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Defining Gas Turbine Engine Performance Requirements for the Large Civil TiltRotor (LCTR2)

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December 2013

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Abstract

Defining specific engine requirements is a critical part of identifying technologies and operational models for potential future rotary wing vehicles. NASA's Fundamental Aeronautics Program, Subsonic Rotary Wing Project has identified the Large Civil TiltRotor (LCTR) as the configuration to best meet technology goals. This notional vehicle concept has evolved with more clearly defined mission and operational requirements to the LCTR-iteration 2 (LCTR2). This paper reports on efforts to further review and refine the LCTR2 analyses to ascertain specific engine requirements and propulsion sizing criteria. The baseline mission and other design or operational requirements are reviewed. Analysis tools are described to help understand their interactions and underlying assumptions. Various design and operational conditions are presented and explained for their contribution to defining operational and engine requirements. These identified engine requirements are discussed to suggest which are most critical to the engine sizing and operation. The most-critical engine requirements are compared to in-house NASA engine simulations to try to ascertain which operational requirements define engine requirements versus points within the available engine operational capability. Finally, results are summarized with suggestions for future efforts to improve analysis capabilities, and better define and refine mission and operational requirements.

Nomenclature

CRP	Contingency rated power
HOGE	Hover, out of ground effect
IRP	Intermediate rated power
ISA	International standard atmosphere
LCTR2	Large Civil TiltRotor—iteration 2
MCP	Maximum continuous power
MRP	Maximum rated power
NDARC	NASA Design and Analysis of Rotorcraft
NPSS	Numerical Propulsion System Simulation
OEI	One engine inoperative
OGE	Out of ground effect
PR	Pressure ratio
PT	Power turbine
SLS	Sea level static
T3	Compression system exit temperature, °F
T4	Combustor exit temperature, °F
V_{br}	Velocity at best range
VSPT	Variable-speed power turbine
W	Mass flow, lbm/sec
Wcorr	Corrected mass flow, $W * \sqrt{\theta}/\delta$, lbm/sec
δ	Ratio of actual to standard pressure
θ	Ratio of actual to standard temperature

Introduction

The NASA Heavy Lift Rotorcraft System Investigation (Ref. 1) identified a large tiltrotor as the best concept to meet the various airspace and other requirements for the projected, future, short-haul regional market. This evolved into a conceptual vehicle designated as Large Civil TiltRotor—iteration 2 (LCTR2) (Ref. 2) as seen in Figure 1.

This iteration of the conceptual vehicle was designed to carry 90 passengers, at a minimum cruising speed of 300 knots and 1,000 nautical mile range. It is powered by four turboshaft engines designed for 7,500 HP each [maximum rated power (MRP), at sea level static (SLS), International standard atmosphere (ISA)]. Other design features included a rotor tip speed of 650 ft/sec in hover and 350 ft/sec during cruise, enabled by a two-speed gearbox; this range of rotor tip speeds was needed to achieve the high level of performance and efficiency at two very different flight conditions. Subsequent studies (Refs. 3 to 5) have suggested that minimum vehicle gross weight (indicative of development and purchase costs) and minimum mission fuel (related to operational costs) might be achieved at slightly higher rotor cruise tip speeds, with Reference 3 suggesting a weak minimum around 400 ft/sec. While these studies have further and more clearly defined the vehicle size and overall vehicle operation, results have not been reported from an engine-centric point of view. Reporting specific engine requirements clarifies the engine performance assumptions in the vehicle analyses, while also enabling the engine technologists and designers to better understand and match requirements. For this study, the LCTR2 vehicle and mission model from Reference 3, assuming the 400 ft/sec rotor cruise tip speed, was further exercised to elicit further

Figure 1.—Conceptual view of LCTR2.

engine performance and vehicle sensitivity to changes in engine performance assumptions.

This report gives details for the baseline vehicle and mission, focusing on engine assumptions and requirements. The analysis tools are briefly described, then results from the vehicle and mission sizing and analysis code from an engine requirements point of view are presented. The engine performance points are compared to data from a NASA in-house engine performance code, further refining engine performance requirements. Results are summarized and future plans are discussed.

Vehicle/Mission Requirements

The LCTR2 mission requirements/summary are given in Table 1 (from Ref. 3) and except for takeoff and landing operations, are similar to a regional jet mission. Table 2 lists a matrix of takeoff conditions used to check engine power levels and examine their effect on vehicle sizing. Takeoff at the high/hot condition had the highest engine power requirement; while takeoff from sea level, standard day had a slightly higher mission fuel load. Both takeoff conditions were set as constraints for the vehicle sizing. Landing at 5,000 ft, ISA+ 20 °C was chosen for all missions, which has the highest landing engine power requirement, although it was still significantly less than takeoff. Another operational requirement is one engine inoperative (OEI); the most critical condition would be during low speed departure just after takeoff, when the rotorcraft is at its heaviest without sufficient forward speed to augment lift from the wings. During this OEI event, the vehicle must execute a vertical landing as soon as possible with just three of its four engines operational.

