33RD CONGRESS
OF THE INTERNATIONAL COUNCIL
OF THE AERONAUTICAL SCIENCES
STOCKHOLM, SWEDEN, 4-9 SEPTEMBER, 2022

LOW BPR TURBOFAN PERFORMANCE WITH POWER EXTRACTION

Daniel Rosell[1], Tomas Grönstedt[2], Pedro David Bravo-Mosquera[3] & Fernando Martini Catalano[3]

[1] Saab Aeronautics, Bröderna Ugglas gata, 581 88 Linköping, Sweden;
daniel.rosell@saabgroup.com, phone: +46 10 216 14 76
[2]Division of Fluid Dynamics, Chalmers University of Technology, Mechanics and Maritime Sciences,
412 96 Göteborg, Sweden; tomas.gronstedt@chalmers.se, phone: +46 31 772 14 09
[3]Aerodynamic Laboratory, São Carlos Engineering School, University of São Paulo, Brazil

Abstract

Military aircraft require more electrical power than they used to do. The increased power consumption is due to a transition from pneumatic and hydraulic systems to electrical and the introduction of new, more power consuming equipment. This paper summarizes an engine performance study, performed with a modeled low bypass ratio mixed flow turbofan engine, where power is extracted from the low-pressure shaft, the high-pressure shaft or a combination of the two. High-pressure shaft power extraction results in a considerable turbine inlet temperature increase. If the operating point has sufficient margin to the maximum turbine inlet temperature limit and if the power extraction is acceptable from an operability point of view, power can be extracted from the high-pressure shaft without causing much penalty on engine thrust. If the engine is running close to its maximum turbine inlet temperature, which is typically the case at low altitude and high aircraft speed, power extraction from the low-pressure shaft could be a better alternative due to the lower turbine inlet temperature increase. This gives a higher margin to the maximum turbine inlet temperature limit. However, if the full potential of low-pressure shaft power extraction is to be utilized, the high-pressure compressor must have some aerodynamic overspeed margin for the low-pressure shaft power extraction case. At part power, the lower specific thrust of the low-pressure shaft extraction case compared to the high-pressure shaft power extraction case, is favorable from a propulsive efficiency and fuel consumption perspective.

Keywords: low bypass ratio mixed flow turbofan, engine performance, power extraction, combined shaft power extraction, fighter aircraft

1. Introduction

Electrical power is traditionally consumed by aircraft components such as pumps and systems used for hydraulic, pneumatic and control [1,2], but the amount of electric power consumed by military aircraft is continuously increasing [3]. Advanced radars and mission systems require more and more power and systems that used to be hydraulic are being replaced by electric machinery [4-7]. A development to drastically reduce centralized hydraulic equipment of military aircraft started in the late 80’s and early 90’s [5,8,9]. The main objectives of this shift were improved reliability, maintainability and supportability of the introduced electrical systems, but also to reduce volume and weight compared to hydraulic systems [9,10]. Weight and volume reductions of the fighter aircraft fuselage may also be accomplished by integrating the starter/generator with the aircraft engine, thereby eliminating the engine´s accessory gearbox [9,10], such solutions have been evaluated for at least forty years [11].

As higher amounts of power extraction are required by the fighter aircraft, the impact of power extraction on engine performance is a topic of increasing interest. A two-shaft low bypass ratio mixed flow turbofan engine has been the subject for this investigation. For this engine type, power can be extracted from the low-pressure (LP) shaft or the high-pressure (HP) shaft. Power is normally extracted from one of the shafts, but if power extraction from both shafts is an option and if the power extraction can be distributed arbitrary between the shafts, benefits can be achieved, both from a performance perspective [12-14] and from an operability point of view [12-15]. The purpose of the performed investigation was to evaluate how power extraction from the high-pressure and low-pressure shaft, or a combination of both, affect engine performance. Similar investigations have previously been performed for high bypass ratio turbofan engines [12-14,16] and alternative cycles for military engines [17,18]. This work complements an earlier investigation that focused solely on high pressure shaft power extraction on a low bypass ratio mixed flow turbofan engine [19]. It will be shown that the performance impact of low-pressure shaft power extraction is different from high-pressure shaft power extraction and that power extraction from either the high-pressure shaft or the low-pressure shaft can be favorable in different circumstances.

The paper is divided into three main sections. The methods applied are presented in the Methods section, describing the aircraft conceptual design, engine model, the design point and key parts of the fighter mission. The research results are presented in the Results section, which is subdivided into two main parts. The first sub part evaluates engine performance at the key points of the fighter mission. The second sub part is a performance analysis of the engine running at its maximum power, with and without the use of afterburner at a constant altitude but at different Mach numbers. Each case is evaluated with power extraction from the low-pressure shaft, the high-pressure shaft and without power extraction. The paper is summed up in a final conclusions section.

2. Method

2.1 Aircraft conceptual design

Conceptual design is a procedure, in which important aircraft characteristics such as weight, aerodynamics, configuration, size and performance are first estimated to achieve a balanced aircraft design. In this section, a brief summary of fighter conceptual design is presented. The design requirements for new fighter aircraft involve defining threats, targets and scenarios for the future. Current fighter requirements emphasize the need for close-in-combat and beyond visual range combat capability to achieve superiority in the air-to-air role. High sortie rates and the ability to perform air-to-surface missions are also a primary requirement [20]. Some design requirements and objectives include:

- Short take-off and landing distances for quick military operation.
- High Thrust-to-Weight (T/W) ratio, as it helps in low altitude maneuverability in order to quickly ingress and egress from the combat area.
- High weapons load capacity, as it enables engagement of a large number of targets.
- Reduced RCS, as it decreases the distance at which the enemy can detect the aircraft using radar.
- Ruggedness, as the aircraft should be able to take some amount of punishment and return to base station.
- High range and endurance on target, as the ground troops may require support for an extended period of time, with corresponding weapons load.
- High supersonic speed for quick escape dash and evasion [21-24].

For this preliminary characterization of the generic fighter aircraft, it shall be capable of performing the following specific mission (Figure 1):

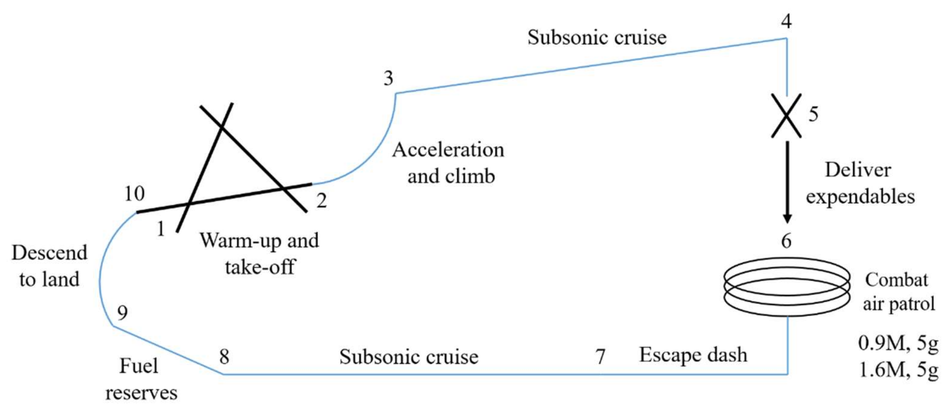

Figure 1 – Typical mission profile of a fighter aircraft (derived from [24]).

