						
Max Load (KW)	0.474	3.229	11.77	0.104	0.597	2.124
Size/Power (HP)						
Motor	318	2165	7894	318	2165	7894
Generator	318	2165	7894	318	2165	7894
Speeds (RPM)						
Motor	350	257	179	350	257	179
Generator	21500	17900	11900	21500	17900	11900
Efficiencies (%)						
Motor	99.9	99.9	99.9	99.98	99.98	99.98
Generator	99.9	99.9	99.9	99.98	99.98	99.98
SYSTEM WEIGHTS						
Power Drive Train						
Main Rotor (LBS.)						
1. Mechanical Sys.						
A. Main Rotor	182	1387	5731	182	1387	5731
2. HTS Systems :						
A. Total C/Loop	499	1815	5380	312	990	2950
B. Total Expend.	380	1230	3798	351	912	2626
C. Total Air cool	309	943	2908	325	839	2427
PERFORMANCE						
Specific Power (HP/LB)						
1. Mechanical Sys.	1.747	1.561	1.377	1.747	1.561	1.377
2. HTS Systems						
A. C/Loop System	0.637	1.193	1.467	1.019	2.187	2.676
B. Expnd LN2 Sys	0.887	1.917	2.290	0.919	2.427	3.084
C. Air Cooled Sys	1.029	2.296	2.715	0.978	2.580	3.253
TOGW CHANGE (%)						
Due to Changes in Weight and Power						
A. C/Loop System	16.5	5.2	-2.1	5.4	-6.5	-16.5
B. Expnd LN2 Sys.	7.1	-5.1	-14.1	6.7	-8.1	-18.9
C. Air Cooled Sys.	4.5	-7.4	-17.0	5.6	-8.7	-19.6

Figure 3-3 shows that the helicopter main rotor drive weights for conventional mechanical drives are lighter than any of the HTS candidates for helicopters requiring less than 500 Horsepower. The crossover point for larger drives can be seen to depend strongly on the electrical motor/generator construction,the cooling load,and the type of cooling devices used.

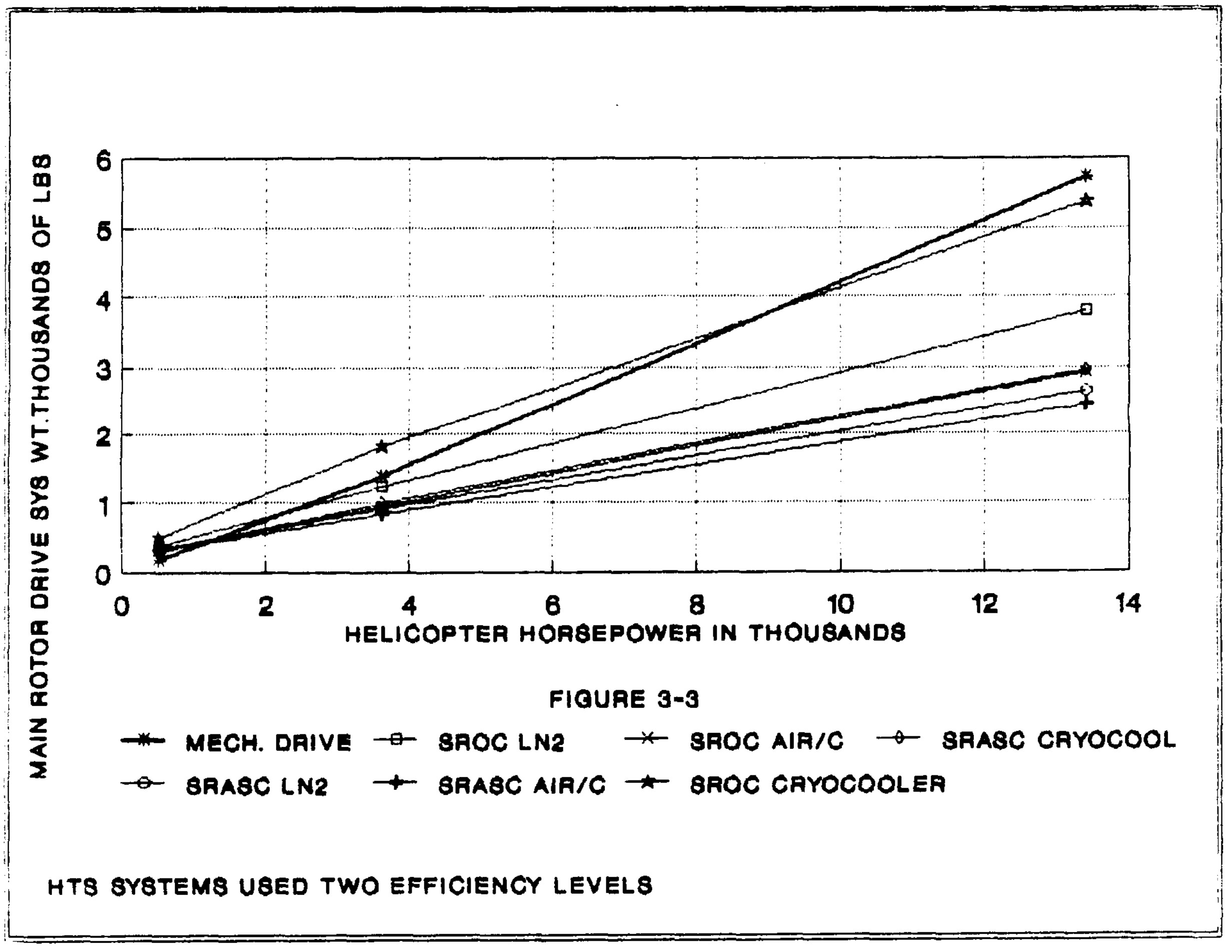

Figure 3-3. Helicopter Main Rotor Drive System HTS Replacement of Main Rotor Drive.

Figure 3-4 is similar to 3-3 except that the main rotor drive system weight is plotted against horsepower transmitted through the main rotor rather than the helicopter total rated horsepower. Figure 3-4 shows that under about 500 horsepower, the mechanical drives are lighter and above about 5500 horsepower the HTS systems are lighter.

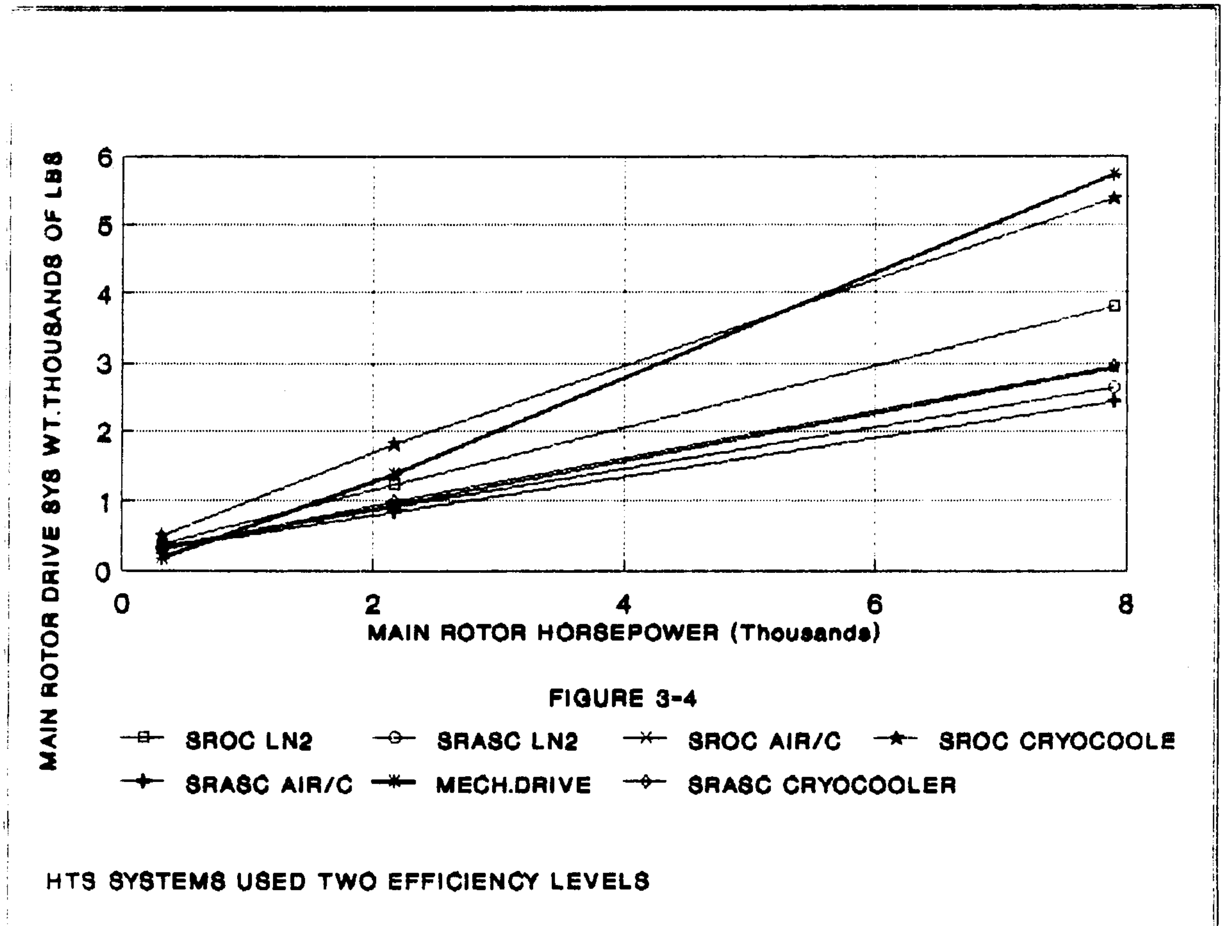

Figure 3-4. Helicopter Main Rotor Drive System HTS Replacement of Main Rotor Drive.

Figure 3-5 shows the specific power transmitted to the main rotor vs helicopter total rated horsepower.

The study is summarized using two levels of electrical generating efficiencies: one of 99.9% (not including cooling requirements) and a second level of 99.99+%. This much higher efficiency according to CPI is thought to be possible by the year 2000.

