NASA
Technical Memorandum 103132

AVSCOM
Technical Memorandum 90-C-006

Transmission Research Activities at NASA Lewis Research Center

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Prepared for the
Helicopter Transmission Design and Maintenance Workshop
sponsored by the Canadian Department of National Defense
Quebec City, Canada, May 21-25, 1990

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SYSTEMS COMMAND
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(NASA-TM-103132) TRANSMISSION RESEARCH ACTIVITIES AT NASA LEWIS RESEARCH CENTER (NASA) 31 p CSCL 13I

N90-21394

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ABSTRACT

The NASA Lewis Research Center and The U.S. Army Aviation Systems Command (AVSCOM) are involved in a joint research program to advance the technology of rotorcraft transmissions. The program consists of analytical and experimental efforts to achieve the overall goals of reducing transmission weight and noise, while increasing life and reliability. The work includes in-house studies and tests, university grants, industry contracts, and joint programs with other military organizations. This paper highlights recent activities in the areas of transmission and related component research. Current areas include specific technologies in support of military rotary wing aviation, gearing technology, transmission noise reduction studies, a recent interest in gearbox diagnostics, and advanced transmission system studies. Results of recent activities are presented along with near term research plans.

INTRODUCTION

The NASA Lewis Research Center has had a strong research program for aircraft mechanical components since the early 1940's. The helicopter came into wide use as a military and commercial air mobile vehicle during the late 1940's to the late 1960's. By then the U.S. Army had a wide spectrum of helicopters in its inventory along with the requirement to increase their performance. The established capability in aerospace mechanical component research at Lewis was recognized as being applicable to helicopter transmissions.

Joint rotorcraft transmission research began in 1970 with NASA Lewis and the Army, and continues to the present (refs. 1 to 7). The major goals of the program were (and continue to be) to increase the life, reliability, and maintainability, reduce the weight, noise, and vibration, and maintain the relatively high mechanical efficiency of the drive train in helicopter transmissions. Lighter transmissions increase vehicle range, payload, and performance. Higher life and reliability produce safer operation and lower operating costs. Quieter transmissions increase pilot and passenger safety and comfort. The approach in achieving these goals was to identify advanced materials and lubrication schemes, as well as advanced design concepts for both transmission components and total transmission systems. Also, in-house and university grant efforts developed analytical codes for analysis and design. Unique experimental testing facilities were established at Lewis for testing mechanical components, materials, and lubrication techniques, as well as demonstrating advanced design concepts and verifying analytical codes.

The purpose of this paper is to review the current activities at Lewis on helicopter transmission research. The present major efforts at NASA Lewis consist of: research in support of military activities, basic research in gearing technology, a comprehensive transmission noise reduction program, a newly developed effort in transmission diagnostic research, and advanced transmission configuration studies. Results of recent activities are presented along with near term research plans.

TRANSMISSIONS
TECHNOLOGY REQUIRED FOR 1990's

REQUIREMENT	GOAL	BENEFIT
LIGHTER STRONGER	DRIVE TRAIN SPECIFIC WEIGHT .3 TO .5 LB/HP (CURRENTLY .4 TO .6 LB/HP)	INCREASED RANGE AND PAYLOAD
MORE RELIABLE	5000 HR MTBO (CURRENTLY 500-2000 HRS)	LOWER OPERATING COST AND SAFER OPERATION
QUIETER	70-80 db IN CABIN (CURRENTLY 100-110 db)	GREATER USE FOR COMMERCIAL COMMUTER SERVICE INCREASED PASSENGER AND PILOT COMFORT

CD-87-24948

C-87-1854

RESEARCH AREAS

- Military support
- Gear technology
- Noise reduction
- Diagnostics
- Advanced transmissions

SUPPORT OF MILITARY ACTIVITIES

Advanced Rotorcraft Transmission Program

The Advanced Rotorcraft Transmission (ART) program is an Army-funded, joint Army/NASA program to develop and demonstrate lightweight, quiet, durable drivetrain systems for next generation rotorcraft (ref. 8). Contract participants in ART include Boeing Helicopters, Sikorsky Aircraft, McDonnell Douglas Helicopter Company, and Bell Helicopter Textron, Inc. Some in-house technical support is also being provided at Lewis Research Center. ART addresses the general requirements of two distinct next generation aircraft classes: 1) Future Air Attack Vehicle, a 10 000 to 20 000 lb aircraft capable of undertaking tactical support and air-to-air missions; 2) Advanced Cargo Aircraft, a 60 000 to 80 000 lb aircraft capable of heavy lift field support operations. Both tiltrotor and more conventional helicopter configurations are included in the ART program. Specific objectives of ART included reduction of drivetrain weight by 25 percent compared to baseline state-of-the-art drive systems configured and sized for the next generation aircraft, reduction of noise level at the transmission source by 10 dB relative to the suitably sized and configured baseline, and attainment of at least a 5000 hr MTBR.

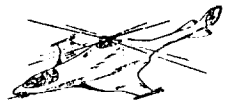
The technical approach toward achieving the ART goals includes application of the latest available component, material, and lubrication technologies to advanced concept drive trains that utilize new ideas in gear configuration, transmission concepts, and airframe/drivetrain integration. To date, candidate drivetrain systems have been carried to a conceptual design stage, and trade-off studies have been conducted resulting in selection of the ART transmission for each of the four participating contractors. The actual selection was based on comparative weight, noise, and reliability studies. Preliminary designs of each of the four selected ART transmissions have been completed, as have mission impact studies. Comparisons of aircraft mission performance and life cycle costs were undertaken for the next generation aircraft with ART and with the baseline transmission.

All four contractors have projected that the ART goals for weight, noise, and life are attainable. The transmission configurations chosen for ART varied between contractors, ranging from planetary systems to novel split-path and split-torque arrangements. All contractors deduced from the mission analysis that huge savings in life cycle costs could be achieved if an advanced transmission design is incorporated in the aircraft during development of the airframe. That is, a lighter transmission would allow a lighter airframe. This along with high transmission life and reliability projected large savings in acquisition and operating costs.

