Short and Long Range Mission Analysis for a Geared Turbofan with Active Core Technologies

A. Alexiou, N. Aretakis, I. Roumeliotis, K. Mathioudakis

Laboratory of Thermal Turbomachines
National Technical University of Athens

NEWAC
new aero engine core concepts

ECATS Network of Excellence

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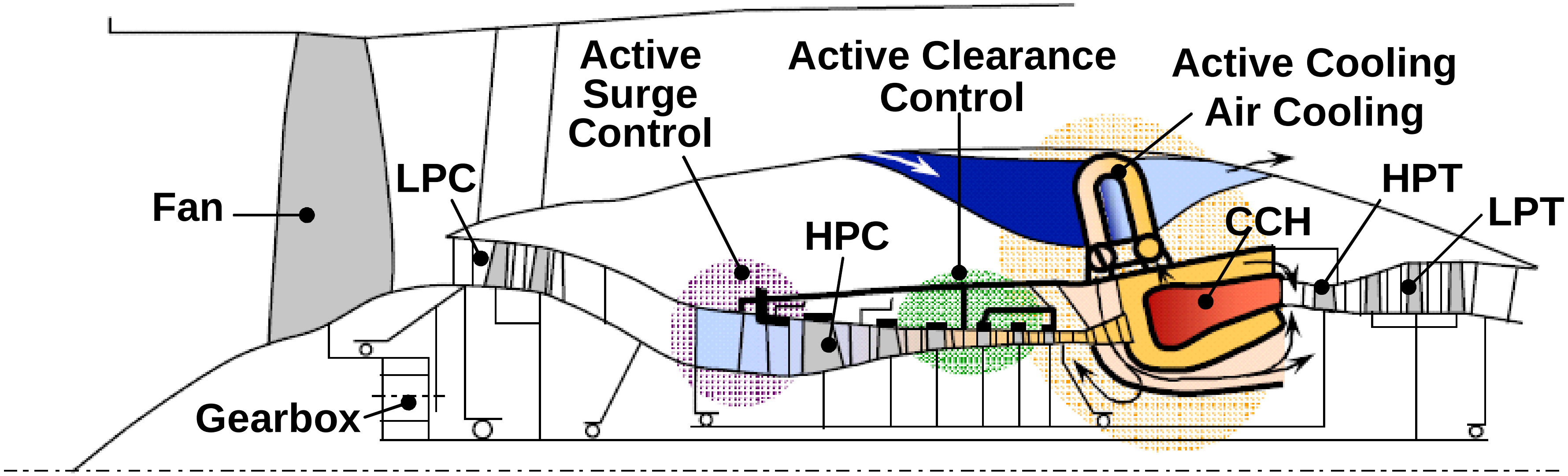
ACARE Targets for Year 2020

The engine contribution towards ACARE goals are:

- **80% NO_x emissions reduction relative to CAEP/2 ICAO LTO cycle limits**
- **20% reduction in fuel consumption (and hence CO_2 emissions) per passenger-kilometre**
- **10 dB noise reduction per certification point compared to a year 2000 in service engine (e.g. CFM56, Trent 700).**

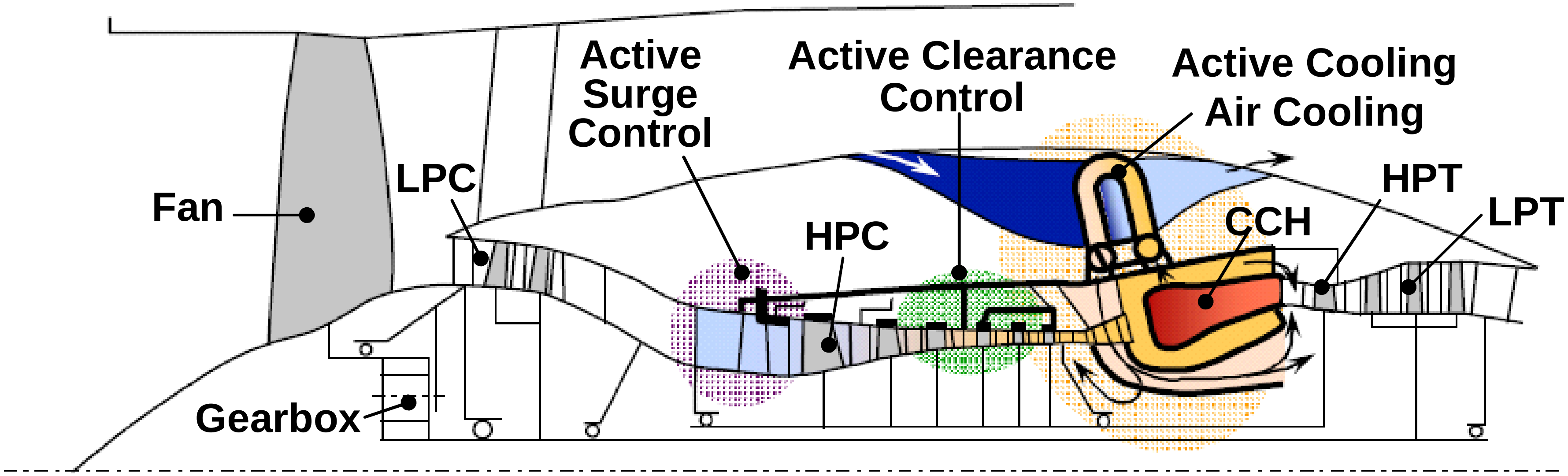
Geared Turbofan with Active Core Technologies (GTAC)



High BPR → gives higher Propulsive Efficiency, Lower Jet Noise

Gear → allow each LP component to run on optimum speed in terms of efficiency, stage loading, stage count and noise

Geared Turbofan with Active Core Technologies (GTAC)

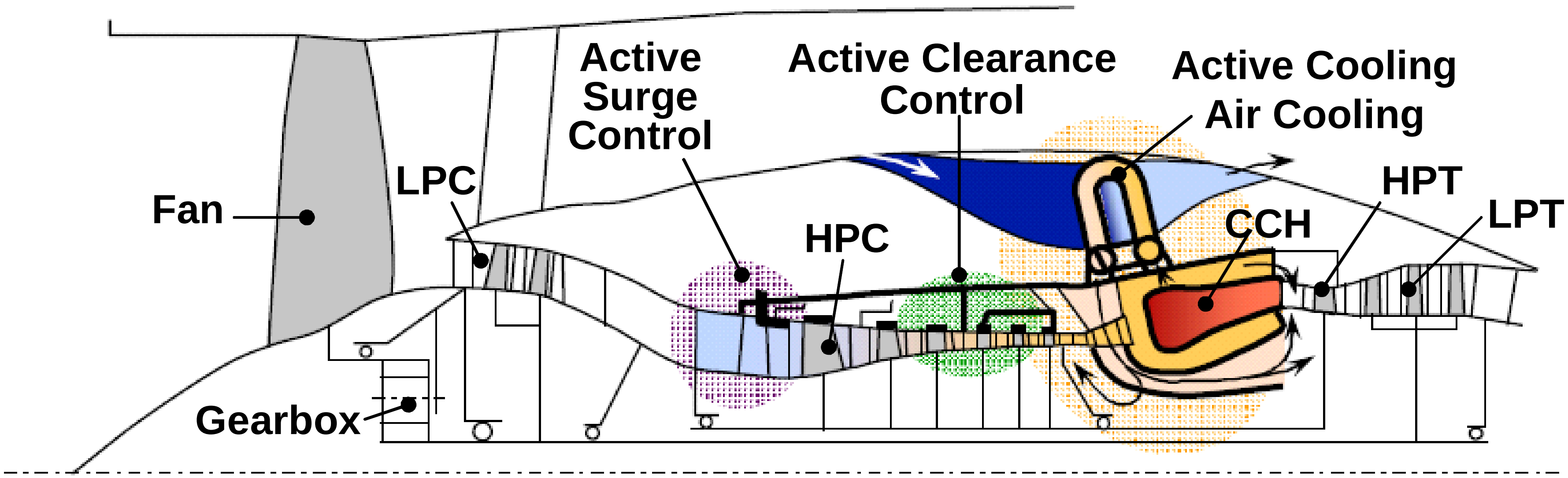


Active Systems

→ enable engine to be adjusted for optimum performance and safety at component or engine level according to its actual operating conditions or component/engine health status

→ increases flexibility during the design phase since it is no longer required to base the design on a worst case scenario.

