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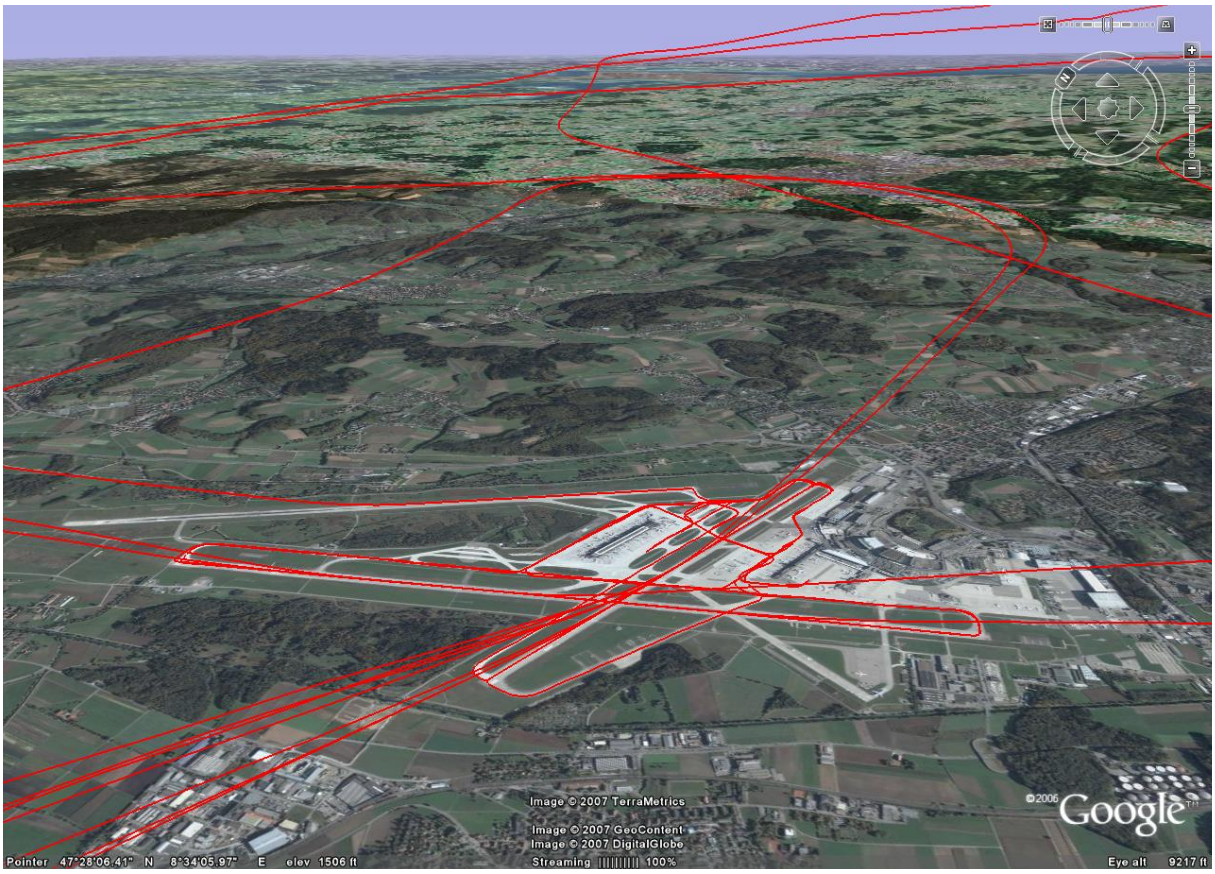
Division Aviation Policy and Strategy

10.8.2007

Validation of ADAECAM (Advanced Aircraft Emission Calculation Method)

Report on fuel calculation



Picture 1: Flight paths of selected flights for ADAECAM validation part 1 in a three dimensional view.
[Picture from Google Earth™, not to be used for commercial purposes]

FOCA, CH-3003 Bern

Reference: 0 / 3/33/33-05-007.021
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1. Introduction

This report focuses on the validation of an Advanced Aircraft Emission Calculation Method (ADAECAM)[1] for fuel calculations in the landing and take-off cycle (LTO) for different selected airframe/engine combinations, taking operational and ambient conditions into account. Existing models like the ICAO certification LTO cycle, the ICAO advanced method and ADAECAM are directly compared to actual measured and recorded aircraft fuel flows and fuel burn.

ADAECAM is a method for the calculation of aircraft emissions in the vicinity of airports. For each movement (take-off or landing), the model defines a flight path (including the ground movements) and calculates the fuel flow and the emissions produced by the engines fitted to the aircraft, for a number of points along this path. ADAECAM input files contain airport data and information that is non-sensitive, non-proprietary and publicly available. The method can be incorporated into inventory and dispersion models for airport local air quality. It provides an enhancement to the CAEP[2] “Simple” and “Advanced” approaches.

As far as emissions calculations are concerned, ADAECAM uses the calculated fuel flows during the phases of the LTO together with the emission index data from the ICAO Engine Emissions Database. For those portions of the operation where the thrust setting does not correspond to one of the standard ICAO certification points (take-off and climb-out in the ADAECAM model), the emission index is obtained by interpolating emission index points in the database. The emission indices are then corrected for the effects of non-ISA[3] ambient conditions and forward speed. This is potentially a big improvement of LTO emissions calculations. Obviously, for validation, there is no actual emission measurement on an aircraft during flight. However, realistic fuel calculations of a model are essential for emissions calculations and the quality of fuel flow calculations can be validated with FDR[4]. Furthermore, the real fuel flow for every second of the FDR can be used to compute corrections for ambient conditions and forward speed based on actual measured engine parameters. This allows checking assumptions made in ADAECAM for the emissions calculation.

Validation work is specified, coordinated and controlled by the Swiss Civil Aviation Authority, (Swiss Federal Office of Civil Aviation, FOCA). FOCA is independent from the model developer (QinetiQ), the initiating ACI member airport (Unique Zurich Airport) and the FDR data provider (Swiss International Airlines).

At start of the validation process (section 2), and after analysis of the first ADAECAM results, there has been some exchange with the model developers and some improvements and fine tunings of ADAECAM were made. Following that, ADAECAM was “frozen” (the development of it was temporarily suspended). All ADAECAM results for the different aircraft/engine combinations in this report (section 2 and section 3 results) were generated with a “frozen” design of the model.

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[1] A method for calculating the emissions from aircraft engines, Gareth Horton, Chris Eyers, QINETIQ/07/02460, 2007
[2] Committee on aviation environmental protection: An expert group of International Civil Aviation Organisation (ICAO).
[3] ISA = International Standard Atmosphere
[4] FDR = Flight Data Recorder

2. Validation Part 1: Selected Flights of A320-200 and A340-300

2.1 Specifications and selection criteria for FDR data and ADAECAM input

For the first part of the validation, a number of individual flights are chosen from detailed FDR airframe, engine and ambient conditions data, according to the following criteria:

- FDR data must come from long haul and short haul aircraft, operating from and to Zurich Airport in a sufficient number of movements during one year.

  The criterion “Operating from and to Zurich Airport” is necessary for the first part of the validation to create an example of a typical ADAECAM input file, containing airport data and information that is non-sensitive, non-proprietary and publicly available. The sample airport has such data available on a regular basis through operational airport databases (e.g. actual taxi-out and taxi-in times for the individual aircraft, aircraft destinations etc.) For all airport data that are used as input in ADAECAM, there are corresponding and clean FDR data available, as described below:

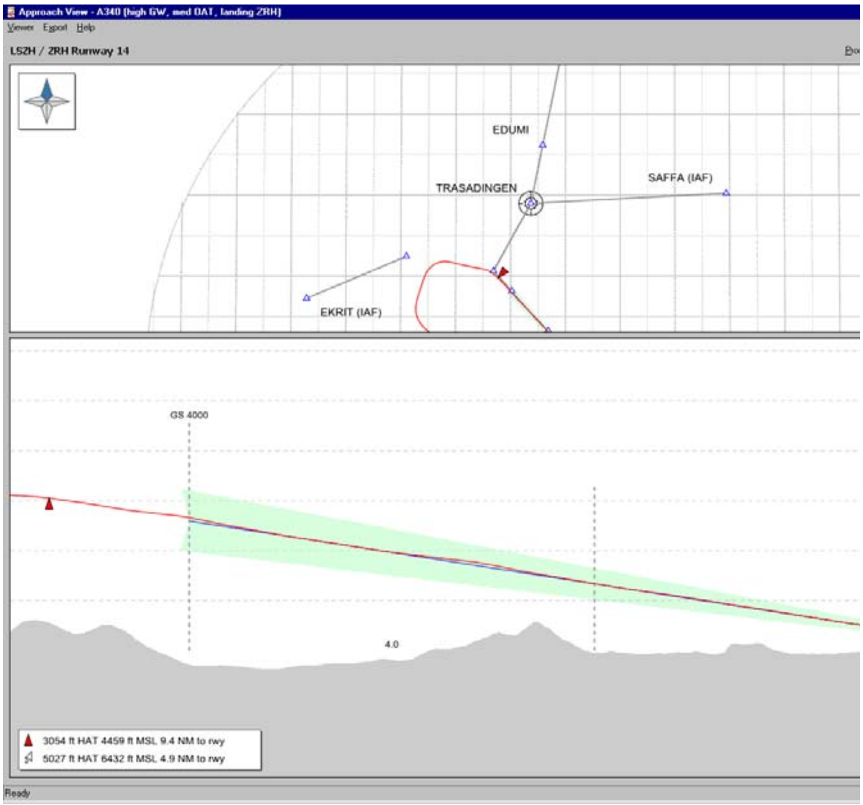
- All selected individual FDR flights of a certain aircraft type must have the same engine type.

- All selected individual FDR flights must not exceed any normal operational parameter ranges (Flights with excessive braking during roll-out, one or more engine parameters outside engine specifications, error flags, etc. are not selected.)

- All selected individual FDR flights must have complete data sets without any missing data.

- All selected individual FDR flights must have departed and landed from the preferential runway, not imposing special pilot operations. Moreover, curved and step approaches below 3000ft AGL and special procedures like “go around” are excluded from the selection.

- All selected individual FDR flights must cover a wide range of aircraft take-off weight and ambient conditions. There is no such thing as a standard flight and ADAECAM is tested against the full range of conditions. All FDR parameter distributions for different aircraft types are listed in Appendix A. As an illustration, examples for A320 and A340-300 FDR parameter distributions are given on the following pages (figures 1 to 10).



Picture 2: Approach path for a selected arrival flight. The red triangle marks the point 3000ft above airport elevation. The selected arrival flight is straight, without special occurrences.

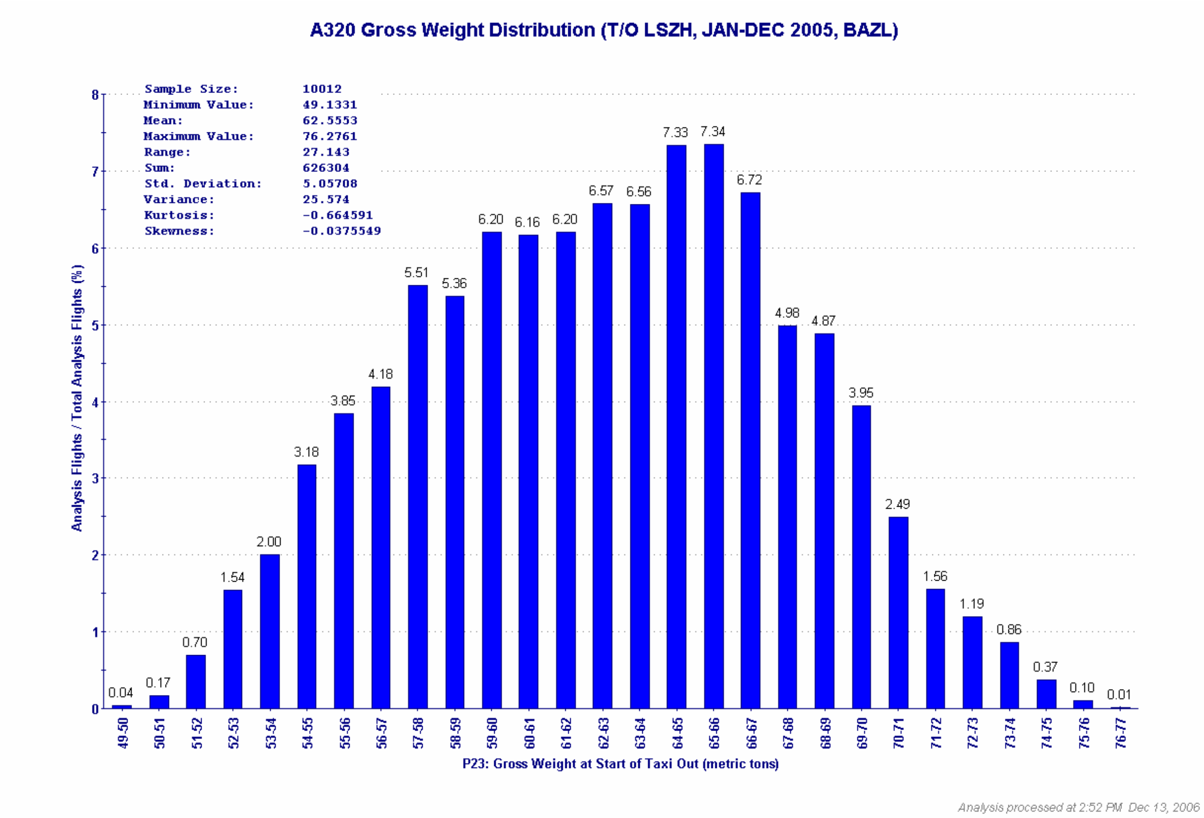


Figure 1: Example of gross weight distribution at start of taxi-out during a one year operation of all aircraft of the selected medium haul type.