ADVANCED ROTORCRAFT TRANSMISSION

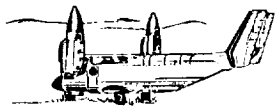
PROGRAM GOALS:
- 25% WEIGHT REDUCTION
- 10 dB NOISE REDUCTION
- 5000 HR MTBR

MILESTONES COMPLETED:
- TECHNICAL EVALUATION
- CONTRACT NEGOTIATIONS
- 4 CONTRACTS AWARDED



FUTURE ATTACK ROTORCRAFT (FAR)

ADVANCED CARGO AIRCRAFT (ACA)



FAR/ACA TILT ROTOR

CD-88-37452

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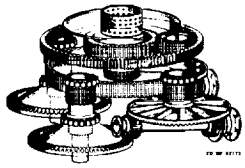
ADVANCED ROTORCRAFT TRANSMISSION (ART) CONTRACT McDONNELL DOUGLAS HELICOPTER COMPANY

MILESTONES COMPLETED:
- BASELINE AIRCRAFT & TRANSMISSION DESIGN GROUND RULES DEFINED.
- TRANSMISSION CONFIGURATION TRADE-OFF STUDY COMPLETED. SPLIT-TORQUE CONFIGURATION CHOSEN.
- AIRCRAFT MISSION ANALYSIS COMPLETED.

SPLIT-TORQUE TRANSMISSION



FUTURE ATTACK ROTORCRAFT

SIGNIFICANCE:
- ART GOALS OF WEIGHT, NOISE, & RELIABILITY ACHIEVABLE.
- SPLIT-TORQUE DESIGN OFFERS LARGE WEIGHT REDUCTION BENEFITS.
- TRANSMISSION ACQUISITION COSTS REDUCED BY 24%, DIRECT OPERATING COSTS REDUCED BY 33%.
- AIRCRAFT FLEET LIFE CYCLE COST SAVINGS OF $420M.

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SUPPORT OF MILITARY ACTIVITIES

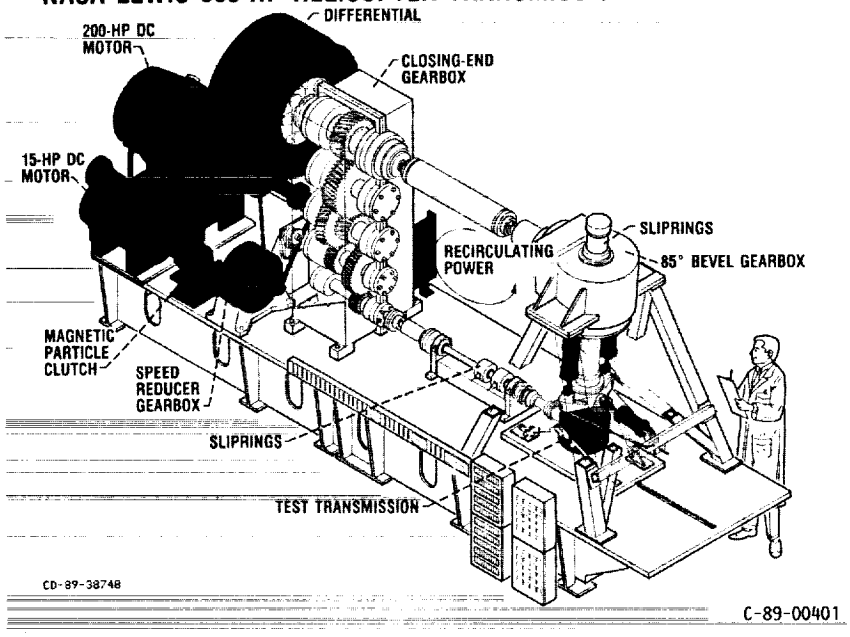
Advanced Lubricants Program

The objective of the joint Navy/NASA/Army Advanced Lubricant Program is to improve life and reliability of current helicopters and provide advanced technology for future designs by developing improved lubricants. Presently, a common engine and transmission oil is used in Army (and up until a few years ago, Navy) helicopters. The oil conforms to either a MIL-L-23699 or a MIL-L-7808 specification. The oil provides satisfactory lubrication for turbine engines but marginal performance for transmissions. Helicopter transmission overhauls show an increasing rate of bearing and gear rejections due to surface distress, corrosion, and wear (ref. 9). Due to this an ongoing Navy/NASA/Army lubricants program exists. The goal is to develop a separate transmission lubricant with improved load-carrying capacity, higher temperature capabilities, and corrosion resistance.

The Naval Air Propulsion Center is developing the advanced transmission lubricants. They have broken this down into three categories: 1) interim oil; an oil with improved gear load capabilities which was commercially available at the time and compatible with the MIL-L-23699 or MIL-L-7808 oils, 2) optimum oil; an oil specially developed for gearboxes with about twice the load carrying capacity as MIL-L-23699 and improved corrosion resistance, 3) advanced oil; a future gearbox oil with high load carrying capacity, high corrosion resistance, and high temperature capabilities. To date, the interim oil was established based on two readily available commercial products, resulting in the publication of a new specification for a transmission oil, DOD-L-85734 (AS), in 1986. Candidates for the optimum oil are currently being evaluated in laboratory and bench testing.

NASA Lewis and the U.S. Army Propulsion Directorate are supporting the program with their unique gear and transmission facilities. The effect of the lubricant on gear pitting fatigue life is being studied using the NASA Gear Fatigue Test Apparatus. Baseline oils have been evaluated (Hercolube A, MIL-L-23699, and MIL-L-7808) and advanced oils are planned to be tested and compared. In addition to the gear tests, full-scale transmission tests are being performed in the NASA 500-hp Helicopter Transmission Test Stand. The OH-58A helicopter main rotor transmission is being used for the tests. An experimental testing procedure is being developed to simulate transmission failures experienced by the Navy in the field. These failures include mast bearing micropitting, planet gear and bearing fatigue failures, and spiral bevel mesh scoring, all of which are related to the lubricant. The goal is to develop the testing procedure to fail the above-mentioned components in the OH-58A transmission using the baseline oil, then run identical tests with an advanced oil and demonstrate an improved performance.