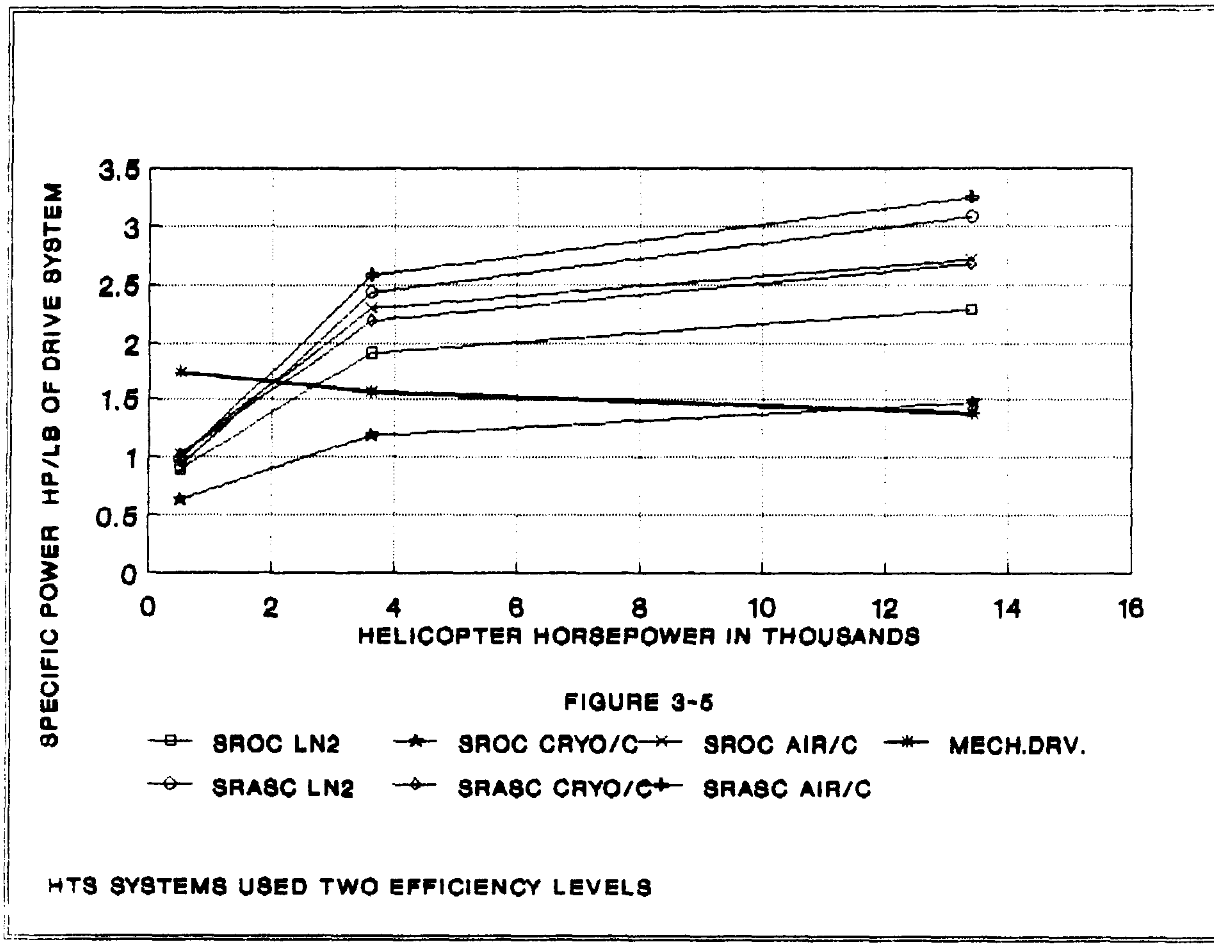

Figure 3-5. Helicopter Main Rotor Drive System Power Transmitted to Main Rotor Drive.

4.0 - Design Criteria

Electric motor and generator design speeds:

This study was begun by making a helicopter power survey, an excerpt of which is shown in table 4-1. References 2 and 6 were used to survey the general power spectrum of present day helicopters. This survey yielded the three helicopter choices used in this study and satisfied the study intent to get rotorcraft in the 500 and 3000 horsepower categories. Main rotor speeds needed for sizing the electric motors were also needed and these were obtained initially from various sources including conversations with the manufacturers. Finally, these data were updated where necessary using data from references 3, 4, and 5.

Table 4-1 -Helicopter Specifications
(From Aviation Week & Space Technology March 24, 1988 and March 9, 1981)

Popular Name	Rotor Diameter (Ft.)	Empty Weight (Lbs.)	Gross Weight (Lbs.)	Maximum Speed (Mph)	Powerplant Gas Turbine Engines	Total Horsepower (HP)
Bell Jet Ranger 206B-JR3	33.3	1635	3200	140	1 Allison 250-C20J	420
Sikorsky Black Hawk UH-60A	53.7	10900	16450	184	2 GE T700-GE-700	3120
Sikorsky Super Stallion CH-53E	79.0	33226	69750	196	3 GE T64-416	13140

The electric generator was to be driven by the power turbine of the gas generator. To make the speeds compatible with the electrical generator's desired design speeds, the power turbines were customized for these applications. Power turbine speeds for each power category were calculated by Pratt & Whitney to be feasible and compatible with the electrical generator speed of 20000 RPM or less, as requested by CPI. To keep these speeds down, all design speeds were calculated based on three stage power turbines (assumed to require no weight addition) with the resulting speeds shown in Table 4-2.

Table 4-2 - Design Ground Rule Summary

APPLICATION	Motor Speed (RPM)	Generator Speed 1 Turbine Engine (RPM)	Generator Speed 2 Turbine Engines (RPM)
500 HP	350	21500	Probably too Small for two
3000 HP	257	17900	19700
13140 HP	179	11900	15000

Drive system power utilization:

The HESCOMP program provided the existing helicopter power distributions used in this study which are shown in Table 9-2. The helicopter accessory drive requirements are the same for both the HTS and conventional systems and so were not adjusted. Power extraction needed for the cryocoolers was specified by UTRC and these values were scaled for the actual equipment sizes. CPI specified that the SRASC machinery requires a cooling fan for air circulation and this power usage is also accounted for.

Since it was assumed that superconducting cables/conduits were to be used, the electrical power transmission losses were considered to be negligible as was suggested by CPI. A 3% loss of power transmitted was used for the conventional mechanical power transmissions due to bearing seal and gear train friction as included in the HESCOMP code. A key item power audit derived from this study is shown in Table 10-2.

System weights:

The helicopter mechanical drive system weights were obtained from references 3, 4, and 5 mentioned previously. The weights for the main rotor drive systems are the ones used in this study since the electric motors and generators were used to replace the main drives in the HTS versions of these helicopters. A key items weight audit is shown in Table 10-1. The same references were also used to obtain the TOGW for the three helicopters in this study.

5.0 - HTS Motor/Generator Concepts

Table 5-1. shows the geometries and weights for key items in the HTS electrical system along with the cooling system requirements used for both motor/generator efficiencies for three levels of power transmission.

Table 5-1 - Motor/Generator Sizing from CPI

	500 HP	3000 HP	13140 HP
Motor Dimensions			
Stator Diameter (In.)	21	49.79	39.78
Rotor Diameter (In.)	14	38.3	30.6
Length (In.)	14	15.32	12.24
Weight (Lbs.)	224	627	1871
Generator Dimensions			
Stator Diameter (In.)	7	8.02	10.28
Rotor Diameter (In.)	3.5	4.01	5.14
Length (In.)	14	20.05	25.7
Weight (Lbs.)	155	627	1871
Motor/Generator Total Weight			
SROC (Lbs.)	379	1254	4678
SRASC (Lbs.)	303	1003	3742
Cooling Load SRASC Requirements			
A.Heat Transfer (WATTS)	23	54	69
B.Ohmic Losses (WATTS)	130	776	3411
C.Electromagnetic (WATTS) Heat Losses (Use Fan Blower)	746	746	1492

In addition to the technical requirements in section 2 above, the design requirements for the motor/generator were specified by reference 8 as shown previously in Table 4-2. The approach was to size an electrical generator driven by a gas turbine to supply power to an electric motor having a direct drive to the helicopter rotor.

Collaborative Planners Inc. generated the information shown in Table 5-1 for the 500 HP ,3000 HP , and 13140 HP motors and generators. Early indications from this study were that that larger horsepower drives would be better suited to HTS applications and so the 13140 HP size was added to the originally specified values of 500 and 3000 horsepower to cover the higher portion of the power spectrum of present helicopters and to more fully investigate the HTS application feasibility. Table 5-1 also shows a detailed weight breakdown of all the options sized by CPI for this study. Figure 5-1 shows the weights of the motors and generators designed by CPI for the superconducting rotor only construction (SROC) and the SRASC designs.

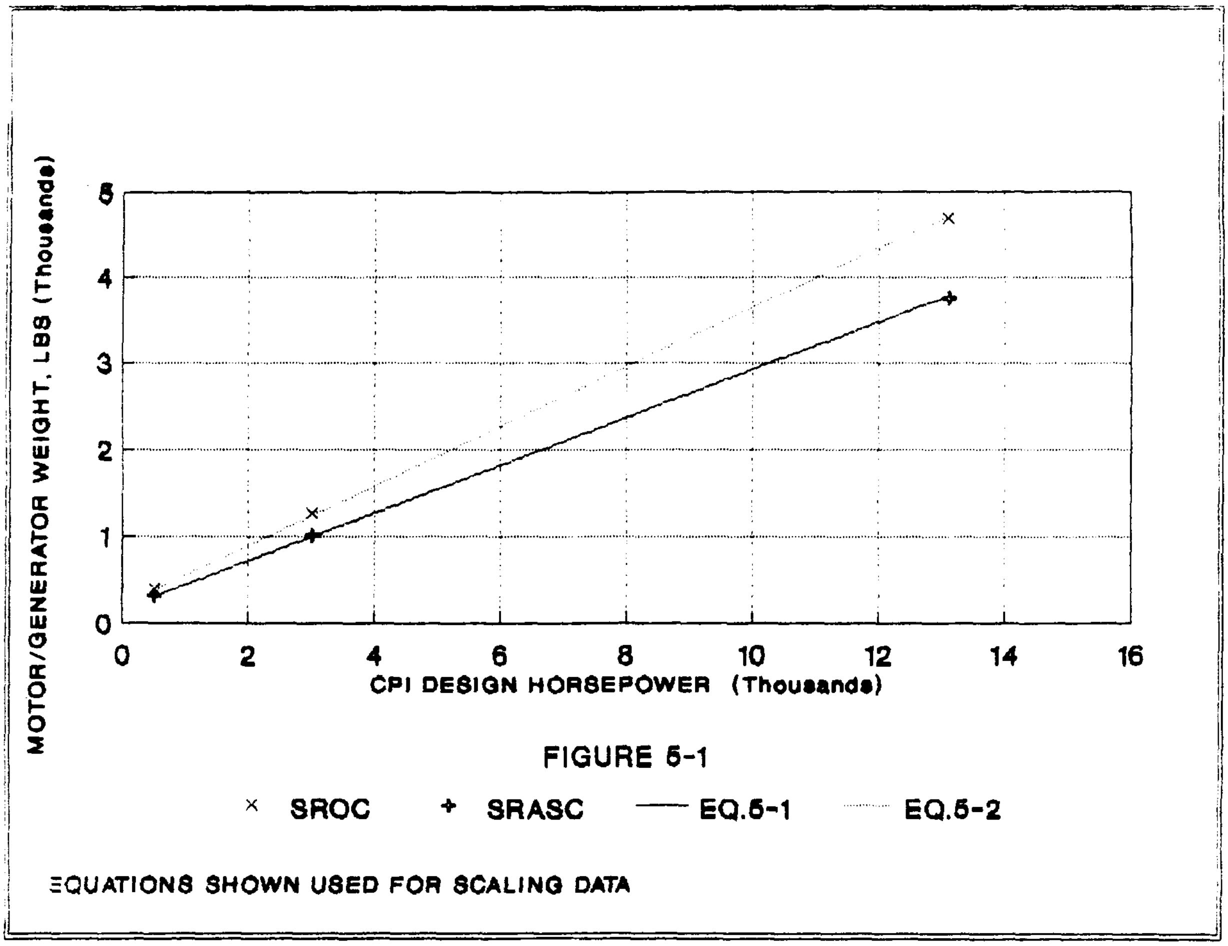

Figure 5-1. CPI Original Designs - Electric Motor Plus Generator Weight.