Based on the mission profile, the first step of the conceptual design study was to define the operational requirements related, for example, to payload weight, flight endurance and flight velocities. The selected values are presented in Table 1 and correspond to a typical fighter aircraft. Considering the presizing calculations, an in-house tool was employed, which has been developed in the Laboratory of Experimental Aerodynamics (LAE), at the Department of Aeronautical Engineering, at the São Carlos School of Engineering - University of São Paulo (EESC-USP), Brazil. Based on aircraft design methods, such as the ones described in [25,26], it also includes particular aspects of fighter aircraft design, combining analytical and low-fidelity methods. It can be used to carry out a complete layout design study and aerodynamic analysis, and has been implemented on other fighter aircraft configurations as well [27]. In particular, first-order mass estimation methods are used to calculate the weight of both systems and structural components.

The process starts with the maximum take-off weight estimation, which is the sum of the crew weight, empty weight, payload, and fuel weight. The empty weight is estimated using historical trends and statistical data set derived from operating aircraft with similar requirements. The fuel weight is calculated by estimating the fuel consumption for each flight segment of the mission profile, using complete semi-empirical aerodynamic analysis. Furthermore, the application of the constraint analysis allowed to calculate the main performance characteristics of the aircraft in relation to each phase of flight, obtaining functional relationships between the minimum thrust-to-weight (T/W) and wing loading (W/S). Other modules include engine selection and intake sizing based on external losses, fuselage sizing in function of the take-off gross weight, and aerodynamic analyzes involving a complete parasite drag buildup and supersonic drag due to lift from the supersonic linear theory. Finally, the performance of the aircraft based on block fuel calculations and discretization of the mission profile was estimated. Warm-up, taxi, take-off and landing segments are estimated using fixed fuel fractions for fighter aircraft [26]. Phases such as climb, descent, and combat are discretized into many segments (time, range, and altitude steps). Therefore, at each time step, the flight dynamics equations are solved with the use of aerodynamic and engine characteristics. The block fuel is then calculated with the product of fuel consumption, dependent on a preliminary estimate of engine SFC, thrust, and time of each phase. The Breguet range equation is used to calculate the fuel consumption in cruise phases.

The preliminary characteristics of the aircraft include: MTOW = 21920 kg; Empty weight = 12620 kg; Payload = 4500 kg; W/S = 3360 Pa; T/W = 1.1; Range 1500 nm; whereas a 3D representation is presented in Figure 2.

Table 1 – Mission requirements.

Phase	Description
1-2	Warm-up and takeoff, field is at 610 m pressure altitude with air temperature of 284K. Fuel allowance is 5 min at idle power for taxi and 1 min at military power for warm-up. Takeoff ground roll plus 3 seg rotation distance must be < 450 m on wet, hard surface runway with friction 0.05. Takeoff velocity = 1.2 (stall velocity)
2-3	Acceleration and climb Initial velocity 64 m/s Final velocity 247 m/s Climb 1, from 610 m to 4876 m Climb 2, from 4876 m to 9144 m
3-4	Subsonic cruise at Mach 0.9, Range = 540 km
4-5	Deliver missiles/bombs. Payload delivered = 30000 N
5-6	Combat is modeled by the following characteristics: Perform one 360 deg, 5g sustained turn at 9144 m. Mach 1.6 Perform two 360 deg, 5g sustained turns at 9144 m. Mach 0.9 Fire ½ of ammunition No range credit is given for combat maneuvers
6-7	Escape dash = Accelerate from Mach 0.9 to Mach 2.0 at 9144 m at enough power
7-8	Subsonic cruise at Mach 0.9, Range = 555 km
8-9	Fuel reserves. 1200 seg
9-10	Descend to land. Initial velocity = 158 m/s. Final velocity = 68 m/s.

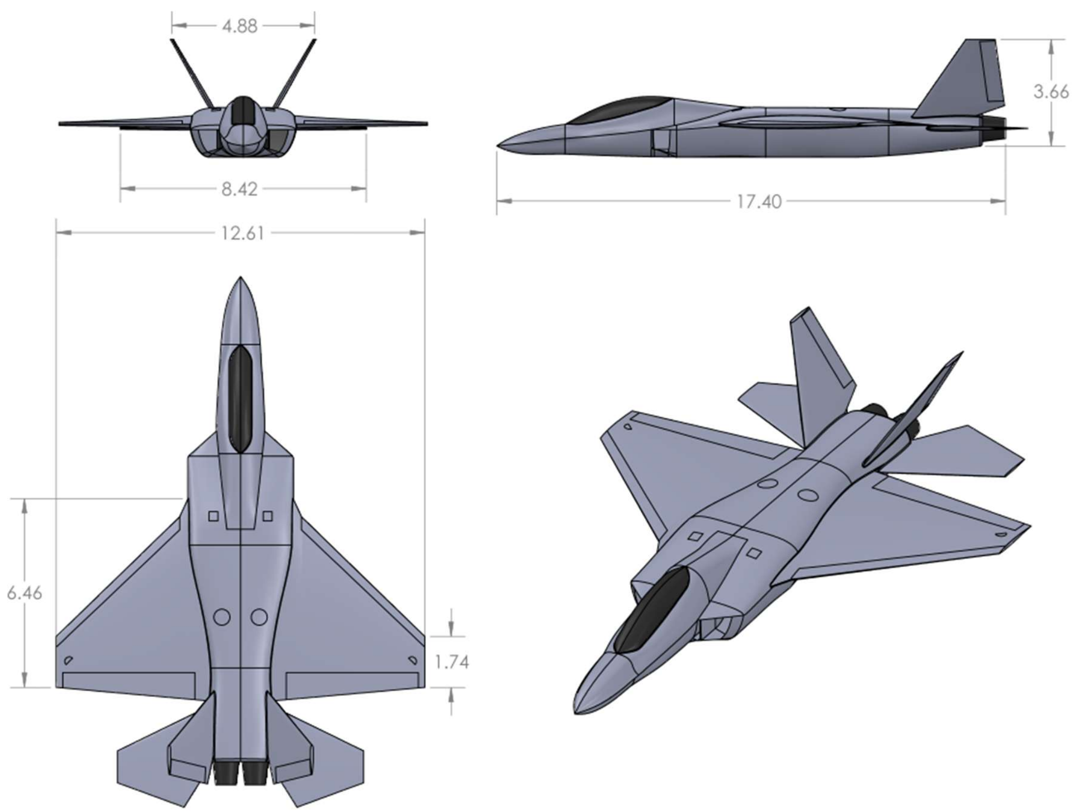

Figure 2 – Four views of the fighter aircraft concept, dimensions in meters.

2.2 Engine performance model

The performance analysis covers engine maximum power and part load operation with and without the use of afterburner at various altitudes and aircraft speeds. The mission thrust requirements per engine, as shown in Table 2, represent key parts of the fighter aircraft mission described in section 2.1 and Table 1. Cases where the afterburner is in operation are referred to as "augmented".

Table 2 – Thrust required for each engine for key parts of the fighter aircraft mission.