Geared Turbofan with Active Core Technologies (GTAC)



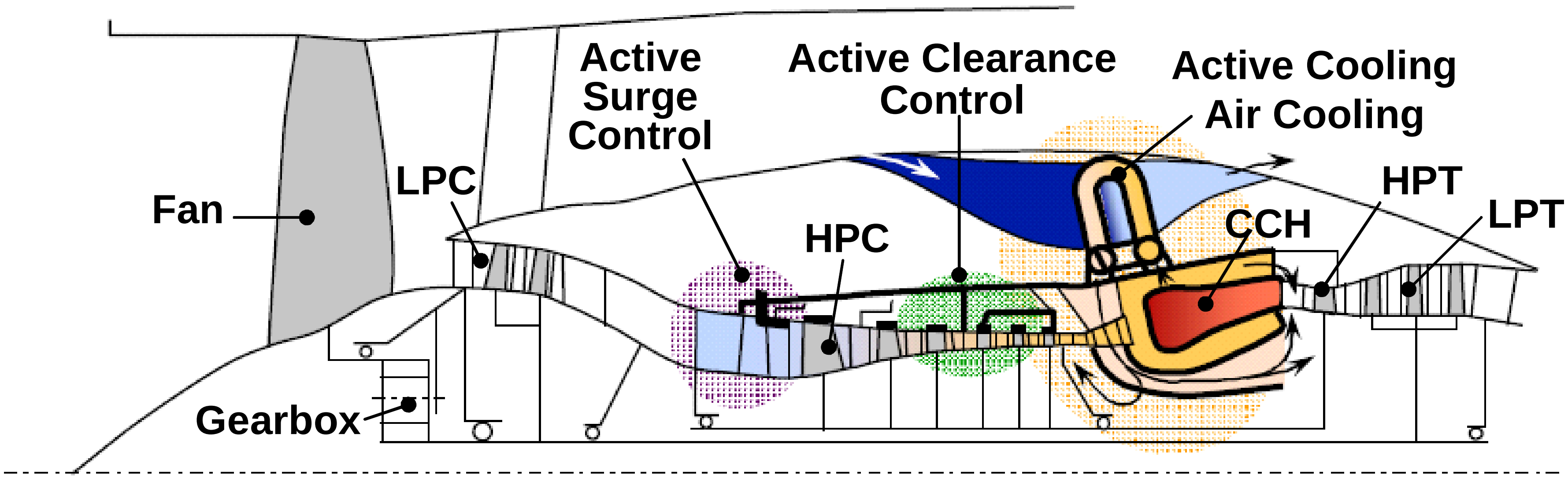
Active Systems

→ ACAC (Active Cooling Air Cooling) to minimize the air required for HPT cooling at cruise (increased engine efficiency)

→ ACC (Active Clearance Control) for minimal tip clearance of HPC last stages

→ ASC (Active Surge Control) to improve engine operability at part speed by air injection at front HPC stages

Geared Turbofan with Active Core Technologies (GTAC)



•The high values of Turbine Entry Temperature and Overall Pressure Ratio of GTAC require low NOx combustion technology.

•For this reason NEWAC is investigating lean low NOx combustion with either a PERM or LDI fuel system, depending on the application (short and long range respectively).

PERM: Partial Evaporation & Rapid Mixing   LDI:Lean Direct Injection

Paper Objectives

- In the present work, an integrated approach is followed to determine the fuel consumption, noise and NOx emissions of this novel engine concept for two different flight missions by coupling together different simulation codes.

- For a short range mission (1000 km), a **140** kN take-off SLS thrust version of the GTAC engine is used while a **325** kN one is used for a long range mission (5500 km)

- The results are compared with corresponding ones for year-2000 in service engines of similar thrust ratings (baseline engines).