NASA LEWIS 500-HP HELICOPTER TRANSMISSION TEST STAND



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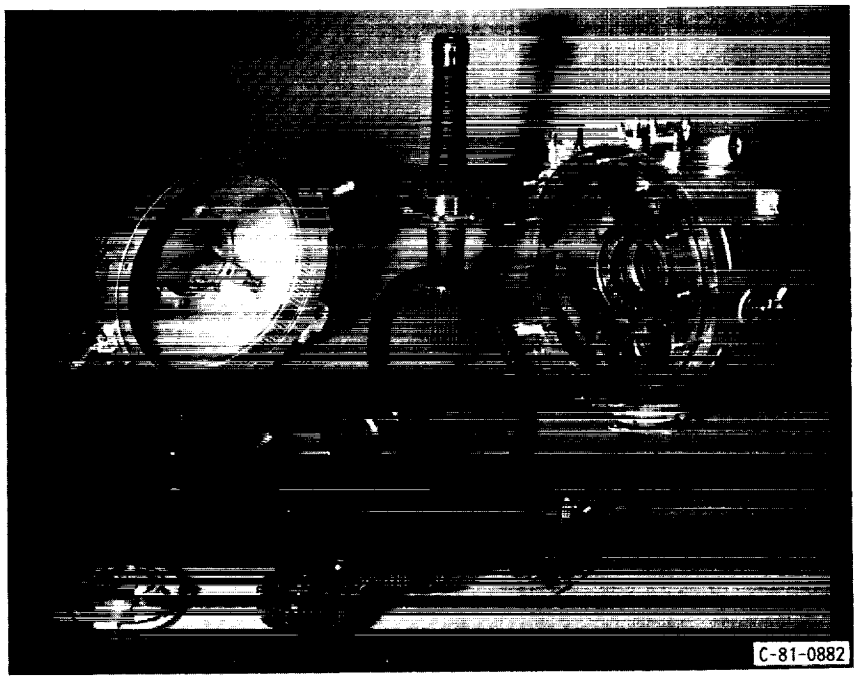
OH-58A TRANSMISSION



SUPPORT OF MILITARY ACTIVITIES

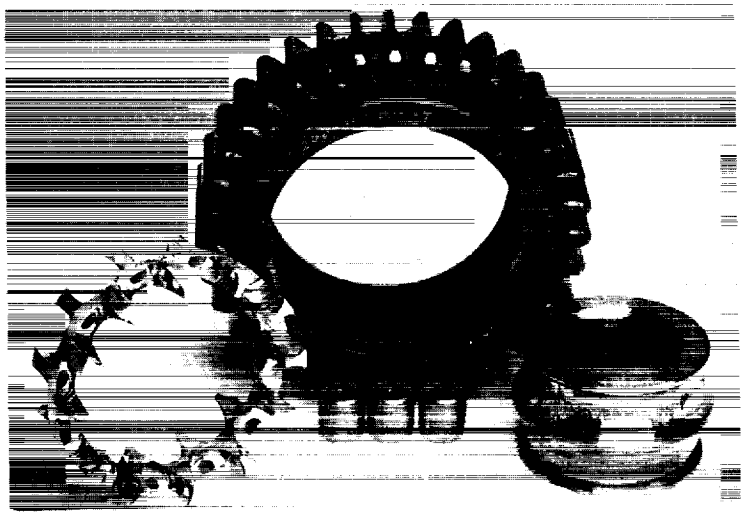
Advanced Lubricants Program (con't)

The experiments in the 500-hp test stand are in the "test development" stage. Parametric studies were performed on the OH-58A transmission to determine the effects of torque, speed, mast loading, oil temperature, oil pressure, and oil flow on transmission performance. Analyses were also performed on selected OH-58A components for stress, life, oil film thickness, and dynamic loads. Based on the analyses and parametric studies, a slight overload condition (117 percent torque and 100 percent speed) and high temperature (250 °F oil inlet temperature) were chosen for further experiments. Tests run under these tightly controlled operating conditions produced sun gear and planet bearing fatigue failures and a single case of a spiral bevel gear scoring/heavy wear failure. Subsequent tests were successful in reproducing the fatigue failures at these operating conditions. The scoring failure was not reproduced and methods to consistently induce this failure mode are being investigated.

A single case of OH-58A mast ball bearing micropitting was also produced in the 500-hp test stand. The micropitting was produced using a specially modified bearing. A standard mast bearing was disassembled and the balls were tumbled with silicon carbide to roughen the surface finish. The bearing was reassembled, installed in the transmission, and run at 100 percent design load with reduced oil flow using a modified oil jet. This produced a micropitting failure. This procedure is currently being investigated for repeatability.

After the complete test procedure is defined and lubricant-related failures are repeatably produced, advanced transmission lubricants conforming to the DOD-L-85734 specification will be evaluated. In addition, prime candidates for the optimum will be evaluated.

OH-58A PLANET GEAR/BEARING



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OH-58A SPIRAL BEVEL PINION

OH-58A MAST BALL BEARING

C-89-14572

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GEAR TECHNOLOGY

Spur Gear Pitting Fatigue Life Studies

Gear research began at NASA Lewis late in the 1960's. The work concentrated on materials and lubrication and established a unique data base in aviation applications. The NASA Spur Gear Fatigue Test Apparatus became operational in 1972, supplying valuable data on gear materials, lubrication, and life analysis. The goal is to improve life and reliability of aircraft gearing and maintain a data base on life for use by industry.

The standard gear material used in the aircraft industry today is AISI 9310, a high-alloy steel. With the ever-increasing trends of higher loads and higher temperatures, however, improved materials are desired to enhance aircraft transmission operational levels. The surface fatigue life for a variety of proposed materials have been evaluated using the NASA Lewis fatigue rig over the past two decades. Some of the materials tested were: Super Nitralloy (ref. 10), AISI M-50 (refs. 10 and 11), Vasco X-2 (ref. 12), CBS 600 (ref. 12), CBS 1000M (ref. 13), EX-53 (ref. 13), hot forged powder metal AISI 4620 and 4640 (ref. 14), and M50NiL (ref. 15). Vasco X-2 is a high temperature material currently used in the Boeing CH-47D helicopter transmission. EX-53 and M50NiL are also high temperature materials and are currently being proposed in some of the transmissions of the ART program. Gear surface fatigue strength and bending strength improvements by shop peening (ref. 16) as well as improved grinding methods (ref. 17) were also studied. In addition, lubricant and lubricant additives were found to significantly affect gear surface fatigue life (refs. 18 and 19).