Motors and generators finally used in this study were much smaller than those initially requested from CPI because as the study progressed and the mission studies were completed it was found that the power required was only about 60% of the maximum sea level rating of the gas turbine engines; and the tail rotor power was small relative to the main rotor power and so better transmitted mechanically. Therefore the motor/generator weights and cooling loads had to be scaled to the smaller sizes. Several types of losses were identified: A type losses are cold section thermal losses. B type losses are wiring ohmic losses and C type losses are electromagnetic shield thermal losses. Scaling was done to represent the type A,B,and C losses for the SRASC equipment while for equipment with efficiencies of less than or equal to 99.9% only type A and B losses were calculated since type C losses are negligible for the SROC machinery.

Electrical conduits and cables were assumed to be of the superconducting types and power transmission losses were assumed to be negligible.
Motor/Generator weight scaling was done using the following equations:

SRASC motor and generator weight = 0.275*HP + 163 lbs. Equation 5-1.

The maximum fit error in equation 5-1 is less than 1.5%.

SROC motor and generator weight = 0.343*HP + 200 lbs. Equation 5-2.

The maximum fit error in equation 5-2 is less than 2.0%.

Motor/Generator heat load estimates and fan power requirements were obtained from the following equations:

SRASC motor/generator heat load = 0.2666*HP + 19.7 watts Equation 5-3.

for the type A plus B losses in the machinery with the SRAC.
The maximum fit error is less than 1.3%.

SRASC motor/generator fan load = 0.0655*HP + 631 watts Equation 5-4.

which is required for the type C losses in the machinery with the SRASC. The maximum fit error is less than 11.%, which is high because the same size fan/blower was specified for both the 500 and the 3000 HP machines and the fit gives an equal plus and minus error to accomodate this data.

SROC motor/generator heat load = 745.7*2 HP*(1-(ETA/100)) watts Equation 5-5.

in watts for the machinery with the SROC. This includes both the types A and B losses since type C losses are negligible for SROC machines.

Figures 5-1 and 5-2 show that the equations just presented are good representations of the CPI supplied data.

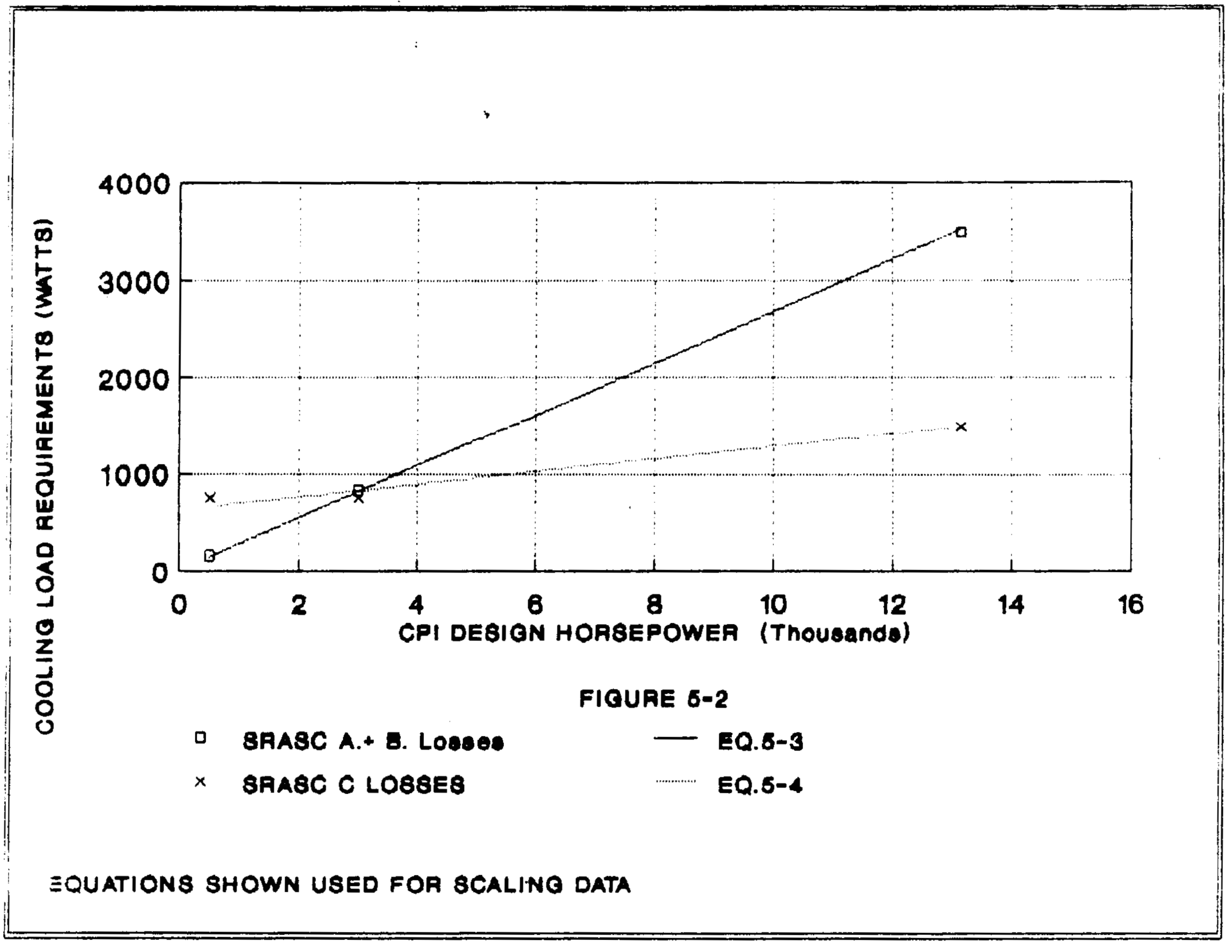

Figure 5-2. CPI Original Designs - Electric Motor Plus Generator Cooling.

6.0 - Closed Loop Cooling Concepts

Cryocooler weight and power scaling were done using data supplied by UTRC and shown in Figures 6-1 and 6-2, respectively. UTRC suggested that we use the Stirling cycle data so that is what was done for this study. The data did not cover the cooling capacity range needed and so the data was extrapolated as can be seen by the points on these figures marked as scaled data. Reference 17 was used by UTRC to guide their recommendations.

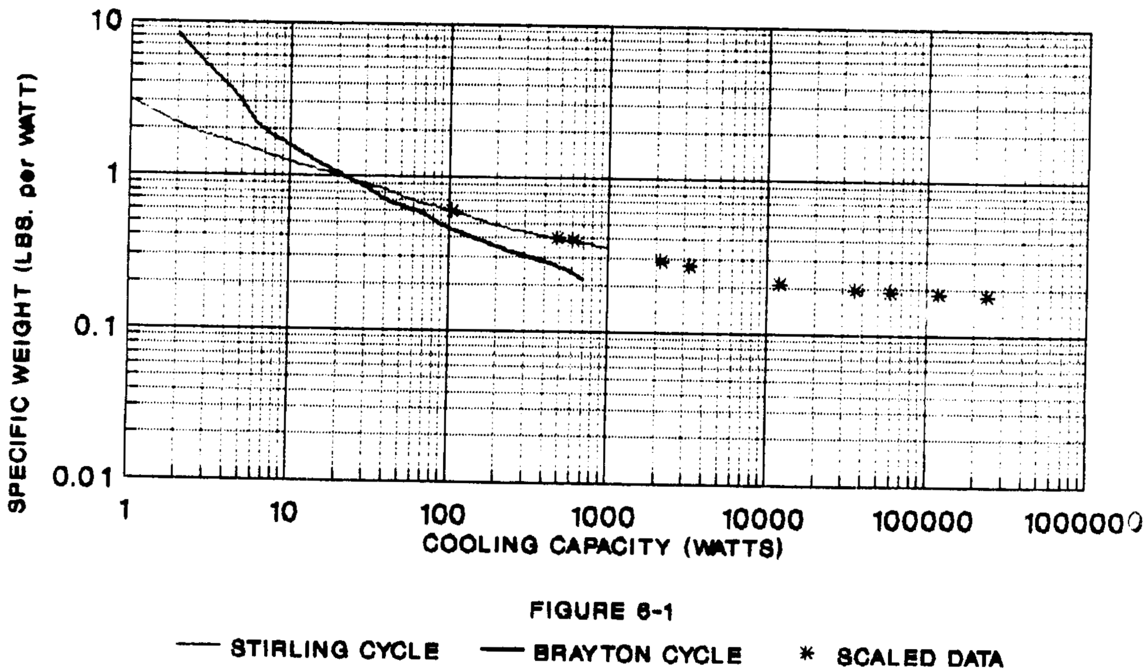

Figure 6-1. Cryocooler Specific Weight vs. Cooling Capacity

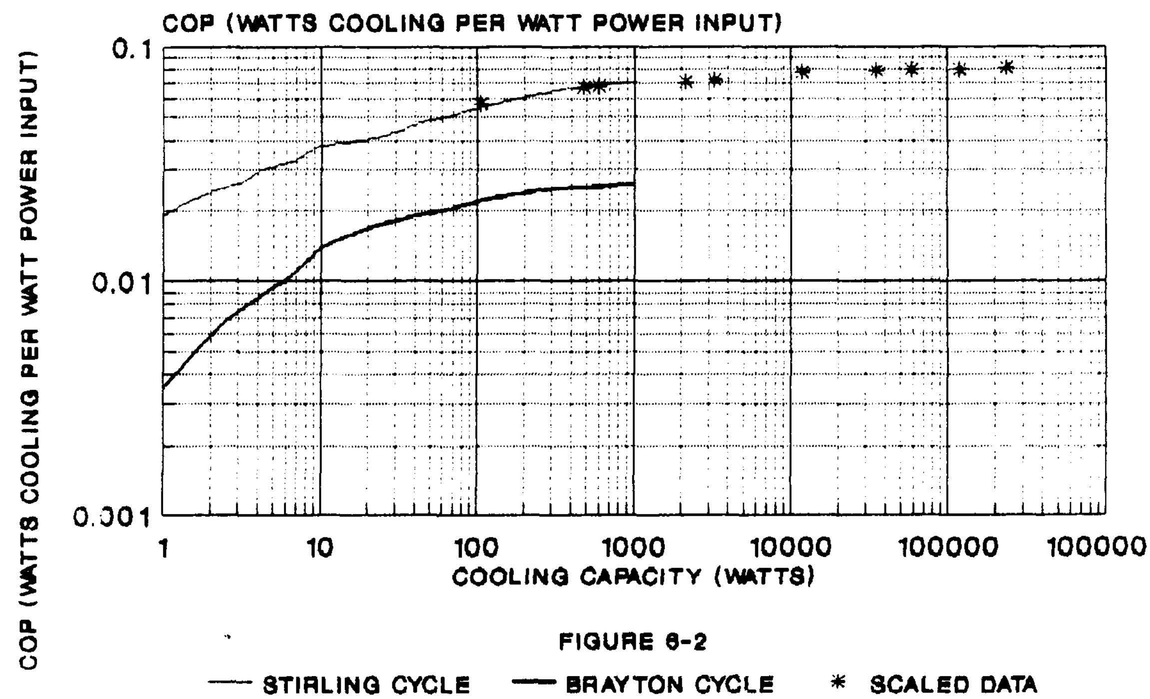

Figure 6-2. Cryocooler Coefficient of Performance vs. Cooling

The specific weight data used ran from about 200 to 600 pounds of cryocooler per kilowatt of cooling required. The power input required to achieve the cooling effect ran from 12 to 18 kilowatts of power input required for each kilowatt of cooling required. Inversely then, the coefficient of performance (COP) is 0.056 to 0.083.