No	Mission Phase		Required Net Thrust	Altitude	Mach Number
1	1-2	Warm up non-augmented	66.0 kN	610 m	0.0
2	1-2	Runway acceleration augmented	110.7 kN	610 m	0.1
3	1-2	Runway acceleration augmented	112.9 kN	610 m	0.18
4	2-3	Flight acceleration augmented	127.3 kN	610 m	0.44
5	2-3	Climb and acceleration augmented	127.8 kN	2743 m	0.775
6	2-3	Climb and acceleration augmented	78.9 kN	7010 m	0.9
7	3-4	Subsonic cruise non-augmented	12.4 kN	9144 m	0.9
8	5-6	Sustained turn augmented	100.6 kN	9144 m	1.6
9	5-6	Sustained turn augmented	53.2 kN	9144 m	0.9
10	6-7	Escape dash augmented	113.9 kN	9144 m	2.0

A low bypass ratio mixed flow turbofan engine has been modeled with the Chalmers in-house tool GESTPAN. A graphical presentation of the engine is given in Figure 3. Figure 3 is a slightly modified version of Figure 1 in [19].

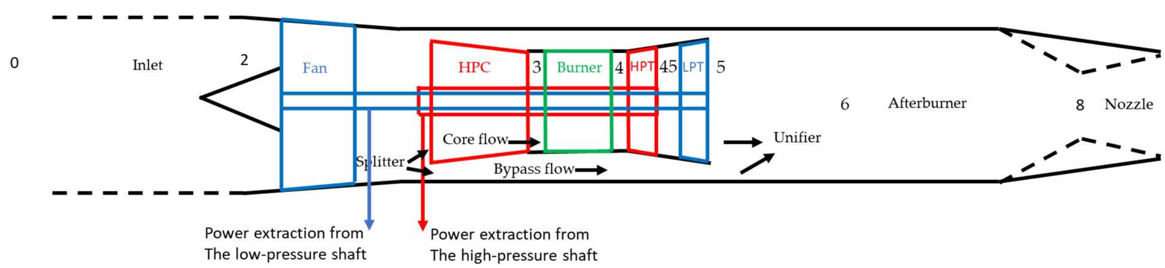

Figure 3 – Overview of the modeled low bypass ratio mixed flow turbofan engine. Based on Figure 1 in [19].

The engine cycle is defined by the design point. Some important cycle parameters of the design point are presented in Table 3. The cycle parameter values are based on information from public sources [28-30].

Table 3 – Cycle parameters of the design point.

Parameter	Value
Altitude	0 m
Mach number	0
Fan pressure ratio	5.4
High pressure compressor pressure ratio	5.1
Inlet mass flow	90 kg/s
Turbine inlet blade temperature	1030 K
Bypass ratio	0.5
Turbine inlet gas temperature	2000 K
Bleed flow	0 kg/s
LPT power extraction	0 kW
HPT power extraction	0 kW

All flight cases are calculated as off design points. Calculations are performed to meet the thrust requirements and the solutions are constrained by either the maximum overall pressure ratio (OPR) or the maximum allowed turbine inlet gas temperature (T_4), applying an engine control methodology described in [24]. The maximum OPR is set to 28 [24] and the maximum allowed T_4 is set to 2260 K, which is the maximum inlet temperature of the F135 jet engine according to [30]. Other limiters of the engine controller, as described in [28,31,32], are not considered.

The study performed herein focuses on engine performance. Engine operability issues associated with large power extraction are not considered. The mission points shown in Table 2 have been simulated with and without power extraction [19]. The following three cases were simulated:

1. The reference run with no power extraction (black color in figures below)
2. Power extracted (900 kW) from the high-pressure shaft (red color)
3. Power extracted (900 kW) from the low-pressure shaft (blue color)

3. Results

Figure 4 shows engine net thrust for the reference case (black), the HP power extraction case (red) and the LP power extraction case (blue) referred to in section 2, together with the thrust requirement (green) of Table 2. It can be observed that, with the engine cycle selected, all thrust requirements are met with both HP and LP power extraction, except point 5 (climb and acceleration) and point 10 (escape dash). Point 5 and 10 illustrate two extremes in the fighter aircraft mission, both are challenging, but for different reasons:

- Point 5 is the aerodynamic design point of the mission and the engine performance is limited by the maximum OPR restriction. Figure 4 illustrates that the thrust requirement is not achieved for the LP power extraction case. In the performed calculations, it was assumed that the HPC could operate at a slightly higher corrected mass flow and pressure ratio compared to the design point, i.e., that the HPC has some aerodynamic overspeed capacity. Otherwise, the LP power extraction case would be limited by the controller and the thrust would be decreased further.
- Point 10 illustrates the other extreme of the aircraft fighter mission in Table 2. In this case, the engine is operating at, and is limited by, its maximum inlet temperature. None of the power extraction cases meet the thrust requirement, but the thrust drop is larger for the HP power extraction case than for the LP power extraction case.

Figure 5 shows that the turbine inlet temperature T_4, increases when power is extracted and that the required temperature increase is significantly higher in the case of HP power extraction compared to the LP power extraction case. The higher temperature increase of the HP power extraction case increases the specific net thrust of the engine, which helps to meet thrust requirements when the engine is operating near or at its max OPR limit [19]. However, the higher temperature increase will also make the engine run into its maximum turbine inlet temperature limitation for more flight cases.

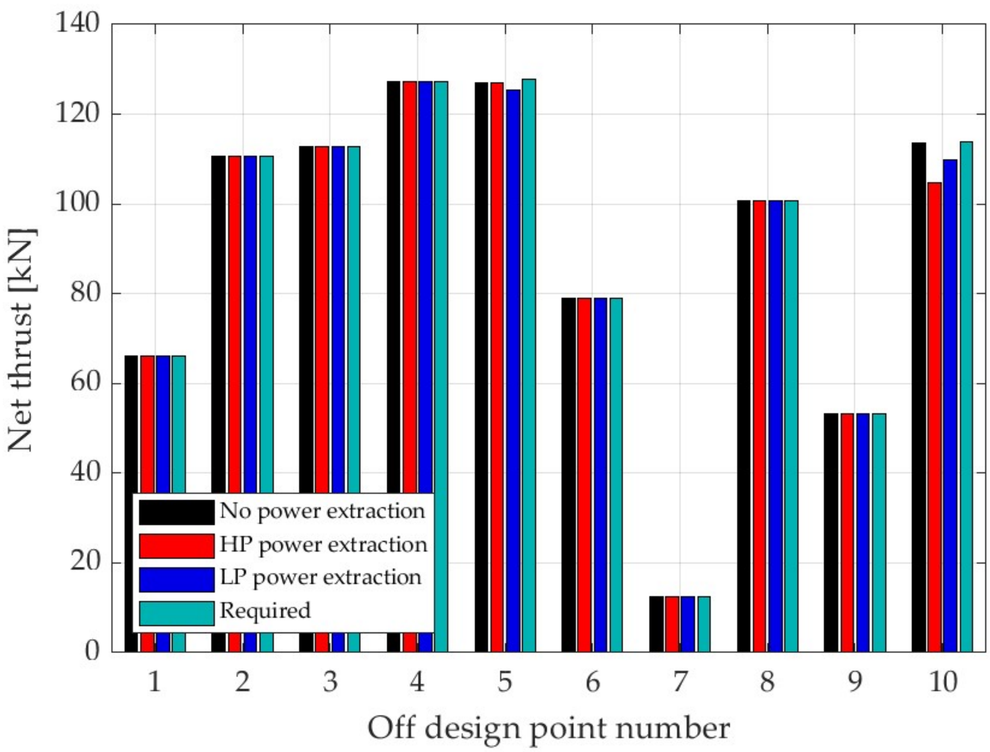

Figure 4 – Net thrust.