The assumed engine power rating structure is an additional vehicle/mission sizing parameter. The engine power available over the various vehicle and mission sizing points is directly linked to the engine design and an engine's power rating structure. Typical engine ratings are used within this study and their definitions are listed in Table 3. At engine power levels above maximum continuous power (MCP), the engine is operating at more stringent temperatures and pressures, which limit engine useful life. The greater the increase in power, the more stress on engine components and reduced time that such power would be available (before engine maintenance or replacement would be required). The balanced use of these higher engine power ratings can result in a smaller vehicle, fuel load and engine size to meet mission requirements, while still meeting reasonable maintainability or life. Typical aircraft missions include engine power levels up to maximum rated power (MRP) for takeoff, although this power level is only maintained within the airport boundaries and reduced to MCP or less for community noise and engine life considerations. The rest of the mission is typically at engine power levels of MCP or less, except for landing. For the 1 min hover, out of ground effect (HOGE) and landing, engine power levels up to MRP may be used if conditions warrant (such as when the vehicle is still near maximum weight, and/or high, hot conditions).

There are additional considerations in defining and sizing a vehicle concept, including relevant missions and other constraints. The baseline vehicle used for this study, as well as additional sizing and design constraints, are discussed further Reference 3. The optimum gross weight design and simulation models from that study were used as the starting point for this effort; baseline LCTR2 vehicle characteristics are given in Table 4.

TABLE 1.—LCTR2 MISSION REQUIREMENTS

Mission summary	Approximate time in mode
Takeoff + 2 min hover OGE 5,000 ft ISA+20 °C	2 min
Climb at V_{br} (credit distance to cruise segment)[a]	20 min
Cruise at V_{br} for at least 1000 nm range, 28,000 ft, ISA	3 hr
Descend at V_{br} (no range credit)	20 min
1 min hover OGE + landing, 5,000 ft, ISA+20 °C	1 min
Reserve (diversion): 100 nm V_{br}, 28,000 ft, ISA	22 min
Reserve (emergency): 30 min V_{br}, 5,000 ft, ISA+20 °C	30 min

[a]Climb segment includes possible engine-rotor gear ratio shift event.

TABLE 2.—TAKEOFF ALTITUDE/ TEMPERATURE DESIGN MATRIX

Altitude	Temperature
5,000 ft	ISA + 20 °C
2,000 ft	ISA + 25 °C
0 ft (SLS)	ISA + 25 °C
0 ft (SLS)	ISA + 0 °C

TABLE 3.—TYPICAL ENGINE POWER RATINGS

Rating	Power rating	Time limit	Power/MCP
MCP	Max continuous	none	1.000
IRP	Intermediate rated	30 min	1.185
MRP	Maximum rated	10 min	1.269
CRP	Contingency rated	2.5 min	1.330

TABLE 4.—BASELINE LCTR2 CHARACTERISTICS

Design	Value
Cruise speed (90 percent MCP), knots	300
Rotor radius, ft	31.4
Engine power (MCP, SLS, ISA), hp	4×6,476
Gross weight, lb	96,500
Payload (90 pax), lb	19,800
Structure, lb	29,000
Fuselage group—9,900 lb	---------
Rotor group—7,400 lb	---------
Wing and empennage—7,600 lb	---------
Gear, engine nacelle, other—4,100 lb	---------
Systems and Equipment, lb	14,600
Engines and drive systems, lb	14,100
Mission fuel, lb	13,900
Other, lb	5,100

Analysis Methodology

The NASA Design and Analysis of Rotorcraft (NDARC) code was used to perform the vehicle design and sizing with multiple requirements and constraints. Reference 6 documents the background behind NDARC and its complete theory. Its theoretical basis and architecture is given in Reference 7. The program includes models for the major components and systems of rotorcraft vehicles (such as fuselage, rotors, wings, tails, and propulsion). These components can be further refined into subcomponents, defining performance and weight attributes that the program combines into a complete model for a given aircraft. During this process, various mission, sizing or operational requirements can be defined that will size (or resize) various aircraft components. For a defined (or sized) aircraft, performance can also be calculated for alternate missions or conditions. As part of this effort, alternative mission and propulsion attributes were assigned to the previous defined LCTR2 vehicle to further understand engine requirements for various aspects of its design and operational mission and the effect of changing propulsion capabilities on its sizing.

Within NDARC, the default method for turboshaft engine performance "is based on curve-fits of engine performance data for existing or projected engines over a range of operating conditions" (Ref. 6). The engine model uses referred conditions to correct power, fuel consumption and net jet thrust for altitude, non-standard temperatures and operation at power turbine (PT) rpm at other than design conditions. Engine performance with technology assumptions equivalent to technology levels for the rest of the LCTR2 vehicle were used. Mission modeling assumes the use of multispeed gearbox systems to maintain engines at or close to optimum PT rpm.