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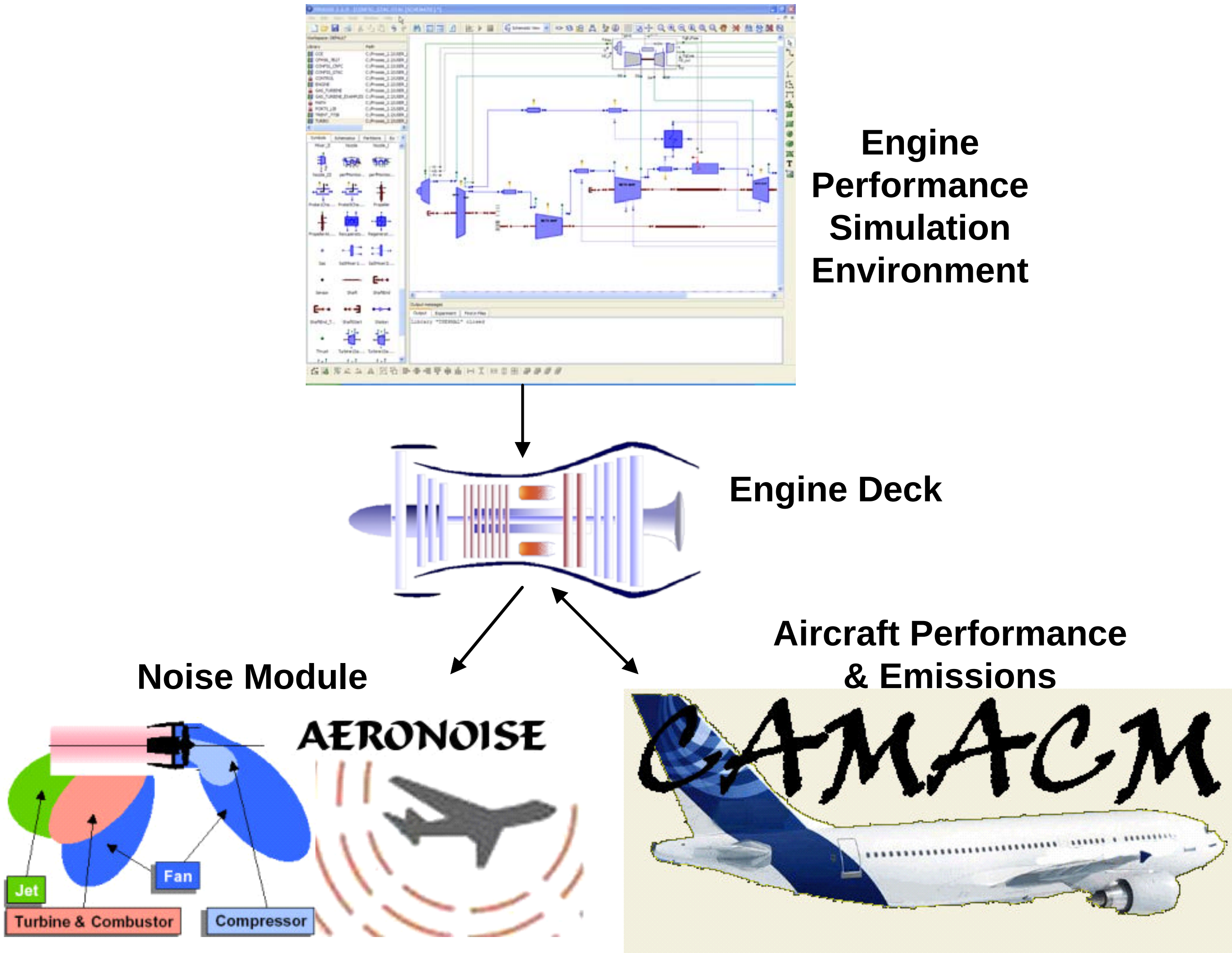
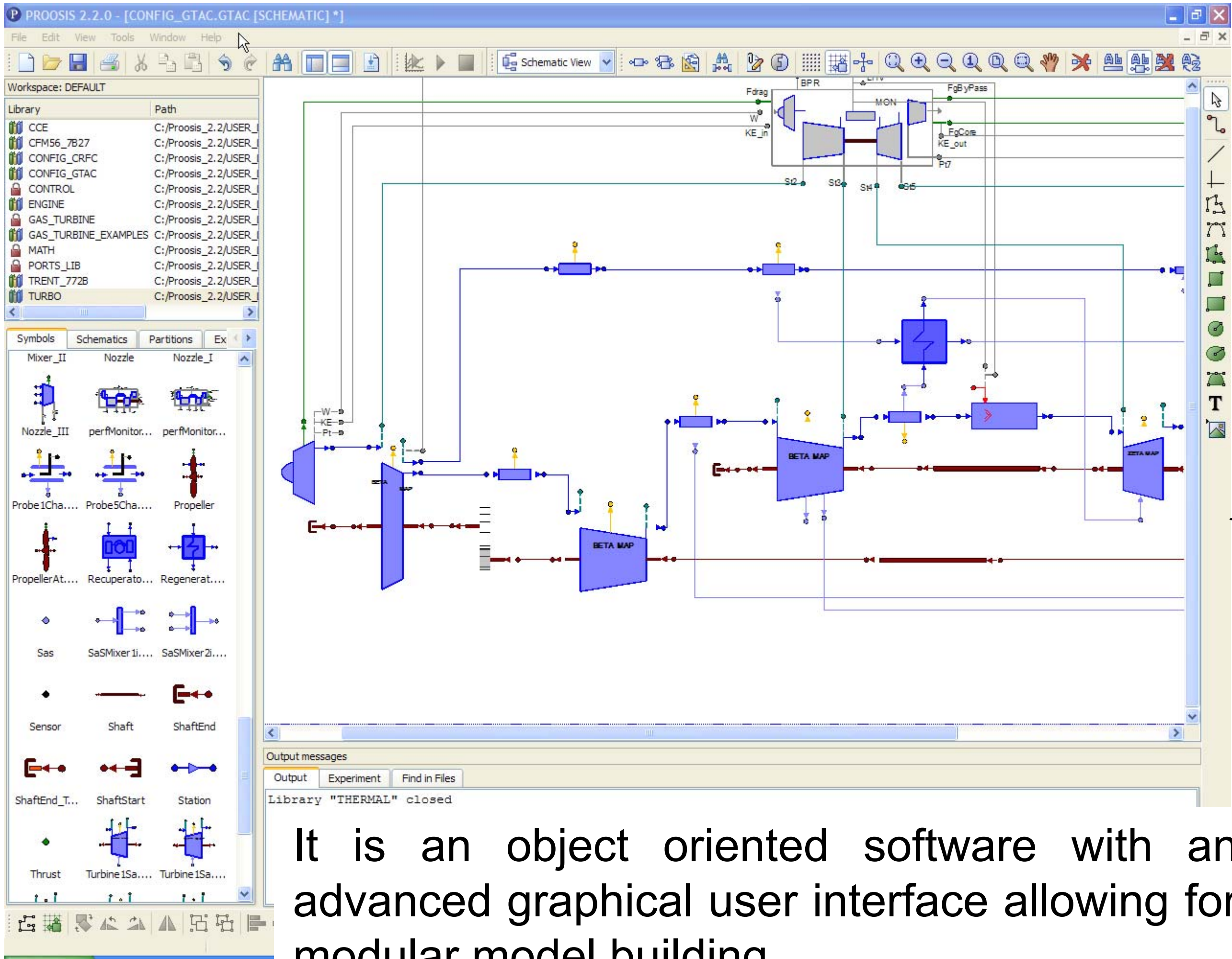
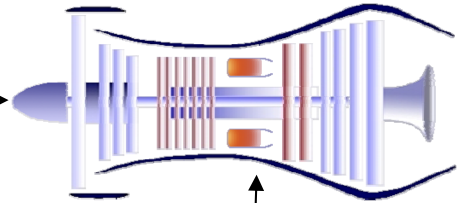
Module Interaction Diagram



Engine Performance (PROOSIS)



