

Advanced Rotorcraft Transmission Program – A Status Review

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American Gear Manufacturers Association



TECHNICAL PAPER

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Advanced Rotocraft Transmission Program

- A Status Report -

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ABSTRACT

Boeing Helicopters has been under contract with the U.S. Army Propulsion Directorate, Aviation Research and Technology Activity (AVSCOM), NASA Lewis Research Center, Cleveland, Ohio since 20 May 1988 to conduct the *Advanced Rotorcraft Transmission (ART)* Technology Integration Demonstration program. This program was structured to incorporate key emerging material and component technologies into an advanced rotorcraft transmission with the intent of making significant improvements in the State-of-the-Art (SOA).

Specific objectives of this program are:

1. Reduce transmission weight by 25% relative to SOA trends (currently in the range of 0.40 lb/hp).
2. Reduce transmission noise by 10 dB relative to SOA.
3. Improve transmission life and reliability, while extending Mean Time Between Removal (MTBR) to 5000 hours.

The effort undertaken by Boeing Helicopters has concentrated on high gain and comparatively high risk developments which can demonstrate these objectives prior to full-scale aircraft development. This paper will describe in some detail the work being conducted at Boeing Helicopters under the first phase of the *ART* program. This work included the selection of the Tactical Tilt Rotor (TTR) drive system and the development of plans for assessing advanced component technologies. The first phase of the *ART* program is approximately halfway completed and testing of components is in the very early stages. Since this program is in its initial implementation phase, this paper will present an overview of the planned program and a broad description of the major tasks to be accomplished.

INTRODUCTION

The *ART* program is structured in two phases. The first phase involves four contracts and is considered the preliminary design and component validation phase. This phase allows each contractor to develop advanced design concepts which incorporate key advanced technologies required to meet the *ART* program objectives. Trade studies and component test and evaluations will be conducted to support each design concept. The second phase will involve the selection of one or two contractors to conduct a demonstrator program.

The *ART* program is viewed as a means of providing the rotorcraft industry with a unique opportunity to advance the technology base for rotorcraft drive system via a path similar to that traditionally followed in engine development.

BACKGROUND

The Advanced Rotorcraft Transmission (*ART*) program is an Army funded, joint Army/NASA program to develop and demonstrate lightweight, quiet, durable drive train systems for the next generation rotorcraft. This program allows the participants, which include Bell Helicopter Textron, Inc., Boeing Helicopters, McDonnell Douglas Helicopter and Sikorsky, to evaluate key emerging material and component technologies and novel design concepts for advancing the technology of future rotorcraft transmissions. The specific objectives of *ART* include the reduction of drive train weight by 25 percent when compared to current state-of-the-art drive systems, a reduction of noise level at the transmission source by 10 dB and the attainment of at least a 5000 hour MTBR drive system.

The *ART* program allowed each participant to select one of the two distinct next generation aircraft classes to demonstrate their proposed advanced concept drive trains. The two classes of aircraft were:

1. Future Air Attack Vehicle (FAAV) - A 10,000 to 20,000 pound aircraft capable of undertaking tactical support and air-to-air missions.

2. Advanced Cargo Aircraft (ACA) - A 60,000 to 80,000 pound aircraft capable of heavy lift field support operations.

The work conducted by Boeing under the *ART* contract was to select a baseline transmission that is representative of a current state-of-the-art production design and then compare this design with an advanced configuration developed during this program. The *ART* program is designed to provide a high return on weight improvement, noise reduction and improved MTBR by developing novel concepts involving relatively high risk factors.

AIRCRAFT SELECTION

The Boeing Helicopters aircraft selection for this program was a Tactical Tilt Rotor (TTR) aircraft which met the requirements outlined for the FAAV (nominal gross weight of 10,000 to 20,000 pounds). The TTR is a small lightweight attack tilt rotor aircraft designed to be highly maneuverable and survivable. It is also applicable to counter air attack and air-to-air combat missions. Its primary mission gross weight is about 17,223 pounds.

In general the TTR drive system arrangement is similar to that of the V-22 Osprey aircraft. It is a twin engine configuration (see Figure 1) with one engine mounted in each wing tip nacelle and pivots with the rotors as on the V-22 aircraft. The engine size is in the 2400 SHP class. A candidate engine for this size was a growth derivative of the T700-701C. Some additional characteristics pertinent to the ART effort are given in Table 1 and Figure 2. Interconnect cross shafting is also required between the rotors and engines so that one engine may drive both rotors in the event of an engine failure. Specifics of accessory drives, APU, and details of the lube system (and cooling) are being developed and the transmissions will be designed to provide for 30 minutes of operation after lube loss or gear/shaft damage. In general all subsystems of the

TTR will provide both crashworthy and damage tolerant characteristics.