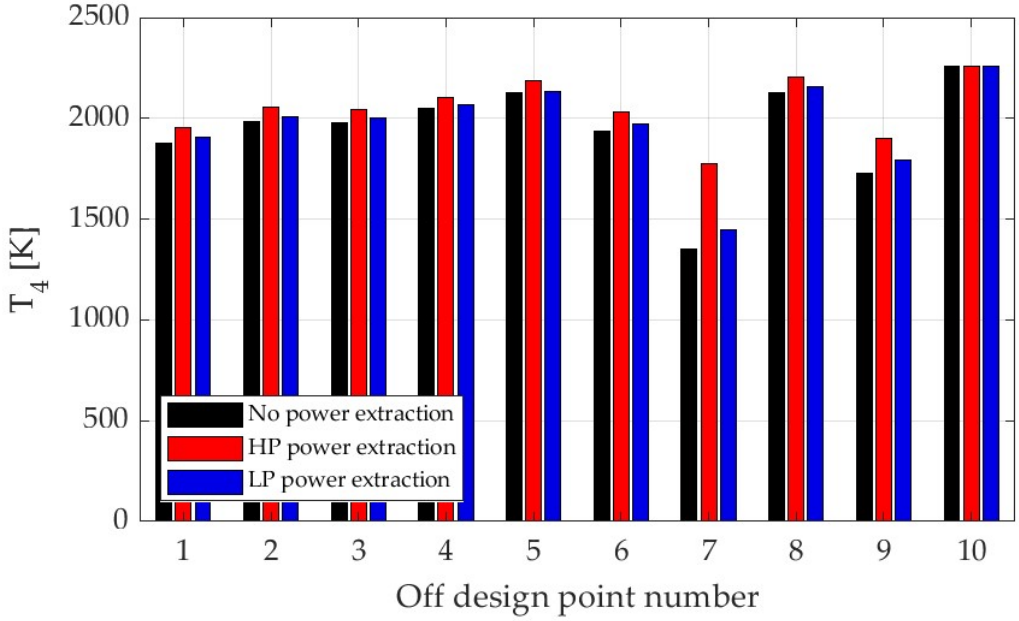

Figure 5 – Turbine inlet gas temperature.

The higher turbine inlet temperature (T_4) increase of the HP power extraction case is also reflected in specific fuel consumption, as illustrated in Figure 6. When specific thrust increases, the amount of air mass flow is reduced. This requires a higher nozzle jet speed to produce the same thrust, which in turn reduces propulsive efficiency when the engine is running non-augmented. The reduced propulsive efficiency has a negative impact on SFC. When the engine is running augmented, a higher turbine inlet temperature of the core engine is desirable, as it increases LPT output temperature, thereby reducing the required amount of afterburner fuel flow [19]. This is favorable from an SFC perspective as the thermal efficiency of the core engine is higher than the thermal efficiency of the afterburner [30].

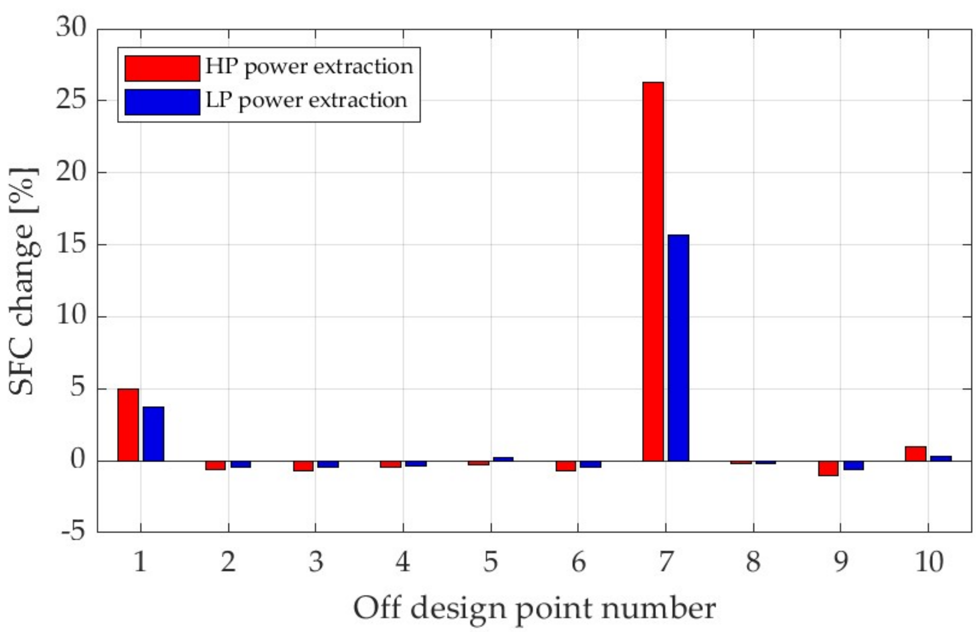

Figure 6 – SFC difference compared to no power extraction.

A parameter study has been performed to evaluate maximum non-augmented power and maximum augmented power when the engine is running, either at its maximum OPR limit or maximum T_4 limit.

Figure 7 through 14 illustrate some key engine parameters plotted as a function of non-dimensional stagnation temperature, θ_0 ($\theta_0 = T_0/288.15$). Figure 7 shows OPR for the non-augmented case and Figure 8 shows OPR for the augmented case. The engine is controlled by either the maximum OPR limit or the maximum T_4 limit [24]. The engine is limited by maximum OPR up to the θ_0 break [24,31,33] (θ_0 =1.13 in Figure 7 and Figure 8 for the case with no power extraction). At stagnation temperatures beyond the θ_0 break, the engine power is limited by the maximum T_4. As soon as the θ_0 break is reached (T_4 reaches its limit value), the engine controller must limit the fuel flow not to exceed the maximum allowed turbine inlet temperature and OPR will be reduced. Figure 7 and Figure 8 illustrate how the engine, when power is extracted from the HP, reaches the turbine inlet temperature limit (the θ_0 break) at a lower θ_0 value compared to the reference case [19] and the LP power extraction case. This is shown explicitly in Figure 9 for the non-augmented case and in Figure 10 for the augmented case. If some of the power is extracted from the HP and some power is extracted from the LP the θ_0 break will be reached somewhere in between the illustrated HP and LP power extraction case.