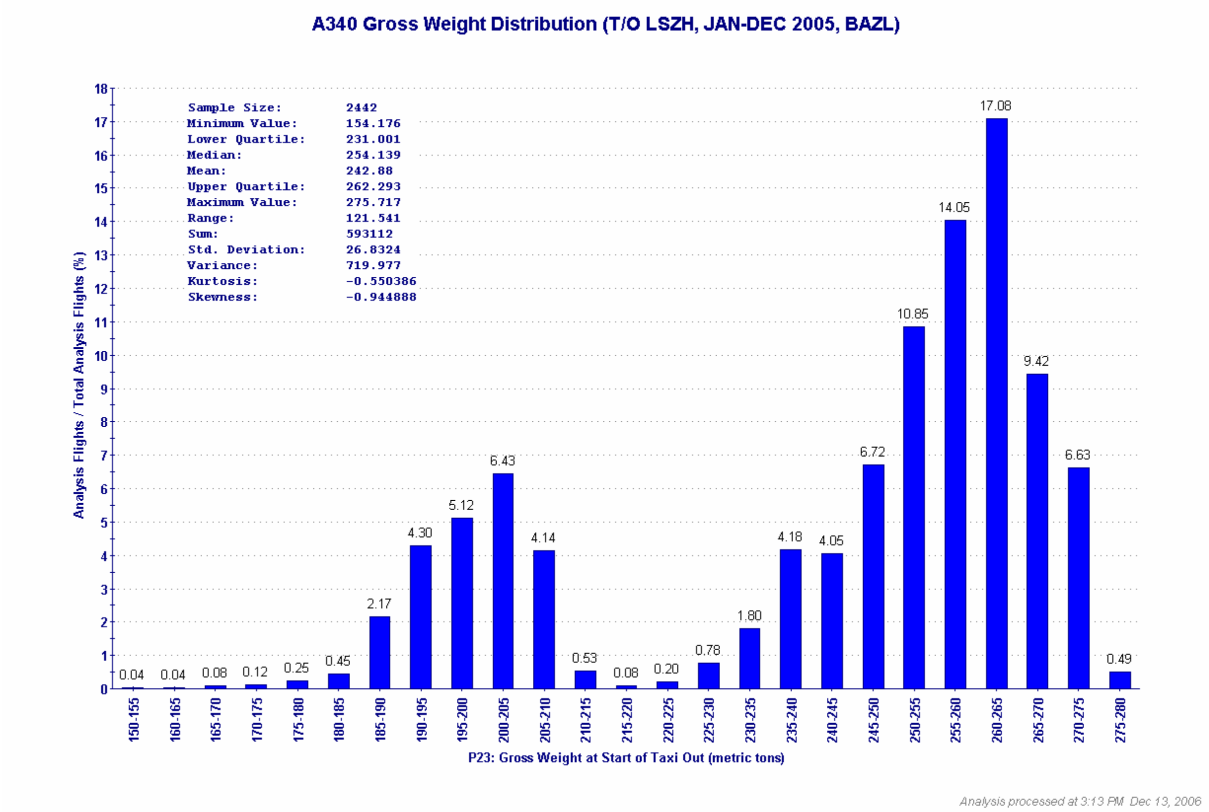


Figure 2: Example of gross weight distribution at start of taxi-out during a one year operation of all aircraft of the selected long haul type.

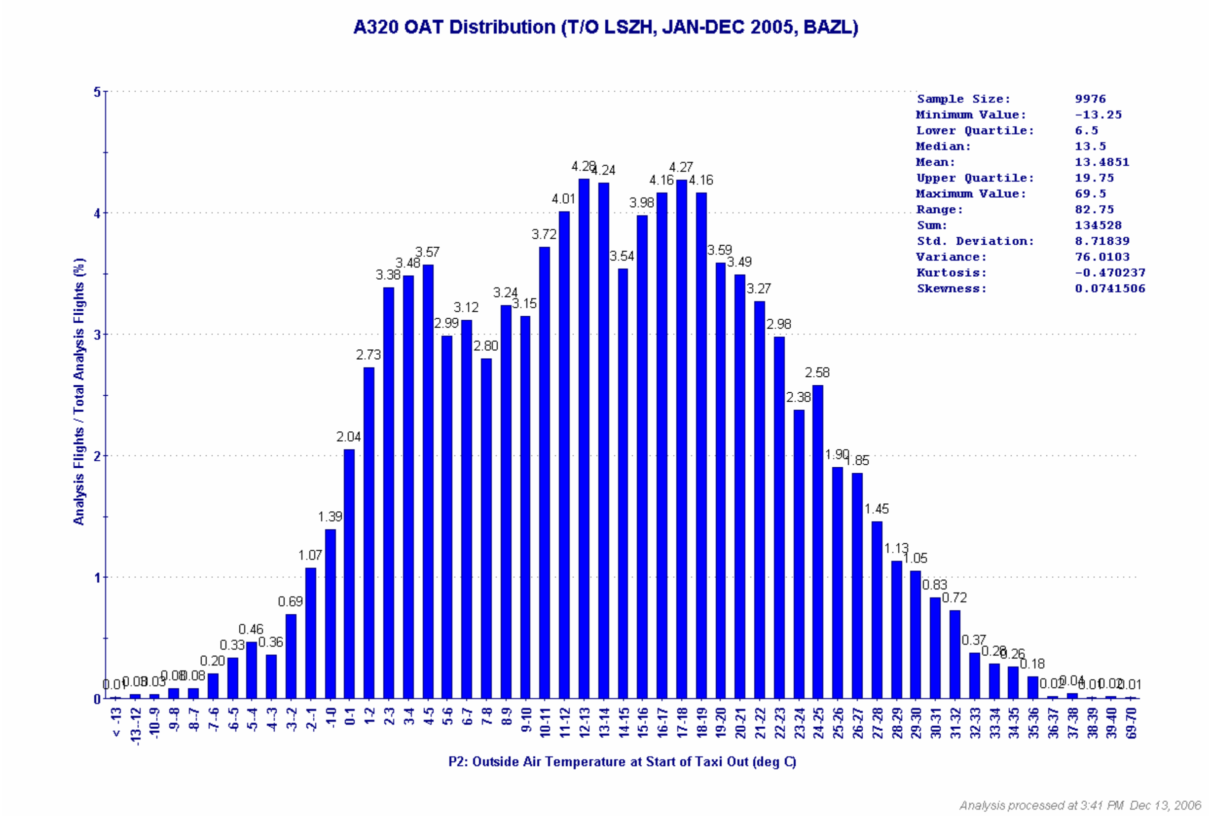


Figure 3: Example of outside air temperature (OAT) distribution at start of taxi-out during a one year operation of all aircraft of the selected medium haul type.

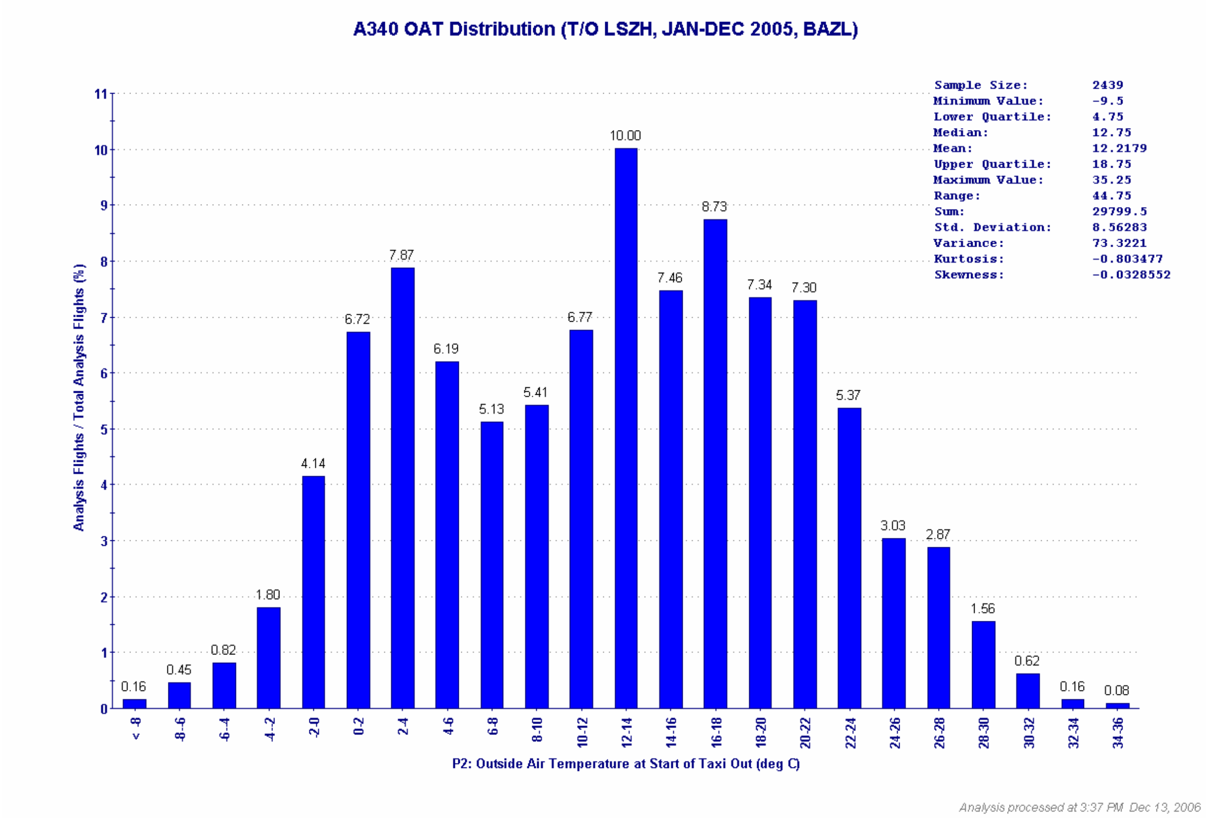


Figure 4: Example of outside air temperature (OAT) distribution at start of taxi-out during a one year operation of all aircraft of the selected long haul type.

