RVLT TC1.2: Two-speed Drive System Demonstration

Brief Summary of Completion / Accomplishment:
Technical Challenge: Two-speed Drive System Demonstration
Tech Challenge Exit Criteria: Develop and demonstrate required technologies and designs for achieving a 50% reduction in rotor rpm via a two-speed drive system that incurs less than 2% power loss and maintains current power-to-weight ratios.

Reduction of rotor speed by 50%: The research program execution demonstrated three mechanical assembles that achieved the required 50% reduction of rotor speed. A gearing concept termed the dual star idler was successfully tested with a dry clutch. Also, a gearing concept termed the offset compound gear was successfully tested with two different clutch concepts (a dry clutch and a wet clutch). All three mechanical assemblies were experimentally demonstrated to TRL-4 with successful transitions from high-speed (*vertical take-off)* mode to low-speed (*forward flight*) mode and then transitioning back to high-speed (*vertical landing*) mode.

Two-speed drive incurs less than 2% power loss: The offset compound gear with a dry clutch was assessed by experiment and analysis to determine the power loss. The results of the power loss evaluation revealed, as anticipated, that the largest contributor to total power loss for the two-speed drive system was the windage loss created when rotating surfaces interact with the oil-air environment. The total power loss for the offset compound gear and dry clutch configuration operating at 1000 horsepower were determined to be 1.3% in high-speed mode and 1.7% in low-speed mode, exceeding the technical challenge objective of less than 2.0% power loss.

Weight reduction technology that offsets two-speed transmission weight increase: The most promising weight reduction technology considered was the replacement of metal with composite material for gear bodies and shafts. A full-scale 16.5 inch diameter hybrid composite gear was successfully demonstrated to operate at 5,000 horsepower, showing viability of the approach. Replacing steel with composite materials at selected locations was determined through analysis to result in a weight benefit of 61lbs for the two-speed drive system.

Beginning TRL 2, Final TRL4 for two-speed drive system

TC Related Patents

Patent Title / Description	Author
“Offset Compound Gear Inline Two-Speed Drive”, U.S. Patent 8.091,445, issued Jan. 10, 2012	Stevens, M., Handschuh, R. and Lewicki, D.
“Offset Compound Gear Inline Two-Speed Drive”, U.S. Patent 8.668,613, issued March 11, 2015	Stevens, M., Handschuh, R. and Lewicki, D.
“Hybrid Gear”, U.S. Patent 9,296,157, issued March 29, 2016	Handschuh, R. and Roberts, G.

TC Related Publications

Publication Title / Description	Authors	Conference(s) Where presented
SRW/Variable Rotor Speed Control	Litt, J.	Propulsion Control and Diagnostics Research Under NASA Aeronautics Research Mission Programs Workshop, Nov. 6-7, 2007, Cleveland, OH
Concepts for Multi-Speed Rotorcraft Drive System	M. Stevens, NASA R. Handschuh, D. Lewicki, ARL	64th American Helicopter Society (AHS) Annual Forum, Montreal, Canada, April 29-May 1, 2008
Variable/Multi-Speed Rotorcraft Drive System Concepts	Mark A. Stevens, Dr. Robert F. Handschuh, and Dr. David G. Lewicki	March 2009 under NASA/TM-2009-215456 / ARL-TR-4758
CFD Technology for Rotorcraft Gearbox Windage Aerodynamics Simulation	Hill, Matthew; Kunz, R.F; Noack, R.W.; Long, L. N.; Morris, P. J.; and Handschuh, R.	The Journal of Gear Manufacturing August 2009, 48-55
Two-Speed Gearbox Dynamic Simulation Predictions and Test Validation	Lewicki, D.G., DeSmidt, H., Smith, E.C., and Bauman, S.W.	Presented at the 66th Annual Forum of the American Helicopter Society, Phoenix, May 10-12, 2010
High Speed Gear Windage CFD Analysis and Application to the NASA Glenn Gear Windage Test Facility	Hill, M., Kunz, R, Noack, R., Long, L. and Handschuh, R.	Presented at the 66th Annual Forum of the American Helicopter Society, Phoenix, May 10-12, 2010
Offset Compound Gear	Mark A. Stevens, Dr. Robert F. Handschuh, Dr. David G. Lewicki	NASA Tech Briefs Magazine (Vol. 34, No. 5, pp. 49-50, 2010)
Summary of the Large Civil TiltRotor (LCTR2) Engine Gearbox Study	Chris Snyder (NASA), Mark Robuck and Joseph Wilkerson (The Boeing Company), and Carl Nordstrom (Rolls-Royce Corporation)	AHS International Powered Lift Conference, Oct. 5-7, 2010 (Philadelphia, PA.)
High Speed Gear Windage Research	R. Handschuh	International Conference on Gearing, Munich Germany Oct 4-6, 2010
High Speed Gear Windage CFD Analysis and Application to the NASA Glenn Gear Windage Test Facility	Hill, M., Kunz, R, Noack, R., Long, L. and Handschuh, R.	ASME Journal of Fluids Engineering
Variable-Speed Simulation of a Dual-Clutch Gearbox Tiltrotor Driveline	DeSmidt, H., Smith, E.C., Wang, K.W., and Lewicki, D.G.,	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.