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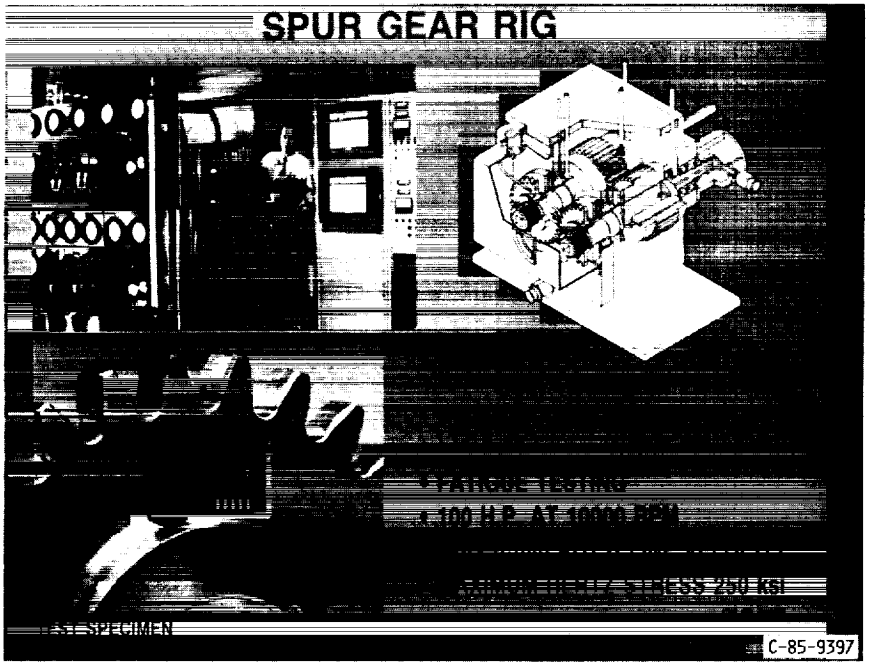
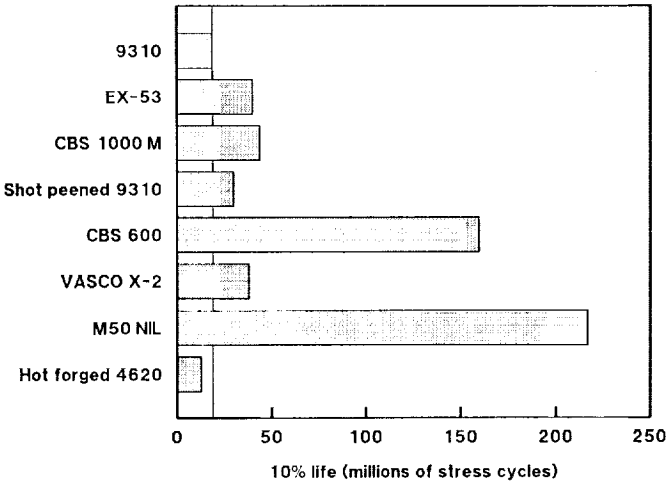


COMPARISON OF GEAR FATIGUE LIVES FOR DIFFERENT MATERIALS



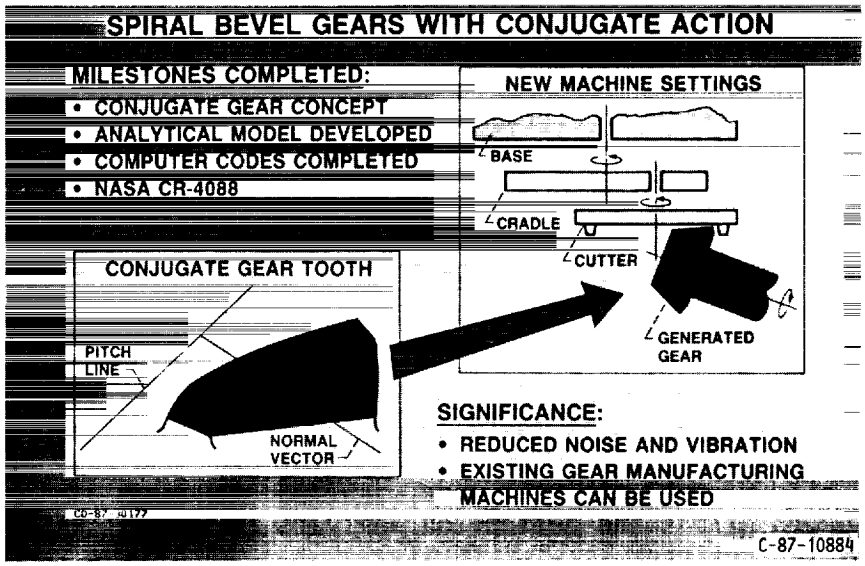
GEAR TECHNOLOGY

Gear Geometry

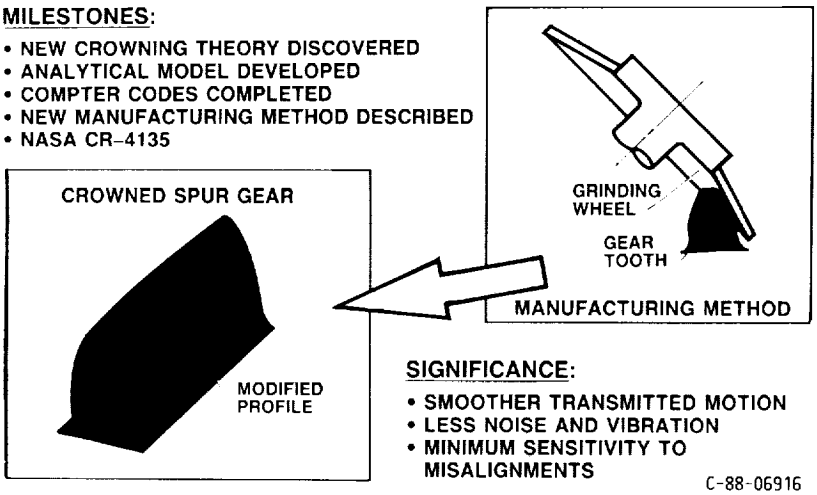
Spiral bevel gears are widely used in helicopter transmissions to transmit power between intersecting axes of drive shafts. For many years, the Gleason Works have provided the machinery for manufacturing spiral bevel gears. The machines are rigid and produce gears of high quality and consistency. The Gleason method of spiral bevel gear generation, however, generally does not provide conjugate gear tooth surfaces. Thus the gear ratio is not constant during tooth engagement and kinematic errors are present in the transformation of rotation from the driver gear to the driven gear. This has the potential of producing high vibration and noise. Under a NASA grant, a new analytical method of generation of spiral bevel gears using existing Gleason machinery was developed to eliminate kinematic errors (ref. 20). The basic idea behind this method is that the normal vector between contacting teeth surfaces maintains its orientation (intersecting the pitch line) while the teeth are in contact. This idea as an extrapolation of how spur gears provide conjugate action.

After further study, it was found that the above proposed method of generating spiral bevel gears produced gears with zero or nearly zero kinematic errors under no misalignment, but produced high kinematic errors when misalignment between the pinion and gear was introduced. In a parallel analytical study of spur gears, the transmission errors produced during misalignment were reduced by special crowning of the pinion tooth (refs. 21 and 22). Previous crowning methods were primarily concerned with improving bearing contact (i.e., avoiding edge contact), with little consideration for reducing transmission errors. The new method determines optimum geometry of a crowned pinion tooth surface to reduce the sensitivity to misalignment, locate the bearing contact, and minimize both magnitude and variation in magnitude of the transmission errors. This was accomplished by control of the manufacturing process for the pinion tooth surface. The manufacturing tool path creates a surface geometry whose axial section deviates slightly from an involute. The result is a gear mesh with a parabolic but continuous transmission error, rather than a stepwise discontinuous function. This would result in a smoother, quieter gear mesh when misalignment exists.