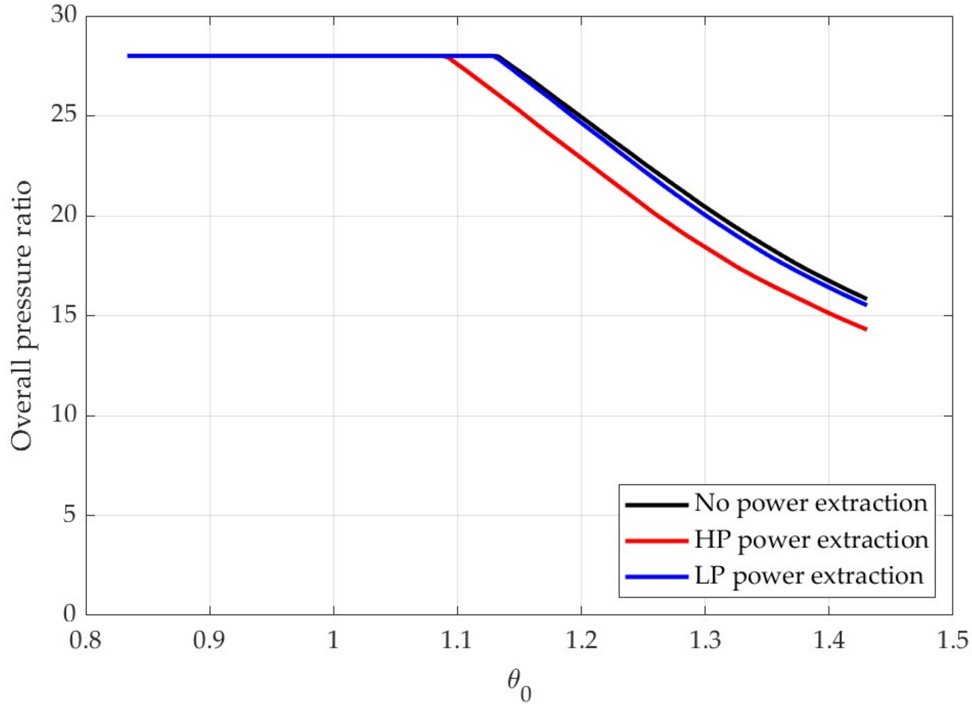

Figure 7 – Maximum non-augmented power at 9144 m. OPR vs θ_0.

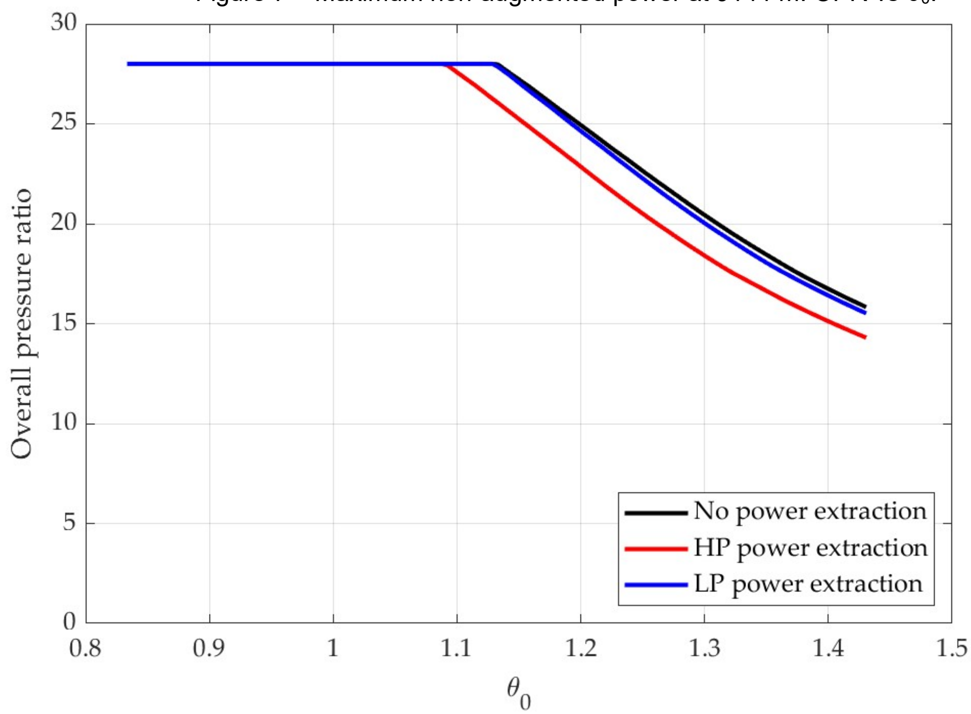

Figure 8 – Maximum augmented power at 9144 m. OPR vs θ_0.

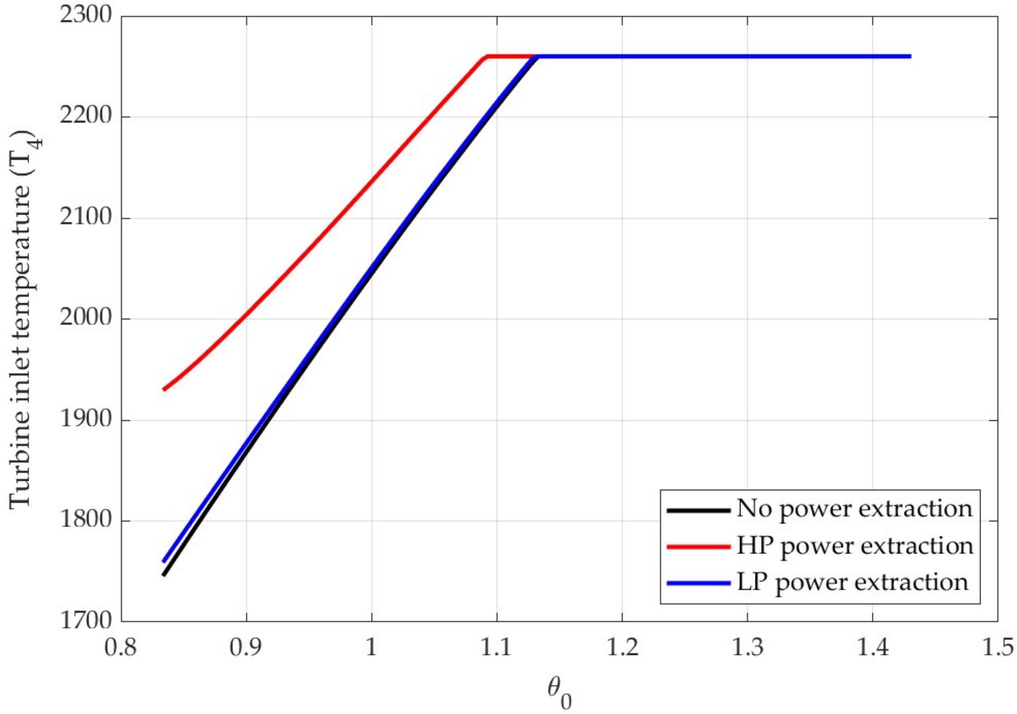

Figure 9 – Maximum non-augmented power at 9144 m. T4 vs θ_0.