Transition From Hover to Cruise Rotor Speed

A new requirement on the engine and drive system is being formulated to address possible constraints during rotor transition from hover to cruise rpm. Once the vehicle converts from helicopter to airplane mode and gains some flight speed, the wings are able to augment lift, significantly reducing rotor power requirements. Reducing rotor rpm from the hover to the cruise condition could further reduce community noise, but could increase drive system torque requirements (and weight) if rotor power levels are not reduced from the takeoff condition. If rotor cruise tip speed reduction is achieved by using multi-speed gearbox/transmissions (which enable the engines to operate most efficiently around a single speed), there will be a transition period during which the gear ratio between the engine PT and rotor is changed. An example block diagram of the drive system with the rotors, gearboxes, engines and speed changing modules is shown in Figure 2 (from Ref. 4).

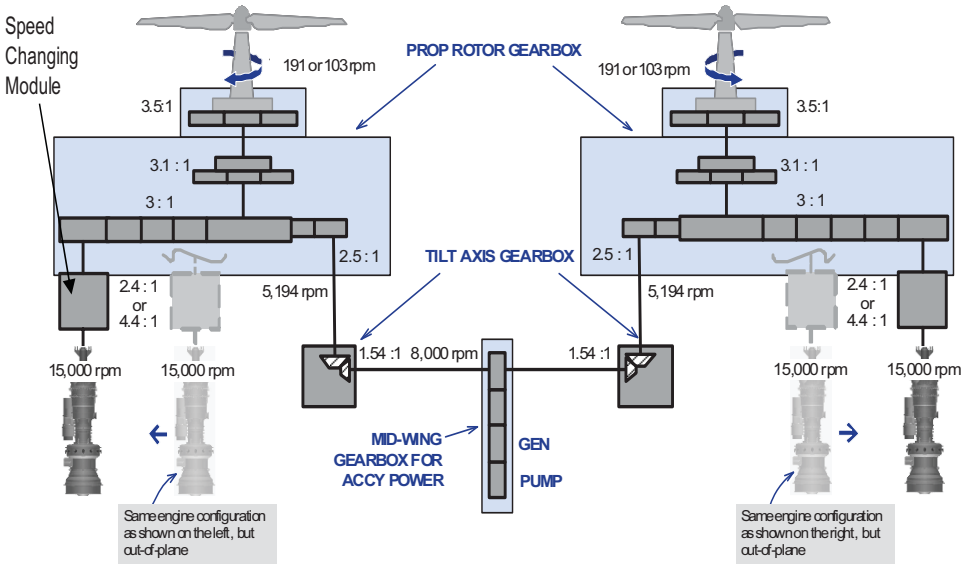

Figure 2.—Drive system block diagram with speed changing modules.

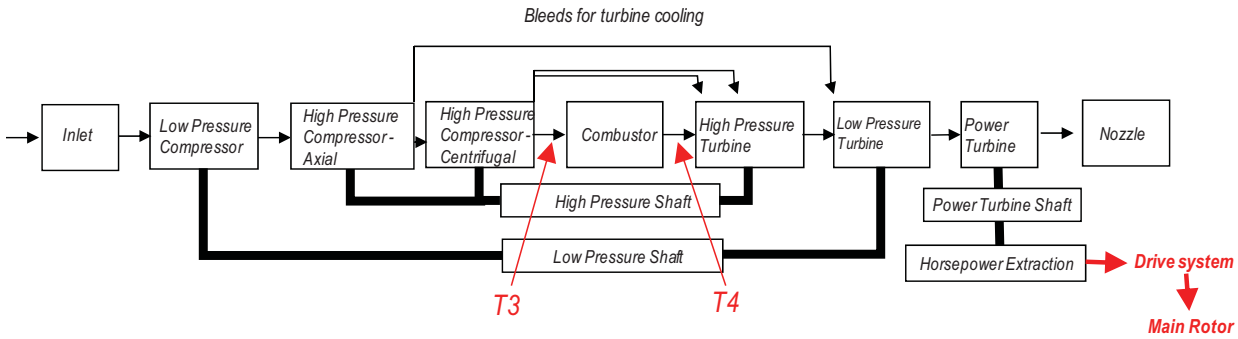

Figure 3.—Block representation of three spool turboshaft engine.

An initial procedure for the speed shift process is proposed here: Slow the rotors from hover to cruise tip speed (maintain rotor power levels to not exceed drive system torque levels—probably defined by takeoff, HOGE). Each engine is operating at less than optimum PT rpm (which can limit engine power and even cause engine instability). For this design, there is insufficient power for only one engine to power each rotor (if the vehicle is to maintain a reasonable climb profile or during cruise). Therefore, it is further assumed to use the cross-shafting between the two rotors to maintain constant rotor power during the shift process. There is a flight envelope (altitude, speed and climb state) where one engine at a time could be reduced in power (the remaining three engines could potentially increase power to maintain constant rotor power levels), to enable that engine to shift from the hover to cruise gear ratio. Maintaining constant rotor power levels would enable the vehicle to continue its flight state, making the LCTR2 integration more seamless in the airspace. This initial effort will focus on describing power requirements for the mission starting at 5,000 ft, ISA + 20 °C, shifting at 6,000 ft (1,000 ft above the takeoff height) with rotor tip speed transitioning from 650 to 400 ft/s, while the LCTR2 is in airplane mode and early in the climb profile (where engine power availability should be the highest). Other cases were run, but this case requires the highest engine power levels (because of altitude and hot day). Investigation of shifting later in the mission profile (i.e., later or near the end of climb, at the start of cruise, etc.) will be deferred to later efforts. Variable-speed power turbine (Ref. 8) (VSPT) technology is also being explored to facilitate or possibly eliminate the gearbox/transmission shift. VSPT technology can be used to increase the PT operating region of highest power availability while maintaining efficiency. There is an increasing PT weight penalty as the PT high power availability operating region increases and minimizing efficiency losses for operation further from the PT optimum design speed. Some system-level analyses that have been performed assuming VSPT technology for the LCTR2 and their effect on the vehicle design are discussed in References 4 and 5.