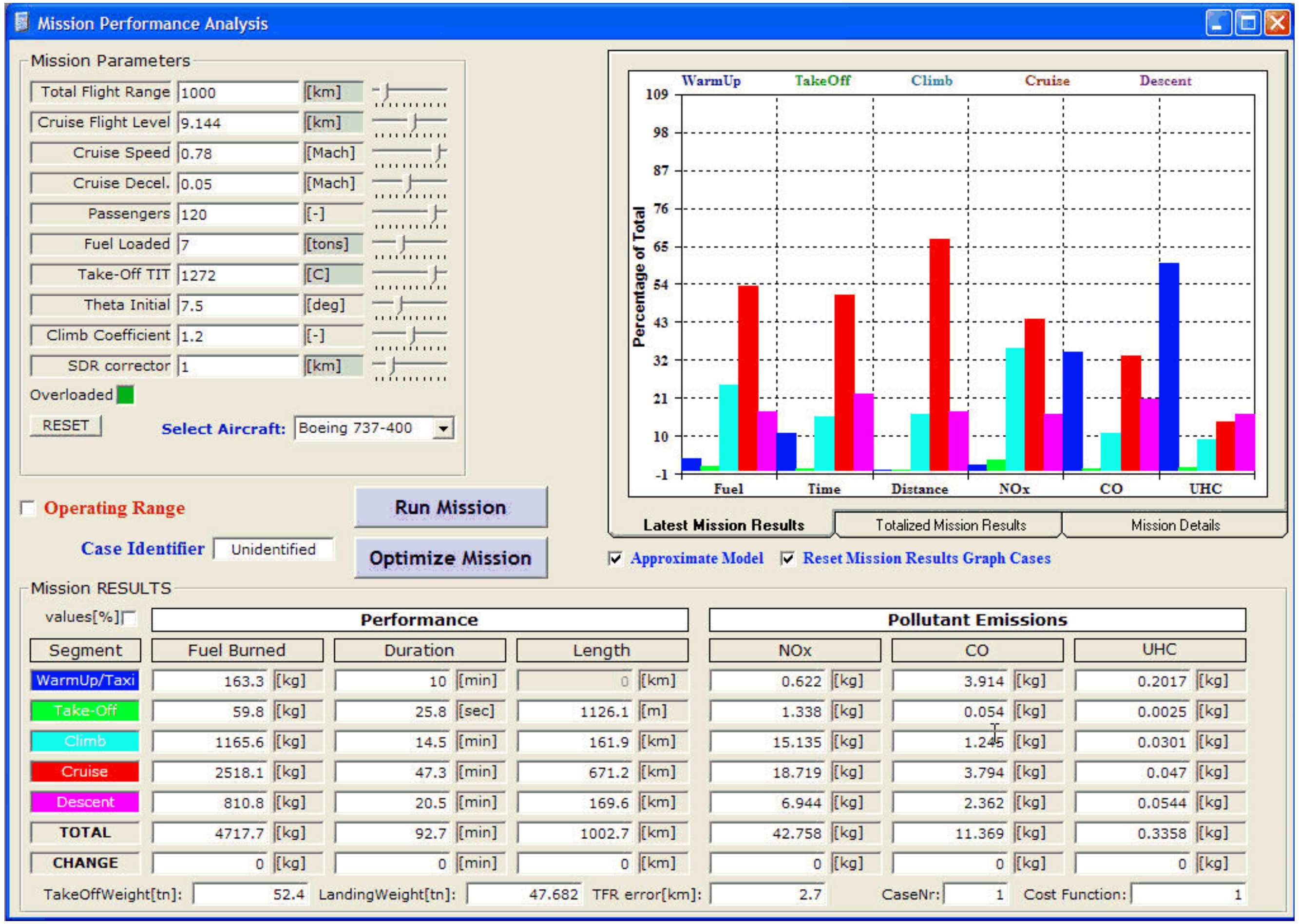
PROOSIS Simulation Environment



PROOSIS generated executable deck

It is an object oriented software with an advanced graphical user interface allowing for modular model building

Aircraft Performance (CAMACM)



- It covers all segments of a modern commercial aircraft's typical flight
- The engine model is externally supplied as an independent module.

NO_x emissions calculated using the **Boeing Fuel Flow Method 2**

Since there are no ICAO data for GTAC engines then:

Approach 1: Assume same combustor technology as Baseline engines and a modified **P3T3** method:

$$EINO_{x,GTAC} = EINO_{x,BASE}(T_{3,GTAC}) \cdot \left[\frac{P_{3,GTAC}(T_{3,GTAC})}{P_{3,BASE}(T_{3,GTAC})}\right]^{0.5} \quad \textbf{Eq. 1}$$

Approach 2: Use publicly available correlations for new technology combustors such as:

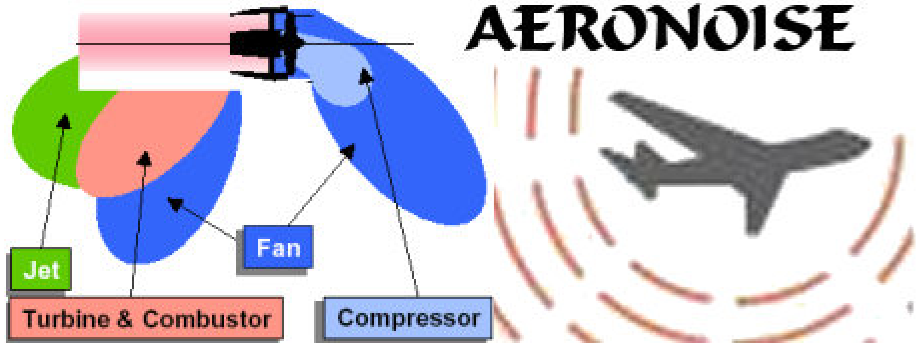
$$EINO_x = 0.0075492 \cdot T_4 \cdot \left(\frac{P_3}{30.267985}\right)^{0.37} \cdot e^{\frac{1.8 \cdot T_3 - 1471}{345}} \quad \textbf{Eq. 2}$$

or

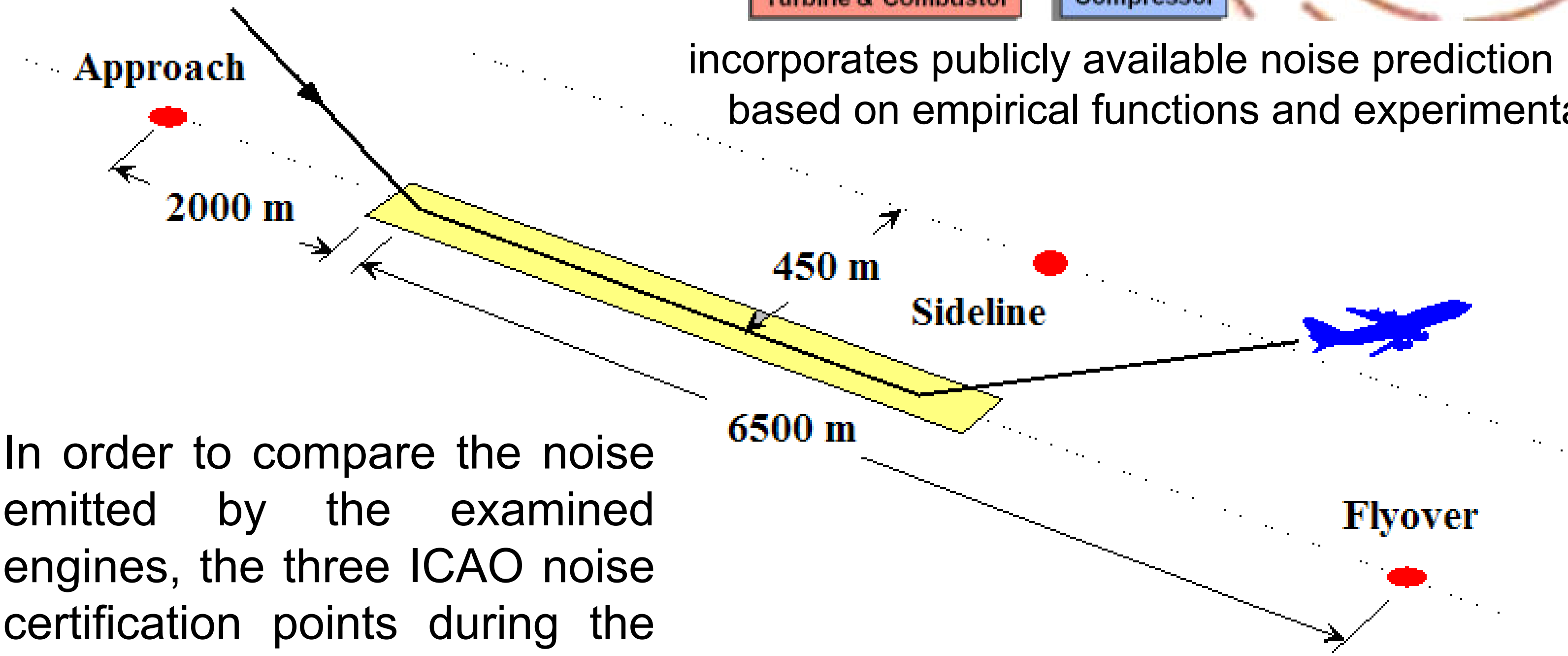
$$EINO_x = 0.104 \cdot e^{\frac{T3}{185}} \cdot FAR^{1.32} \cdot P_3^{\,0.68} \cdot [\Delta P/P_3(\%)]^{-0.36} \quad \textbf{Eq. 3}$$

Noise (AERONOISE)

Engine Performance & Engine Geometry Data



incorporates publicly available noise prediction methods based on empirical functions and experimental data