The opportunity exists to reduce noise for spiral bevel gear meshes with misalignment introduced by using nonconjugate gear pairs with a parabolic function of transmission error. A method to determine improved machine tool setting using existing Gleason machinery was developed (ref. 23). The results produced gears with tooth geometries that have parabolic transmission errors of a low level for various forms of misalignment. This method is currently being used to manufacture OH-58 spiral bevel gears to be tested in the NASA 500-hp test stand.



IMPROVED SPUR GEARS FOR AIRCRAFT APPLICATIONS



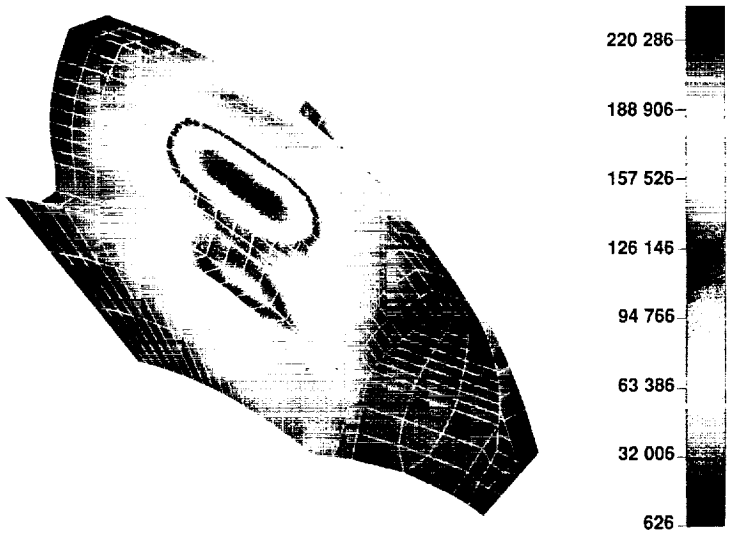
GEAR TECHNOLOGY

Spiral Bevel Gear Analysis and Experiments

Advanced analytical capabilities such as finite element analysis is becoming commonplace in the design and development of components for next generation rotorcraft. Using such techniques is not very straight forward for spiral bevel gears due to the complex tooth geometry considerations. Methods are being developed to use the gear geometry results for spiral bevel gears previously mentioned and merge the data with current finite element code (ref. 24). Tooth surface coordinates and curvatures are taken from the numerical solutions of the gear geometry problem. The load distribution on the spiral bevel gear tooth is currently an assumed pressure load over a region of the tooth surface. In the future the contact locations from a tooth contact analysis will be utilized. Also, as numerical methods for contact between three dimensional surfaces becomes available the contact between meshing spiral bevel pinion and gear will be simulated. The tooth coordinates and loading input to a commercially available solid modeling package, PATRAN, for pre- and post-processing. Currently, the finite element analysis code, NASTRAN, is being used. The result is an in-depth stress and deflection analysis for spiral bevel gears, a valuable tool for the designer.

To verify analytical predictions and to improve the basic understanding of spiral bevel gear operation, the NASA Spiral Bevel Gear Rig is being used. Currently, the facility is being configured to conduct transient temperature tests. The intention of the tests is to closely examine lubrication parameters such as oil temperature, flow, and oil jet orientation, and their effect on gear surface temperature. Surface temperature will be monitored using an infrared pyrometer system and bulk temperature will be monitored using rotating thermocouples. Critical parameters regarding efficient lubrication of high speed spiral bevel gear systems will be investigated and identified. After these tests, material effects on spiral bevel gear fatigue life will be studied. Spiral bevel gears manufactured from six different materials are available for testing. The results of these tests will be compared to the extensive data base collected for spur gears to see if correlation exists between parallel axis and spiral bevel gear life experiments.

SPIRAL BEVEL PINION
VON MISES STRESS



BEVEL GEAR RIG

TEST HEAD

TEST SPECIMEN

- FATIGUE TESTING
- LUBRICATION TECHNIQUES
- NOISE AND VIBRATION TESTING
- LOOP POWER OF 750 H.P. AT PINION ROTATIONAL SPEED OF 15000 RPM

CD-85-18247

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GEAR TECHNOLOGY

Gear Dynamics

Gear dynamic loading in rotorcraft transmissions is a result of a complex interaction between the various gears in mesh and also the dynamic properties of the bearings, shafts, housings, and masses in the system. Gear dynamic load is caused by the unsteady relative angular motion of gear pairs. It is the source of noise and can cause significant reduction in component life. In aerospace applications, gears and transmissions are designed close to their projected limits to reduce weight and size. This leads to highly loaded components, flexible structures, and a potential for high dynamic loads. A number of computer programs have been developed in an effort to predict parameters such as dynamic load, surface damage, and surface temperature, all integral factors in various gear failure modes.

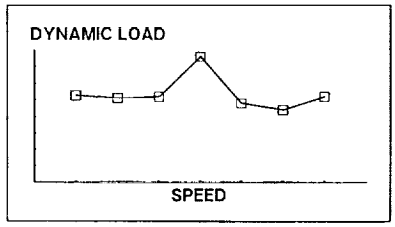
A comparison study was performed on four gear dynamic analysis computer programs developed under NASA/Army sponsorship (ref. 25). These programs are GRDYNMULT (a multimesh program applicable to a number of epicyclic systems), TELSGE (a single mesh program), PGT (a multimesh program applicable to a planetary with three planets), and DANST (a single mesh program). The capabilities and features, input and output options, and technical aspects of the programs were reviewed and compared. Parametric studies of the programs were performed to investigate the predicted results as input parameters such as speed, torque, and mesh damping were varied. In general, the programs predicted similar dynamic load and stress levels as operating conditions were varied. The program GRDYNMULT was found to be the most versatile in system size, type, and analysis capabilities. TELSGE provided the most detailed analysis on lubrication dynamics, yielding quantities such as film thickness, flash, and gear bulk temperatures with dynamic load effects included. DANST incorporated the most versatile tooth profile deviation routine, allowing the user to enter standard or user defined shapes and magnitudes.