The cooling requirements from Collaborative Planners, Inc. were scaled and used to size the cryocooler designs shown in Table 6-1. Sizing was done using 100% power as the design requirement and thus this sizing shows that each cooling load required a relatively large power input to be supplied to the cryocooler system which is also relatively heavy.

Table 6-1 - Stirling Cycle Scaled Data Cryocooler Characteristics for HTS Applications. Superconducting Rotor and Stator Construction (SRASC) and Superconducting Rotor Only Construction (SROC)

	Helicopter Power Plant: Gas Turbine Maximum HP Rating at Sea Level					
	502 HP	3606 HP	13407 HP	502 HP	3606 HP	13407 HP
Key Items Summary	SROC Motor/Generator			SRASC Motor/Generator		
Cooling Required at Max Power (KW)	0.4742	3.229	11.773	0.104	0.596	2.124
Cooler Weight (LB)	190	872	2472	62.4	232	616
Power Input (KW)	7.075	44.85	150.9	1.825	8.765	29.92
Power Input (HP)	9.49	60.14	202.4	2.45	11.75	40.12

Table 6-2 shows that cryocooler system weights increase rapidly as electrical efficiency is reduced below the 99.9% level used in this study.

Table 6-2 - Cryocooler Characteristics for HTS Applications. Comparison at Lower Electrical Efficiency Levels Using the 7894 HP Case with Superconducting Rotor Only Construction (SROC).

Efficiencies (%)					
Motor	99.9	99.7	99.5	99.0	98.0
Generator	99.9	99.7	99.5	99.0	98.0
Cooling Required at Max Power (KW)	11.77	35.32	58.87	117.7	235.5
Power Input (KW)	151	447	740	1472	2907
Power Input (HP)	202	600	993	1973	3898
Cooler Weight (LB)	2472	7064	11185	21780	42383
Motor/Gen. Wt. (LB)	2908	2908	2908	2908	2908
TOTAL SYS. WT. (LB)	5380	9972	14093	24688	45291

7.0 - Expendable Refrigerant Concepts

Expendable cooling LN2 requirements and the equipment required was sized using a computer code written for this application. Liquid nitrogen was used as the expendable coolant and the mission average power was used to size the LN2 volume required. A system boiloff allowance was added to cover the potential heat gain by the tank, plumbing, and motor/generator structure. A spherical tank was chosen to minimize the outside surface area for a given volume of tank. The tank wall thickness of 70 mils was used to accommodate the system pressure and provide structural integrity. Urethane foam insulation was assumed to cover the LN2 storage tank and provide a thermal barrier to the surroundings. Thirty percent of the LN2 cooling volume was provided for tank pressurization space (ullage). Plumbing weights were estimated to be 25% of the tank weight.

Chilldown of the motor,generator, tank, plumbing and insulation was assumed to be done before the tank was topped off to minimize the LN2 needed to be carried in flight and only the amount of LN2 necessary for steady cooling and boiloff from tank heat gain would be supplied in flight.

An ambient air blower for cooling the SRASC motor/generator was also included and the size used is shown in Figure 8-2. The power for this blower can then be an electric motor drawing current from the electrical generator.

Table 7-1 provides a summary of expendable LN2 system sizing for all three power level applications. Some added benefit due to the LN2 use (weight loss) was accounted for in that the aircraft weight reduces throughout the mission due to the LN2 coolant expended for motor/ generator cooling.

Table 7-1 - Expendable Refrigerant Summary for Systems Using Superconducting Rotor and Stator Construction (SRASC) and Superconducting Rotor Only Construction (SROC).

Helicopter Power Plant : Gas Turbine Maximum HP Rating at Sea Level

KEY ITEMS SUMMARY	502 HP SROC Motor/Generator	3606 HP SROC Motor/Generator	13407 HP SROC Motor/Generator	502 HP SRASC Motor/Generator	3606 HP SRASC Motor/Generator	13407 HP SRASC Motor/Generator
Cooling Required At Max Power (KW)	0.4742	3.229	11.773	0.104	0.596	2.124
Flight Time (Minutes)	200	160	160	200	160	160
Mission Average Power Factor (% of Max Power)	47	51	51	47	51	51
LN2 Boil Off Margin (% LN2 Vol)	30	15	10	60	25	15
LN2 Volume (Cu Ft.)	0.764	3.99	13.93	0.206	0.801	2.63
Internal Tank Volume (Cu Ft.)	0.99	5.19	18.11	0.268	1.04	3.42
Internal Tank Radius (Inches)	7.43	12.89	19.07	4.79	7.54	11.2
External Tank Radius (Inches)	7.50	12.96	19.62	4.86	7.61	11.27
External Insul. Radius (Inches)	13.5	18.96	25.6	10.87	13.61	17.3
LN2 Weight (Lbs.)	38.5	201.3	702.1	10.39	40.39	132.0
Tank Weight (Lbs.)	14.01	40.03	96.5	5.88	14.5	31.8
Insulation Weight (LBS)	14.82	33.74	67.36	8.5	15.1	27.1
Plumbing and Valve Wt.(LBS)	3.5	10.5	24.12	1.47	3.62	7.95
Air Blower (LBS.)	None	None	None	75.0	81.0	93.0
Tot. Hdware. Weight (NO LN2) (LBS.)	32.33	86.28	188.0	90.9	114.0	160.0
Tot. Cooler Weight Inc. LN2 (LBS.)	70.83	287.6	890.0	101.2	154.6	292.3

Figure 7-1 shows the effects of cooling load on weight for the expendable LN2 cooling system hardware,the LN2 itself and the total of the two as a total system weight.

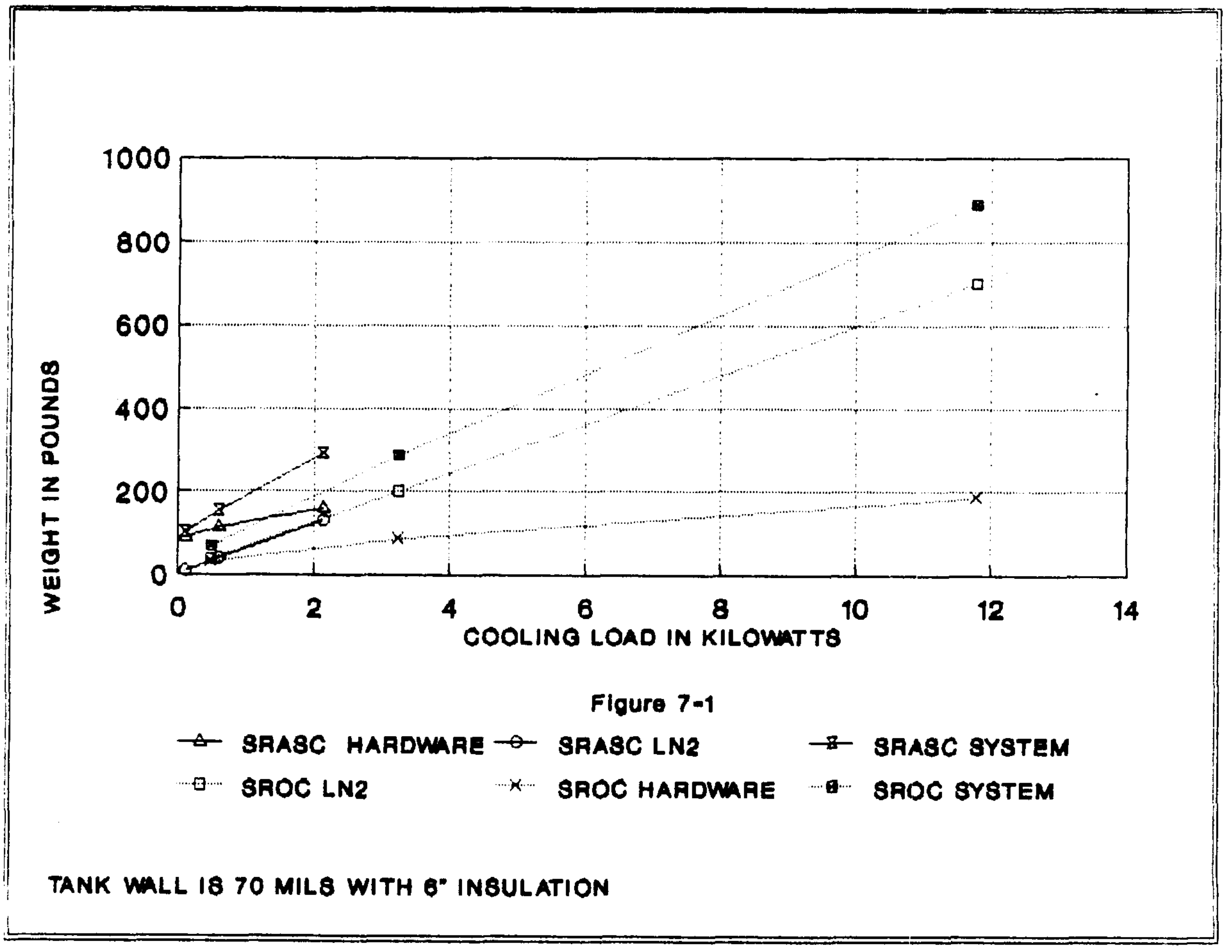

Figure 7-1. Expendable Refrigerant System Weight

Table 7-2 shows that expendable LN2 system weights increase rapidly as electrical efficiency is reduced below the 99.9% level used in this study.

Table 7-2 - Cooler System Weights for HTS Applications at Various Electrical Efficiency Levels using the 7894 HP Case with Superconducting Rotor Only Construction (SROC).

Efficiencies (%)					
Motor	99.9	99.7	99.5	97.0	98.0
Generator	99.9	99.7	99.5	97.0	98.0
Cooling Required at Max Power (KW)	11.77	35.32	58.87	117.7	235.5
Cooler Weight (LB)	890	2378	3863	7269	14261
Motor/Gen. Wt. (LB)	2908	2908	2908	2908	2908
Total System Wt. (LB)	3798	5286	6771	10204	17169

8.0 - Room Temperature HTS Systems

The development of room temperature superconductors could produce revolutionary changes in aeronautical propulsion systems. With room temperature (300K) superconductors, the LN2 cryogenic cooling system would no longer be needed. And cooling of room temperature superconductors would be accomplished with air supplied by a blower or fan.

Figure 8-1 shows the weights of air cooled HTS motor/generator propulsion systems for helicopters as a function of helicopter engine power. Figure 8-1 shows that the SROC weighs roughly 20 percent more than the SRASC over a considerable power range. The difference between the lower two curves in Figure 8-1 represents the weight of the blower system. And, as seen in this figure, the weight of the air blower is relatively small.