Engine Modeling

A 1-D, steady-state, turboshaft engine model using technology levels equivalent to the LCTR2 was developed using the Numerical Propulsion System Simulation (NPSS) (Ref. 9) code and reported in References 10 and 11. A block diagram for this engine model is shown in Figure 3. To meet the stringent fuel efficiency requirements, the turboshaft engine would be a high overall pressure ratio design (overall pressure ratio around 40), with expected maximum combustor exit temperature at or over 3000 °F. To achieve this high pressure ratio, the core engine is envisioned with two separate shafts (or spools), in addition to a “free” PT on its own shaft, connected to the drive system to drive the rotor. Component maps were generated for the compression and turbine systems, which are used within the model to estimate off-design performance. This model was used to generate engine performance at selected flight conditions from the NDARC mission and sizing analyses to perform a more detailed understanding of engine operation and performance margins.

Results and Discussion

Engine Power Levels and Sizing

CRP was the default, engine power rating level used for the OEI sizing condition, assumed at roughly 5 percent more power available than at MRP, and 33 percent more than MCP. For the variety of mission and constraints assumed for the LCTR2, OEI at the high/hot conditions (5,000 ft, ISA + 20 °C) was the most stringent engine power constraint and therefore determined engine size. It makes sense that the high, hot condition was the most stringent, engine power lapses more with increased altitude (5,000 ft, ISA + 20 °C) than for a hotter, but lower altitude (2,000 ft, ISA + 25 °C). A vehicle sized for OEI at 5,000 ft, ISA + 20 °C could meet OEI at 2,000 ft, ISA + 25 °C with the three remaining engines operating at MRP levels and at just above the IRP level for SLS, ISA + 25 °C. To determine the sensitivity of vehicle size

TABLE 5.—EFFECT OF ENGINE POWER ON LCTR2 SIZING

OEI power level	Engine size, hp, SLS MRP	Mission fuel, lb	Gross weight, lb	Max. possible takeoff weight, lb
133 percent MCP (base)	6,480	13,900	96,550	137,500
127 percent MCP	7,000	14,500	99,320	146,400
119 percent MCP	7,900	15,500	104,020	161,100

TABLE 6.—MISSION/FLIGHT POINTS FOR ENGINE POWER

Condition	Speed, knots	Altitude, ft	Temperature	Total HP used/available	Engine rating
OEI	0	5,000	ISA + 20 °C	[a]17,150/15,450	CRP
HOGE/takeoff	0	5,000	ISA + 20 °C	16,550/19,610	MRP
Climb 1 (shift)	172	6,000	ISA + 20 °C	[b]11,084/11,240	75 percent MCP
Climb 2 (MCP)	207	8,000	ISA + 20 °C	10,340/10,350	MCP
Cruise start	284	28,000	ISA	7,620/11,070	MCP
Cruise end	272	28,000	ISA	6,710/10,940	MCP
Reserve-diversion	270	28,000	ISA	6,610/10,920	MCP
Reserve-emergency	218	5,000	ISA	6,610/19,640	MCP
HOGE/land	0	5,000	ISA + 20 °C	13,890/19,610	MRP

[a]OEI modeling assumes 111 percent CRP availability.
[b]Power available is MCP for only three engines (assumes one engine is shifting).

for different levels of engine power capability beyond MCP was performed. The importance of higher power availability beyond MCP (even for limited times, such as 2.5 min for the OEI requirement) on vehicle sizing can be seen in Table 5. Meeting the OEI constraints with reduced levels of contingency power availability (beyond MCP) significantly increases engine sizing, mission fuel and vehicle gross weight. With all those penalties, there are some benefits to these vehicles increased engine sizes (and power). Such vehicles would then have greater maximum possible takeoff weight capability (calculated at MRP engine power, for SLS at ISA) and have even greater climb capability (but climb performance met or exceeded minimum climb requirements for all cases).