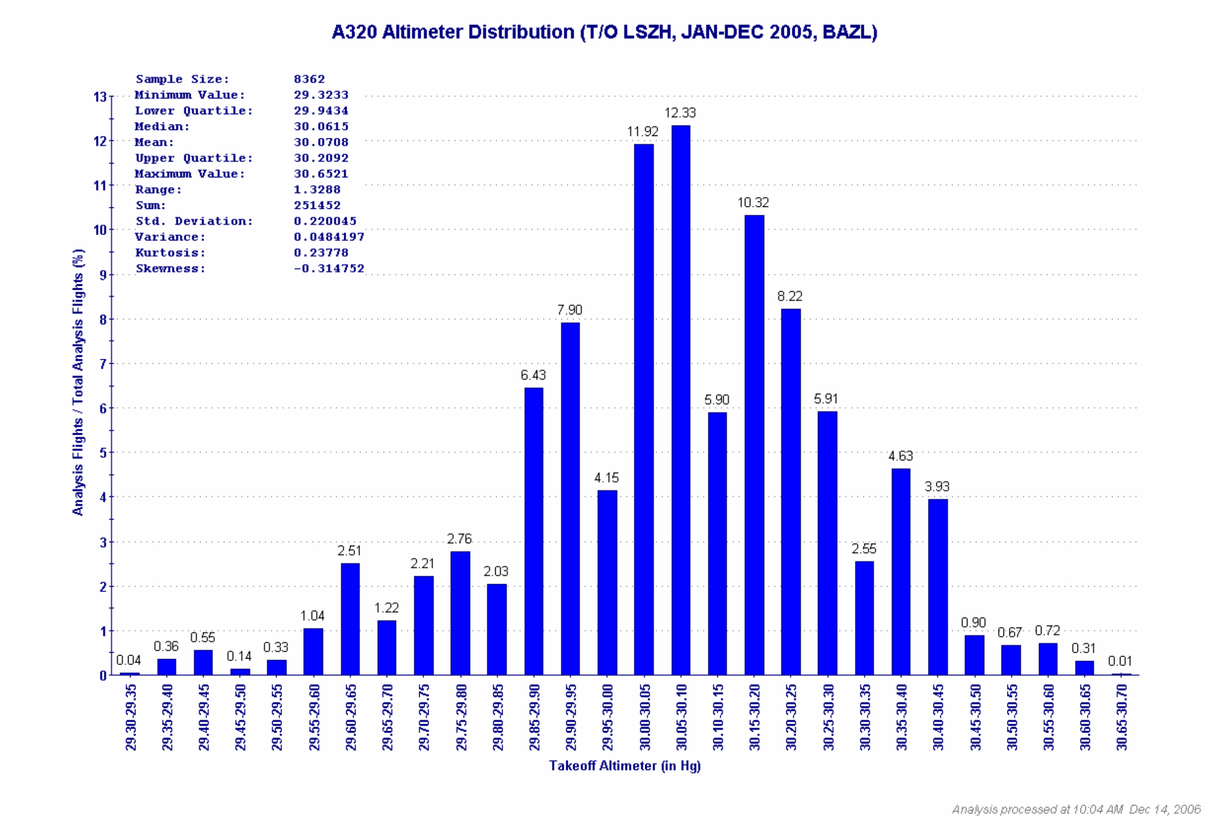


Figure 5: Example of altimeter distribution (QNH) at take-off during a one year operation of all aircraft of the selected medium haul type.

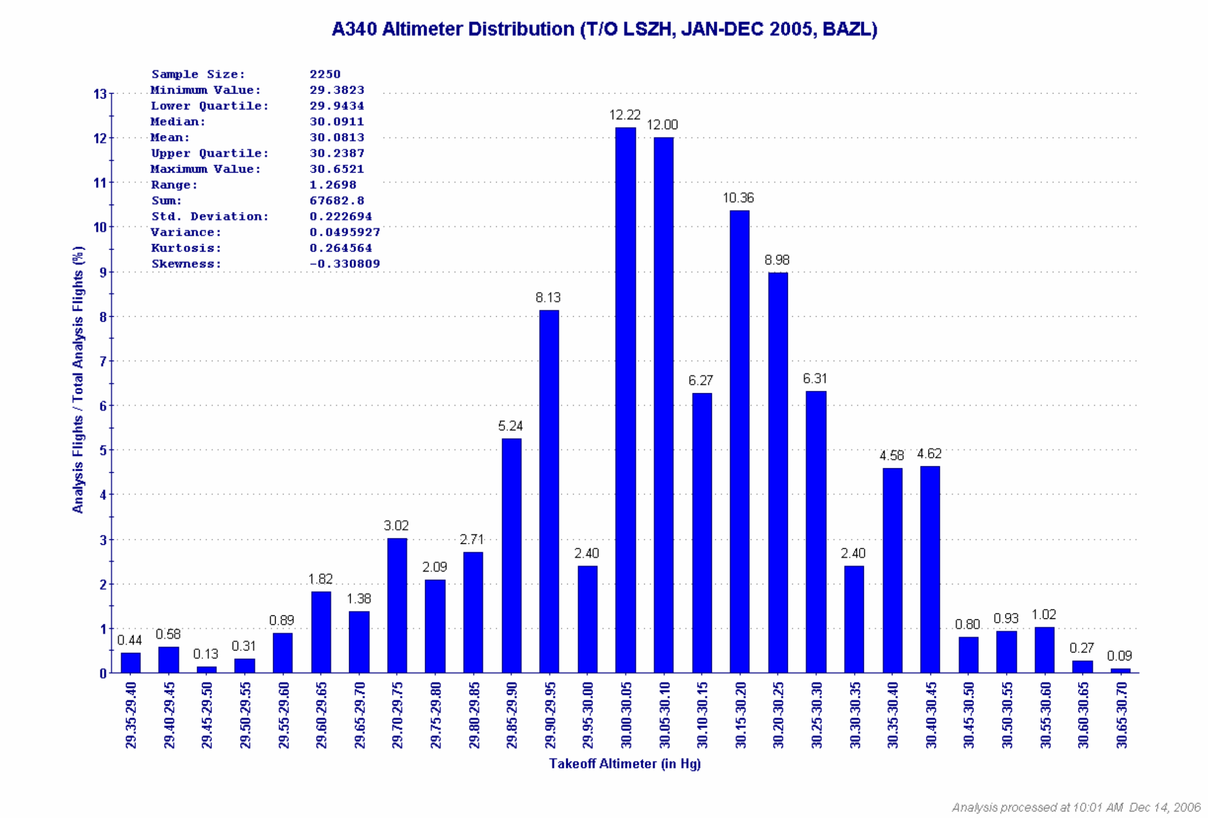


Figure 6: Example of altimeter distribution (QNH) at take-off during a one year operation of all aircraft of the selected long haul type.

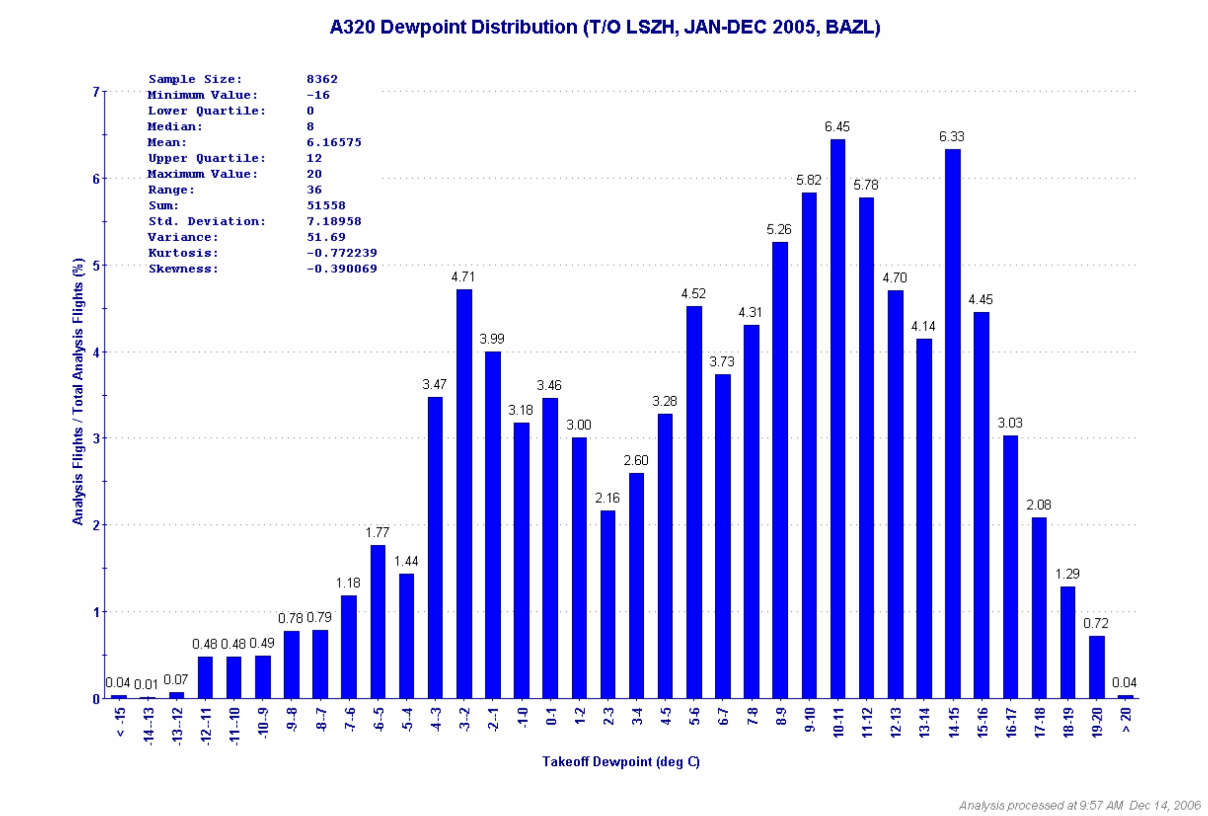


Figure 7: Example of dewpoint distribution at take-off during a one year operation of all aircraft of the selected medium haul type.

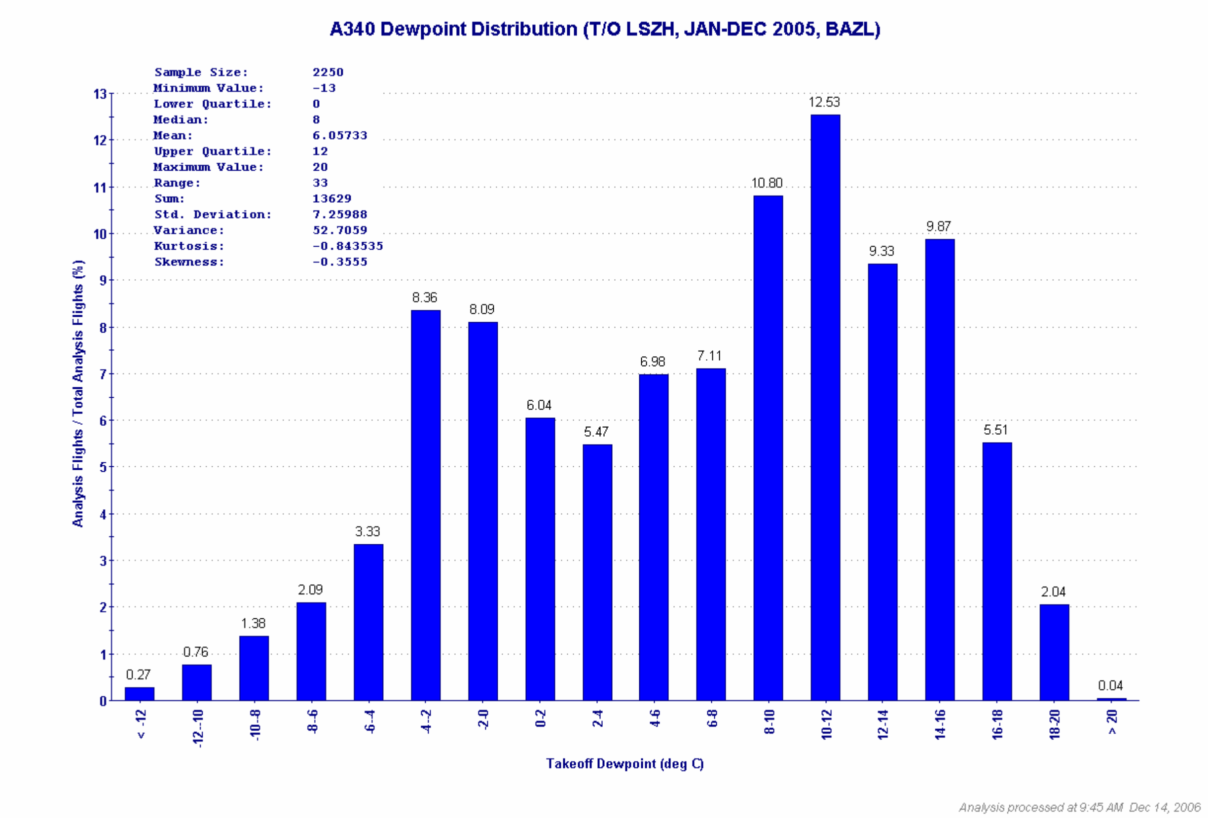


Figure 8: Example of dewpoint distribution (QNH) at take-off during a one year operation of all aircraft of the selected long haul type.