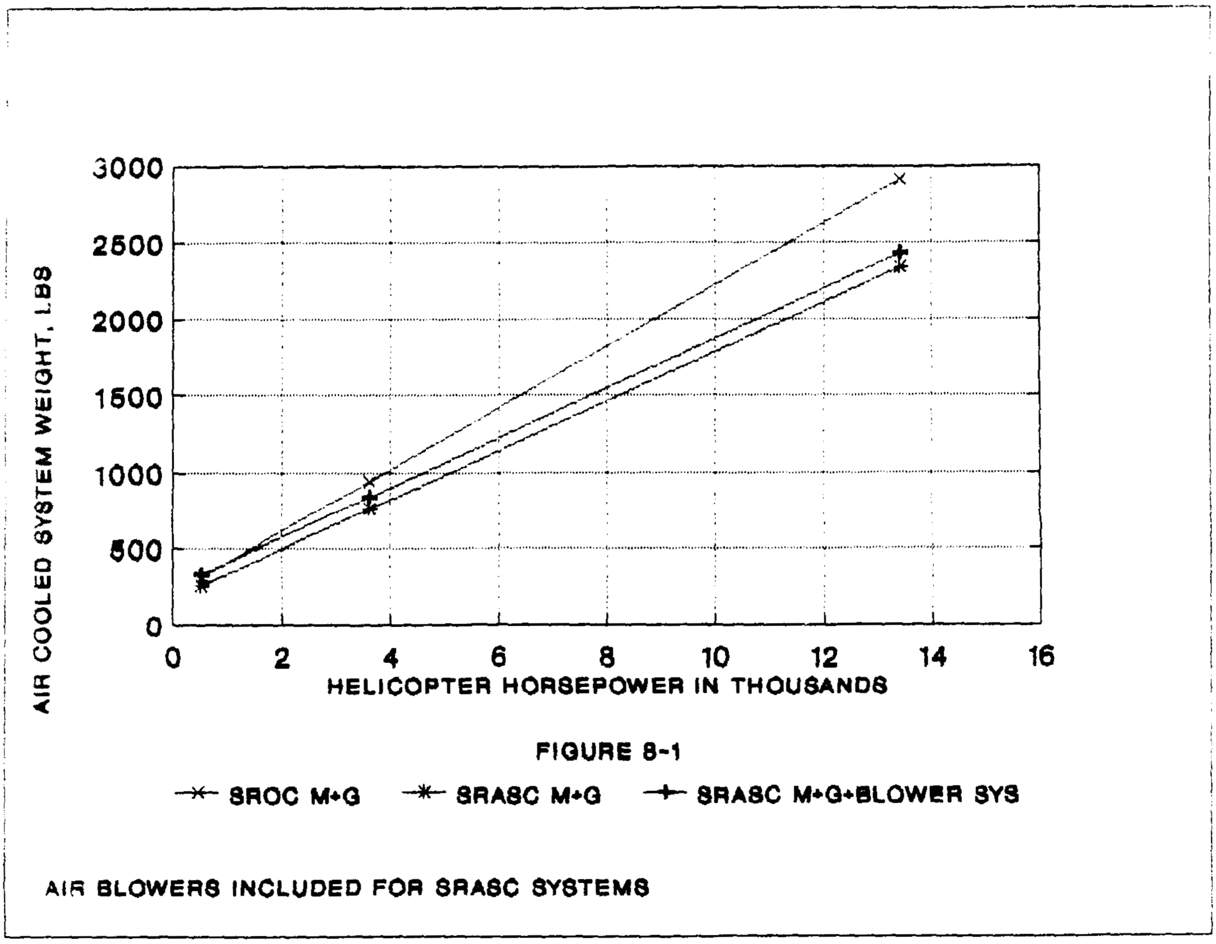

Figure 8-1. Room Temperature (300°K) HTS System Electric Motor Plus Generator Weight.

Figure 8-2 shows the electrical air blower weight. The blower system weights are for induction motors, blowers and ducting. The blowers and ducting were estimated to be 20% of the motor weight. Thus, the air cooling system weight is the sum of the these weights as shown in Figure 8-2.

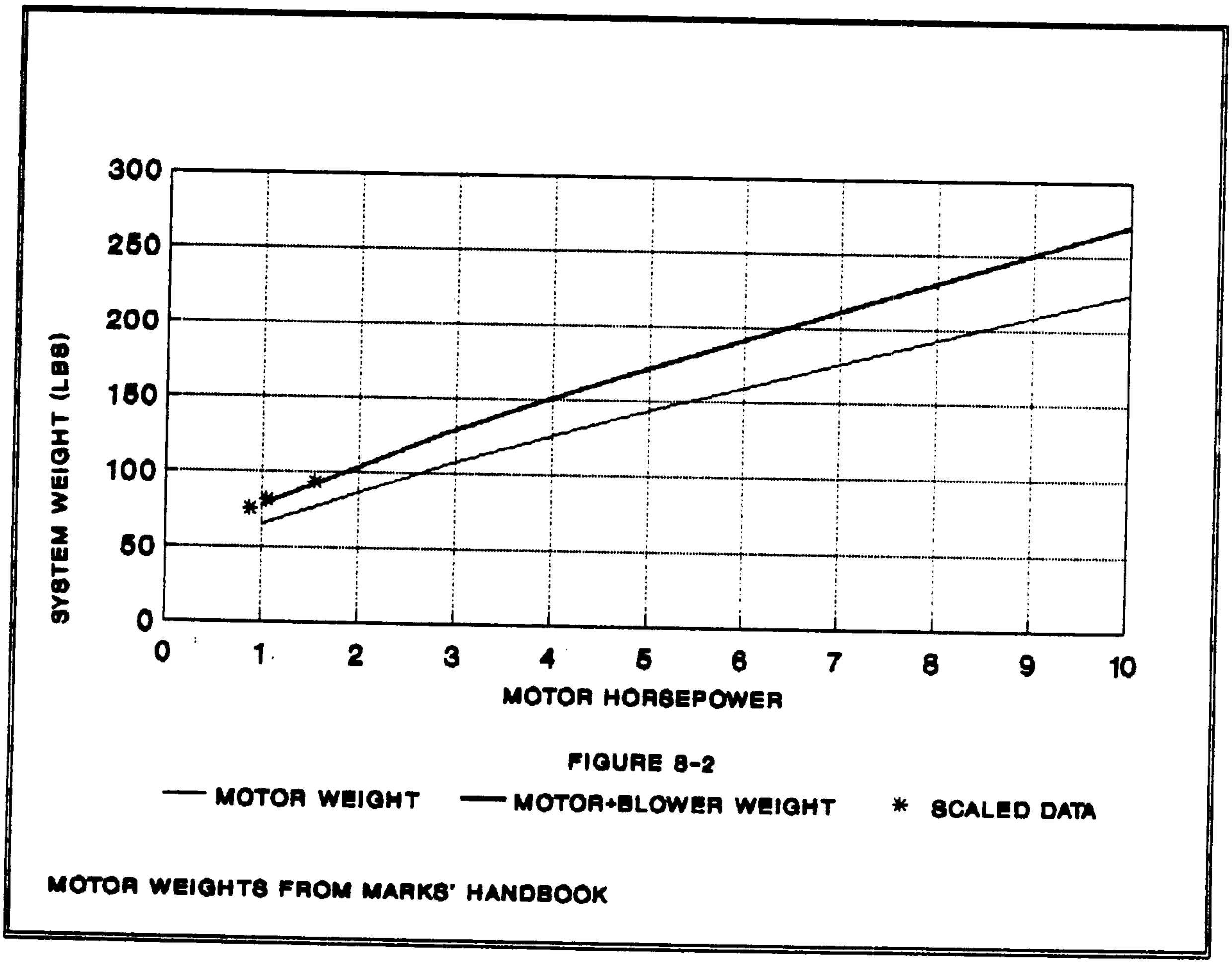

Figure 8-2. Cooling Air Blower System Weight - Induction Electric Motor and Air Blower.

9.0 - Mission Studies

Simulations using the Bell Jet Ranger, the Sikorsky Black Hawk and the Sikorsky Super Stallion helicopters were executed on the HESCOMP helicopter design and performance program to develop trade factors in the 500, 3000, and 13000 total shaft horsepower (SHP) range. The trade factors were developed for "rubberized" versions of the helicopters to show the total magnitude in terms of change in gross weight,fuel burned and delta SHP required due to a perturbation in transmission weight when the helicopter is designed to perform a given mission scenario.

The HESCOMP program scales all components of the helicopter's structure and propulsion system (except cabin size for a given payload requirement) to develop a new configuration with the same disc loading , radius/range capability,and design hover/rate of climb capability at the design sizing ambient altitude and temperature day. Trade factors can then be determined relative to the base configuration in the following manner: A change in transmission weight or power required (both simulated by multiplying factors) is made to the HESCOMP model and the mission is flown to determine the change on TOGW, fuel burned, and SHP requirements. These are used as the trade factors for that particular helicopter. Tables 9-1A, B, and C are the results of these HESCOMP mission "flights" and provide the basis for the trade factors. As noted previously, the results of these mission studies show the influence of engine weight and fuel flow perturbations of TOGW, required fuel weight and shaft HP.

Table 9-1A - AEP HESCOMP Trade Factor Study ... Bell Jet Ranger with Allison 250-C30 Engine.

	Base	+20% Eng. Wt.	-20% Eng. Wt.	-40% Eng. Wt.	+5% Fuel Flow	-5% Fuel Flow
Take Off Gross Wt. TOGW (Lbs.)	3117	3184	3052	3000	3170	3065
Total Engine WT. (Lbs.)	178	218	140	103	181	176
Fuel Req'd (Lbs.)	539	547	531	530	570	509
Delta TOGW (%)	Base	+2.150	-2.085	-3.754	+1.700	-1.668
Delta TOGW (Lbs.)	Base	+67	-65	-117	+53	+52
Delta Engine Wt. (Lbs.)	Base	+40	-38	-75	+3	-2
Delta Fuel Req'd (%)	Base	+1.48	-1.48	-1.67	+5.75	-5.57
Delta Fuel Req'd (Lbs.)	Base	+8	-8	-9	+31	-30
Max. Shaft Horsepower	502	512	492	485	510	494
Delta Shaft Horsepower (%)	Base	+1.99	-1.99	-3.39	+1.59	-1.59

Table 9-1B - AEP HESCOMP Trade Factor Study ... UH-60 Black Hawk with GE T-700 Engines

	Base	+20% Eng. Wt.	-20% Eng. Wt.	-40% Eng. Wt.	+5% Fuel Flow	-5% Fuel Flow
Take Off Gross Wt. TOGW (Lbs.)	16747	17210	16363	15969	17091	16471
Total Engine WT. (Lbs.)	872	1075	682	500	890	859
Fuel Req'd (Lbs.)	2135	2191	2089	2040	2283	1998
Delta TOGW (%)	Base	+2.765	-2.293	-4.645	+2.054	-1.648
Delta TOGW (Lbs.)	Base	+463	-384	-778	+344	-276
Delta Engine Wt. (Lbs.)	Base	+203	-190	-372	+18	-13
Delta Fuel Req'd (%)	Base	+2.62	-2.15	-4.45	+6.93	-6.42
Delta Fuel Req'd (Lbs.)	Base	+56	-46	-95	+148	-137
Max. Shaft Horsepower	3606	3702	3526	3445	3677	3589
Delta Shaft Horsepower (%)	Base	+2.66	-2.22	-4.46	+1.97	-1.58

Table 9-1C - AEP HESCOMP Trade Factor Study ... CH-53 Super Stallion with T65-GE-415 Engines.

	Base	+20% Eng. Wt.	-20% Eng. Wt.	-40% Eng. Wt.	+5% Fuel Flow	-5% Fuel Flow
Take Off Gross Wt. TOGW (Lbs.)	49022	50405	47741	46525	50103	48012
Total Engine WT. (Lbs.)	2204	2718	1718	1256	2252	2159
Fuel Req'd (Lbs.)	6066	6235	5917	5774	6491	5669
Delta TOGW (%)	Base	+2.82	-2.61	-5.09	+2.21	-2.06
Delta TOGW (Lbs.)	Base	+1383	-1281	-2497	+1081	-1010
Delta Engine Wt. (Lbs.)	Base	+514	-486	-948	+48	-45
Delta Fuel Req'd (%)	Base	+2.79	-2.46	-4.81	+7.01	-6.54
Delta Fuel Req'd (Lbs.)	Base	+169	-149	-292	+425	-397
Max. Shaft Horsepower	13407	13779	13062	12735	13697	13135
Delta Shaft Horsepower (%)	Base	+2.77	-2.57	-5.01	+2.16	-2.03

The baseline helicopter configurations were obtained from the actual geometric characteristics of each helicopter and the weight delta was taken from detailed weight breakdowns furnished by the helicopter contractors. Mission profiles were those developed for previous U.S. Army contracted TAGG-M propulsion system studies at Pratt & Whitney. Rotor drive system weights and power requirements used in this study were from the HESCOMP computer program information and are shown in Table 9-2.