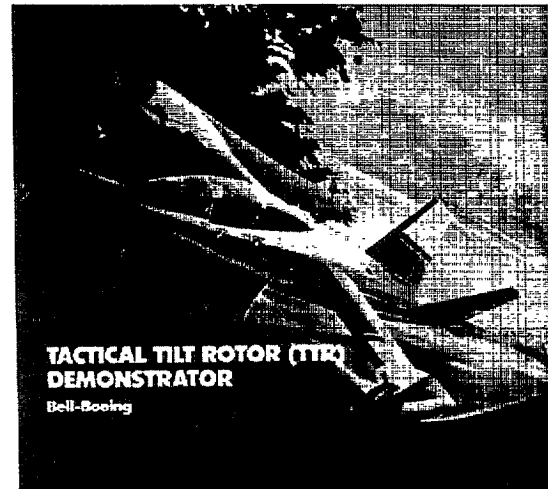


Figure 1. TTR - Artists Concept

Table 1. Baseline Aircraft Parameters

Primary Mission Gross Weight, Lbs	17,223.	
Structural Design Gross Weight, Lbs	16,155.	
Wing Span, Ft	36.2	
Wing Area, Ft ²	224.	
Wing Loading @ SDGW, PSF	72.	
Rotor Diameter, Ft	25.	
Disc Loading @ PMGW, PSF	17.5	
Number of Blades Per Rotor	3	
Rotor Solidity	0.117	
Engines	Two GE 700-701C	
Maximum Power SLS Installed, SHP	2019. (Each)	
Condition:	Cruise	Hover
Output Shaft Power Rating, HP	1955.	2444.
Transmission Input Rating (AEO), HP	1939.	2424.
Mast Output Torque, Ft-Lb	21,396.	21,396.
Main Rotor Speed, RPM	480.	600.

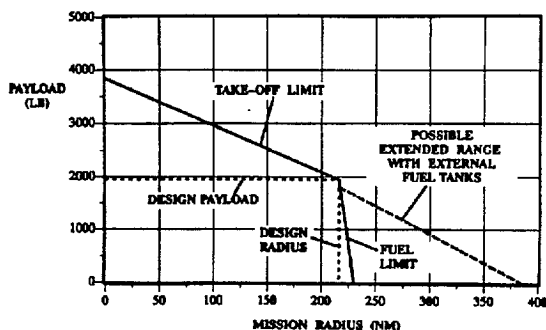


Figure 2. Baseline Aircraft Mission Performance

TRADE STUDIES

In order to evaluate the effect of Advanced Technology improvements on aircraft size and performance, computer programs were initially used to develop the reference aircraft design. In the early stage of this program a few key parameters were used to develop the drive system design. As the design progressed, detailed rotor and engine performance data were entered to improve the precision of the calculations. The program was used to discover broad trends early in the design process and it was also used to determine the effect of relatively small modifications once the design is more developed.

During the early development of the *ART* drive system, comparisons and trade studies were conducted between novel transmission configurations with high payoff potential. In addition to the configuration, advance technology features such as high temperature materials, novel gear and bearing designs, composites, and lubrication methods were also evaluated in achieving the goals of the *ART* Program. The Boeing Helicopters approach included the study of the following transmission configurations:

1. Selfaligning Bearingless Planetary (SABP) Configuration - The basic attributes of this configuration was the elimination of planet carriers and bearings and the static gear load cancellation through aligned gear meshes.

2. Split Torque Configuration - The basic attributes of this configuration was the multiple parallel torques load paths which provided design/flexibility in optimizing the gear mesh loads.

3. Conventional Single Stage Planetary Configuration - The basic attributes of this configuration was its compact geometric arrangement and an extensive experience with effective mesh load sharing.

Extensive studies were conducted of each of these configurations to establish weight trends, reliability factors and predicted noise characteristics. This data was compared with baseline data established for current state-of-the-art transmissions. For Boeing Helicopters, this baseline data was the CH-47 and YUH-61 drive systems. Upon completion of the various comparisons and trade studies, a selection methodology was developed to rank the three configurations. The results of this selection process are summarized in Figure 3 and discussed in detail below.