In order to compare the noise emitted by the examined engines, the three ICAO noise certification points during the LTO cycle were considered

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Baseline Engines Performance

PARAMETER	BASESR	BASELR
BPR	5	5
OPR	29	36
W1 (kg/s)	360	920
FN (kN)	120	315
SFC (gr/kN?s)	10.4	10.1

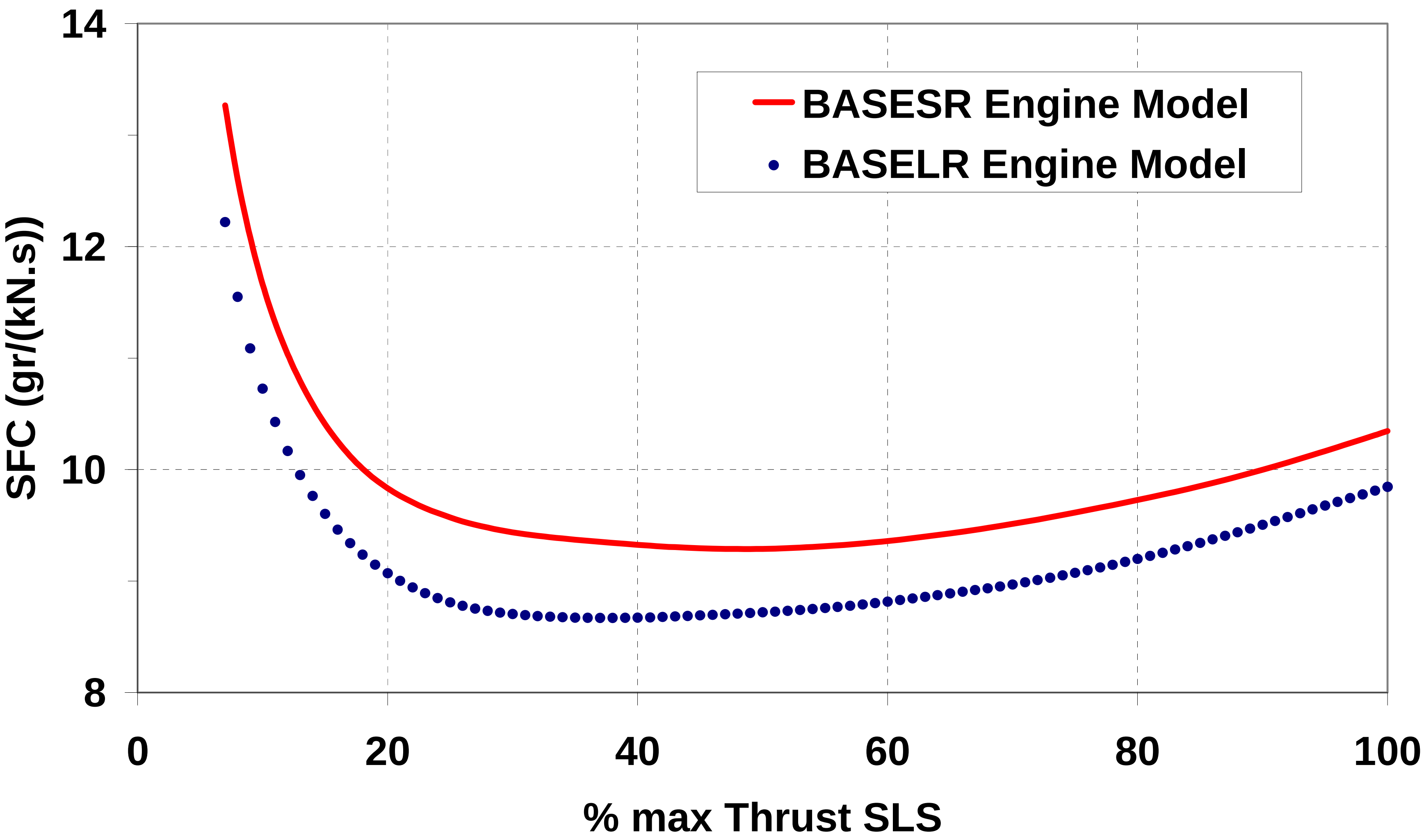
Main Cycle Parameters for Baseline Engines at **T/O SLS**

PARAMETER	BASESR	BASELR
Altitude (m)	10668	11500
Mach Number	0.78	0.82
FN (kN)	21.0	47.4
SFC (gr/kN·s)	17.5	17.0
W1 (kg/s)	134	306
BPR	5.2	5.2
OPR	26.6	32.4

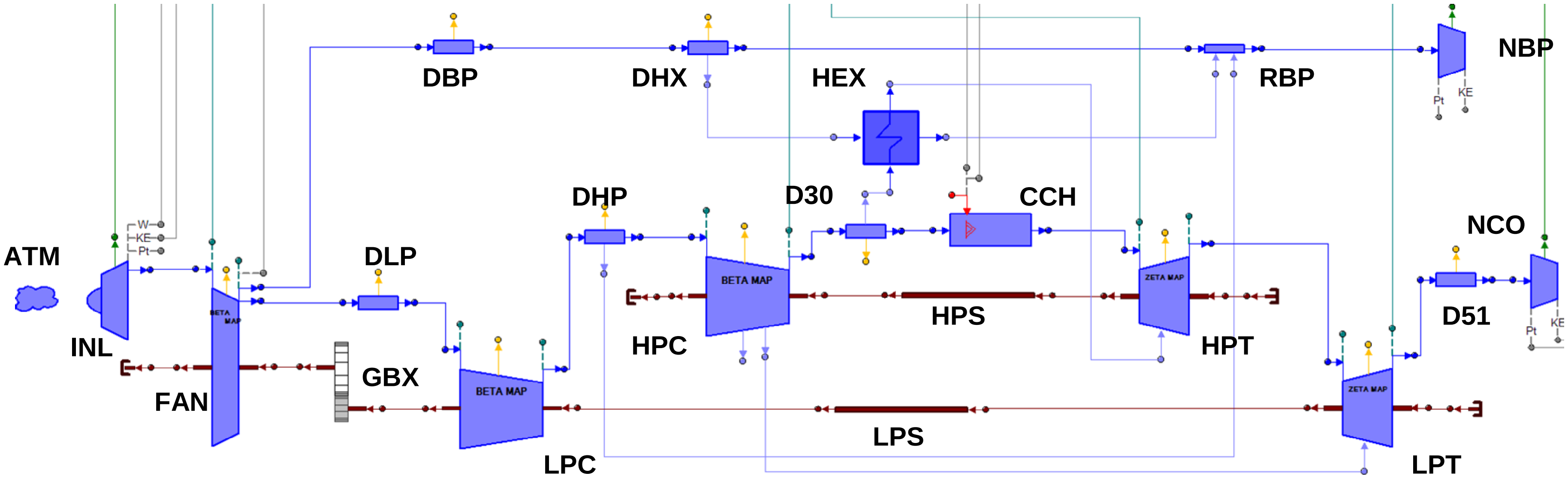
Predicted Main Cycle Parameters for Baseline Engines at **Mid-Cruise** (ISA, installed)

Publicly available data have been used in order to ensure that the models are representative of in service engines with a technology level of year-2000.