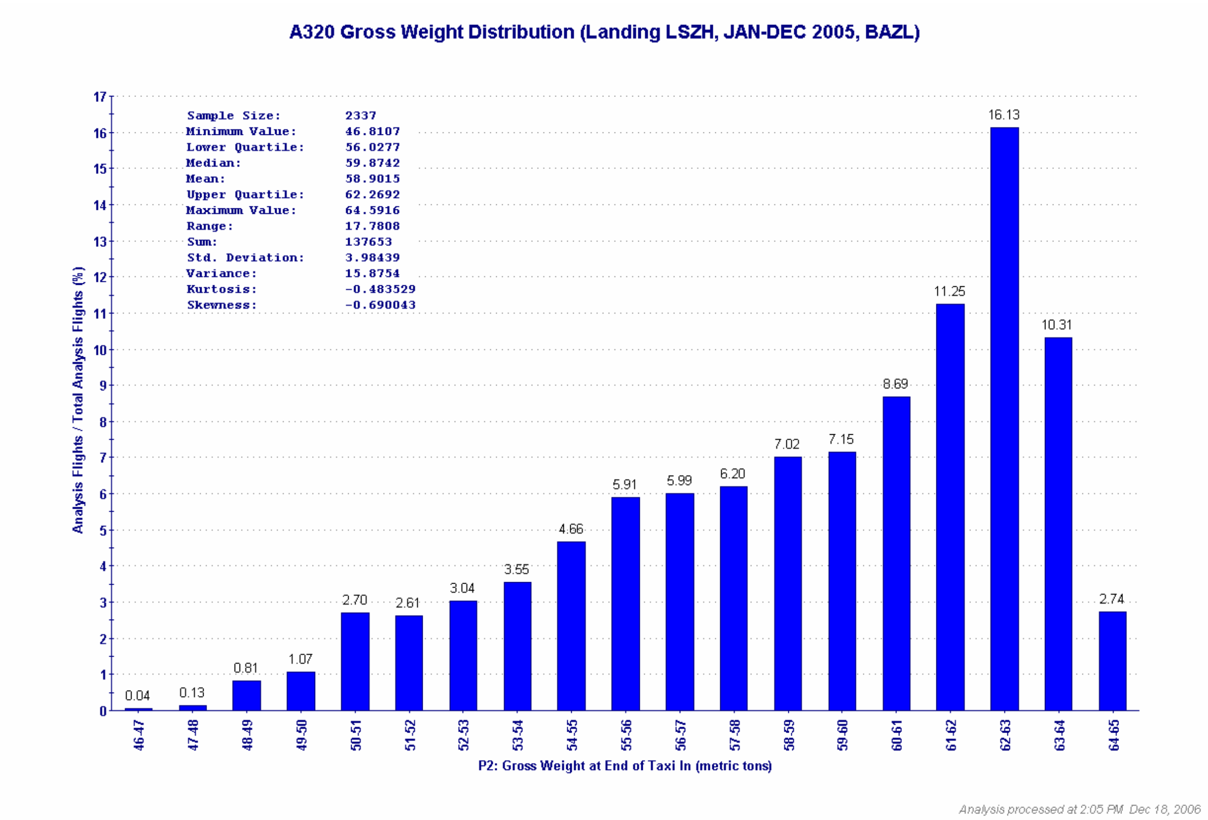


Figure 9: Example of gross weight distribution at taxi-in during a one year operation of all aircraft of the selected medium haul type.

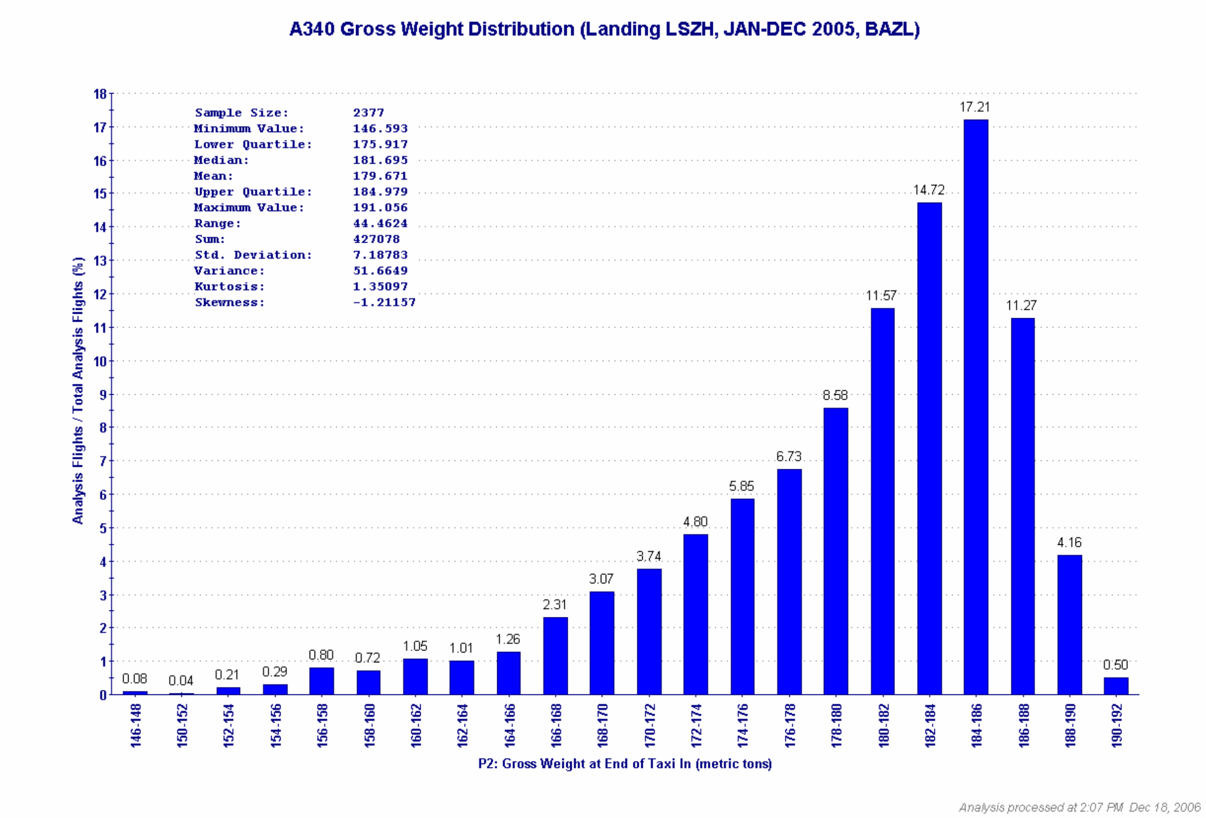
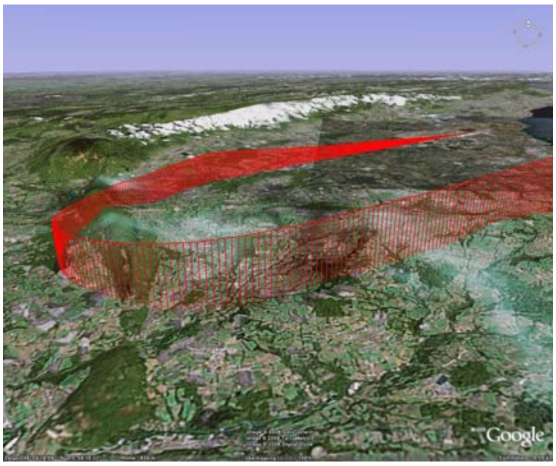


Figure 10: Example of gross weight distribution at taxi-in during a one year operation of all aircraft of the selected long haul type.

Apart from the aircraft weight and balance, performance variations of a given aircraft are largely dependent on the so called density altitude. This is a theoretical altitude dependent on actual ambient air pressure and deviations from ISA ambient air temperature (both influencing air density, therefore lift and drag and engine performance). The selected individual flights cover density altitudes which correspond to atmospheric conditions from below sea level to high altitude airports. (The selection of flights was made in a way that the aircraft performance e.g. for take off, was in a range between sea level and high altitude conditions.)

The flight selection criteria help to make the FDR validation data independent from Zurich Airport elevation and runway layout and the results, in their full range, can be considered applicable to any airport. Furthermore, part 2 of the validation contains selected flights which are departing from and arriving at other airports than Zurich and which are operated by several different airlines.



Picture 3: Approach path of a selected flight for ADAECAM validation in a three dimensional view. The LTO approach segment below 3000ft AGL is the last straight path down to the runway.
[Picture from Google Earth™, not to be used for commercial purposes]

2.2 Summary of selection for FDR data and ADAECAM input

Analysis of FDR data and application of the above criteria lead to the following choice for the first part of the validation (summary):

- Long haul and short haul aircraft types: A340-300 / 4x CFM56-5C4/P and A320-200 / 2x CFM56-4B4
- Low, medium and high take-off weight (taken from figures 1, 2, 9 and 10)
- Low, medium and high ambient air temperature (taken from figures 3 and 4). For arrivals, only medium temperature was selected. Previous FDR analysis showed that outside air temperature had an insignificant effect on arrival fuel (the fuel burn during approach, landing and taxi-in).

2.3 Data sets, used for validation

Validation part 1 was performed on the basis of the following three data sets:

1. Input table for ADAECAM: Flight movement database and ambient meteorological parameters from the airport operator Unique for the selected flights (see table 2).
2. Aircraft tables and ICAO engine emissions database from QinetiQ.
3. Detailed FDR aircraft data (airframe, engine (e.g. fuel flow) and ambient conditions) for the selected flights from Swiss International Air Lines (see table 1).

Table 1: Structure of a FDR departure file provided by Swiss International Air Lines.

Fleet	Flight Date	Tail Number	Takeoff Airport Code	Landing Airport Code	P2: GMT at Start of Taxi Out	P41: Duration of Taxi Out (min)
values..	values..	values..	values..	values..	values..	values..
values..	values..	values..	values..	values..	values..	values..

P41: EPR: mean percent of maximum for takeoff (during taxi-out)	P41: thrust: mean percent of maximum for takeoff (LTO BAZL: during taxi-out)	P41: Fuel Burned by APU during Taxi Out (kg)	P41: Average Fuel Flow to APU during Taxi Out (kg/hr)	P41: average fuel flow per engine during taxi-out (kg/hr)	P41: Average Fuel Flow to all Engines during Taxi Out (kg/hr, if defined!	P41: Outside Air Temperature at Liftoff
values..	values..	values..	values..	values..	values..	values..
values..	values..	values..	values..	values..	values..	values..

P41: EPR: mean percent of maximum for takeoff (begin takeoff --> liftoff)	P41: N1: mean percent of maximum for takeoff (start of takeoff --> liftoff)	P41: thrust: mean percent of maximum for takeoff (LTO BAZL: begin takeoff --> liftoff)	P41: thrust (LTO BAZL: takeoff max, max. value during T/O per engine)	P41: average fuel flow per engine during takeoff (kg/hr)	P41: Duration of Takeoff (start --> liftoff, sec)	P41: Gross Weight at Start of Takeoff (metric tons)
values..	values..	values..	values..	values..	values..	values..
values..	values..	values..	values..	values..	values..	values..

P41: EPR: mean percent of maximum for takeoff (liftoff --> throttle back)	P41: EPR: mean percent of maximum for takeoff (begin takeoff --> throttle back)	P41: EPR: mean percent of maximum for takeoff (throttle back --> 3000ft HATO)	P41: N1: mean percent of maximum for takeoff (liftoff --> throttle back)	P41: N1: mean percent of maximum for takeoff (begin takeoff --> throttle back)	P41: N1: mean percent of maximum for takeoff (throttle back --> 3000ft HATO)	P41: thrust: mean percent of maximum for takeoff (LTO BAZL: liftoff --> throttle back)
values..	values..	values..	values..	values..	values..	values..
values..	values..	values..	values..	values..	values..	values..

P41: thrust: mean percent of maximum for takeoff (LTO BAZL: begin takeoff --> throttle back)	P41: thrust: mean percent of maximum for takeoff (LTO BAZL: throttle back --> 3000ft HATO)	P41: average fuel burned per engine from begin taxi-out --> 3000ft HATO (kg)	P41: average fuel flow per engine from liftoff --> throttle back (kg/hr)	P41: average fuel flow per engine from begin takeoff --> throttle back (kg/hr)	P41: average fuel flow per engine from throttle back --> 3000ft HATO (kg/hr)	P41: duration begin liftoff --> throttle back (sec)
values..	values..	values..	values..	values..	values..	values..
values..	values..	values..	values..	values..	values..	values..