Engine/Flight Requirements

To define the flight state and engine power requirements, this paper focuses on what the author considers the most relevant points during a typical mission (summarized in Table 1). These flight points and power requirements are in Table 6 and come from the vehicle sizing and mission analyses performed by NDARC. The OEI requirement at 5,000 ft, ISA + 20 °C (at the default CRP of 133 percent MCP) is a critical sizing point for the engines and the vehicle. For the OEI calculation, the methodology from Reference 2 was used, paraphrased here: assuming a 10 percent reduction for OEI hover power, modeled as 111 percent (100/90 percent) increase in power available as a practical approximation. HOGE was assumed to determine the takeoff condition (HOGE is more stringent as ground effects reduce power required). The next flight point could be the transition from hover to airplane mode (assumed to occur shortly after leaving the takeoff area). But with any forward speed, the accompanying lift would reduce engine requirements from the HOGE/takeoff requirements, so that flight point was omitted. Climb was modeled in two segments; the first segment is during rotor tip speed transition from hover to cruise and is assumed to occur 1,000 above the takeoff point (while still assuming hot day conditions). With any gearbox/transmission shift occurring here, only 75 percent of engine MCP is available (three engines out of four). Engine conditions were also generated before and after shift; before the shift, the PT would be at non-optimum conditions (just to note any differences in engine conditions between these two operating conditions). The second climb segment is after transition, continuing ascent to top-of-climb (all four engines would be capable of MCP, at optimum PT rpm). Power at the start and end of cruise defines the range of power required for the constant altitude cruise segment. The two reserve segments (for diversion and emergency) are included, but should not require high power levels. Power requirements for rotor speed transition from cruise back to hover rpm will not be discussed, but would probably occur during the low-power descent and would also not require high power levels (especially since the bulk of the mission fuel was consumed during the cruise portion and the vehicle is significantly lighter). The final point is HOGE and landing at the high/hot condition (5,000 ft, ISA + 20 °C), but since the vehicle is again significantly lighter without the bulk of the mission fuel, this point should be within engine MRP capabilities.

Engine Requirements: Relating Mission Results (NDARC) to Engine Performance Deck (NPSS)

Engine data was generated for these flight points using the previously mentioned NPSS turboshaft model. This data was used to verify engine performance (power) and internal parameters (mass flows, turbomachinery operating conditions,

pressures and temperatures) that help define the various performance requirements. Even with the wide range of flight points, plotting the turbomachinery operating points on their specific compressor and turbine performance maps suggests that the turbomachinery operates in a fairly small portion of their operating envelopes to meet LCTR2 power requirements, as can be seen in Figure 4 to Figure 9. In fact, the high-pressure compressors (Figure 5 and Figure 6), high-pressure turbine (Figure 7) and low-pressure turbine (Figure 8) are operating at close to or essentially at constant aerodynamic conditions. The PT (Figure 9) does operate over a greater range of its operating envelope than the other components, but much of the greatest variance occurs at low power levels. The most notable is the "Reserve Emergency" condition, a low altitude diversion to another airport. For such conditions, engine capability is much greater than required; engines are operating at significantly less than MCP. The PT is also operating significantly off-design, but able to meet the low power requirements.

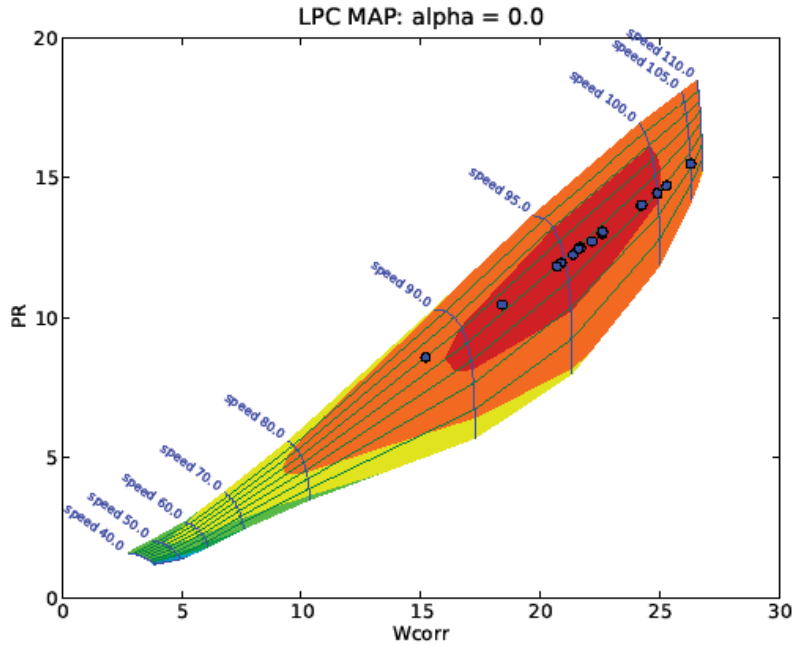

Figure 4.—Low-pressure compressor performance map.