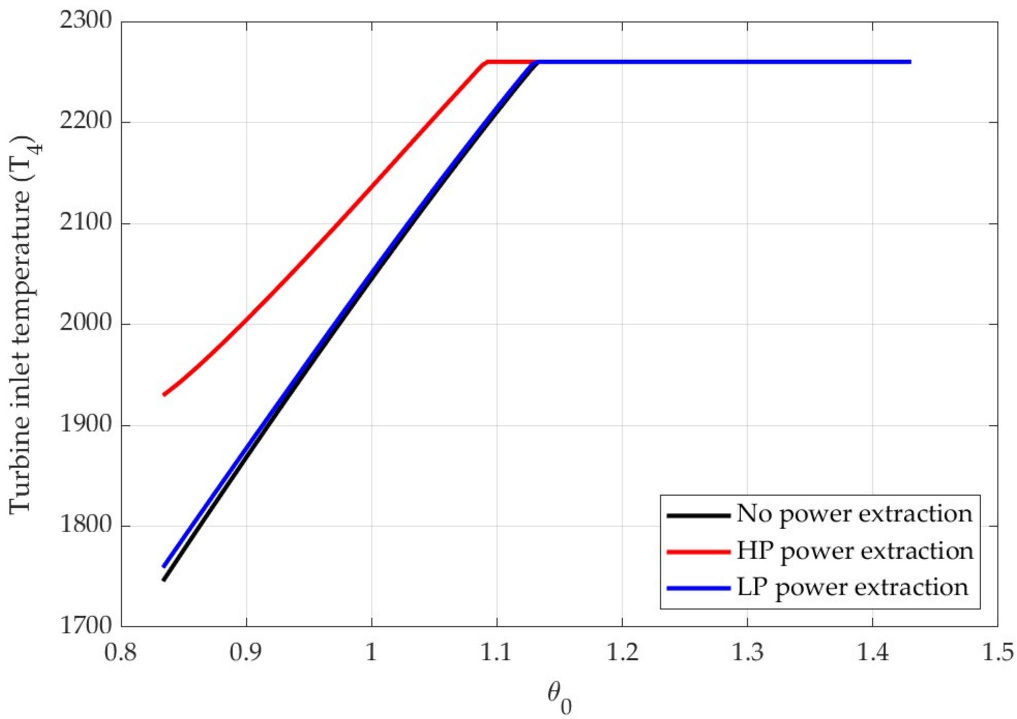

Figure 10 – Maximum augmented power at 9144 m. T4 vs θ_0.

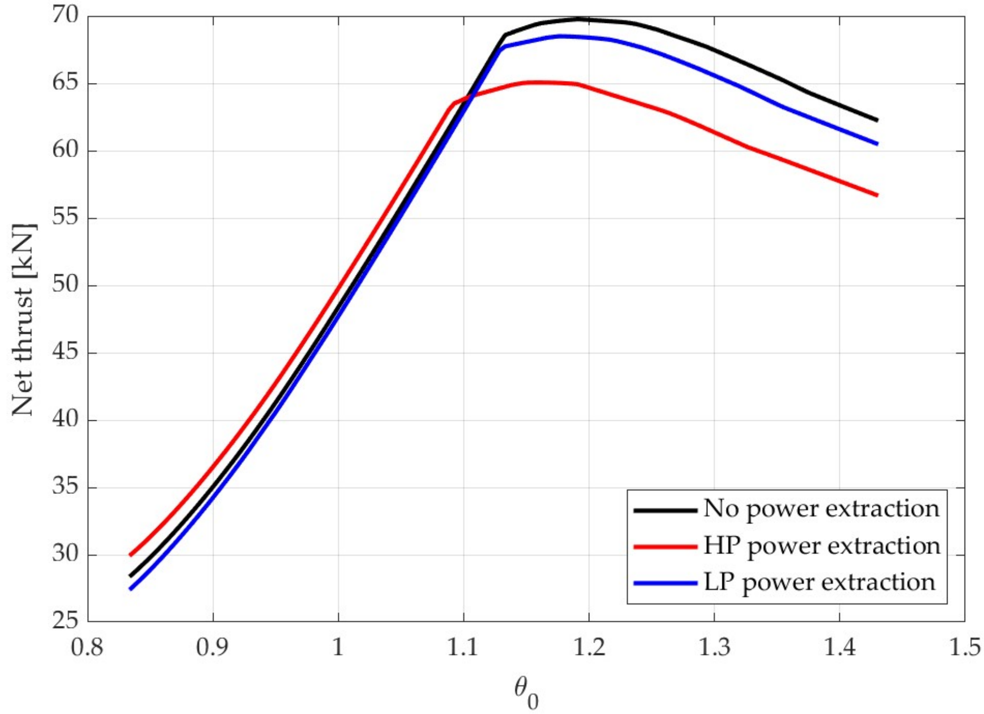

Figure 11 – Maximum non-augmented power at 9144 m. Net thrust vs θ_0.

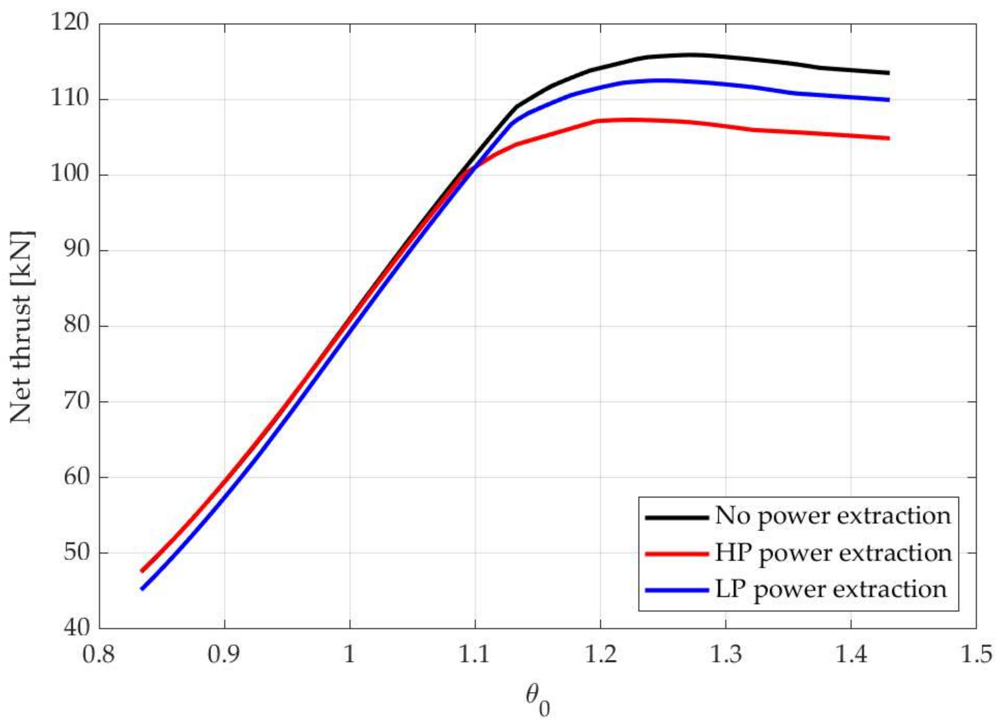

Figure 12 – Maximum augmented power at 9144 m. Net thrust vs θ_0.

The net thrust of the non-augmented and augmented cases, shown in Figure 11 and Figure 12, increases rapidly with increased θ_0 until the θ_0 break is reached. For θ_0 values beyond the θ_0 break, the rate of net thrust increase is reduced and eventually replaced by a net thrust reduction. As the HP power extraction case reaches the θ_0 break for lower θ_0 values, this net thrust reduction occurs at lower θ_0 compared to the reference run and the LP power extraction case. The T_4 increase with LP power extraction compared to the reference case is small, causing a thrust reduction for θ_0 values below the θ_0 break. However, the θ_0 break is located more to the right compared to the HP power extraction case due to the modest T_4 increase. This allows the engine to operate at higher OPR and net thrust levels at higher θ_0 values when power is extracted from the LP shaft compared to power extraction from the HP shaft. If power is extracted from both the HP shaft and the LP shaft, the T_4 increase will be higher compared to the LP power extraction case but lower than the HP power extraction. A curve illustrating net thrust and SFC of a combined LP and HP power extraction case would then fall in between the lines illustrating LP and HP power extraction in Figure 11 through 14.