P41: duration begin takeoff --> throttle back (sec)	P41: duration throttle back --> 3000ft HATO (sec)
values..	values..
values..	values..

Airport Data for Input in ADAECAM, validation part 1
January 11, 2007

Departures

TYPE OF FLIGHT	IDENT	AC_TYPE	AC_SUBTYPE	ENGINE_UID	ENGINE_NAME	DESTINATION_ICAO	DESTINATION_IATA	TAXI_OUT_TIME_MIN	TEMP_°C	PRESSURE_hPa	REL_HUMIDITY_%
A340-cold-heavy	DEP1	A343	300	7CM047	CFM56-5C4/P	RJAA	NRT	12.7	-6.2	978.4	57.9
A320-cold-light	DEP2	A320	200	2CM014	CFM56-5B4	LIRF	FCO	6.9	-3	973.9	91.6
A320-cold-medium	DEP3	A320	200	2CM014	CFM56-5B4	EHAM	AMS	20.7	-3.4	966.7	74.7
A340-medium-heavy	DEP4	A343	300	7CM047	CFM56-5C4/P	FAJS	JNB	10.4	10.1	957.1	91.2
A320-medium-light	DEP5	A320	200	2CM014	CFM56-5B4	LFPG	CDG	7.4	11.4	964.7	47.7
A320-hot-light	DEP6	A320	200	2CM014	CFM56-5B4	EGLL	LHR	5.4	27.1	963.4	32.4
A320-medium-medium	DEP7	A320	200	2CM014	CFM56-5B4	EGLL	LHR	8.5	11	966.7	87.8
A320-hot-heavy	DEP8	A320	200	2CM014	CFM56-5B4	LEBL	BCN	8.4	28.3	966.6	42.4
A340-hot-light	DEP9	A343	300	7CM047	CFM56-5C4/P	HECA	CAI	8.6	26.6	964.9	54.8
A340-hot-heavy	DEP10	A343	300	7CM047	CFM56-5C4/P	VHHH	HKG	8.0	23.4	963.5	70.4
A320-hot-medium	DEP11	A320	200	2CM014	CFM56-5B4	LFPG	CDG	8.6	28.1	965.7	45
A340-medium-light	DEP12	A343	300	7CM047	CFM56-5C4/P	LLBG	TLV	16.9	11	970	77.4
A320-medium-heavy	DEP13	A320	200	2CM014	CFM56-5B4	LLBG	TLV	3.3	10.3	968.9	97.7
A320-cold-heavy	DEP14	A320	200	2CM014	CFM56-5B4	UUDD	DME	11.8	-1.5	982.1	78.9
A340-cold-light	DEP15	A343	300	7CM047	CFM56-5C4/P	LLBG	TLV	21.8	-8.4	968.4	64.2

Arrivals

TYPE OF FLIGHT	IDENT	AC_TYPE	AC_SUBTYPE	ENGINE_UID	ENGINE_NAME	ORIGIN_ICAO	ORIGIN__IATA	TAXI_IN_TIME_MIN	TEMP_°C	PRESSURE_hPa	REL_HUMIDITY_%
A320-medium-medium	ARR1	A320	200	2CM014	CFM56-5B4	LFPG	CDG	2.7	8.6	978.1	62.5
A340-medium-medium	ARR2	A343	300	7CM047	CFM56-5C4/P	LLBG	TLV	3.0	11.6	975.8	67
A430-medium-light	ARR3	A343	300	7CM047	CFM56-5C4/P	HECA	CAI	2.9	11.6	960.7	68.2
A320-medium-light	ARR4	A320	200	2CM014	CFM56-5B4	LTAI	AYT	3.2	10.8	958.7	91.5
A340-medium-heavy	ARR5	A343	300	7CM047	CFM56-5C4/P	RJAA	NRT	3.5	11.4	970.2	88.7
A320-medium-heavy	ARR6	A320	200	2CM014	CFM56-5B4	LIRF	FCO	4.3	12	965.5	91.4

Remark: Taxi-out and taxi-in times are matching FDR recorded times

Table 2: Airport data of the chosen flights for Input in ADAECAM.

2.4 Naming of the selected flights

The chosen flights were named in the following way (type of flight):

A320-cold-heavy: Operation at low ambient air temperature and near MTOM
A320-cold-light: Operation at low ambient air temperature and low take-off weight
A320-cold-medium: Operation at low ambient air temperature and medium take-off weight
A320-hot-heavy: Operation at high ambient air temperature and near MTOM
A320-hot-light: Operation at high ambient air temperature and low take-off weight
A320-hot-medium: Operation at high ambient air temperature and medium take-off weight
A320-medium-heavy: Operation at medium ambient air temperature and near MTOM
A320-medium-light: Operation at medium ambient air temperature and low take-off weight
A320-medium-medium: Operation at medium ambient air temperature and medium take-off weight

And named accordingly:

A340-cold-heavy
A340-cold-light
A340-hot-heavy
A340-hot-light
A340-medium-heavy
A340-medium-light

2.5 Determination of LTO fuel with five different methods

For the chosen flights, the LTO fuel was determined, using

1. CAEP Guidance Material (DOC9884): Simple Method (UNFCCC look-up table), called “ICAO-Simple”
2. CAEP Guidance Material (DOC9884): Certification LTO Cycle (correct engine type), called
“ICAO-Cert.”
3. CAEP Guidance Material (DOC9884): Advanced Method (correct engine type and airport specific taxi times), called “ICAO-Adv.”
4. ADAECAM: Advanced Aircraft Emission Calculation Method (correct engine type, flight destination, airport specific taxi times and ambient conditions), called “ADAECAM”
5. FDR: Sophisticated Method: Actual measured fuel flow, called “FDR”

2.6 Comparison of LTO fuel consumption

The following figures 11 and 12 show the results for total fuel consumption during the LTO cycle, calculated for the selected Airbus A340-300 and A320-200 flights, based on four different methodologies (respectively models) and compared to the FDR data.

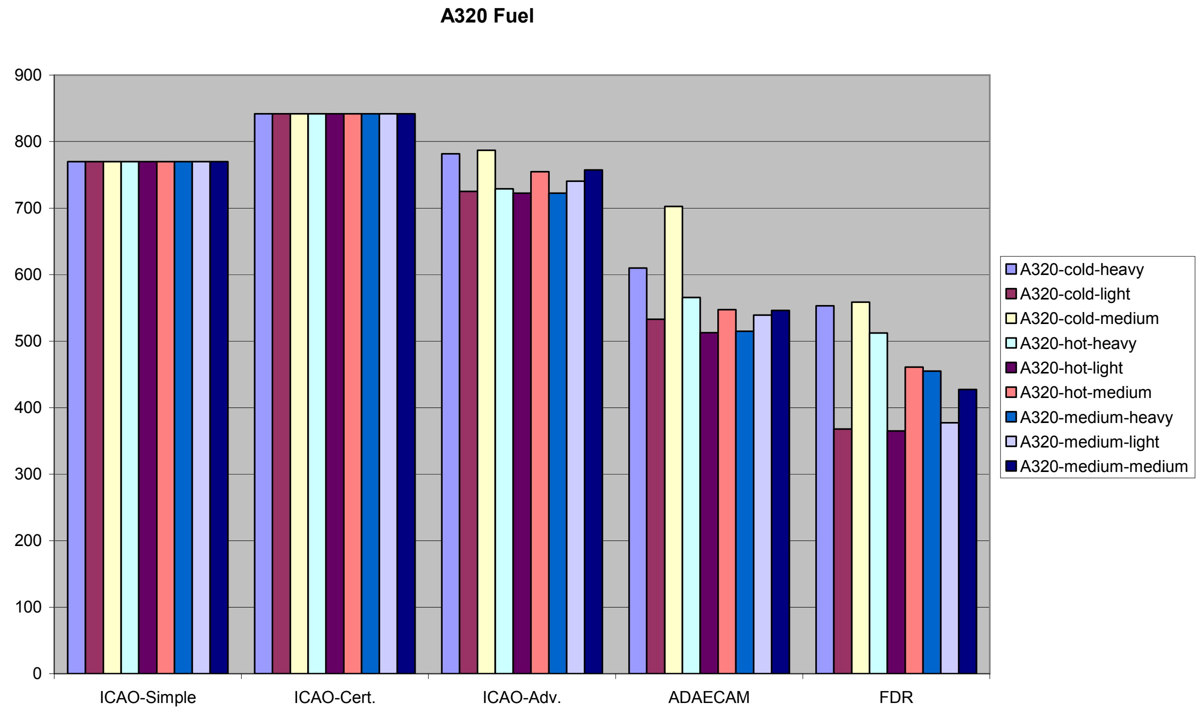


Figure 11: Comparison of LTO fuel consumption (kg), determined with “ICAO-Simple”, “ICAO-Cert.”, “ICAO-Adv.”, “ADAECAM” and “FDR” (real case) for A320 / CFM56-5B4.

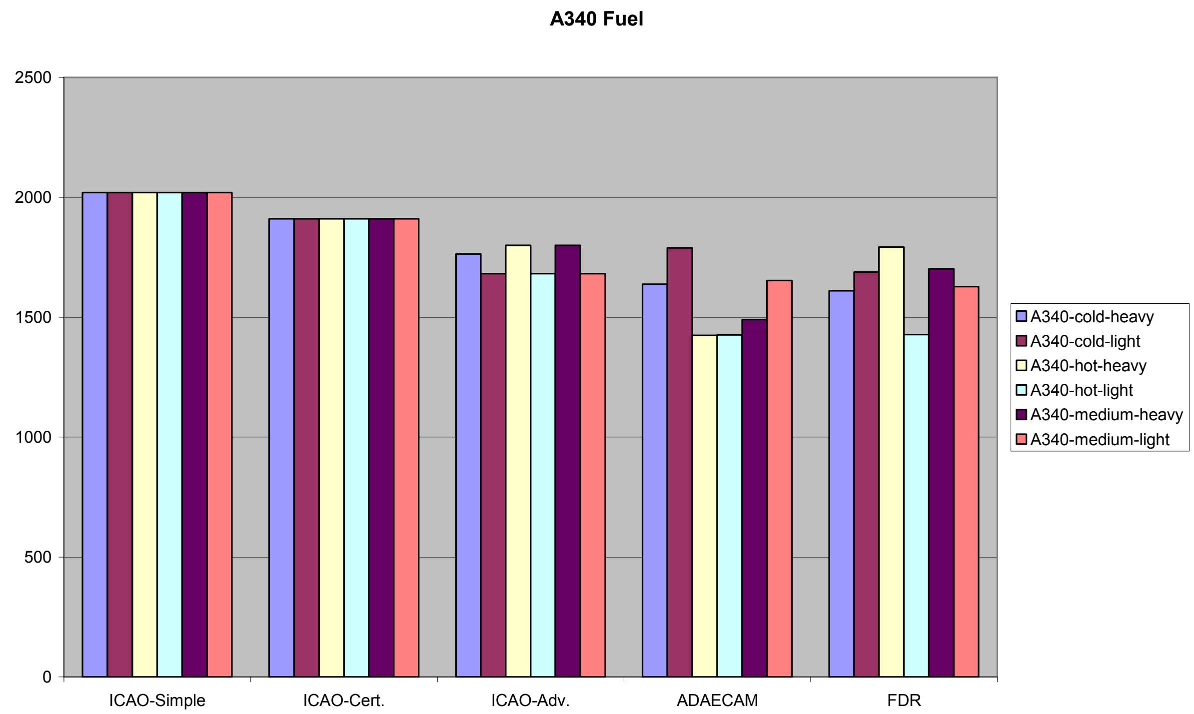


Figure 12: Comparison of LTO fuel consumption (kg), determined with “ICAO-Simple”, “ICAO-Cert.”, “ICAO-Adv.”, “ADAECAM” and “FDR” (real case) for A340-300 / CFM56-5C4/P.

The following figures show a more detailed comparison between ADAECAM fuel burn results and FDR data. For this purpose, Departure and Arrival have been divided into seven segments. The definitions of the segments are listed below and have been agreed with the ADAECAM developers prior to validation, so that ADAECAM would be able to calculate the fuel burn results for the individual segments. Accordingly, the FDR measurement data processing was tailored to the seven segments, as well.