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Publication Title / Description	Authors	Conference(s) Where presented
Gear Mesh Loss-of-Lubrication Experiments and Analytical Simulation	R. Handschuh, J. Polly and W. Morales, NASA GRC	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Investigation of Bearing Fatigue Damage Life Prediction Using Oil Debris Monitoring	Dempsey, Paula, J.; Bolander, Nathan; Haynes, Chris; Toms, Allison, M.	NASA/TM-2011-217117, November 2011
Initial Experiments of High-Speed Drive System Windage Losses	Handschuh, R. and Hurrell, M.	NASA TM-2011-216925, November 2011, also presented at the International Conference on Gears, Munich, Germany, October 2010
Gear Mesh Loss-of-Lubrication Experiments and Analytical Simulation	Handschuh, R., Polly, J., and Morales, W.	NASA TM-2011-217106, Nov 2011, also presented at the 2011 AHS Forum, Virginia Beach, VA, May 2011
A Survey of Current Rotorcraft Propulsion Health Monitoring Technologies	Irebert Delgado, Paula Dempsey, and Donald Simon	NASA/TM—2012-217420 January 2012
Hybrid Gear Preliminary Results--Application of Composites to Dynamic Mechanical Components	Handschuh, R.; Roberts, G.; Sinnamon, R.; Stringer, D.; Kohlman, L.; Dykas, B.	AHS 68th Annual Forum and Technology Display, May 1-3, 2012, Ft. Worth
Full-field Deformation Measurement Techniques for a Rotating Composite Shaft	Kohlman, L.; Ruggeri, C.; Roberts, G.; Handshuh, R.; Roth, D.; Martin, R.	AHS 68th Annual Forum and Technology Display, May 1-3, 2012, Ft. Worth
An Integrated Approach for Gear Health Prognostics	He, D.; Ma, J.; Bechhoefer, E.; Dempsey P.	AHS 68th Annual Forum and Technology Display, May 1-3, 2012, Ft. Worth
A Computational Investigation of Gear Windage	Hill, M. and Kunz, R.	NASA/CR-2012-217807, December 2012
Improvements in High Speed, High Resolution Dynamic Digital Image Correlation for Experimental Evaluation of Composite Drive System Components	Kohlman, L., Ruggeri, C., Roberts, G., and Handschuh, R.	AHS 69th Annual Forum, Phoenix, AZ, May 21-23, 2013 ; NASA TM 216537, July 2013
On the Correlation of Specific Film Thickness and Gear Pitting Life	Krantz, T. L.	Society of Tribologists and Lubrication Engineers Annual Meeting (STLE), Detroit, MI, May 2013