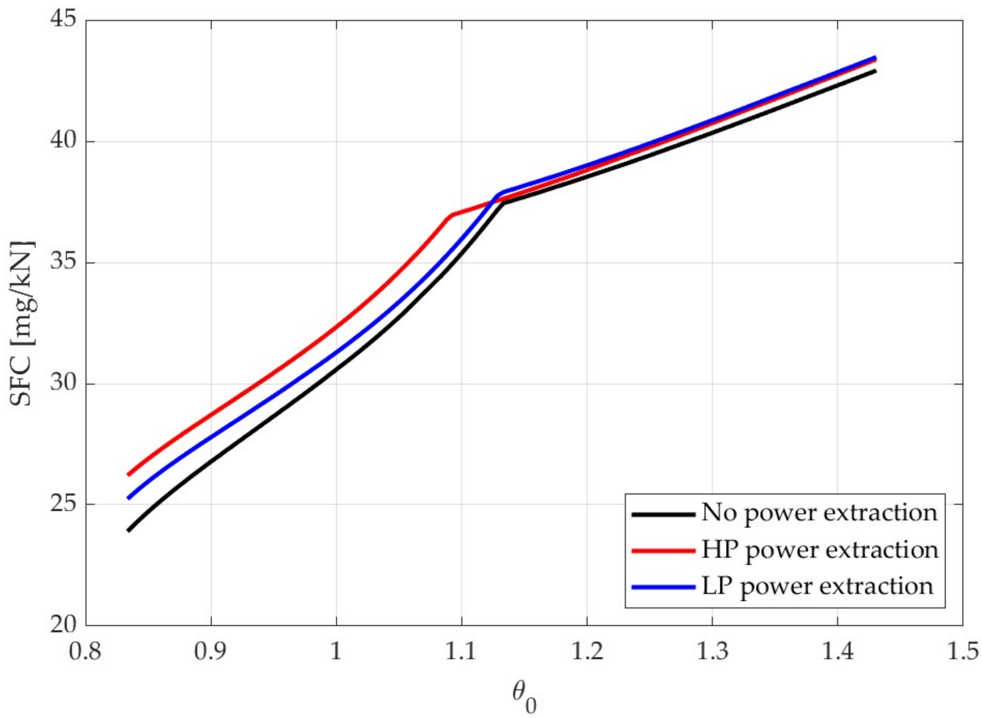

Figure 13 – Maximum non-augmented power at 9144 m. SFC vs θ_0.

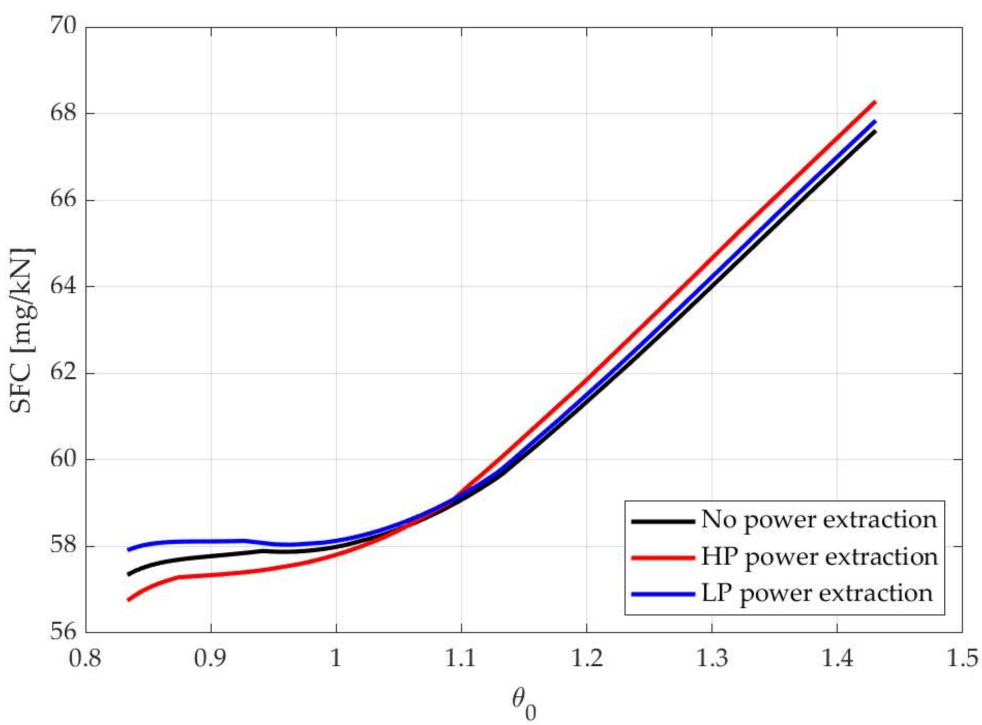

Figure 14 – Maximum augmented power at 9144 m. SFC vs θ_0.

4. Conclusions

The investigation shows that turbine inlet temperature increases when power is extracted, whether it is extracted from the HP shaft or the LP shaft. However, the temperature increase is more significant when power is extracted from the HP shaft. This may be both favorable and unfavorable from an engine performance point of view, depending on the flight conditions and engine power settings. Higher temperature increases specific thrust, which allows the engine to meet the thrust requirements of aerodynamically challenging operating conditions, provided that sufficient surge margin of the engine can be maintained. If the engine is running augmented, the temperature increase of the core engine helps to reduce the amount of fuel burn in the afterburner. This is desirable, since afterburning is a thermodynamically less efficient process compared to the core engine. However, at non-augmented conditions, high specific thrust reduces air mass flow and impairs propulsive efficiency, which increases SFC. Moreover, the turbine inlet temperature increase associated with HP power extraction will make the engine run into the maximum turbine inlet temperature limit at more flight cases, thereby reducing the net thrust. Extracting power from the LP shaft does not raise turbine inlet temperature as much as HP power extraction. The lower specific thrust makes it harder to reach the net thrust requirements at aerodynamically challenging cases (high OPR required) and the aerodynamic overspeed capacity of the HPC will determine the net thrust reduction. However, lower turbine inlet temperatures of the LP power extraction case improve SFC at part load operation compared to the HP power extraction case, due to the better propulsive efficiency. The lower turbine inlet temperature compared to the HP extraction case increases the margin to the turbine inlet temperature limit, which allows the engine to run at higher net thrust when the turbine inlet temperature is high. Such operating conditions typically occur at low altitude and high aircraft speed.

5. Contact Author Email Address

mailto: daniel.rosell@saabgroup.com

6. Copyright Statement

7. Acknowledgements

This work has been funded by the Swedish Governmental Agency for Innovation Systems (VINNOVA), the Swedish Defense Materiel Administration (FMV) and the Swedish Armed Forces within the International Aviation Research Programme (IFFP diary number 2020-00690) and Saab Aeronautics.

Nomenclature

BPR	Bypass ratio
FPR	Fan pressure ratio
GESTPAN	Generic stationary and transient propulsion analysis
HP	High pressure / high pressure shaft
HPC	High pressure compressor
HPCPR	High pressure compressor pressure ratio
HPT	High pressure turbine
LAE	Laboratory of experiment
LP	Low pressure / low pressure shaft
LPC	Low pressure compressor
LPT	Low pressure turbine
OPR	Overall pressure ratio
SFC	Thrust specific fuel consumption
T	Stagnation temperature
T_0	Free stream stagnation temperature
T_4	Turbine inlet gas temperature
T/W	Thrust-to-weight ratio
W/S	Wing loading
θ_0	Non-dimensional stagnation temperature (T_0/288.15)

References

[1] Saravanamuttoo, H.I.H.; Rogers, G.F.C.; Cohen, H.; Straznicky, P.V.; Nix, A.C. *Gas turbine theory*, 7th ed.; Pearson Education Limited.: London, UK, 2017; pp. 101, 127–130, 407–408, 510.