The 7 segments are:

1) Taxi-out
2) Take-off roll (=brake release and engine spool up, acceleration to lift off until 35ft AGL)
3) Initial climb-out until potential cut-back at 1500ft AGL
4) Climb from potential cut-back at 1500 to 3000ft AGL
5) Approach from 3000ft AGL
6) Landing roll (= touch down to leaving runway)
7) Taxi-in

The comparison of the fuel burn calculations and the FDR measurements in the seven segments allows a more detailed view of the model capabilities. For validation purposes, it can help to identify match or mismatch issues for different phases of the LTO.

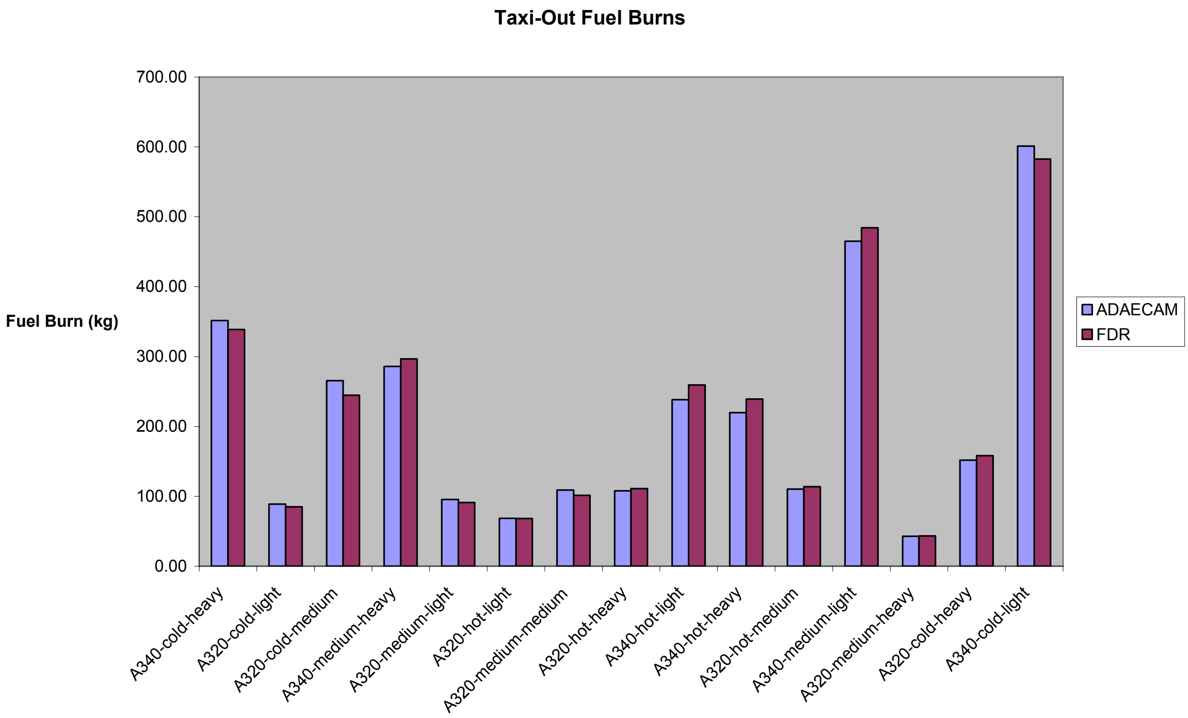


Figure 13: Comparison of taxi-out fuel burn between ADAECAM and FDR for A320 / CFM56-4B4 and A340-300 / CFM56-5C4/P.

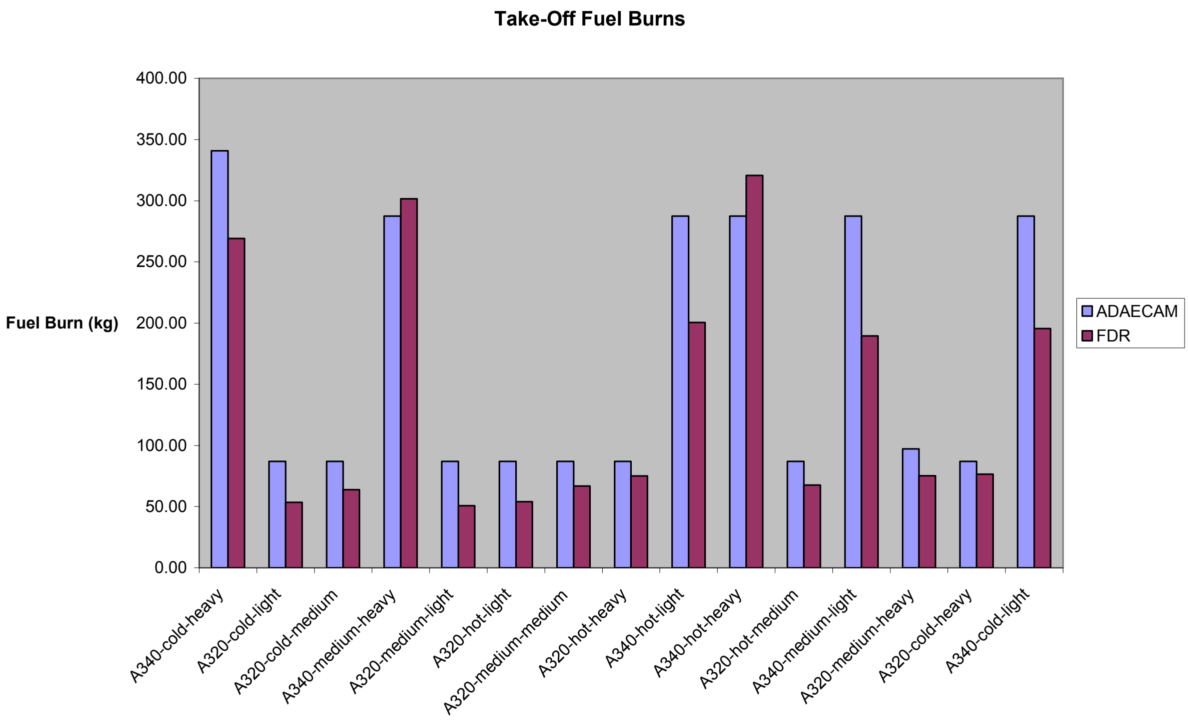


Figure 14: Comparison of take-off fuel burn between ADAECAM and FDR for A320 / CFM56-4B4 and A340-300 / CFM56-5C4/P.

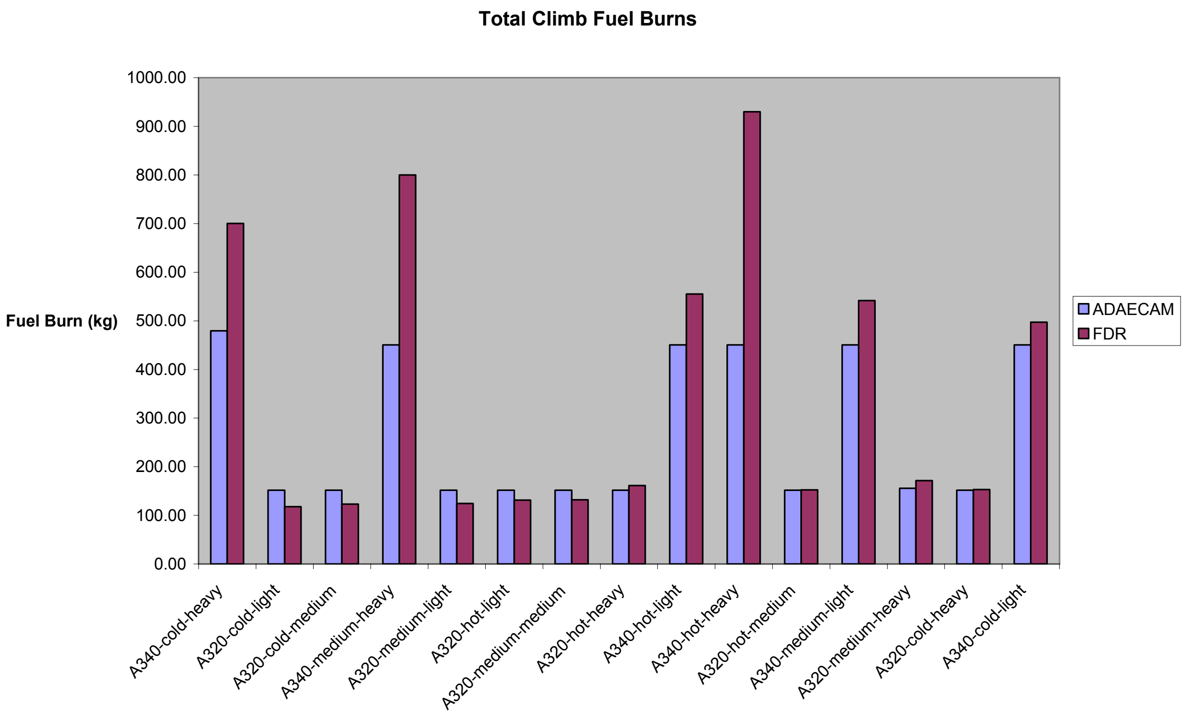


Figure 15: Comparison of climb fuel burn between ADAECAM and FDR for A320 / CFM56-4B4 and A340-300 / CFM56-5C4/P.

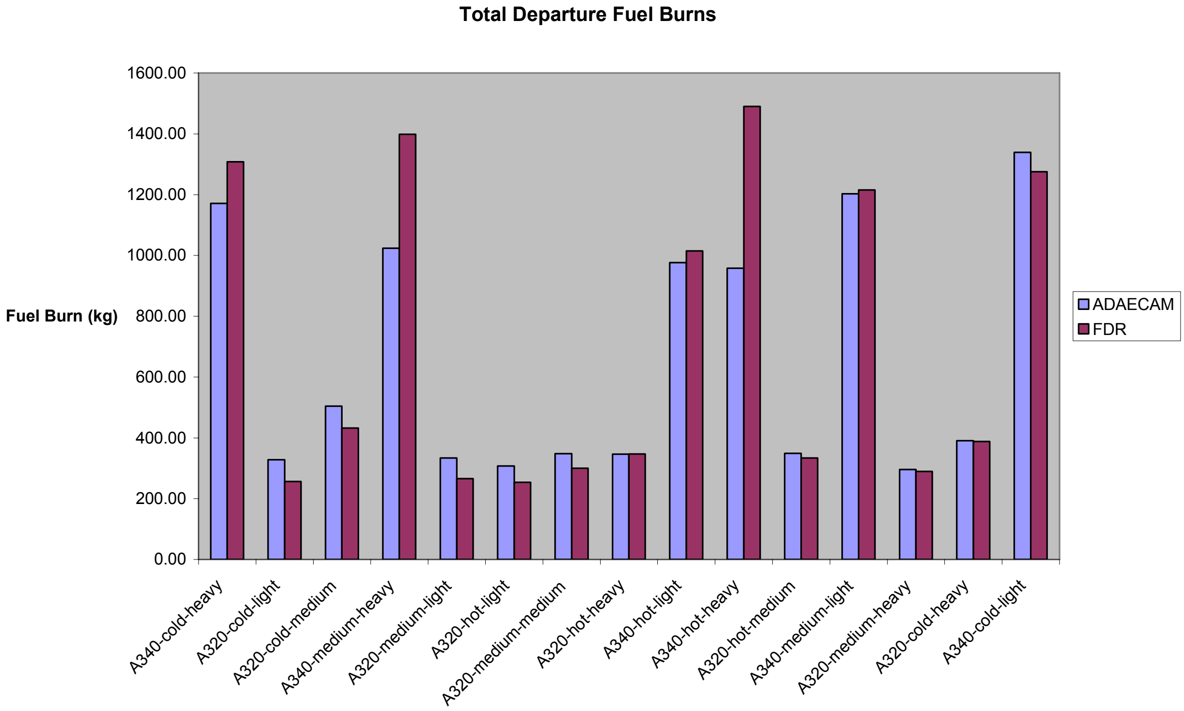


Figure 16: Comparison of departure fuel burn (taxi-out, take-off and climb) between ADAE-CAM and FDR for A320 / CFM56-4B4 and A340-300 / CFM56-5C4/P.