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Dynamics of a Dual-Clutch Gearbox System: Analysis and Experimental Validation	Lewicki, D., Desmidt, H., Smith, E., and Bauman, S.	Journal of the American Helicopter Society, Vol. 58, No. 1, January 2013, pp17-28 (12)
Study and Sub-System Optimization of Propulsion and Drive Systems for the Large Civil TiltRotor (LCTR2) Rotorcraft	Robuck, M., Wilkerson, J., Snyder, C. A., Zhang, Y., and Maciolek, B.	AHS 69th Annual Forum, Phoenix, AZ, May 21-23, 2013
The Effect of Rotor Cruise Tip Speed, Engine Technology, and Engine/Drive System RPM on the NASA Large Civil Tiltrotor (LCTR2) Size and Performance	Robuck, M., Wilkerson, J., Snyder, Maciolek, R., and Vonderwell, D.	NASA CR 2013-216593, September 2013
Vibration and Operational Characteristics of a Composite-Steel (Hybrid) Gear	Handschuh, R. F., LaBerge, K. E. DeLuca, S. and Pelagalli, R.	NASA/TM—2014-216646, ARL–TR–6973 June 2014
High Fidelity CFD Analysis and Validation of Rotorcraft Gearbox Aerodynamics under Operational and Oil-Out Conditions	Kunz, R. F.	NASA/CR-2014-216651, July 2014
A hybrid composite/metal gear concept for rotorcraft drive systems	Roberts, G. D., Kohlman, L. W., Ruggeri, C. R., Handschuh, R. F., and Thorp, S. A.	CompositesWorld Carbon Fiber 2013, Knoxville, TN, December 2013
Investigation And Evaluation Of Condition Indicators, Variable Selection, And Health Indication Methods And Algorithms For Rotorcraft Gear Components	Siegel, D., Lee, J., and Dempsey, P.	MFPT 2014 Conference, Virginia Beach, VA, May 2014
Investigation of Gearbox Vibration Transmission Paths on Gear Condition Indicator Performance	Dempsey, P. J., Islam, A. A., Feldman, J., and Larsen, C.	NASA TM—2013-216617, December 2013.
NASA Technology for Next Generation Vertical Lift Vehicles	Gorton, S., López, I., and Theodore, C.	AIAA Paper 2015-0949, AIAA 53rd AIAA Aerospace Sciences Meeting, Kissimmee, FL, January 5-9, 2015
Thermal Behavior of Aerospace Spur Gears in Norman and Loss-of-Lubrication Conditions	Handschuh, R.	AHS 71st Annual Forum, Virginia, Beach, VA, May 2015
On the Correlation of Specific Film Thickness and Gear Pitting Life	Krantz, T.	AGMA 2014 Fall Technical Meeting, Washington D.C., Oct 2014

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Gear Mesh Loss-of-Lubrication Experiments and Analytical Simulation	R. Handschuh, J. Polly and W. Morales, NASA GRC	Proceedings of the 67th Annual Forum of the American Helicopter Society, Virginia Beach, VA, May 3-5, 2011.
Investigation of Bearing Fatigue Damage Life Prediction Using Oil Debris Monitoring	Dempsey, Paula, J.; Bolander, Nathan; Haynes, Chris; Toms, Allison, M.	NASA/TM-2011-217117, November 2011
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Gear Mesh Loss-of-Lubrication Experiments and Analytical Simulation	Handschuh, R., Polly, J., and Morales, W.	NASA TM-2011-217106, Nov 2011, also presented at the 2011 AHS Forum, Virginia Beach, VA, May 2011
A Survey of Current Rotorcraft Propulsion Health Monitoring Technologies	Irebert Delgado, Paula Dempsey, and Donald Simon	NASA/TM—2012-217420 January 2012
Hybrid Gear Preliminary Results--Application of Composites to Dynamic Mechanical Components	Handschuh, R.; Roberts, G.; Sinnamon, R.; Stringer, D.; Kohlman, L.; Dykas, B.	AHS 68th Annual Forum and Technology Display, May 1-3, 2012, Ft. Worth
Full-field Deformation Measurement Techniques for a Rotating Composite Shaft	Kohlman, L.; Ruggeri, C.; Roberts, G.; Handshuh, R.; Roth, D.; Martin, R.	AHS 68th Annual Forum and Technology Display, May 1-3, 2012, Ft. Worth
An Integrated Approach for Gear Health Prognostics	He, D.; Ma, J.; Bechhoefer, E.; Dempsey P.	AHS 68th Annual Forum and Technology Display, May 1-3, 2012, Ft. Worth
A Computational Investigation of Gear Windage	Hill, M. and Kunz, R.	NASA/CR-2012-217807, December 2012
Improvements in High Speed, High Resolution Dynamic Digital Image Correlation for Experimental Evaluation of Composite Drive System Components	Kohlman, L., Ruggeri, C., Roberts, G., and Handschuh, R.	AHS 69th Annual Forum, Phoenix, AZ, May 21-23, 2013 ; NASA TM 216537, July 2013
Testing of Two-Speed Transmission Configurations For Use In Rotorcraft	Lewicki, D.G. and Stevens, M.A.	NASA/TM-2015-218816