[2] Rolls-Royce plc. *The jet engine*, 5th ed.; The Technical Publication Department. Rolls-Royce plc.: Derby, UK, 1996; p. 65.

[3] Mahefkey, T.; Yerkes, K.; Donovan, B.; Ramalingam, M. L., Thermal management challenges for future military aircraft power systems. *SAE Transactions*, 113, 1965–1973, 2004.

[4] Clark, R.A.; Shi, M.; Gladin, J.; Mavris, D. Design and analysis of an aircraft thermal management system linked to a low bypass ratio turbofan engine. *J. Eng. Gas Turbines Power* 2022, 144, 011019.

[5] Charrier, J.-J.; Kulshreshtha, A. Electric actuation for flight & engine control system: evolution, current trends & future challenges. In *Proceedings of the 45th AIAA Aerospace Sciences Meetings and Exhibit* (AIAA 2007-1391), Reno, NV, USA, 8–11 January 2007.

[6] Oyori, H.; Morioka, N.; Kakiuchi, D.; Shimomura, Y.; Onishi, K.; Sano, F. System design for the more electric engine incorporated in the electrical power management for more electric aircraft; *SAE Technical Paper* 2012-01-2169; SAE: Warrendale, PA, USA, 2012.,

[7] Boglietti, A.; Cavagnino, A.; Tenconi, A.; Vaschetto, S.; di Torino, P. The safety critical electric machines and drives in the more electric aircraft: A survey, 2009 35th *Annual Conference of IEEE Industrial Electronics*, 2009, pp. 2587-2594.

[8] Walters, E.; Iden, S.; McCarthy, K.; Amrhein, M.; O'Connell, T.; Raczkowski, B.; Wells, J.; Lamm, P.; Wolff, M.; Yerkes, K.; et al. INVENT modeling, simulation, analysis and optimization. In *Proceedings of the AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition* (AIAA 2010-287), Orlando, FL, USA, 4–7 January 2010; p. 3.

[9] Cloyd, J. S., Status of the United States air force's more electric aircraft initiative, in *IEEE Aerospace and Electronic Systems Magazine*, vol. 13, no. 4, pp. 17-22, April 1998.

[10] Quigley, R. E. J., More electric aircraft, *Proceedings Eighth Annual Applied Power Electronics Conference and Exposition*,, 1993, pp. 906-911

[11] Demel, H.F. Installation of electric generators on turbine engines; 19840001994; NASA. *Lewis Research Center Aircraft Elect. Secondary Power*: Cleveland, OH, USA, 1983.

[12] Chapman, J.W. A study of large scale power extraction and insertion on turbofan performance and stability. In *Proceedings of the 2020 AIAA/IEEE Electric Aircraft Technologies Symposium (EATS)*, New Orleans, LA, USA, 26–28 August 2020.

[13] Zähringer, C.; Stastny, K.; Ardey, S. Towards the powerhouse for more electric aircraft–dedicated engine concepts. In *Proceedings of the 19th International Symposium on Air Breathing Engines*, 2009.

[14] Pluijms, A., Schmidt, K. J., Stastny, K., & Chibisov, B. (2008, January). Performance comparison of more electric engine configurations. In *Turbo Expo: Power for Land, Sea, and Air*, Vol. 43116, pp. 113-122.

[15] Culley, D.E.; Kratz, J.L.; Thomas, G.L. Turbine electrified energy management (TEEM) for enabling more efficient engine designs. In *Proceedings of the Joint Propulsion Conference 2018*, Cincinnati, OH, USA, 9–11 July 2018.

[16] Faidi, A. *Effect of accessory power take-off variation on a turbofan engine performance*; Air Force Institute of Technology. Wright-Patterson Air Force Bace: Dayton, OH, USA, 2012.

[17] Corbett, M. Shaft power extraction and waste heat rejection using a three stream variable cycle engine. *SAE Int. J. Aerosp*. 2012, 5, 371–385.

[18] Meng, Xin-yu Jang; Min Xen; Zhi-li Zhu. High level power extraction from adaptive cycle engine for directed energy weapon. In *Proceedings of the 2018 Joint Propulsion Conference*, Cleveland, OH, USA, 9–11 July 2018.

[19] Rosell, D.; Grönstedt, T. Design considerations of low bypass ratio mixed flow turbofan engines with large power extraction. *Fluids* 2022, 7, 21

[20] Sacher, P. W., Orlik-Rückmann, K. J., Gödel, H., Costes, B., Leynaert, J., Perrier, P., ... & Yoshihara, H. (1986). Special course on fundamentals of fighter aircraft design. AGARD Report, 740.

[21] Endsley, M. R. (1993). A survey of situation awareness requirements in air-to-air combat fighters. The International Journal of Aviation Psychology, 3(2), 157-168.

[22] Mavris, D., & DeLaurentis, D. (1995, September). An integrated approach to military aircraft selection and concept evaluation. In Aircraft Engineering, Technology, and Operations Congress (p. 3921).

[23] Bennett Jr, W., Schreiber, B. T., & Andrews, D. H. (2002). Developing competency-based methods for near-real-time air combat problem solving assessment. Computers in Human Behavior, 18(6), 773-782.

[24] Mattingly, J. D., Heiser, W. H., & Pratt, D. T. (2002). Aircraft engine design. American Institute of Aeronautics and Astronautics. SCHOOL MONTEREY CA.

[25] Nicolai, L. M., & Carichner, G. E. (2010). Fundamentals of aircraft and airship design, Volume 1–Aircraft Design. American Institute of Aeronautics and Astronautics.

[26] Raymer, D. (2012). Aircraft design: a conceptual approach. American Institute of Aeronautics and Astronautics, Inc..

[27] Bravo-Mosquera, P. D., Abdalla, A. M., Cerón-Muñoz, H. D., & Catalano, F. M. (2019). Integration assessment of conceptual design and intake aerodynamics of a non-conventional air-to-ground fighter aircraft. Aerospace Science and Technology, 86, 497-519.

[28] Grieb, H. *Projektierung von turboflugtriebverken*; Springer: Basel, Switzerland, 2004; pp. 562–564, 735.

[29] Kurzke, J.; Halliwell, I. *Propulsion and power. An exploration of gas turbine performance modeling*; Springer International Publishing: Basel, Switzerland, 2018; p. 32.

[30] Langston, L.S. Fahrenheit 3,600. *Mechan. Eng.-CIME* 2007, 129, 34–37.
[31] Jaw, L.C.; Mattingly, J.D. *Aircraft engine controls: design, system analysis, and health monitoring*; American Institute of Aeronautics and Astronautics, Inc.: Blacksburg, VA, USA, 2009.
[32] MacIsaac, B.; Langton, R. *Gas turbine propulsion systems*; John Wiley and Sons Ltd: Chichester, UK, 2011; pp. 63–65, 184–186.
[33] Mattingly, J.D. *Elements of propulsion: Gas turbines and rockets*; American Institute of Aeronautics and Astronautics: Reston, VA, USA, 2006; pp. 455-458.