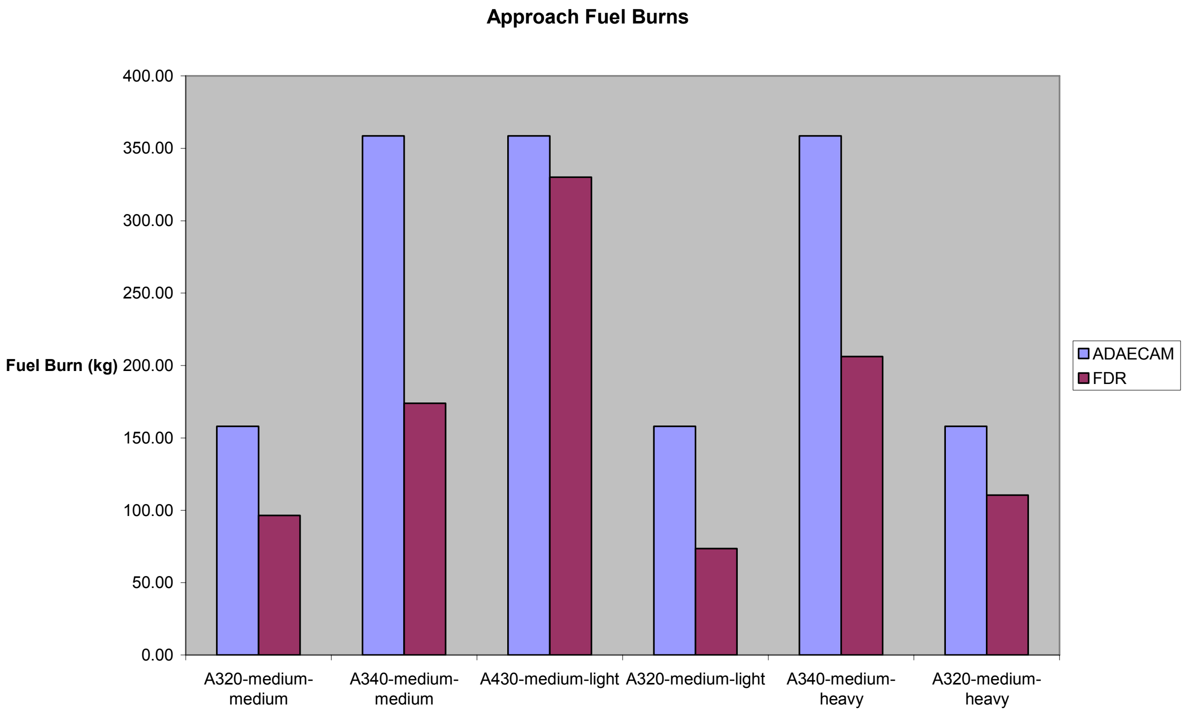


Figure 17: Comparison of approach fuel burn between ADAECAM and FDR for A320 / CFM56-4B4 and A340-300 / CFM56-5C4/P.

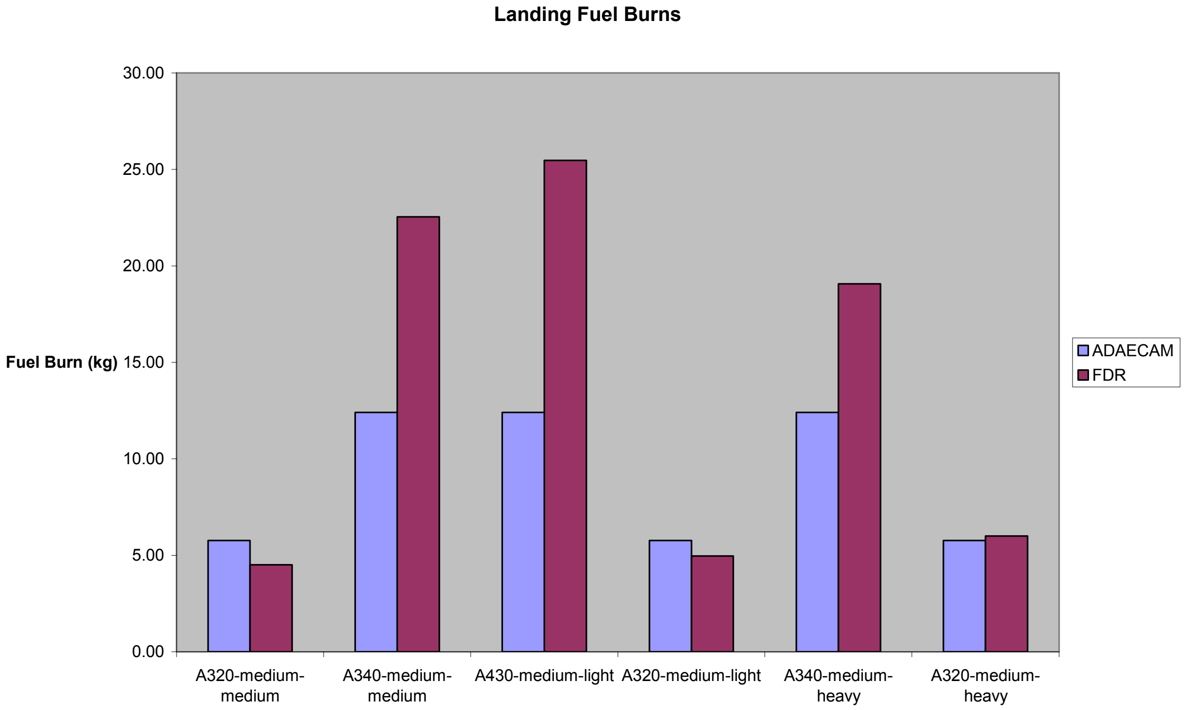


Figure 18: Comparison of landing fuel burn between ADAECAM and FDR for A320 / CFM56-4B4 and A340-300 / CFM56-5C4/P.

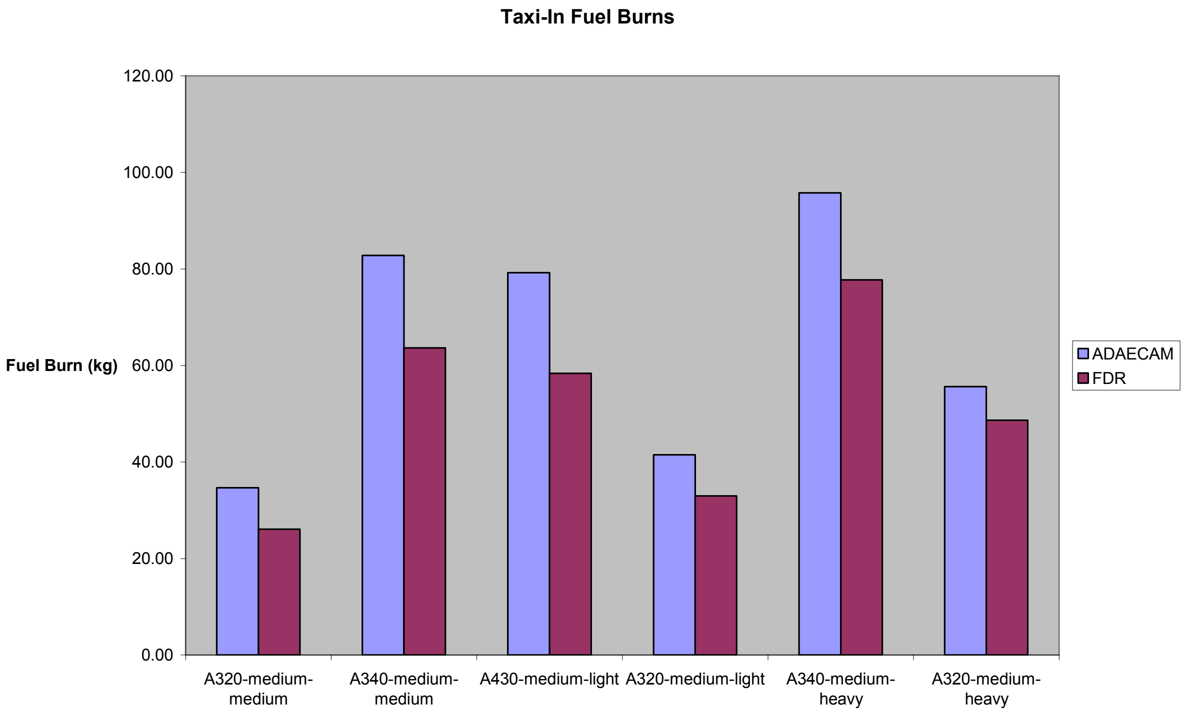


Figure 19: Comparison of taxi-in fuel burn between ADAECAM and FDR for A320 / CFM56-4B4 and A340-300 / CFM56-5C4/P.

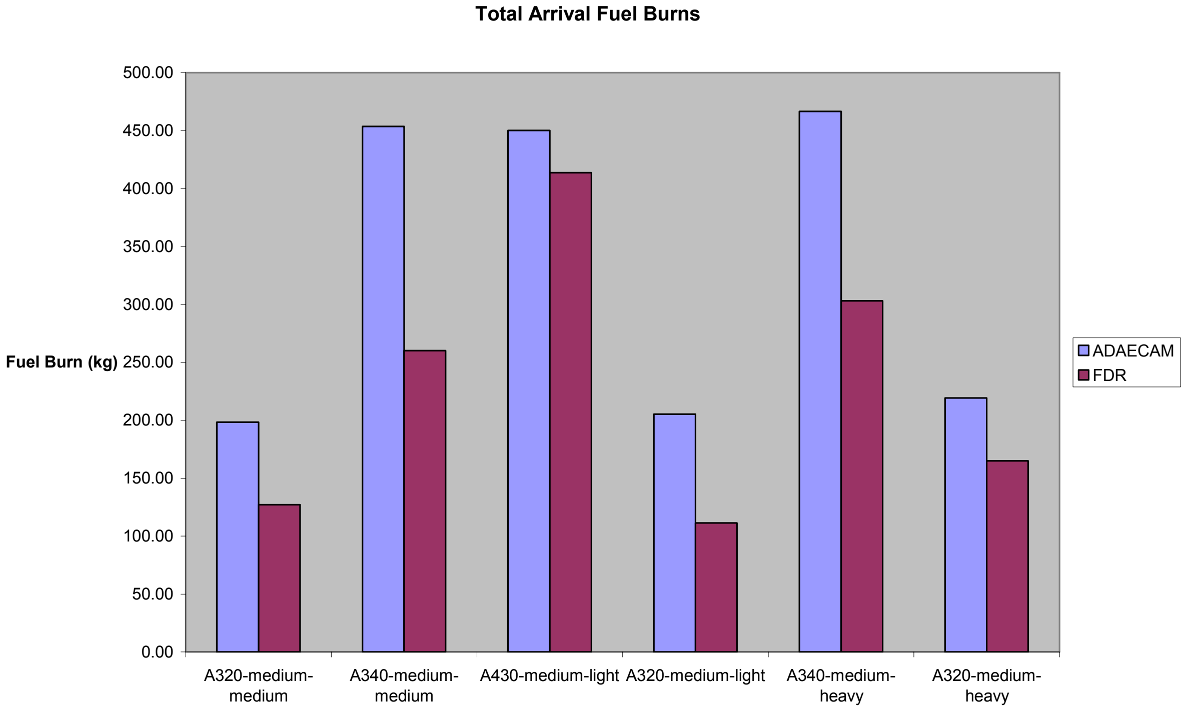


Figure 20: Comparison of arrival fuel burn (approach, landing and taxi-in) between ADAE-CAM and FDR for A320 / CFM56-4B4 and A340-300 / CFM56-5C4/P.

