Engine Thrust Reverser Emissions at Zurich Airport

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1 Introduction

The scope of this study is to make a first approximation of thrust reverser fuel consumptions and emissions of different aircraft types at Zurich airport.

2 Airport

2.1 Airport Layout and Conditions

The airport has three main runways for landings:

RWY 14:	3300 m	ILS III B
RWY 16:	3700 m	ILS III B
RWY 28:	2500 m	VOR/DME

Runways 28 and 16 are intersecting.

The average elevation is 424 msl.

Zurich Airport experiences prevailing westwinds. Ambient temperature conditions of all evaluated flights ranged from -9°C to +35°C (minimum: -9.0° to -5.5°; average: +4.8° to +12.5°; maximum: +12.0° to +35.0° over the nine aircraft types).

Figure 2-1: Zurich airport orthophoto

2.2 Thrust Reverser Regulation

Unique, the operator of Zurich airport, has issued regulations pertaining to the use of thrust reverser:

> **Operating Manual**
>
> **Art. 35**
> When using engine reverse, idle thrust may only be exceeded if this is unavoidable for operational or safety reasons.

The decision, how to apply thrust reverser, remains with the pilot in command. One procedure is to set reverse idle right after touchdown for a period of time which is determined by aircraft weight, touchdown speed, wind, braking coefficient. If needed, a quick full reverse thrust might be set. The FADEC will record this maximum N1, but only little power will be applied to the engine.

3 Operational Data

Data for this study has been derived from the Aircraft Data Acquisition System (ADAS) and Event Measurement System (EMS) of Swiss International Air Lines.

Table 3-1: Aircraft/engine-combination for evaluation

Aircraft	Engines	No.	Remarks
Swiss A319	CFM56-5B6/2P	2	DAC (double annular combustor)
Swiss A320	CFM56-5B4/2P	2	DAC
Swiss A320	CFM56-5B4/P	2	SAC (single annular combustor)
Swiss A321	CFM56-5B1/2P	2	DAC
Swiss A330-200	P&W 4168A	2	Floatwall, 68’000lbs rated thrust
Swiss A340-300	CFM56-5C4/P	4	34’000lbs
Edelweiss A320	CFM56-5B4/2P	2	DAC
Edelweiss A330-243	RR Trent 772B-60/16	2	71’000lbs rated thrust
Belair 757	RR RB211-535E4	2	Phase 5
Belair 767	P&W 4060	2	

Data available from the EMS were:

- Thrust Reverse relevant:
  - Maximum N1 with Thrust Reversers Deployed during Roll Out
  - Duration of Thrust Reverser Deployment during Roll Out (sec.)
  - Total Duration touch down to end of roll out (sec.)
- Other data:
  - Max N1 for 3000 HAT > touchdown
  - Fuel flow per engine for 3000 HAT > touchdown
  - Max N1 for 3000 HAT > end-of-rollout
  - Fuel flow per engine for 3000 HAT > end-of-rollout

Table 3-2: Duration of thrust reverser deployed during landings

Aircraft	Total Duration touch down to end of roll out (sec.)	Duration of Thrust Reverser Deployment during Roll Out (sec.)	% of time of thrust reverser deployed from touch-down to end-of-rollout
Airbus A319	46.7	28.4	61%
Airbus A320-DAC	44.2	29.5	67%
Airbus A320-SAC	47.0	30.8	66%
Airbus A321	46.0	32.3	70%
Airbus A330	45.8	31.6	69%
Airbus A330-RR	46.7	32.5	70%
Airbus A340	46.6	34.7	74%
Boeing B757	49.5	29.7	60%
Boeing B767	46.4	29.4	63%

4 Fuel Flow and Emission Factors

The data for the fuel flow during the thrust reverser deployment has initially not been derived from the ADAS/EMS. Only the value for the maximum N1 with thrust reverser deployed during roll-out has been extracted from the data base. Some interpretation with other, similar data, has thus been made. This data is the maximum N1 during approach for the phases 3000 HAT (ft) to touch-down and to end-of-rollout for which also the fuel flow per engine and aircraft type is available.