SFC-FN variation of Baseline Engines at SLS

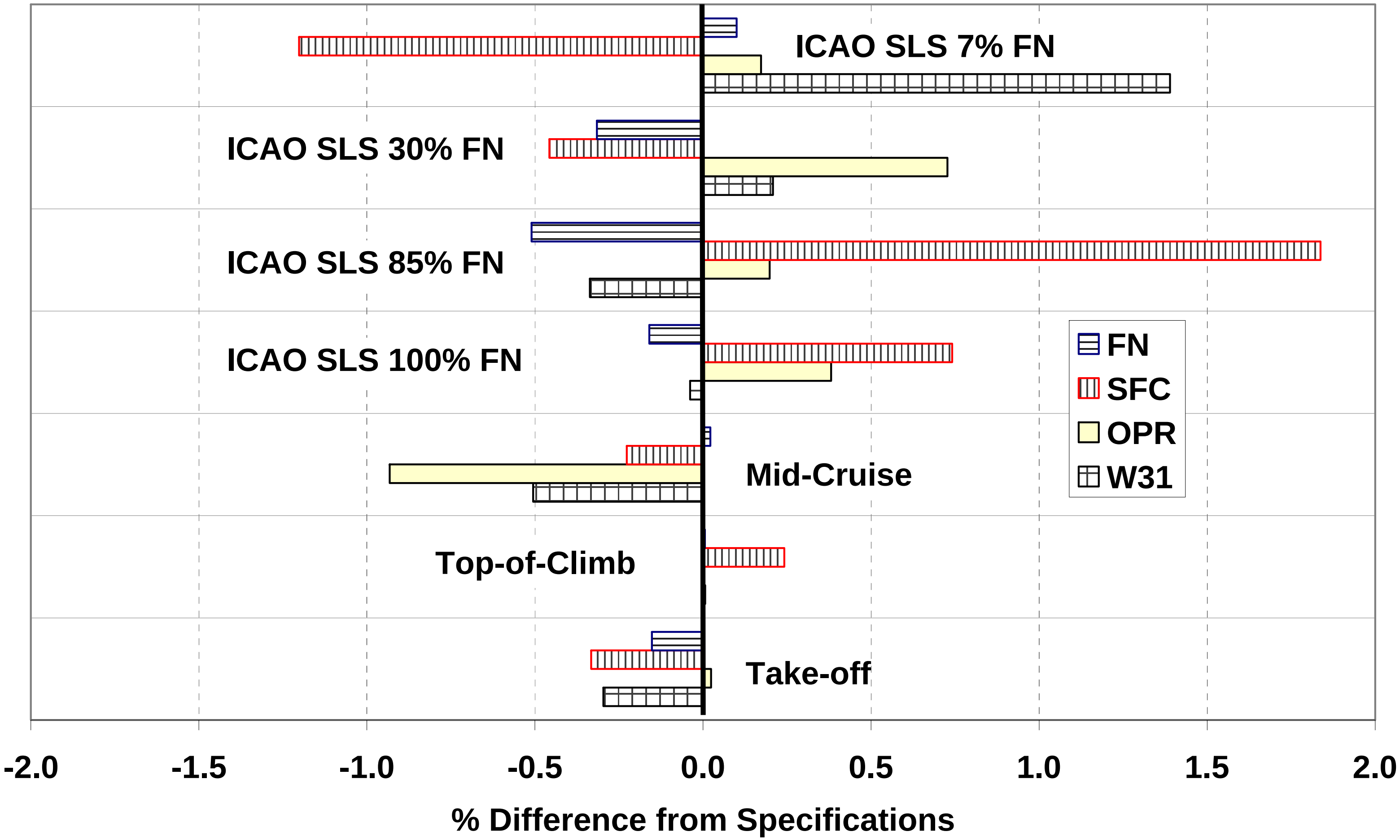


GTAC Performance Model & Data



PARAMETER	GTAC SR			GTAC LR		
Condition	T/O	ToC	CR	T/O	ToC	CR
Altitude (m)	0	10668	10668	0	10668	10668
Mach Number	0.25	0.78	0.78	0.25	0.82	0.82
ΔT ISA (K)	15	10	0	15	10	0
BPR	13.4	11.8	13.0	14.0	12.6	14.0
OPR	36.7	47.0	39.0	46.6	57.8	47.0
FN (kN)	100.9	28.1	22.0	252.1	67.4	51.2
W1 (kg/s)	522.2	216.2	207.9	1317.0	556.3	532.5

Comparison of Model Predictions and NEWAC Specifications for GTACSR



For both SR and LR applications, the agreement between model predicted and specified values is less than 2%.

Aircraft Performance

PARAMETER	SR	LR
Typical Pax No	150	295
MTOW (t)	77	233
No Engines	2	
Wing Area (m^2)	122.6	361.6
Max Range (km)	5700	10500
Max Altitude (m)	11887	12497
Max Mach No.	0.82	0.86

Aircraft Characteristics

Main Mission Parameters

PARAMETER	SR	LR
Distance (km)	1000	5500
Cruise Altitude (m)	10668	11500
Cruise Mach No.	0.78	0.82
Payload (t)	10.8	13.5
Fuel Loaded (t)	7	50
Climb Coefficient	1.2	
Initial Climb Angle (°)	7.5	

Typical aircrafts and missions for short and long range applications are modelled and simulated.