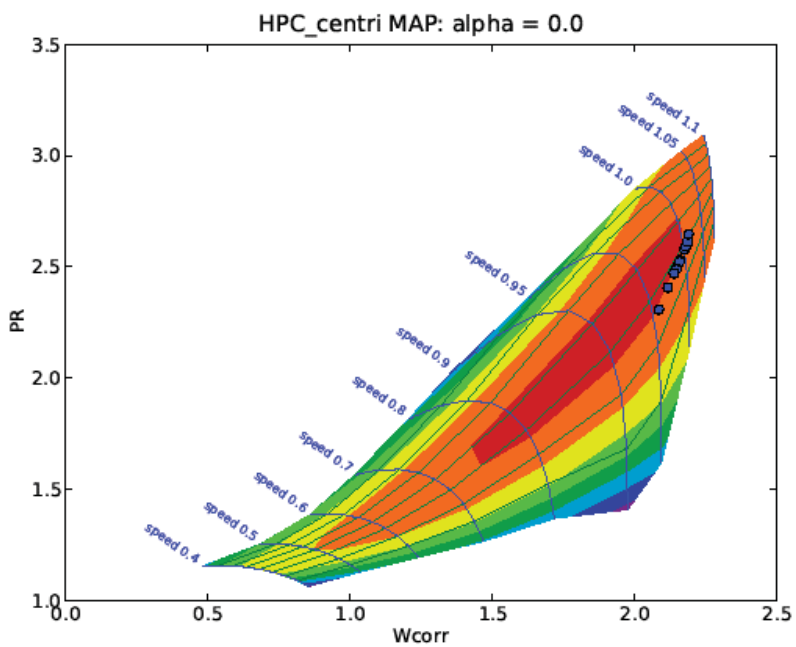

Figure 5.—High-pressure axial compressor performance map.

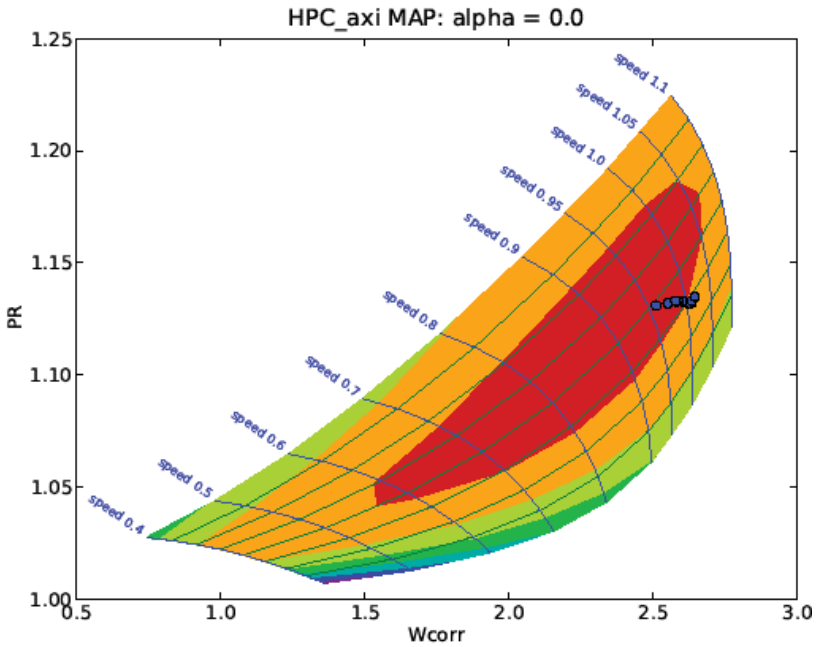

Figure 6.—High-pressure centrifugal compressor performance map.

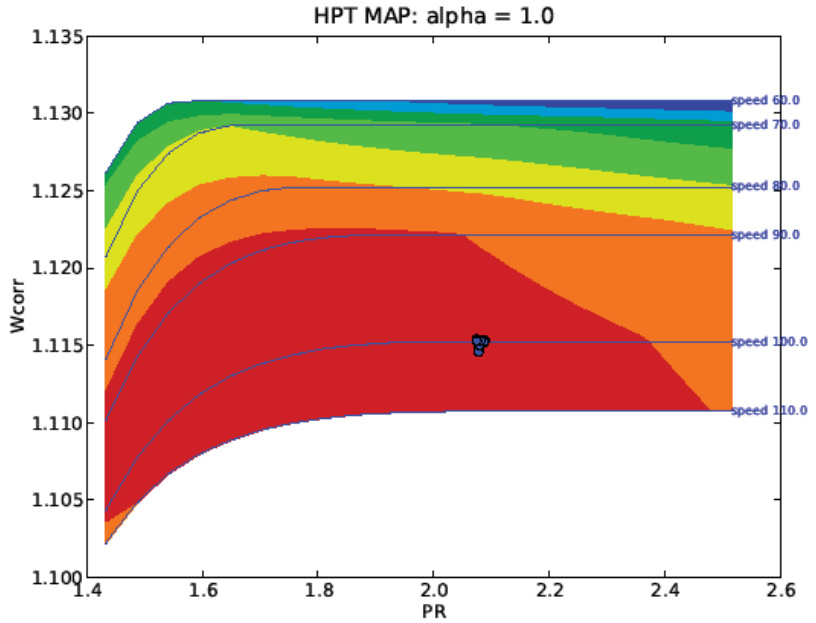

Figure 7.—High-pressure turbine performance map.