For this study, the fuel flow of N1 during approach or landing, which was closest to the maximum N1 during thrust reverse, has been chosen. The fuel flow during thrust reverse has been linearly calculated, using maximum N1. This approximation will overestimate the fuel flow and subsequently the NOx emissions, as the maximum N1 is considerably higher than the N1 for reverse idle and might only be applied for a very short period of time (maybe 5 seconds or less). In addition N1 doesn't reliably describe the power, as the torque setting is not known. Only precise fuel flow data could give reasonably accurate results.

The emission factors for NOx, HC, CO have then been calculated using the Boeing Fuel Flow curve fit method[1].

Table 4-1: N1, Fuel Flow and Emission Indices

	EMS Data	Reference Data EMS		Fuel Flow	Emission Indices		
Aircraft	Maximum N1 with Thrust Reversers Deployed during Roll Out	Max N1 for 3000 HAT > touchdown and > end-of-rollout (for Boeing A/C)	Fuel flow per engine for approach (3000 HAT > touchdown and end-of-rollout) (kg/hr)	Estimated Mean Fuel Flow per engine during thrust reverser deployment (kg/s)	Calculated EI NOx (g/kg)	Calculated EI HC (g/kg)	Calculated EI CO (g/kg)
Airbus A319	40.94	38.07	760.89	0.227	6.67	0.83	26.81
Airbus A320-D	42.31	39.69	817.11	0.242	5.50	4.67	32.31
Airbus A320-S	39.51	38.77	726.68	0.206	7.27	1.16	5.53
Airbus A321	47.35	42.7	910.44	0.280	6.33	3.35	25.87
Airbus A330	38.39	36.36	1620.55	0.475	6.84	0.14	4.29
Airbus A330-RR	41.59	39.31	1552.61	0.456	8.46	0.58	5.43
Airbus A340	50.57	42.68	887.43	0.292	8.28	0[2]	2.93
Boeing B757	39.23	39.44	1171.29	0.324	6.29	0.10	6.67
Boeing B767	36.78	40.65	1650.3	0.415	8.08	0.42	5.22

[1] CAEP/6-IP/5, Appendix B, November 2003

[2] ICAO Data: 0

5 Fuel Flow and Emissions

The fuel flow and NOx-emissions are listed in table 5-1. The values have been compared with the fuel consumption and emissions for both the ICAO reference LTO-cycle and also an operational LTO cycle.[3]

Table 5-1: Fuel Flow and NOx-Emissions

Aircraft	Fuel Flow (kg/aircraft)				NOx (kg/aircraft)			
	ICAO ref. LTO-cycle	Operational LTO-cycle	Thrust Reverser	Share of Thrust Reverser on operational LTO-cycle	ICAO ref. LTO-cycle	Operational LTO-cycle	Thrust Reverser	Share of Thrust Reverser on operational LTO-cycle
Airbus A319	787	431	12.9	3.0%	6.0	3.6	0.09	2.4%
Airbus A320-SAC	884	467	14.3	3.1%	7.7	4.3	0.08	1.8%
Airbus A320-DAC	816	452	12.7	2.8%	11.3	6.4	0.09	1.4%
Airbus A321	945	535	18.1	3.4%	10.0	5.8	0.11	2.0%
Airbus A330	2'232	1'252	30.0	2.4%	35.6	21.0	0.21	1.0%
Airbus A330-RR	1'925	1'358	29.7	2.2%	39.4	31.6	0.25	0.8%
Airbus A340	1'911	1'643	40.5	2.5%	30.6	31.9	0.34	1.1%
Boeing B757	1'363	689	19.2	2.8%	15.0	7.5	0.12	1.6%
Boeing B767	1'775	1'005	24.4	2.4%	28.2	14.8	0.20	1.3%

The results suggest an overestimation of both fuel flow and NOx-emissions. Nevertheless, the share of thrust reverser on operational LTO-cycle NOx seems to be approximately 1%.

6 Annex: Abbreviations

ADAS	Aircraft Data Acquisition System
CO	Carbon Monoxide
DAC	Double Annular Combustor
EMS	Event Measurement System
FADEC	Full Authority Digital Engine Control
HAT	Height Above Terrain
HC	Hydrocarbons
LTO	Landing and Take-Off
NOx	Nitrogen Oxides
SAC	Single Annular Combustor

[3] Unique (Flughafen Zürich AG): Aircraft NOx-Emissions within the operational LTO-cycle. August 2004.