Overall Mission Results for Baseline Engines

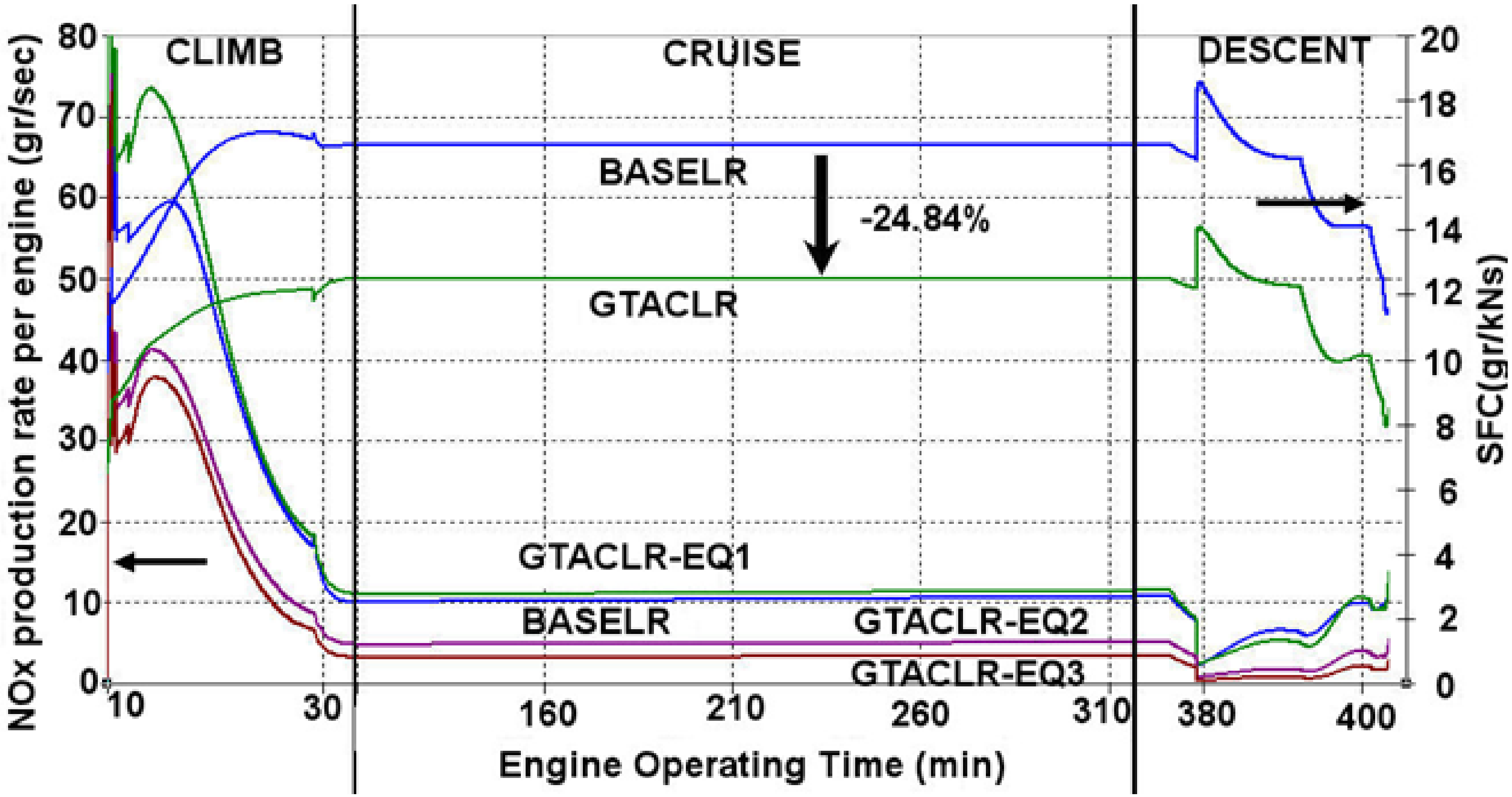
BASESR						
Segment	Time		Fuel Burned		NO_x	
	min	% Total	kg	% Total	kg	% Total
W&T	10.0	10.35	165.1	3.7	0.753	1.67
T/O	0.4	0.41	63.3	1.42	1.291	2.86
CL	17.8	18.43	1381.5	30.96	18.07	40.07
CR	44.8	46.38	1941.2	43.5	17.819	39.51
DE	23.6	24.43	911.6	20.43	7.164	15.89
TOTAL	**96.6 min**		**4462.8 kg**		**45.097 kg**	
BASELR						
W&T	10	2.47	431.5	1.08	2.285	0.41
T/O	0.5	0.12	193.7	0.48	6.509	1.16
CL	18.5	4.57	3985.3	9.96	95.185	16.9
CR	350.3	86.54	33223.3	83.02	436.803	77.55
DE	25.5	6.30	2186.8	5.46	22.439	3.98
TOTAL	**404.8 min**		**40020.6 kg**		**563.221 kg**	

NOx production at cruise is not covered by regulations for emissions

Comparison of GTAC with BASE Engines

SR (%)				
Segment	**Fuel Burned**	**NO_x (Eq. 1)**	**NO_x (Eq. 2)**	**NO_x (Eq. 3)**
W&T	-35.25	-27.36	-87.92	-96.41
T/O	-30.49	+5.58	-32.77	-35.24
CL	-23.00	+20.23	-35.33	-48.88
CR	-21.84	+15.75	-47.06	-65.45
DE	-32.35	-14.48	-69.46	-85.02
TOTAL	**-24.97**	**+11.73**	**-46.19**	**-61.57**
LR (%)				
W&T	-34.83	-32.34	-84.20	-94.97
T/O	-32.27	-5.39	-43.80	-45.61
CL	-26.61	+13.66	-38.33	-45.40
CR	-25.40	+7.88	-52.30	-68.02
DE	-28.90	-8.67	-67.05	-83.24
TOTAL	**-25.85**	**+7.88**	**-50.56**	**-64.65**

Variation of SFC and NO_x with Mission Time for LR



LTO Cycle NO_x Emissions

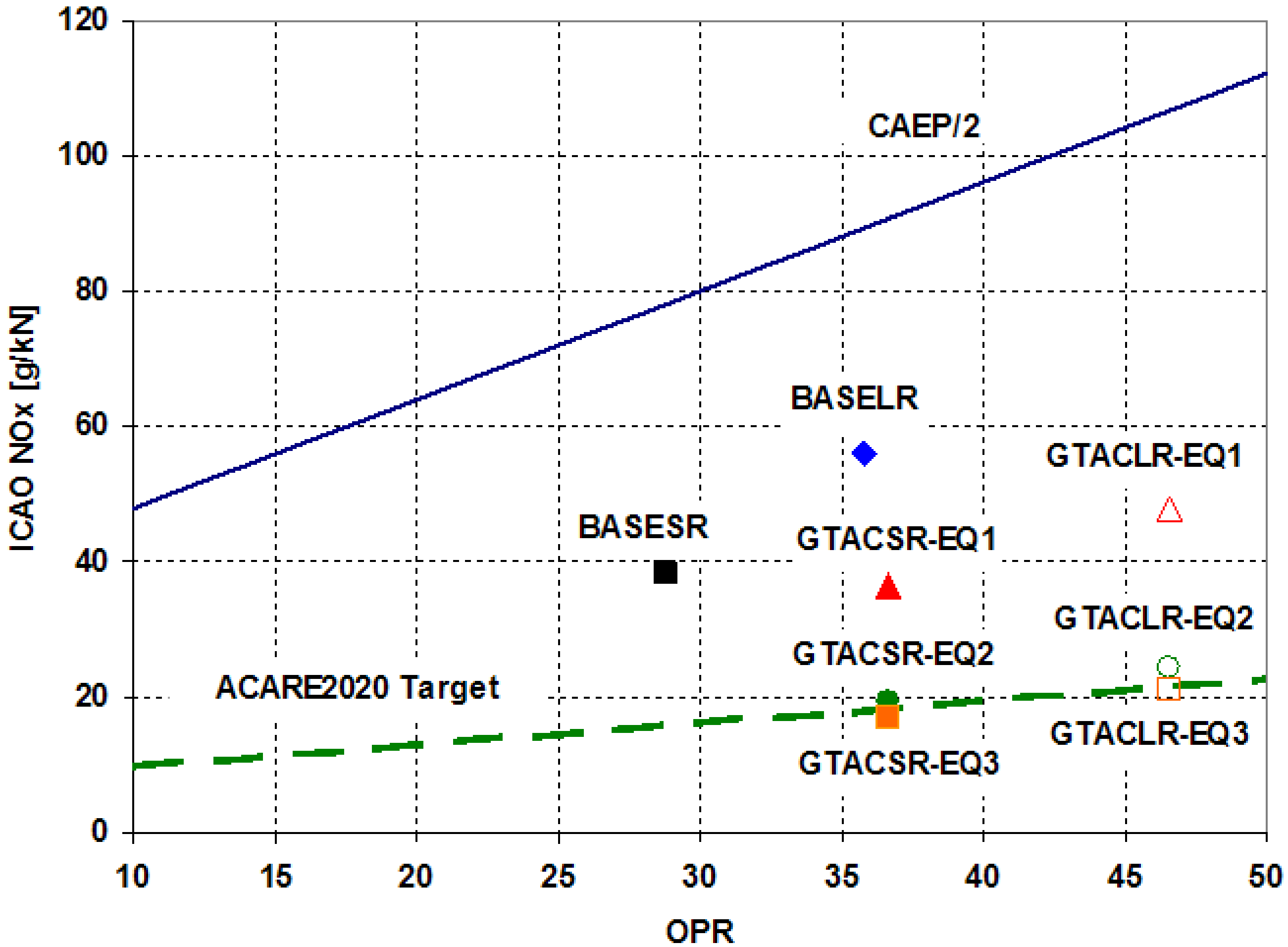
Short Range

	BASESR	GTACSR-EQ1	GTACSR-EQ2	GTACSR-EQ3
EI_{NOx} T/O	20.81	31.34	20.04	19.41
EI_{NOx} C/O	15.59	25.42	14.97	13.12
EI_{NOx} AP	7.53	8.92	2.97	1.33
EI_{NOx} ID	4.36	4.79	0.74	0.21
LTO NO_x (gr)	4647.94	5082.43	2696.87	2320.68
Vs. Baseline (%)	-	+9.35	-41.98	-50.07