Table 10-4 shows power train performance as well as the TOGW for the hardware weight changes and the TOGW due to the power extraction differences. Additional weight changes due to the differences in power use were calculated and are also shown on table 10-4.

Table 9-2 - HESCOMP Weight and Horsepower Summary

HELICOPTER WEIGHT SUMMARY (LBS.)	Bell Jet Ranger 206-B-JR3	Sikorsky Black Hawk UH-60A	Sikorsky Super Stallion CH-53E
Take Off Gross Weight (TOGW)	3117	16747	49022
Engine(s)	178 (1)	872 (2)	2204 (3)
Drive Systems:			
Main Rotor	182	1387	5731
Tail Rotor	25	97	872
Total	207	1484	6603
HELICOPTER HORSEPOWER SUMMARY (HP)			
Engine (s) Maximum Rating at Sea Level	502	3606	13407
Power Rating** Total at Rotors	353	2469	9178
Main Rotor	318	2165	7894
Tail Rotor	35	304	1284
Accessories	33	100	153
Main Rotor Transmission Losses (3%)	11	74	283

**WHEN SIZED FOR THE FOLLOWING CONDITIONS PER MISSION SPECIFICATIONS :
BELL 206B POWER RATING AT 95% MAX POWER, 95°DAY, 2000 FT., 300 FPM CLIMB.
SIK. UH-60 POWER RATING AT 95% MAX POWER, 95°DAY, 4000 FT., 500 FPM CLIMB.
SIK. CH53-E POWER RATING AT 95% MAX POWER, 95°DAY, 4000 FT., 500 FPM CLIMB.

10.0 - Weight, Power, Performance and Cooling Audits

Table 10-1 shows the weights of the key components of the study which were calculated and provides an overview of the study results. The system weights were obtained from compiling all the individual weights from the individual contributors as were the power extractions shown on Table 10-2.

Table 10-1 - HTS System Weights Key Items Summary

	Helicopter Power Plant : Gas Turbine Maximum HP Rating at Sea Level					
	502 HP	3606 HP	13407 HP	502 HP	3606 HP	13407 HP
KEY ITEMS SYSTEMS WEIGHTS AUDIT (LBS.)	SROC Motor/Generator			SRASC Motor/Generator		
Gas Turb. Engines	178	872	2204	178	872	2204
Power Drive Train						
1. Mechanical Sys.						
A. Main Rotor	182	1387	5731	182	1387	5731
B. Tail Rotor	25	97	872	25	97	872
Total Train	207	1484	6603	207	1484	6603
2. HTS Systems :						
A. Closed Loop						
Cryocooler	190	872	2472	62	232	616
Motor/Gen.	309	943	2908	250	758	2334
Total C/Loop	499	1815	5380	312	990	2050
B. Expendable LN2						
Tank	14	40	97	6	14	32
Insulation	15	34	67	9	15	27
Plumbing	4	11	24	1.0	4.0	8.0
Fan	none	none	none	75	81	93
Motor/Gen.	309	943	2908	250	758	2334
Hardware Tot.	341	1029	3096	341	872	2494
LN2	39	201	702	10	40	132
Total Expend.	380	1230	3798	351	912	2626
C. Air Blower SYS						
Fan/Blwr/Duct	none	none	none	75	81	93
Motor/Gen	309	943	2908	250	758	2334
Total Air cool	309	943	2908	325	839	2427
3. WEIGHT CHANGE FROM BASE (1A.)						
a. C/Loop System	317	428	-351	130	-397	-2781
b. Expnd LN2 Sys	198	-157	-1933	169	-475	-3105
c. Air Cooled Sys	127	-444	-2823	143	-548	-3304

Table 10-2 - HTS System Power Extraction Key Items Summary

Helicopter Power Plant : Gas Turbine Maximum HP Rating at Sea Level

KEY ITEMS POWER AUDIT (HORSEPOWER)	502 HP	3606 HP	13407 HP	502 HP	3606 HP	13407 HP
	SROC Motor/Generator			SRASC Motor/Generator		
Power Requirement						
Maximum to Main	318	2165	7894	318	2165	7894
Maximum to Tail	35	304	1284	35	304	1284
Maximum Total	353	2469	9178	353	2469	9178
Main Rotor Power						
1. TRANSMISSION						
A. Mech Drive (3% Loss)	9.54	64.95	236.8	9.54	64.95	236.8
B. HTS Conduit (0% Loss)	Negl.	Negl.	Negl.	Negl.	Negl.	Negl.
2. HTS Sys. Rqmts						
A. Closed loop (Crycool Pwr)	9.49	60.14	202.4	3.32	12.79	41.66
B. Expend LN2 (Air Fan)	none	none	none	0.874	1.04	1.54
C. Air Cool fan	none	none	none	0.874	1.04	1.54
3. HTS-Mech Loss						
A. Closed loop	-0.52	-4.81	-34.4	-6.21	-52.2	-195.2
B. Expend LN2	-9.54	-65.0	-237.0	-8.66	-63.9	-235.0
C. Air Cool fan	-9.54	-65.0	-237.0	-8.66	-63.9	-235.0

The values shown have been scaled to the required horsepower conditions from those supplied by the individual contractors where necessary. Table 10-1 shows weights for the gas turbine engines used in the three helicopters selected for this study. The values shown are the total engine weights for the aircraft. The power drivetrain weights shown have been apportioned to the main and tail rotor systems by HESCOMP. The total weights shown for the closed loop cryocooler systems are those scaled values needed for replacing the main rotor drive with an HTS motor/generator, cryocooler and air blower system where required. The total weight shown for the expendable LN2 system includes HTS motor and generator, the supporting equipment and a full tank of LN2.

The total weights shown for the air cooled fan (room temperature 300°K HTS) option are those scaled values needed for replacing the main rotor drive with an HTS motor, generator and an air blower where needed.

Item 3 on Table 10-1 shows the weight change from the base mechanical main drive system made by replacing it with an HTS system to transmit main drive system power from the gas turbine engine to the main rotor of each helicopter.

Table 10-2 shows a power audit of the key items used in this study. Maximum power requirements are shown for the main and tail rotors. The main rotor values are the horsepowers used for designing the HTS systems to replace the conventional mechanical system. Power transmission losses are shown for each system but not for the HTS systems since they are considered negligible. All the HTS system power requirements are shown but the most significant power usages are the ones needed to drive the cryocoolers for the lower efficiency (99.9%) SROC motor generators. Item 3 on Table 10-2 shows the power usage differences between the mechanical and the HTS systems; the mechanical losses are for geared transmissions while the only significant HTS losses are for the cryocoolers.

Table 10-3 shows the scaled HTS motor/generator cooling load requirements (type A.and B.losses) as well as the motor/generator efficiencies relative to these losses.

Table 10-3 - HTS Electrical System Cooling Requirements Key Items Summary

Helicopter Power Plant: Gas Turbine Maximum HP Rating at Sea Level

Helicopter Power Plant: Gas Turbine Maximum HP Rating at Sea Level

	502 HP	3606 HP	13407 HP	502 HP	3606 HP	13507 HP
KEY ITEMS	SROC Motor/Generator			SRASC Motor/Generator		
COOLING						
SYSTEM AUDIT						
Efficiencies (%)						
Motor	99.9	99.9	99.9	99.98	99.98	99.98
Generator	99.9	99.9	99.9	99.98	99.98	99.98
Cooling Required						
Max Load (KW)	0.474	3.229	11.77	0.104	0.597	2.12
Max Load (HP)	0.636	4.33	15.79	0.140	0.80	2.85

Table 10-4 provides a drive system performance comparison of specific power (HP/LB) for the conventional mechanical systems and the HTS systems. Also included in this table are the TOGW changes related to each of the systems. The weight changes are presented in pounds and in percent of TOGW. The effects of system weight and power on TOGW are shown separately. Figure 10-1 shows the helicopter TOGW changes due to each HTS system. The HTS changes can be seen to be beneficial at helicopter horsepowers above about 1000 HP. But for the SROC with cryocooler, HTS is not a good choice at any power level under 11000 HP. The expendable LN2 and the room temperature HTS SROC systems become competitive from 2000 to 3000 HP where the helicopter TOGW begins to drop.

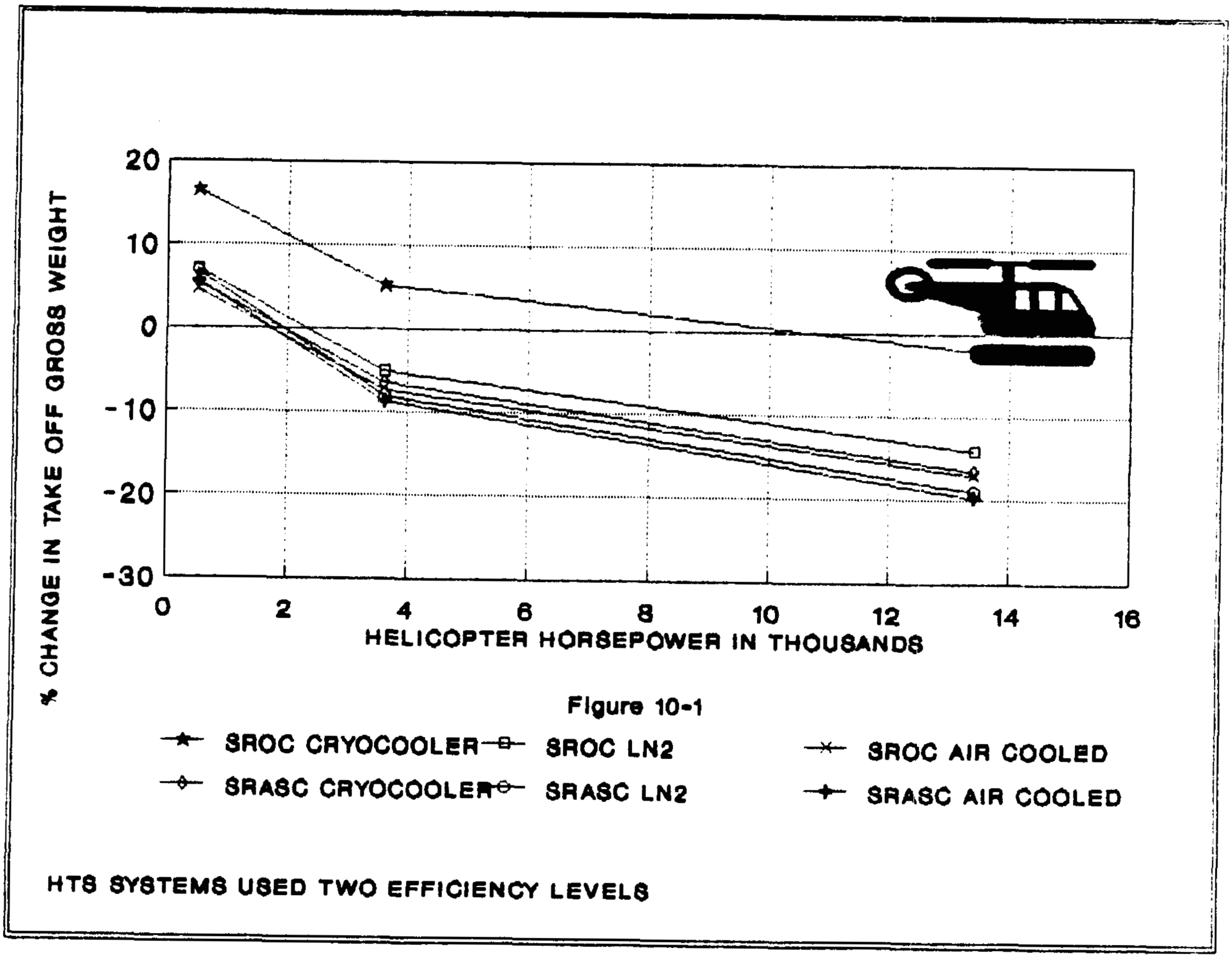

Figure 10-1. Helicopter TOGW Comparisons vs. Power HTS Replacement of Main Rotor Drive.