Computer program DANST was further used to investigate the effects of both linear and parabolic tooth profile modifications on the dynamic response of low-contact-ratio spur gears (refs. 26 and 27). The dynamic loading response of unmodified (perfect involute) gear pairs was compared with that of gears with various profile modifications. The effects of the total amount of modification and the length of the modification were studied at various loads and speeds to find the optimal profile to minimize dynamic loading and noise. Normalized design charts were generated for gear systems operating at various loads and tooth modifications. The amount and type of tooth profile modification had a significant effect on the predicted dynamic response. Linear profile modifications produced the lowest dynamic loads when the gears operated at nearly a constant load. When the gears operated over a range of loads, parabolic profile modifications were preferred. Extremely accurate gears of various tooth profiles are currently being manufactured and the dynamic response will be tested and compared to the computer predictions.

COMPARISON STUDY OF GEAR DYNAMIC COMPUTER PROGRAMS

MILESTONES COMPLETED:

- FOUR NASA/ARMY DEVELOPED PROGRAMS EVALUATED.
- PROGRAM CAPABILITIES AND FEATURES COMPARED.
- PARAMETRIC STUDIES PERFORMED.
- NASA TP-2901.



GEAR DYNAMICS CODES:

DANST

GRDYNMULT

TELSGE

PGT

SIGNIFICANCE:

STRONG POINTS OF EACH PROGRAM IDENTIFIED:

DANST, MOST VERSATILE TOOTH PROFILE DEVIATION ROUTINE.

TELSGE, MOST DETAILED LUBRICATION DYNAMICS.

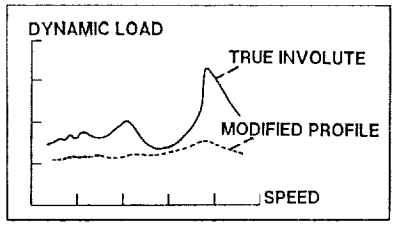
GRDYNMULT, MOST VERSATILE OVERALL.

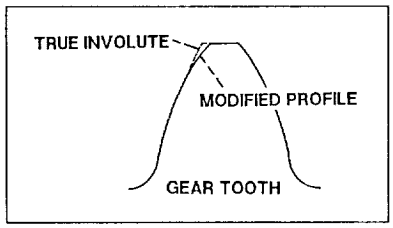
9008201

GEAR TOOTH PROFILE STUDIES

MILESTONES COMPLETED:

- COMPREHENSIVE ANALYTICAL STUDY OF EFFECT OF GEAR TOOTH PROFILE ON DYNAMIC LOADS COMPLETED.
- EXPERIMENTAL VERIFICATION PLAN ESTABLISHED; TEST GEARS ORDERED.
- NASA TM-89901, TM-101444.





SIGNIFICANCE:

- SLIGHT MODIFICATIONS OF THE GEAR TOOTH PROFILE PRODUCES SIGNIFICANT CHANGE IN DYNAMIC LOADS.
- DYNAMIC LOADS CAN BE SIGNIFICANTLY REDUCED THROUGH OPTIMIZED GEAR TOOTH PROFILES.

9008202

TRANSMISSION NOISE REDUCTION PROGRAM

Helicopter noise and vibration are important topics because of health and environmental concerns, passenger comfort, and pilot efficiency. As power increases so does the weight penalty associated with cabin soundproofing materials. This has led to an effort to reduce noise and vibration at their origin. Transmissions are the main source of noise in today's helicopter interiors, with the noise originating from the gear mesh. The goal of the NASA Lewis transmission noise reduction program is to reduce by 10 dB the gearbox noise in the next generation transmission for advanced rotorcraft (ref. 28).

The noise reduction program consists of a mixture of university grant activities and in-house analytical and experimental studies. As previously mentioned, extensive studies have been performed in gear dynamics with the goal of reducing gear dynamic loading which would lead to overall lower transmission noise. Also, work has resulted in the development of a finite element model of a geared rotor system with flexible bearings (ref. 29). A computer program was developed capable of calculating the natural frequencies, corresponding mode shapes, and the dynamic loads at various positions in the system when excited by mass imbalance, geometric eccentricities, and transmission errors.

An understanding of the interaction between the gear mesh and housing dynamics is a crucial step in the overall plan of reducing vibration and noise in rotorcraft transmissions. Several research activities at Lewis have focused on modeling the dynamics, transmissibility, and acoustics of a simple transmission. One study analyzed the dynamics of the gear housing from the NASA Gear Noise Rig using both finite element analysis and experimental modal analysis (ref. 30). Another study concentrated on the complex transmission of vibration through rolling element bearings and resulted in the development of a new methodology for modeling transmissibility of vibration (ref. 31). In addition, the acoustic intensity program BEMAP (Boundary Element Method for Acoustic Prediction) was adapted to predict the sound field of a gearbox (ref. 32). Near and far field acoustic intensity or sound intensity can be predicted for a gearbox using as input the housing dynamics determined from finite element analysis or experimental modal analysis.

These new computer codes and analyses will form an important design tool for meeting the noise reduction goals. As a method to verify the codes, the NASA Gear Noise Rig was recently installed at Lewis. The gear noise rig will allow studies of gear design parameters and their effect on dynamic loads, vibration and noise production, propagation, and radiation. Measurements will be made to assess the effects on dynamic loads and noise caused by tooth profile, tooth spacing errors, gear misalignment, and damping.

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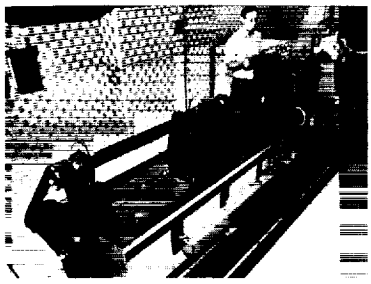
GEAR NOISE RIG—FACILITY DESIGN & INSTALLATION

GEAR NOISE RIG



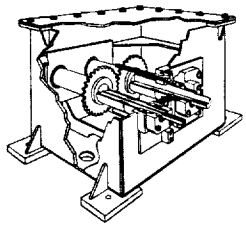
MILESTONES COMPLETED:

- DESIGN & FABRICATION OF HIGHLY-INSTRUMENTED TEST GEARBOX
- TEST RIG DESIGNED & CONSTRUCTED
- FACILITY IS FULLY OPERATIONAL

C-88-08756

SIGNIFICANCE:

- PARAMETRIC STUDIES OF GEAR DESIGN VARIABLES
- VERIFICATION OF COMPUTER MODELS FOR GEAR DYNAMICS AND NOISE
- TECHNOLOGY BASE FOR FUTURE QUIET TRANSMISSION DESIGN



TEST GEARBOX

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TRANSMISSION DIAGNOSTICS

There has been a recent interest in transmission diagnostics for both safety and economical reasons. A comprehensive transmission diagnostics program is being developed at Lewis consisting of basic and applied diagnostic research. The basic research consists of evaluation and development of new and improved transmission component failure prediction techniques. The applied research consists of evaluating existing commercially available diagnostic devices using the unique facilities at NASA Lewis.