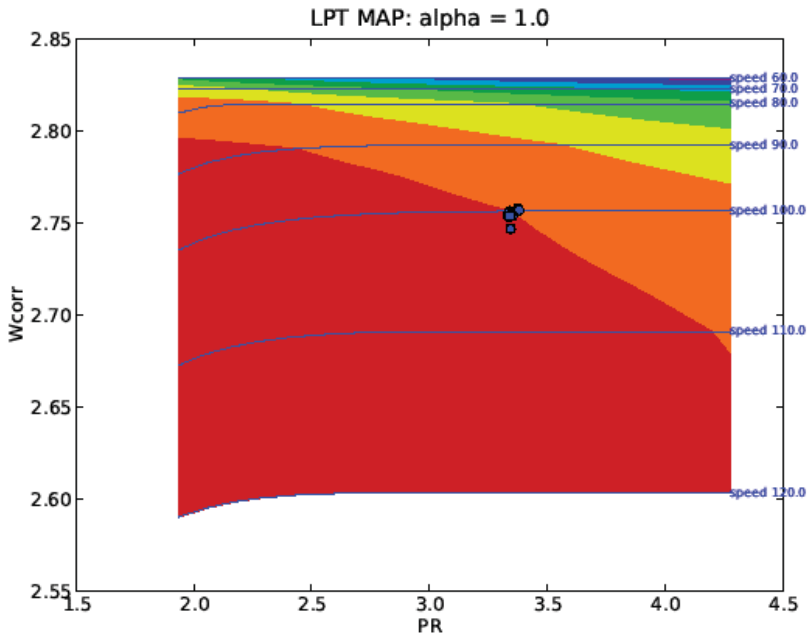

Figure 8.—Low-pressure turbine performance map.

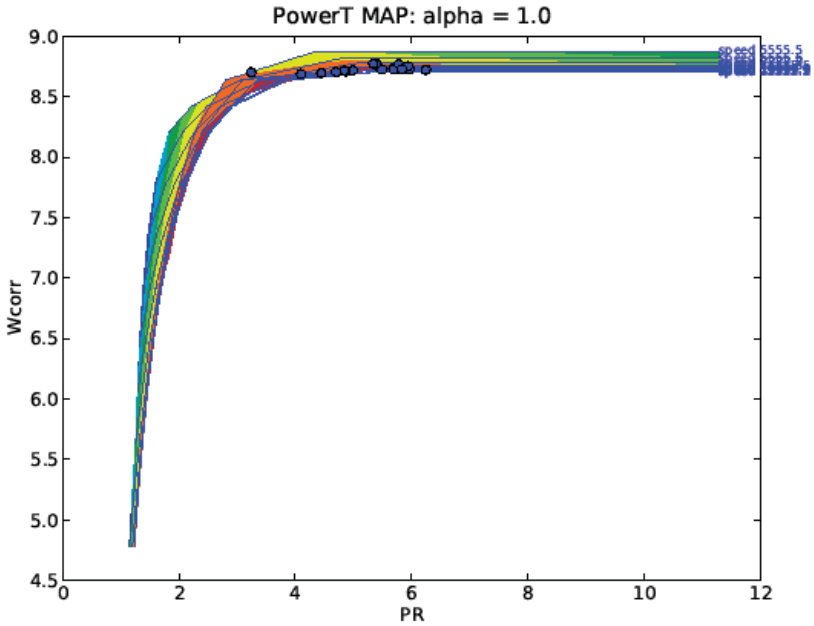

Figure 9.—Power turbine performance map.

Results from the engine performance analyses, at typical engine points at SLS and for the operating conditions listed in Table 6 are shown in Table 7. The OEI requirement at high, hot conditions determines engine size (for the assumed level of CRP), and that requirement is so demanding, that the engines are able to meet all other mission power requirements at or under their respective engine rating power levels (either MRP or MCP). After takeoff, engines stay at MCP combustor exit temperature levels through the climb profile (much like regional aircraft); the compressors experience some temperature reductions, mainly from altitude effects. There was sufficient engine power available for the transition from hover to cruise rotor tip speeds; before the shift, the engine PT is at non-optimum conditions, which slightly increases engine power setting (to get the same power output), internal conditions and specific fuel consumption. Also during that climb segment, right after transitioning to the lower rotor tip speed, drive system torque levels could be slightly higher than the HOGE takeoff torque levels if the engines are at MCP, which suggests one would have to be careful how quickly (and how much) to slow the rotors (or set engine power levels) as altitude increases (and engine power falls) to stay within drive system torque limits. Cruise requirements are fairly reasonable; temperatures are significantly less than takeoff or climb levels. There is actually sufficient cruise power available to run on only three engines and still be below engine MCP limits (cruise power levels are from 62 to 67 percent of MCP—with four engines operating). The first reserve leg is at the cruising altitude, so it looks very similar to conditions at end of cruise. The second reserve leg was a late-in-flight diversion at low altitude (5,000 ft, ISA, at velocity for best range). At such a low altitude, there is a lot of available power and the engine meets power requirements at very low power levels. At such low power levels, the turbomachinery is operating away from design conditions, which results in reduced component efficiencies and higher power specific fuel consumption. For the HOGE landing requirement, since the vehicle is significantly lighter than takeoff without most of the mission fuel, only 85 percent of the HOGE takeoff power level is required, with significantly lower combustor temperature (approximately 140 °F cooler), operating effectively below MCP conditions (although it could be running up to MRP levels). One last thing to note from the SLS engine power rating conditions is the effect of diminishing returns for the increase in available power with increase in combustor temperature (and amount of time such power levels would be available).