Long Range

	BASELR	GTACLR-EQ1	GTACLR-EQ2	GTACLR-EQ3
EI_{NOx} T/O	33.74	47.38	28.27	27.47
EI_{NOx} C/O	27.08	38.31	20.37	17.74
EI_{NOx} AP	10.42	10.90	3.60	1.59
EI_{NOx} ID	4.07	4.18	0.85	0.24
LTO NO_x (gr)	17783.61	15560.01	7952.04	6874.17
Vs. Baseline (%)	-	-12.50	-55.28	-61.35

ICAO-LTO Cycle NO_x Emissions Predictions



Noise Results

Short Range

GTAC vs. BASE SR EPNL (EPNdB)			
	Flyover	Approach	Sideline
FAN	-5.3	-7.8	-5.0
JET	-6.9	-8.0	-9.1
TURBINE	-0.3	0.5	-0.6
CORE	-4.2	-4.1	-3.4
TOTAL	-5.6	-6.6	-5.9
Cumulative		-18.1	

Long Range

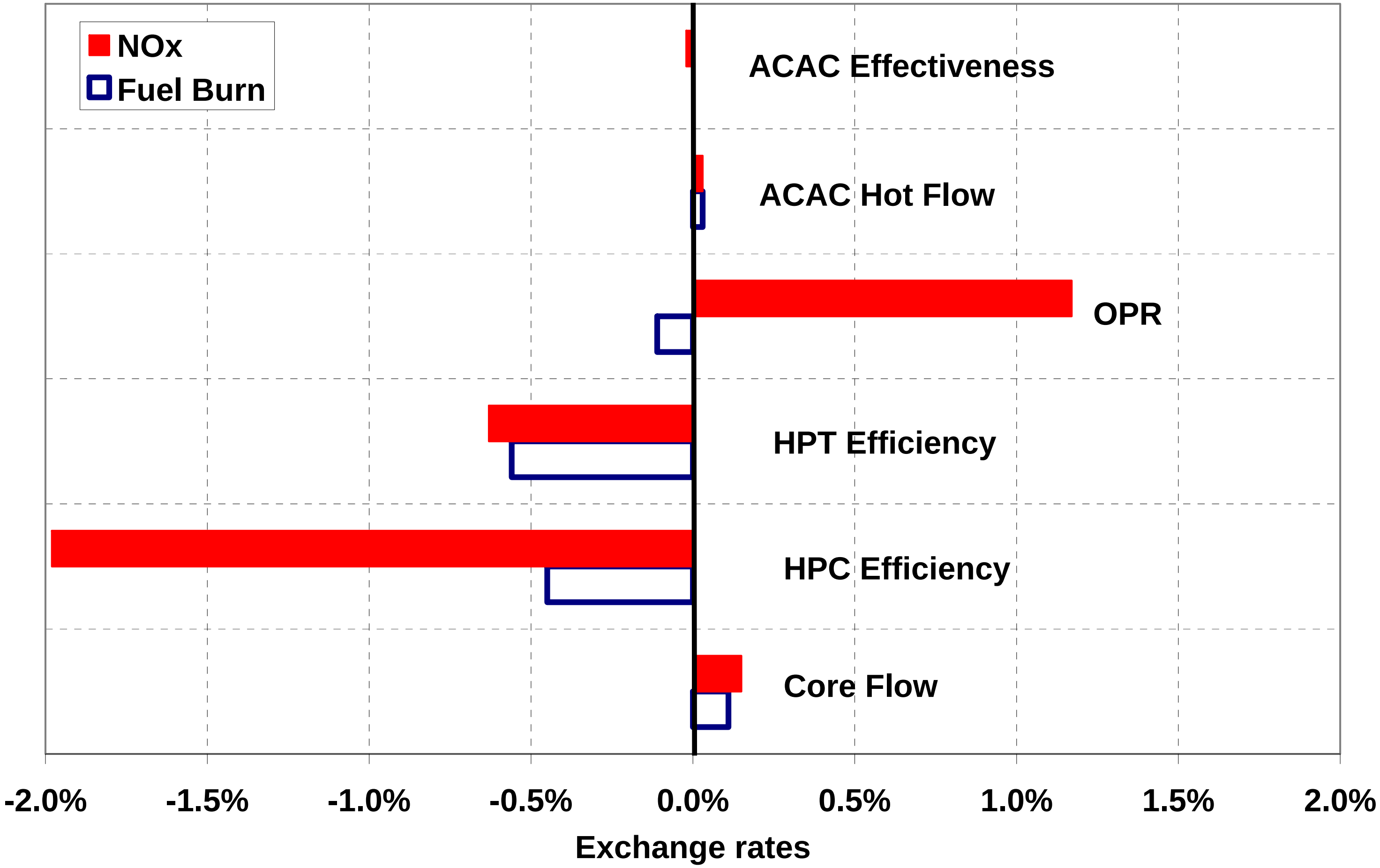
GTAC vs. BASE LR EPNL (EPNdB)			
	Flyover	Approach	Sideline
FAN	-9.8	-11.9	-7.5
JET	-7.7	-8.0	-8.5
TURBINE	-5.8	-4.3	-6.2
CORE	-3.8	-3.7	-2.6
TOTAL	-9.6	-9.9	-8.0
Cumulative		-27.5	

Effect of -1 EPNdB per source on total noise

	Flyover	Approach	Sideline
FAN	-0.72	-0.89	-0.52
JET	-0.17	-0.02	-0.37
TURBINE	-0.04	-0.05	-0.03
CORE	-0.02	-0.02	-0.02

	Flyover	Approach	Sideline
FAN	-0.84	-0.89	-0.65
JET	-0.06	0.00	-0.20
TURBINE	-0.06	-0.08	-0.08
CORE	-0.01	-0.01	-0.02

Fuel Burn and NO_x Variation for 1% Increase of Selected Core Design Parameters (GTACSR)



HPT and HPC efficiencies have the larger influence

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Summary & Conclusions (I)

➢ An integrated approach is used to assess the potential benefits of the GTAC concept in terms of fuel burned, NO_x emissions generated and noise produced, over equivalent thrust engines of Year 2000 technology during typical short and long range aircraft missions.

➢ According to the performance expected by the manufacturer for this engine and the modelling methods and assumptions the following conclusions are drawn:

- The GTAC engines burn **~25%** less fuel than their corresponding baseline engines for the same mission.
- For the **same combustor design**, the GTAC engines **produce more NO_x** emissions during the whole mission.

Summary & Conclusions (II)

- Assuming **new technology combustor designs**, **significant reductions in NOx** are achieved at mission and LTO cycle.
- The combination of **high BPR, low fan speed and fan pressure ratio and smaller core** of GTAC engines result in **noise reduction** at all three noise certification points.

➢ From the above, it appears that the **GTAC concept has the potential to meet current targets** for reducing fuel consumption, NO_x emissions and community noise.

➢ A sensitivity analysis has shown that even **further improvements are possible** by optimising the most influential engine design parameters.