As an initial study, vibration signatures from eleven gear sets that were run from start to failure were collected from instrumentation installed on a single mesh gear fatigue test stand (ref. 33). Several gear mesh failure prediction methods were applied to the data to determine if a correlation existed between the various techniques and the observed modes of failure. The gear failures consisted of heavy wear and scoring, tooth breakage, single tooth pitting, and distributed pitting over several teeth. The analytical methods investigated were FM0 and FM4 developed by Stewart (ref. 34), the Hilbert transform proposed by McFadden (ref. 35), crest factor, sideband level ratio, and nonharmonic to harmonic RMS level energy ratio (ref. 36). Results showed that the prediction methods were able to detect only those gear failures which involved heavy wear or distributed pitting. None of the methods detected single tooth pitting and none detected fatigue cracks which led to tooth breakage. It is suspected that the fatigue cracks were not detected because of limitations in data acquisition rather than in the methodology. Additionally, the modal frequency response between the gear shaft and transducer was found to significantly affect the vibration signal. The specific frequencies affected were filtered out of the signal average prior to application of the methods.

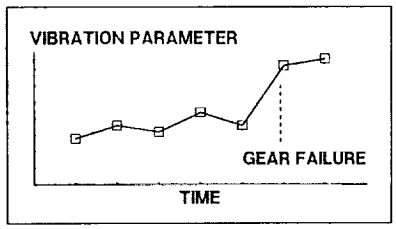
Future plans include installation of an on-line computer based system on the single mesh gear fatigue test stand. The objective will be to continue to evaluate the most promising gear failure detection algorithms and develop new methods were needed. Also, the on-line system eliminates the data acquisition problems mentioned above.

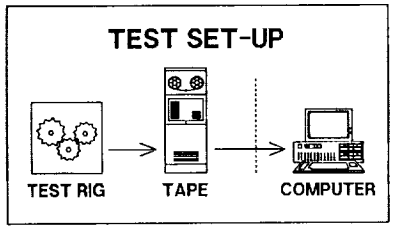
Transmission diagnostics is also being performed in conjunction with the Advanced Lubricants Program 500-hp Test Stand experiments. Vibration data on the OH-58 transmission are being recorded and investigations correlating the component failures with various failure prediction algorithms will be performed. In addition, oil debris monitoring methods are being investigated as a diagnostic tool.

GEAR FAILURE PREDICTION STUDIES

MILESTONES COMPLETED:

- VIBRATION SIGNATURES OF VARIOUS MODES OF GEAR FAILURES COLLECTED.
- SIGNATURES ANALYZED USING SEVERAL FAILURE PREDICTION TECHNIQUES.
- NASA TM-102340.





RESULTS:

- ALGORITHMS TO PREDICT GEAR FAILURES IDENTIFIED.
- GEAR/BEARING/HOUSING MODAL PROPERTIES AFFECTED RESULTS.

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ADVANCED TRANSMISSIONS

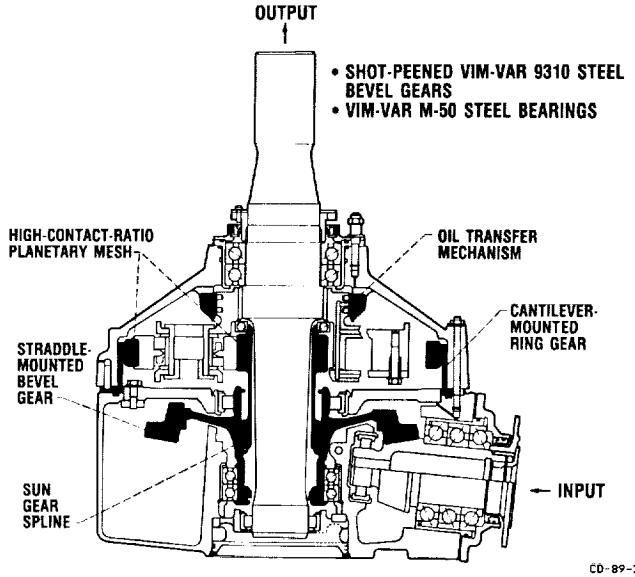
The design and performance requirements of helicopters are continuously becoming more demanding. Helicopter drive trains and in particular, transmissions, require advances in state-of-the-art technology in order to meet these requirements. Advances can come from either improved components or improved designs of the transmission systems.

Experimental tests were performed on the NASA/Bell Helicopter Textron (BHT) 500-hp advanced technology transmission (ATT) at the NASA Lewis Research Center (ref. 37). The ATT was a retrofit of the OH-58C helicopter 236-kW (317-hp) main rotor transmission, upgraded to 373 kW (500 hp), with a design goal of retaining long life with a minimum increase in cost, weight, and size. This was accomplished by implementing advanced technology developed during the last decade and improvements dictated by field experience. The advanced technology components, concepts, and improvements incorporated in the ATT were: 1) high-contact-ratio planetary spur gears, 2) a cantilever-mounted planetary ring gear, 3) an oil transfer mechanism designed into the planet carrier, 4) a straddle-mounted bevel gear, 5) an improved sun gear spline, and 6) cleaner, stronger spiral-bevel gear steel.

The final size and weight of the ATT resulted in a decrease in weight-to-power ratio from 0.37 lb/hp for the OH-58C to 0.26 lb/hp for the ATT. Vibration, strain, efficiency, deflection, and temperature experiments were performed and the results were compared to previous experiments on the OH-58A, OH-58C, and UH-60A transmissions. The high-contact-ratio gears and the cantilever-mounted, flexible ring gear of the ATT reduced vibration compared to that of the OH-58C. The ATT flexible ring gear improved planetary load sharing compared to that of the rigid ring gear of the UH-60A transmission. The ATT mechanical efficiency was lower than that of the OH-58A transmission, probably due to the high-contact-ratio planetary gears.