Table 10-4 - HTS System Performance and TOGW Key Items Summary

Helicopter Power Plant : Gas Turbine Maximum HP Rating at Sea Level

KEY ITEMS	502 HP	3606 HP	13407 HP	502 HP	3606 HP	13407 HP
		SROC Motor/Generator			SRASC Motor/Generator	
MAIN ROTOR DRIVE						
PERFORMANCE						
Specific Power (HP/LB)						
1. Mechanical Sys	1.747	1.561	1.377	1.747	1.561	1.377
2. HTS Systems						
a. C/Loop System	0.637	1.193	1.467	1.019	2.187	2.676
b. Expnd LN2 Sys	0.887	1.917	2.290	0.919	2.427	3.084
c.Air Cooled Sys	1.029	2.296	2.715	0.978	2.580	3.253
TOGW CHANGE (LBS)						
Due to Changes In System Weight						
a. C/Loop System	517	907	-930	212	-842	-7370
b. Expnd LN2 Sys	288	-546	-6053	267	-1049	-8403
c. Air Cooled Sys	207	-941	-7481	233	-1162	-8756
Due to Changes In Power Used						
a. C/Loop System	-0.3	-23.1	-128	-41.7	-251	-726
b. Expnd LN2 Sys	-64.2	-313	-881	-58.2	-308	-875
c. Air Cooled Sys	-64.2	-313	-881	-58.2	-308	-875
Due to Changes in Weight and Power						
a. C/Loop System	516	884	-1058	170	-1093	-8096
b. Expnd LN2 Sys	223	-859	-6933	209	-1357	-9278
c. Air Cooled Sys	143	-1254	-8362	175	-1470	-9631
TOGW CHANGE (%)						
Due to Changes In System Weight						
a. C/Loop System	16.5	5.4	-1.8	6.7	-5.0	-15.0
b. Expnd LN2 Sys	9.2	-3.2	-12.3	8.5	-6.2	-17.1
c. Air Cooled Sys	6.6	-5.6	-15.2	7.4	-6.9	-17.8
Due to Changes In Power Used						
a. C/Loop System	0.0	-0.1	-0.2	-1.3	-1.5	-1.4
b. Expnd LN2 Sys	-2.0	-1.8	-1.7	-1.8	-1.8	-1.7
c. Air Cooled Sys	-2.0	-1.8	-1.7	-1.8	-1.8	-1.7
Due to Changes In Weight and Power						
a. C/Loop System	16.5	5.2	-2.1	5.4	-6.5	-16.5
b. Expnd LN2 Sys	7.1	-5.1	-14.1	6.7	-8.1	-18.9
c. Air Cooled Sys	4.5	-7.4	-17.0	5.6	-8.7	-19.6

Figures 10-2 and 10-3 show the actual system weights for both the SROC and the SRASC motor/generator construction. The mechanical drive system weight is also included to give a reference for the conventional system weight which the HTS systems would replace. These figures also show that some HTS system weights are beneficial relative to mechanical drive system weights at helicopter power levels of about 1000 HP.

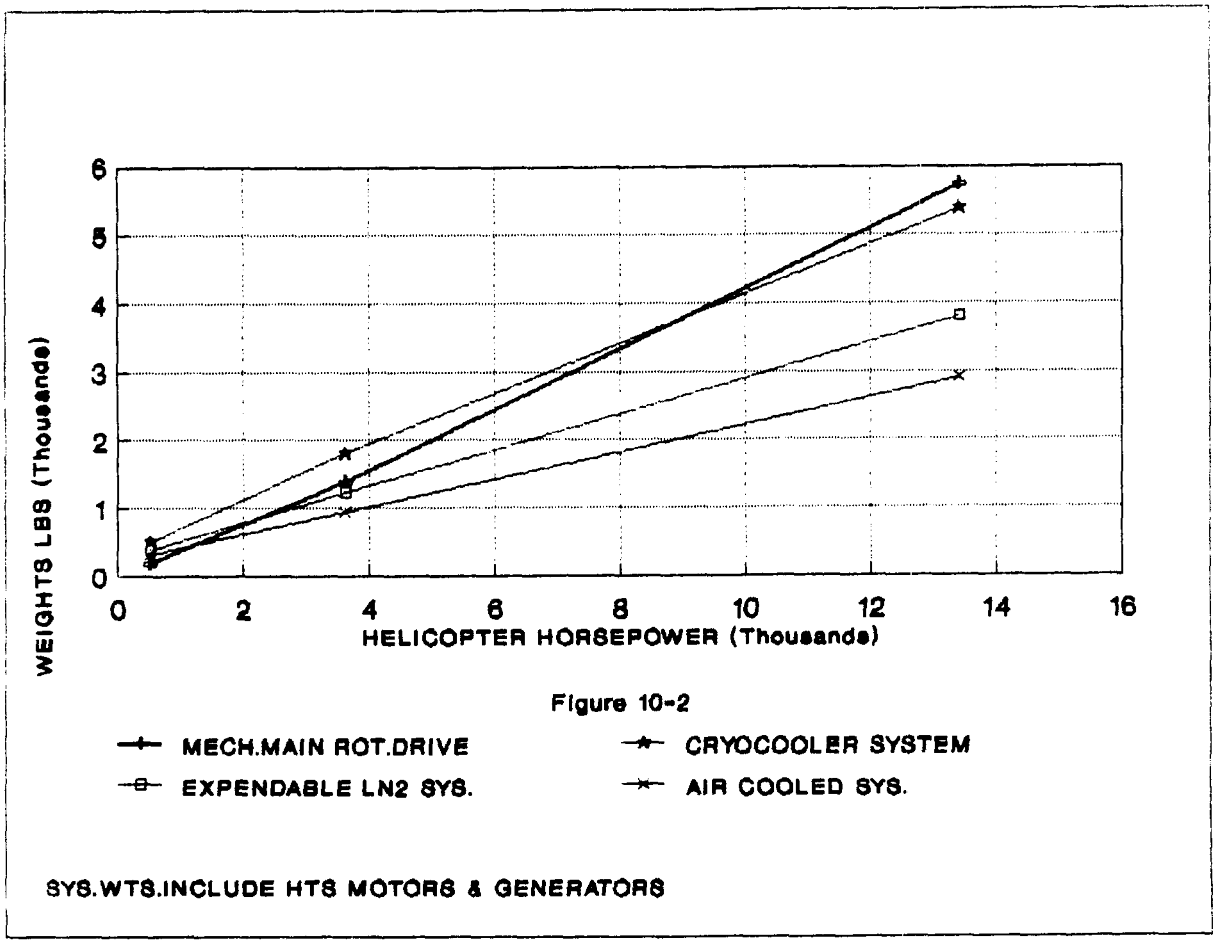

Figure 10-2. HTS SROC and Mechanical Drive System HTS Replacement of Main Rotor Drive.

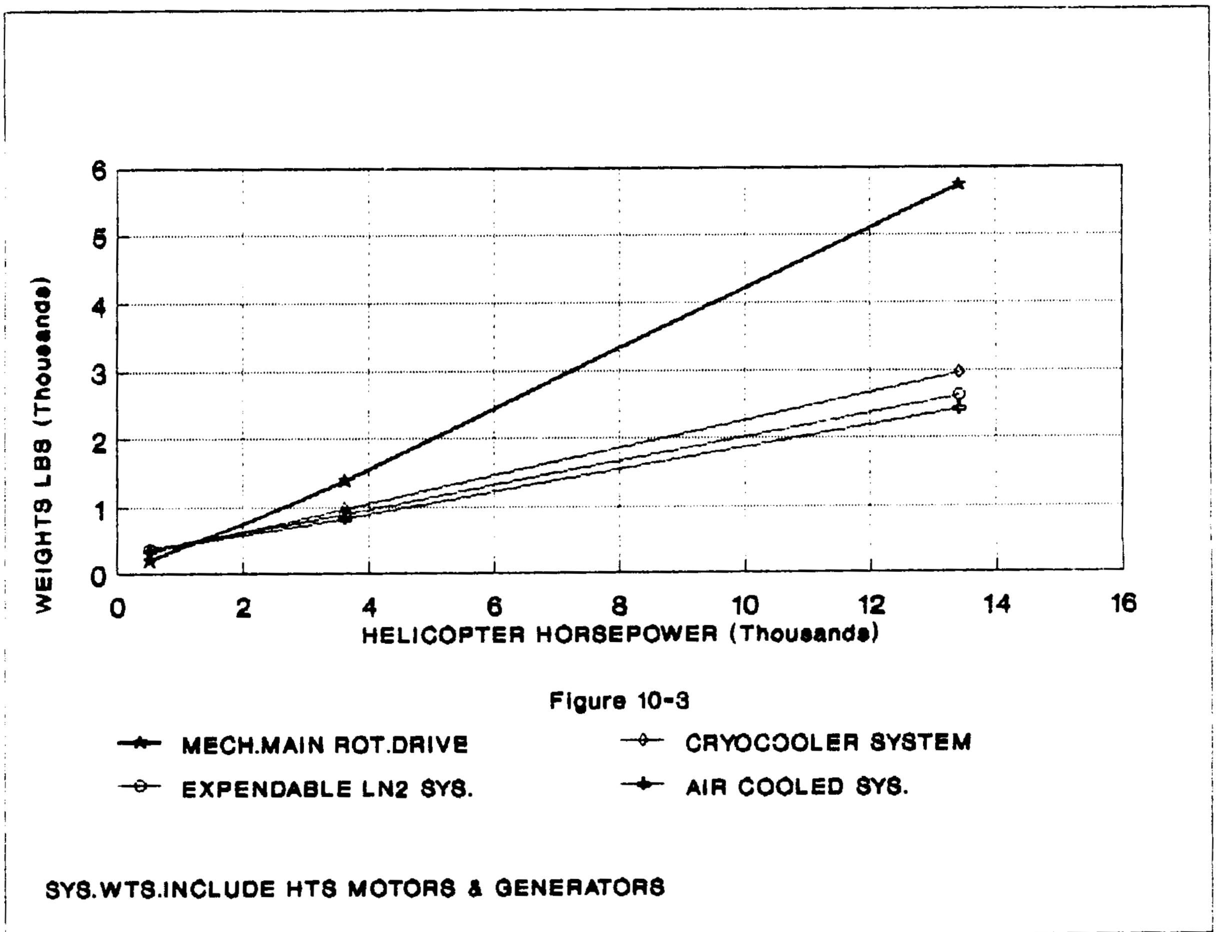

Figure 10-3. HTS SROC and Mechanical Drive System HTS Replacement of Main Rotor Drive.