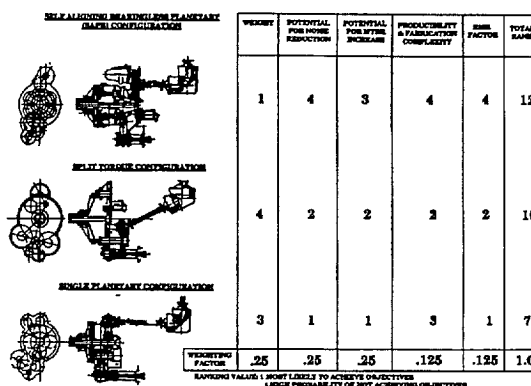


Figure 3. Total Ranking - Selection Methodology

1. Selfaligning Bearingless Planetary Configuration

The low weight (0.306 lb/HP) and reduced number of bearings of this configuration appear to be the most significant advantages of this design. All other ranking factors are considered very high for achieving the objectives of the *ART* program. The critical indexing of three gears on each of six planet spindles appears to be the major concern of this design. Problems with current gear manufacturing would make this requirement hard to achieve. In addition, any indexing problems would result in high noise and vibration and unknown dynamic loads. Although planetary bearings are eliminated, a new type of bearing problem will be created by each spindle rotating within two sets of rings. Long-term performance of this concept is unknown. The potential for improving MTBR is also quite low for this design. Overall, this design offers many potential problems for

a relatively low return on benefits. Therefore, this design was not considered further.

2. Split Torque Configuration

Overall this design showed considerable promise in many areas except weight (0.340 lb/HP). The projected weight of this design appears to be the highest of all configurations studied. The biggest unknown with this configuration is the ability to split the torque uniformly (50/50) between the rotors under actual flight conditions. To ensure an even split, additional features would have to be added which would further increase weight (and number of components required) while reducing the other benefits. Therefore, this design was also rejected.

3. Single Stage Planetary Configuration

Based upon the proposed ranking methodology, this design appears to have the greatest potential for achieving all objectives of the *ART* program. Although the transmission trend weight (0.317 lb/HP) is not the lowest, it appears that further work could reduce the weight and achieve the desired goal of 0.30 lb/HP or less. The use of single and double helical gears would significantly reduce noise and vibration. Also, this configuration achieves the best improvement in MTBR when compared to the baseline. Although the system still has several potential problem areas, it still appears to provide the lowest risk path for achieving the overall objectives of the *ART* program when compared to the other configurations considered.

Based upon this evaluation, Boeing Helicopters selected the single stage planetary configuration as the TTR drive system concept most likely to achieve the *ART* program objectives. The basis for selection was a combination of weight, noise and reliability considerations. The basic configuration is shown in Figure 4. This configuration allowed the combination the extensive application of hybrid (ceramic rolling element), bidirectional tapered roller bearings; advanced gear and bearing materials; double helical planetary gear mesh; and helical gearing throughout the rest of the drive train. The speed reduction taken in the planetary stage, at roughly 5.1:1, is slightly higher than typical rotorcraft planetary reductions which are usually in the range of 3 or 4:1. This configuration resulted in a lightweight compact design and high reliability gains are expected through a significant reduction in parts count.

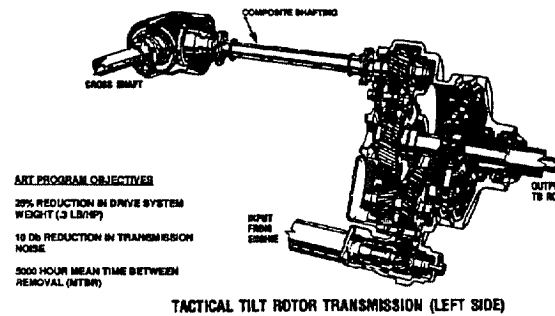


Figure 4. *ART* Program TTR Configuration

EFFECT OF TRANSMISSION IMPROVEMENTS

After the selection of the *ART* transmission, studies were conducted to determine what effects improvements in transmission weight would have on aircraft size, performance and operating cost. With the basic parameters of the baseline TTR aircraft established, it was possible to examine the effects on performance of the baseline vehicle by simply reducing the transmission weight without resizing the whole aircraft. Similar studies were also conducted to evaluate mission performance and expected aircraft flyaway cost based upon the expected improvement in the drive system only.

The aircraft performance was evaluated by retrofitting an existing baseline vehicle with the advanced transmission design. In this case, the empty weight reduction of the vehicle was used to increase the useful load capacity of the vehicle without increasing the gross take-off weight. This useful load increase can then be either applied to fuel or payload. If it is used to increase the fuel load, an extension of the radius of action can be achieved as shown in Figure 5. This figure illustrates a significant improvement in aircraft mission performance when compared with the original baseline data, as shown in Figure 2.

The second application of the advanced transmission technology is to apply the new design to a totally new aircraft design where the drive system benefits can be incorporated into the basic vehicle sizing. In this case, the reduced transmission weight has a spin-off effect with lower gross weight which can perform the same mission. The effect on major aircraft design parameters is illustrated in Figure 6. The advanced drive system contributes greatly to a reduction in vehicle gross weight and empty weight. Also, engine size can be reduced from 4038 HP to 3724 HP. The reduction in vehicle gross weight and engine power rating will factor into the acquisition cost of such a vehicle.