A second advanced design concept transmission in the 223 to 373 kW (300 to 500 hp) class is the self-aligning bearingless planetary (SABP) transmission (ref. 38). In this transmission conventional planet gears are replaced by planet spindles. The spindles each have three gears on them; one gear meshes with a sun gear, one with a fixed ring gear, and one with a rotating output ring gear. The gears on the spindle are spaced such that tangential gear forces are balanced and the spindles are in equilibrium. Tooth separating and centrifugal forces are reacted by cylindrical rings concentric with the sun gear axis. Thus, the planet bearings and planet carrier are eliminated, reducing the transmission weight. Planet bearing failures and power losses commonly associated with conventional planetary transmissions are eliminated. Also, transmission vulnerability due to loss of lubrication is decreased. The design study projected a weight savings of 17 to 30 percent and a reliability improvement factor of 2 to 1 over standard transmissions.

500-HP ADVANCED TECHNOLOGY TRANSMISSION



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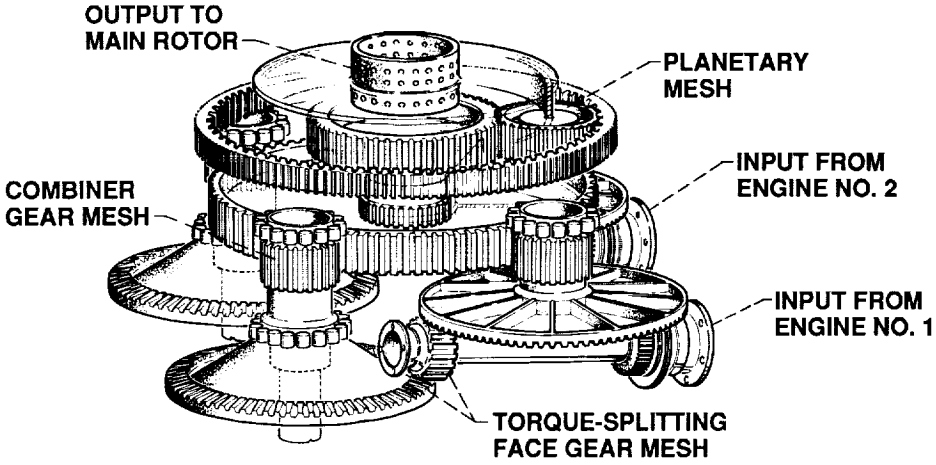
A third promising advanced design concept resulted from the Advanced Rotorcraft Transmission Program. The McDonnell Douglas Helicopter Company chose a novel split torque/planetary hybrid configuration for their Future Air Attack Vehicle. A unique feature of the selected ART transmission is the use of a face gear arrangement to simultaneously split the torque between two input paths (per engine input) to the collector bull gear and to provide for the change in rotation axis normally accomplished with spiral bevel gears. In effect, an entire mesh has been eliminated from the drivetrain, and a very compact torque-splitting arrangement identified. The free end of the spur gear input shaft will actually be spring mounted; the relative end freedom will help assure efficient load sharing between the two torque paths. This configuration resulted in a drivetrain that was 43 percent lighter than a conventional spiral bevel/planetary system.

The unique face gear design involves a rather high risk program since face gears have not been demonstrated to date in aircraft power transmission applications. To reduce this risk, tests will be performed at NASA Lewis to demonstrate the feasibility of face gears in high load, high speed applications.

SPLIT-TORQUE CONFIGURATION



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CONCLUDING REMARKS

The purpose of this paper was to review significant accomplishments of the past few years in helicopter transmission technology as a result of NASA/Army research activities at the NASA Lewis Research Center. Research program goals were to reduce transmission weight and noise and increase life and reliability. A variety of analytical and experimental studies from in-house activities, university grants, and industry contracts were presented. Significant transmission weight reduction potentials have been identified through use of novel configuration arrangements and/or advanced components. Transmission life improvement potentials have been identified through use of advanced materials, lubrication, and component design.

One result of the Advanced Rotorcraft Transmission (ART) program was that a generalized, comprehensive, noise prediction methodology for transmissions did not exist at the time of the configuration trade-off studies. During these studies, baseline transmission noise data were used as a starting point. Extrapolation to each of the ART candidates was accomplished by comparing number of gear meshes, mesh loading, gear geometry features, and mesh speeds with those of the baseline. The result was typically a very qualitative comparison with a net judgment for each candidate as whether it would be better, worse, much better, much worse, or the same as the baseline. Goals of the ongoing NASA transmission noise reduction program are to increase the basic understanding of the complex noise generation and transmissibility phenomena and to develop sound, analytical tools for noise prediction. This will aid in the overall goal of reducing transmission noise and become a basis for next generation design.

It is reasonable to expect that helicopters will continue to evolve in the future. To achieve the necessary advances in rotary wing flight capabilities, drive train technology must keep pace with advances in engines, controls, structures, and rotors. The current plan for NASA/Army transmission research calls for a continued effort in noise reduction, an increased emphasis in diagnostics, and continued support of military aviation activities.

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Report Documentation Page

1. Report No. NASA TM-103132 AVSCOM TM 90-C-006	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Transmission Research Activities at NASA Lewis Research Center		5. Report Date
		6. Performing Organization Code
7. Author(s) D.G. Lewicki		8. Performing Organization Report No. E-5469
9. Performing Organization Name and Address NASA Lewis Research Center Cleveland, Ohio 44135-3191 and Propulsion Directorate U.S. Army Aviation Research and Technology Activity—AVSCOM Cleveland, Ohio 44135-3127		10. Work Unit No. 505-63-51 1L12211A47A
		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546-0001 and U.S. Army Aviation Systems Command St. Louis, Mo. 63120-1798		14. Sponsoring Agency Code

15. Supplementary Notes

Prepared for the Helicopter Transmission Design and Maintenance Workshop sponsored by the Canadian Department of National Defense, Quebec City, Canada, May 21-25, 1990.

16. Abstract

The NASA Lewis Research Center and The U.S. Army Aviation Systems Command (AVSCOM) are involved in a joint research program to advance the technology of rotorcraft transmissions. The program consists of analytical and experimental efforts to achieve the overall goals of reducing transmission weight and noise, while increasing life and reliability. The work includes in-house studies and tests, university grants, industry contracts, and joint programs with other military organizations. This paper highlights recent activities in the areas of transmission and related component research. Current areas include specific technologies in support of military rotary wing aviation, gearing technology, transmission noise reduction studies, a recent interest in gearbox diagnostics, and advanced transmission system studies. Results of recent activities are presented along with near term research plans.

17. Key Words (Suggested by Author(s)) Transmissions Gears Noise Diagnostics	18. Distribution Statement Unclassified—Unlimited Subject Category 37

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price*
Unclassified	Unclassified	30	A03

NASA FORM 1626 OCT 86

*For sale by the National Technical Information Service, Springfield, Virginia 22161