TABLE 7.—ENGINE PERFORMANCE PARAMETERS

Condition	Airflow, lb/s	Compression exit temperature, °F	Compression exit pressure, psia	Combustor exit temperature, °F	Delivered power, HP	Power specific fuel consumption, lb/hour/HP
Standard engine rating points, SLS						
MCP	22.6	1136	546	2980	5105	0.359
IRP	24.2	1185	600	3135	6050	0.349
MRP	24.9	1205	623	3200	6476	0.345
CRP	25.3	1226	639	3267	6787	0.345
Flight points from Table 6						
OEI	19.8	1237	500	3248	5156	0.350
HOGE/takeoff	18.1	1163	443	3046	4141	0.363
Climb 1 (shift)[a]	17.6	1157	425	2983	3691	0.382
Climb 1 (shift)[b]	17.2	1142	412	2937	3695	0.365
Climb 2 (MCP)	14.4	1068	332	2712	2583	0.390
Cruise start	9.4	911	209	2500	1902	0.324
Cruise end	8.9	881	195	2411	1675	0.333
Reserve-diversion	8.8	878	193	2400	1649	0.334
Reserve-emergency	13.8	922	296	2311	1656	0.471
HOGE/landing	16.9	1128	404	2905	3474	0.377

[a]Before shift, PT not at optimum rpm (61.5 percent of hover mechanical rpm)
[b]After shift, PT at optimum rpm (100 percent mechanical rpm)

Conclusions

Additional mission analyses were performed on the LCTR2 vehicle from an engine-centric point of view; in hopes of further understanding and refining engine power requirements and their effect on the LCTR2 vehicle sizing and mission. During this effort, a process was described for the transition of the rotors from hover to cruise rpm. Based on the assumed mission, engine ratings and constraints, the OEI requirement at 5,000 ft, ISA+20 °C was the most stringent condition that defined engine power requirements and had the greatest effect on the vehicle and engine sizing. Lower levels of CRP beyond MRP and MCP would increase vehicle weight, mission fuel and engine sizing, but would potentially enable higher climb rates or a greater maximum takeoff weight. Results from the NPSS turboshaft engine simulation suggests that under the assumed engine power ratings, constraints, and missions that there are very limited conditions where engines are required to operate beyond MCP levels, with most conditions comfortably at or below this level. Engine turbomachinery components operate within a fairly narrow portion of their overall operational envelopes, except for the PT; but even its operating range was well within its performance envelope. After transition from helicopter to airplane mode, there is sufficient power available to maintain constant rotor power and climb rate while shifting the gear ratio between the engines and rotors to better match engine PT rpm for the slower, rotor cruise tip speed. For some conditions, depending on the amount of rotor tip speeds reduction and assumed power used during climb (MCP), torque levels under these conditions would be the higher than the typical torque limit design, increasing drive system torque requirements and weight (minor operational constraints could alleviate such occurrences). For the assumed turbomachinery performance and efficiencies, diminishing increases in power beyond MCP are achieved for further increases in combustor temperature, with significant reductions in engine life. These must be balanced with vehicle sizing and performance, and potentially other items that are beyond the scope of this study.

Future Efforts

Optimum rotor cruise tip speed is highly dependent on many interconnected assumptions. Recent NASA in-house and contracted efforts have tried to further refine engine and drive system performance and weights; this new understanding needs to be folded into this work. VSPT technology can change the shape and range of engine performance; new drive system designs and material technologies could change the weight and efficiency trends for a given speed reduction from engine PT to vehicle rotor. Combined, these may lead to a different vehicle and drive system design and operation to minimize vehicle gross weight and mission fuel and need to be applied to the LCTR2 design and optimization. These efforts are on-going and are within present research plans. Other missions and requirements continue to be defined that may lead to configurations other than the tiltrotor. With generic, new technologies and learning being applied, capabilities to model these vehicles faster and with greater fidelity offer the opportunity to find and define the next generation of rotary wing vehicles to help people get there faster, easier, and cheaper.

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14. ABSTRACT

Defining specific engine requirements is a critical part of identifying technologies and operational models for potential future rotary wing vehicles. NASA's Fundamental Aeronautics Program, Subsonic Rotary Wing Project has identified the Large Civil TiltRotor (LCTR) as the configuration to best meet technology goals. This notional vehicle concept has evolved with more clearly defined mission and operational requirements to the LCTR-iteration 2 (LCTR2). This paper reports on efforts to further review and refine the LCTR2 analyses to ascertain specific engine requirements and propulsion sizing criteria. The baseline mission and other design or operational requirements are reviewed. Analysis tools are described to help understand their interactions and underlying assumptions. Various design and operational conditions are presented and explained for their contribution to defining operational and engine requirements. These identified engine requirements are discussed to suggest which are most critical to the engine sizing and operation. The most-critical engine requirements are compared to in-house NASA engine simulations to try to ascertain which operational requirements define engine requirements versus points within the available engine operational capability. Finally, results are summarized with suggestions for future efforts to improve analysis capabilities, and better define and refine mission and operational requirements.

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