11.0 - Conclusions and Recommendations

Figure 10-1 shows that the HTS concept has weight benefits when applied to a helicopter drive system. The best applications (negative changes in TOGW) are the larger horsepower ones as can be seen in the 3000 and the 13140 HP cases where a take off gross weight saving is apparent. The closed loop refrigeration systems are too heavy for all cases except the high horsepower, high efficiency ones. The expendable LN2 and the air cooled (300°K HTS) are applicable to lower horsepower helicopters with air cooled being the most widely acceptable for the helicopters in this study.

The original power sizing requirements were chosen as the gas turbine power horsepower ratings. As the study progressed, two observations changed the initial electric motor/generator sizing requirements. The first was that the HTS power transmission equipment in the lower horsepower sizes would be heavier than mechanical transmission equipment so the HTS driven tail rotor motors which require relatively little power would not be beneficial except perhaps for the CH-53E which could go either way depending of motor efficiency and cooling methods. This lowered the initial power requirements by from 10% to 14%. Then as the study progressed a second major observation was that the mission studies showed the main rotor maximum power use was from only 59 to 63% of the maximum gas turbine power so the sizings were scaled down to the mission required levels of main rotor horsepower.

Electrical efficiencies used in this study are quite high (99.9% and 99.9+%) and thought to be attainable by the year 2000; however, some questions naturally arise about what the effects lower efficiencies would have on the results of this study. Consideration was given to this in Figure 11-1. which shows that for the largest aircraft the HTS room temperature (aircooled) system is a good choice in terms of weight compared to mechanical drives at the lower efficiencies. However, the LN2 system becomes too heavy at efficiencies below 99.5% and the cryocooler system is too heavy even at 99.7%.

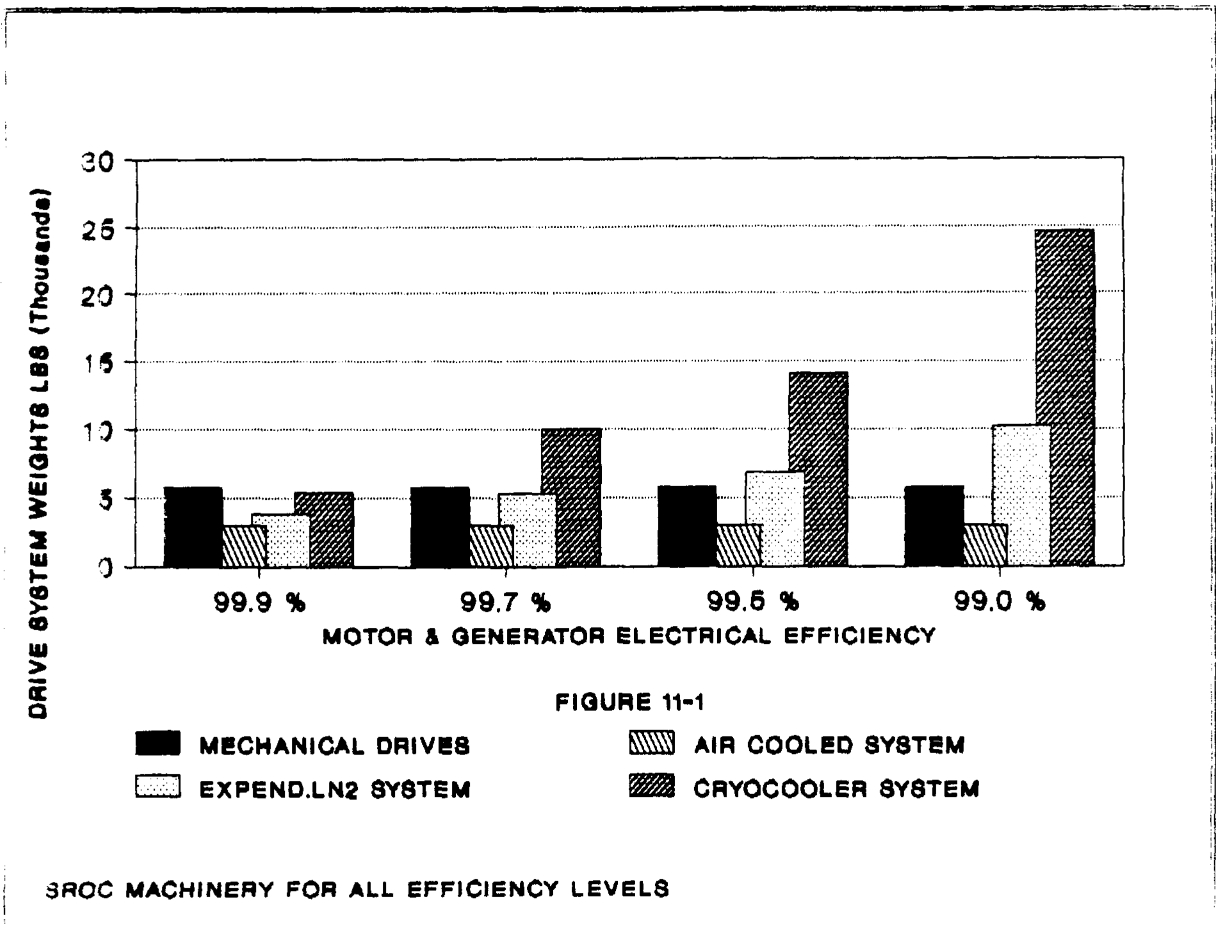

Figure 11-1. Largest Helicopter Drive System Weights for Systems with Lower Efficiency Levels.

Information gained from this study suggests that any future efforts should begin with a preliminary design for a large helicopter with tail rotor power requirements greater than 500 HP so that it may be a candidate for an HTS tail rotor motor as well as a main rotor motor. Cooling candidates should include cryocoolers, and expendable LN2. For room temperature superconductors, an air blower may be used for cooling.

12.0 - List of Abbreviations

SYMBOL	UNITS	UNITS
BTU	British Thermal Unit	BTU
COP	Coefficient of Performance for Cooling	Watts/Watt
C/Loop	Closed Loop Refrigeration System (Cryocooler)	
CPI	Collaborative Planners ,Inc.	
CU FT	Cubic Feet	CU.FT.
CU M	Cubic Meter	CU.M.
D	Change (Delta)	
($000)	Thousands of Dollars	Dollars
ENG.	Engine	
ETA	Motor or Generator Efficiency	
EXPND.	Expendable	
FPM	Feet per Minute	FT/Min.
FT	Feet	Feet
G	Generator	
HESCOMP	Helicopter Computer Sizing Program	
HP	Horsepower	Horsepower
HR	Hours	Hours
HTS	High Temperature Superconductor	
IN	In	Inches
K	Thermal Conductivity	BTU FT/HR/SQ. FT./°F
°K	Absolute Temperature	Deg. Kelvin
LB(S)	Pound(s)	LB
KW	Kilowatt	Kilowatts
LN2	Liquid Nitrogen	
M	Motor	
MAX.	Maximum	
MIL	Thousandths of an Inch	In/1000
MIL-STD	Military Standard	
MPH	Miles per Hour	Miles/Hour
NEGL	Negligible	
%	Percent	
REQ'D	Required	
RPM	Revolutions per Minute	RPM
SP.WT.	Specific Weight	LB./Watt
SP.POWER	Specific Power	HP./LB
SRASC	Superconducting Rotor and Stator Construction	
SROC	Superconducting Rotor Only Construction	
SYS.	System	
TAD	Technology availability date	
TOGW	Take Off Gross Weight	Lbs or %
TOT.	Total	
UTRC	United Technologies Research Center	
WT	Weight	LBS.

13.0 - References

1. *National Bureau of Standards Technical Note 129A, "The Thermodynamic properties of Nitrogen from 114 to 540° R Between 1 and 3000 PSIA", T.R.Strobridge NBS February 1963.*

2. *Aviation Week & Space Technology, "Forecast & Inventory Specifications" March 9,1981.*

3. *MIL-STD-1374A, Bell Helicopter Textron ,"Group Weight Statement for the Model OH-58A Helicopter", Undated.*

4. *MIL-STD-1374A, Sikorsky Aircraft ,"Group Weight Statement for the Model UH-60A Helicopter", October 12,1987.*

5. *MIL-STD-1374A, Sikorsky Aircraft ,"Group Weight Statement for the Model CH-53E Helicopter", October 12,1987.*

6. *Aviation Week & Space Technology, "Forecast & Inventory Specifications" , March 14, 1988.*

7. *Meeting Notes, "Requirements for Task 009", Meeting at NASA Lewis Research Center among NASA, Collaborative Planners, Inc. and Pratt & Whitney. December 7,1988.*

8. *Pratt & Whitney Memorandum, "Design Speeds for Helicopter Application" J.Doernbach, March 6,1989.*

9. *Collaborative Planners,Inc. Progress Letter #1. containing Motor /Generator Sizes for the 500 and 3000 HP Cases ,March 29,1989.*

10. *Pratt & Whitney Trade Factor Study "Sikorsky UH-60A Black Hawk Trade Factor Study" W.J.Grunske and B.E.Trembly, April 6,1989.*

11. *United Technologies Research Center Memorandum "Cryocooler Characteristics for HTS Applications, Frank Biancardi, April 6,1989.*

12. *Pratt & Whitney Trade Factor Study "Bell 206B Jet Ranger Trade Factor Study" W.J.Grunske and B.E.Trembly, May 5. 1989.*

13. *Pratt & Whitney Trade Factor Study "Sikorsky CH-53E Super Stallion Trade Study" W.J.Grunske and B.E.Trembly, June 1,1989.*

14. *Materials Engineering Volume 78 No. 4 , "1974 Materials Selector" Reinhold Publishing Co.,Inc. Stamford Conn. September 1973.*

15. *Collaborative Planners,Inc.Feasibility Study "Superconducting Power Transmission for Helicopters" June 1989.*

16. *Marks' Mechanical Engineers' Handbook, McGraw-Hill Book Company New York, 1958.*

17. *UTRC supplied reference :"Cryocoolers",Graham Walker, Plenum Press New York, 1983. This includes references to 1971 NASA report by Jensen et.al. and to a NBS report by Strobridge.*

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National Aeronautics and Space Administration

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15. Supplementary Notes

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16. Abstract The successful development of high-temperature superconductors (HTS)could have a major impact on future aeronautical propulsion and aeronautical flight vehicle systems. Applications of high-temperture superconductors have been envisioned for several classes of aeronautical systems, including subsonic and supersonic transports, hypersonic aircraft, V/STOL aircraft, rotorcraft and solar powered aircraft.

The study presented herein examines the potential of HTS electric motors and generators for providing primary shaft power for rotorcraft propulsion. Three different sized production helicopters were investigated; namely, the Bell Jet Ranger,the Sikorsky Black Hawk and the Sikorsky Super Stallion. These rotorcraft have nominal horsepower ratings of 500, 3600, and 13400, respectively.

Preliminary results from this study indicated that an all-electric HTS drive system produces an improvement in rotorcraft (TOGW) for those rotorcraft with power ratings above 2000 horsepower. The predicted TOGW improvements are up to 9% for the medium-sized Sikorsky Black Hawk and up to 20% for the large-sized Sikorsky Super Stallion. The small-sized Bell Jet Ranger,however, experienced a penalty in TOGW with the all-electric HTS drive system.

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