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Publication Title / Description	Authors	Conference(s) Where presented
Concepts for Multi-Speed Rotorcraft Drive System -- Status of Design and Testing at NASA GRC	Stevens, M., Lewicki, D., Handschuh, R.	AHS 71st Annual Forum, Virginia, Beach, VA, May 2015
Performance Investigation of a Full-Scale Hybrid Composite Bull Gear	LaBerge, K.E., Handschuh, R.F., Roberts, G. and Thorp, S.	American Helicopter Society International's 72nd Annual Forum & Technology Display, May 2016.
A review of noise and vibration control technologies for rotorcraft transmissions	Scheidler, J.; Asnani, V	45th International Congress and Exposition on Noise Control Engineering, Hamburg, Germany, August 21 -24, 2016
Contact and Bending Durability Calculation for Spiral-Bevel Gears	Vijayakar, S.	NASA/CR-2016-219112
Testing Aerospace Gears for Bending Fatigue, Pitting, and Scuffing	Krantz, T., Anderson, C., Shareef, I., and Fetty, J.	ASME DETC-68470, ASME IDETC/CIE 2017, Aug. 6-9, Cleveland, Ohio
Baseline Experimental Results on the Effect of Oil Temperature on Shrouded Meshed Spur Gear Windage Power Loss	Delgado, I. and Hurrell, J.	ASME DETC-67818, ASME IDETC/CIE 2017 Aug. 6-9, Cleveland, Ohio
Experimental Investigation of Shrouding on Meshed Spur Gear Windage Power Loss	Delgado, I. and Hurrell, J.	American Helicopter Society's 73rd Annual Forum, Fort Worth, TX, 2017
Effects of Nanosilica Filler on the Ballistic Impact Tolerance of Carbon/Epoxy Tubes Loaded in Torsion	Vashisth, A., Bakis, C., Ruggeri, C., Henry, T. and Roberts, G.	American Helicopter Society's 73rd Annual Forum, Fort Worth, TX, 2017
Hybrid Gear Performance Under Loss-of-Lubrication Conditions	LaBerge, K., Berkebile, S., Handschuh, R. and Roberts, G.	American Helicopter Society's 73rd Annual Forum, Fort Worth, TX, 2017

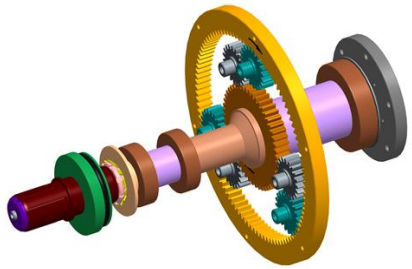
RVLT TC.1.2 Two-Speed Drive System Tech Demo

Objective

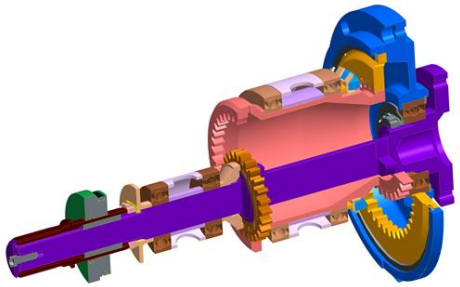
Demonstrate two-speed drive system capable of 50% rpm reduction with less than 2% power loss while maintaining current power-to-weight ratios

Technical Areas and Approaches

- ✓ Specify, procure, and commission new test facility for two-speed drive experiments
- ✓ Two-speed drives innovations and concepts, downselect concepts for hardware demo
- ✓ Design, fabricate, balance, assemble, and test two-speed drive concepts
- ✓ Research lightweight drivetrain technologies, especially use of composite materials to replace steel
- ✓ Research methods to reduce power loss of high-speed gearing
- ✓ Demonstrate two-speed gear systems, assess the weight and power loss goals



Dual Star Idler



Offset Compound Gear



Variable Speed Transmission Test Rig



Hybrid gear/shaft/bearing assembly