2.7 Discussion

a) Total LTO fuel burn (figures 11 and 12)

- Generally, the simple methods ("ICAO-simple" and "ICAO-cert.") significantly overestimate the real LTO fuel burn.
- "ICAO-simple" does not take the actual engine into account and the results for "ICAO-simple" and "ICAO-cert." are independent from actual aircraft operation and performance. Therefore, their totals do not show any variation between the selected flights.
- "ICAO-cert." takes the actual engine fitted to the airframe into account, which leads to higher LTO fuel consumption in the case of the A320 and to lower LTO fuel burn in the case of the A340-300, compared to "ICAO-simple". Whether "ICAO-cert." is higher or lower as "ICAO-simple" only depends on the choice of engine that has originally been made to produce the figure for "ICAO-simple". The difference is therefore a matter of chance.
- The results for "ICAO-Adv." show slight variations in LTO fuel burn between the selected flights. The variations result from actual taxi times that are taken into account. The LTO fuel burn for the A320 is significantly overestimated. For the A340-300, the differences compared to FDR are relatively small.
- ADAECAM LTO fuel consumption for the A320 is much closer to the real A320 LTO fuel burn than the results obtained with the other models. It can be seen that ADAE-CAM reproduces some of the FDR data variations in excess of the different taxi times. For the A320 LTO fuel burn, the ADAECAM results for all flights are conservative (slightly overestimating the real case, safe side).
- ADAECAM LTO fuel burn for the A340-300 is in two cases lower than FDR. LTO fuel burn for "A340-medium-heavy" and "A340-hot-heavy" are underestimated. The other selected flights match the total fuel consumption quite precisely.

b) Detailed comparison of fuel burn in individual LTO segments (figures 13 to 20)

- ADAECAM taxi-out and taxi-in fuel burn is close to and higher than FDR recorded fuel burn in most cases. It must be noted that ADAECAM input taxi times from airport are matching FDR taxi times and ADAECAM uses the standard 7% thrust fuel flow from the ICAO engine emissions data sheet.
- ADAECAM take-off fuel burn is always higher than FDR fuel burn for the A320. With the exception of one heavy A320 take-off, the ADAECAM calculated fuel burn is constant in all cases.
- ADAECAM take-off fuel burn is higher than FDR fuel burn for the light A340-300 and slightly lower in two heavy A340-300 cases.
- ADAECAM total climb fuel burn (35ft to 3000ft AGL) is constant for the A320 in all cases. It is higher than A320 FDR fuel burn, with the exception of the “medium-heavy” and “hot-heavy” climb.
- ADAECAM underestimates the A340-300 climb fuel burn. In the case of the A340 “hot-heavy” climb, the difference is a factor of two.

- Total departure fuel is slightly overestimated by ADAECAM for the A320 flights and underestimated for the A340-300.

- ADAECAM approach fuel burn is constant for a certain aircraft (see ADAECAM description). It overestimates FDR Approach fuel burn in all cases, in some cases by a factor of two. Note that it can be seen in the FDR results that aircraft weight does not need to be directly correlated to fuel burn during approach – on the contrary. The lightest A340 of the selected flights shows the significantly highest fuel burn (in this example). Apart from aerodynamic properties and operational choices, wind can have a significant influence on the fuel burn during approach. Wind components and turbulence have not been taken into account for the FDR flight selection.
- ADAECAM landing fuel burn matches A320 FDR landing fuel burn very closely, but A340-300 landing fuel burn is significantly underestimated in all cases.

- Total arrival fuel burn is overestimated by ADAECAM in all cases.

3. Validation Part 2: Extended Selection of Aircraft

3.1 General remarks

The flight selection procedure in this section is identical to the one described in the previous section 2. Therefore, the description is not repeated. However, for transparency, the whole range of selected performance and emissions affecting factors is summarized in the Appendix A. This includes the gross weight distribution for take-off and landing, outside air temperature and altimeter setting for every selected airframe/engine combination. In this part of the validation, some FDR data from aircraft that have been operated at other airports than Zurich and which were operated by other airlines than SWISS are used. Normally, the selected aircraft types differ in both, airframe and engine. In one case, the ADAECAM results are compared against the FDR data of an airframe (A330-200) with two different engine models.

3.2 A330-200 / PW4168A Floatwall

As explained in section 2, FDR data have been analyzed to provide the full range of possible flights with very different performance (and aircraft emissions) affecting parameters, as shown in the distributions of Appendix A. Based on this analysis, 9 flights for take-off and 3 flights for landing emissions comparisons have been chosen. They were named according to the section 2 terminology:

Table 3: Naming of the selected flights with the coding "Aircraft-Temperature-Weight"

Departures
TYPE OF FLIGHT
A330-cold-light
A330-medium-heavy
A330-hot-medium
A330-hot-heavy
A330-hot-light
A330-medium-medium
A330-medium-light
A330-cold-heavy
A330-cold-medium

Arrivals
TYPE OF FLIGHT
A330-medium-medium
A330-medium-heavy
A330-medium-light

In order to generate the input table for ADAECAM, the airport gave the tail number, day and time of flight for each of the selected flights. Airport available data used for ADAECAM input are summarized in table 4 below.

Airport Data for Input in ADAECAM, validation part 2
May 16, 2007

Departures

TYPE OF FLIGHT	IDENT	AC_TYPE	AC_SUBTYPE	ENGINE_UID	ENGINE_NAME	DESTINATION_ICAO	DESTINATION_IATA	AXI_OUT_TIME_MIN	TEMP_°C	PRESSURE_hPa	REL_HUMIDITY_%
A330-cold-light	DEP21	A332	200	4PW067	PW 4168A Floatw.	OMDB	DXB	7.3	-1.2	971.2	54.2
A330-medium-heavy	DEP22	A332	200	4PW067	PW 4168A Floatw.	KMIA	MIA	16.9	13.2	964.9	60.4
A330-hot-medium	DEP23	A332	200	4PW067	PW 4168A Floatw.	CYUL	YUL	11.6	29.4	970.4	42.6
A330-hot-heavy	DEP24	A332	200	4PW067	PW 4168A Floatw.	KMIA	MIA	13.5	29.3	970.2	53.2
A330-hot-light	DEP25	A332	200	4PW067	PW 4168A Floatw.	OMDB	DXB	14.0	30.7	966.5	41.1
A330-medium-mediu	DEP26	A332	200	4PW067	PW 4168A Floatw.	VABB	BOM	11.2	16.3	970.9	77.7
A330-medium-light	DEP27	A332	200	4PW067	PW 4168A Floatw.	OERK	RUH	4.8	16.3	971.7	67.2
A330-cold-heavy	DEP28	A332	200	4PW067	PW 4168A Floatw.	KMIA	MIA	38.4	-5	956.3	81.5
A330-cold-medium	DEP29	A332	200	4PW067	PW 4168A Floatw.	FGSL	SSG	24.3	-3.2	965.2	76.4

Arrivals

TYPE OF FLIGHT	IDENT	AC_TYPE	AC_SUBTYPE	ENGINE_UID	ENGINE_NAME	ORIGIN_ICAO	ORIGIN__IATA	TAXI_IN_TIME_MIN	TEMP_°C	PRESSURE_hPa	REL_HUMIDITY_%
A330-medium-	ARR21	A332	200	4PW067	PW 4168A Floatw.	OERK	RUH	8.8	6.9	966.9	96.3
A330-medium-	ARR22	A332	200	4PW067	PW 4168A Floatw.	VABB	BOM	5.8	7.9	969.1	99.5
A330-medium-	ARR23	A332	200	4PW067	PW 4168A Floatw.	LSGG	GVA	2.5	9.1	983.4	90.6

Remark: Taxi-out and taxi-in times are matching FDR recorded times

Table 4: Input table for ADAECAM.

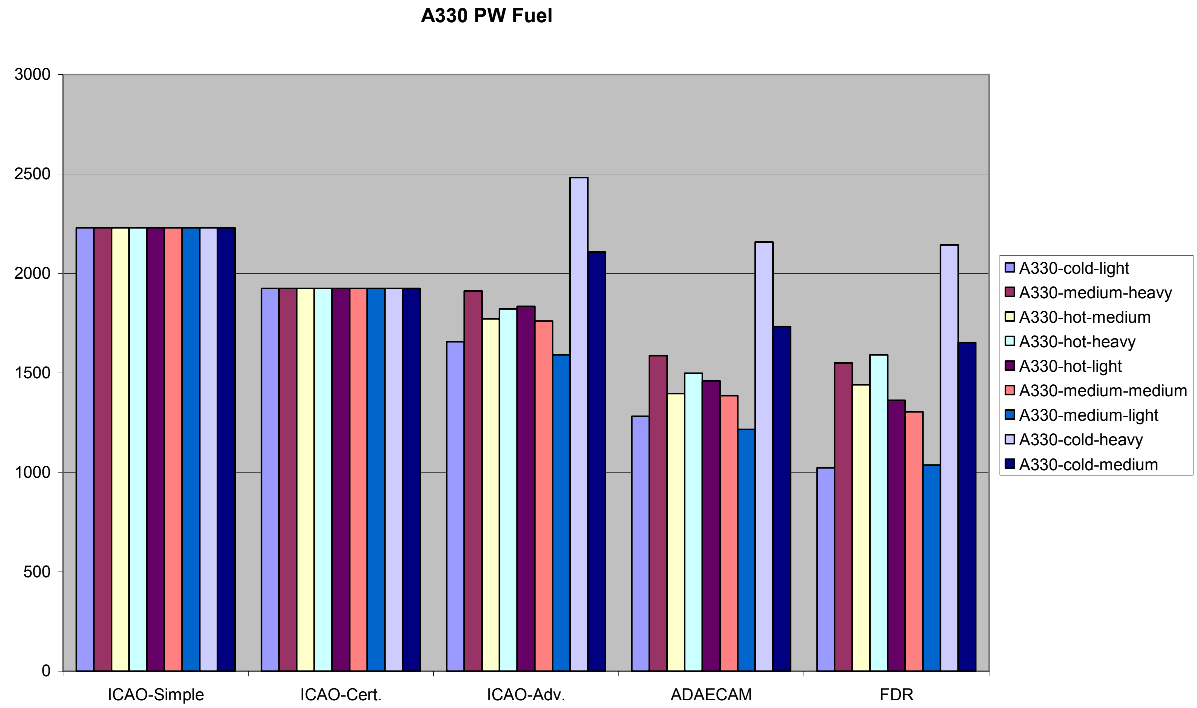


Figure 21: Comparison of LTO fuel use (kg), determined with “ICAO-Simple”, “ICAO-Cert.”, “ICAO-Adv.”, “ADAECAM” and “FDR” (real case) for A330 / PW4168A Floatwall.

Figures 22 to 29 show the comparison of ADAECAM calculated and FDR measured fuel burn for the seven previously defined LTO segments.

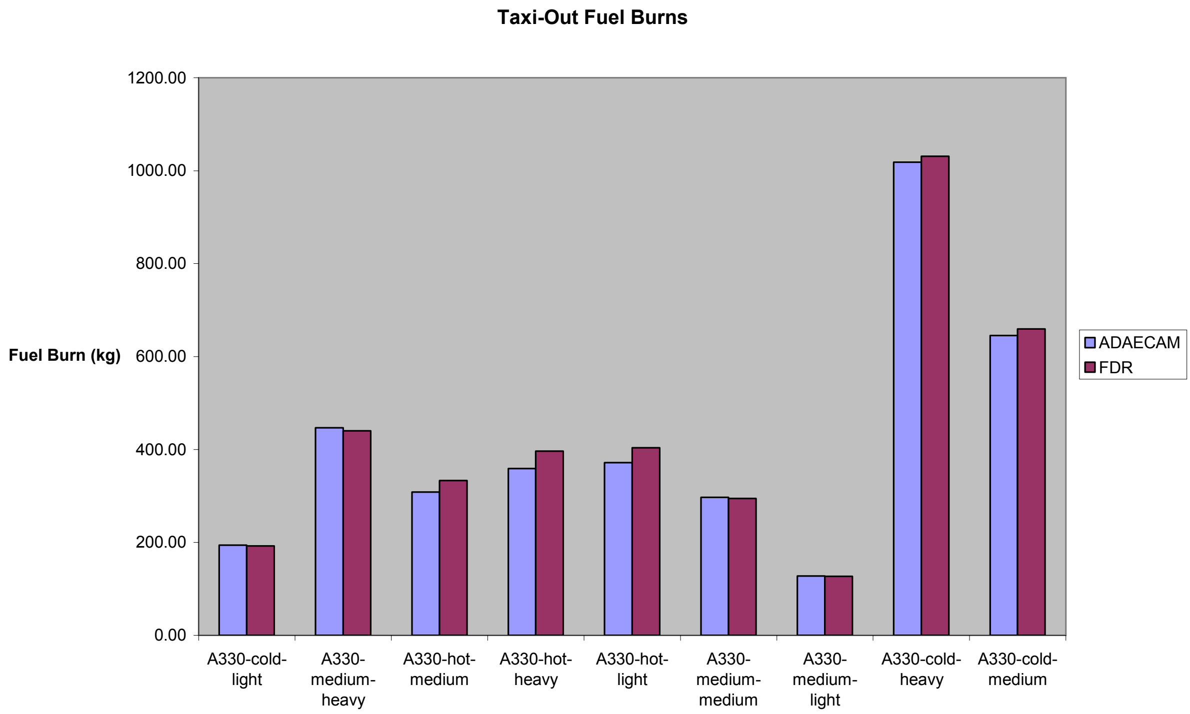


Figure 22: Comparison of taxi-out fuel burn between ADAECAM and FDR for A330 / PW4168A Floatwall.

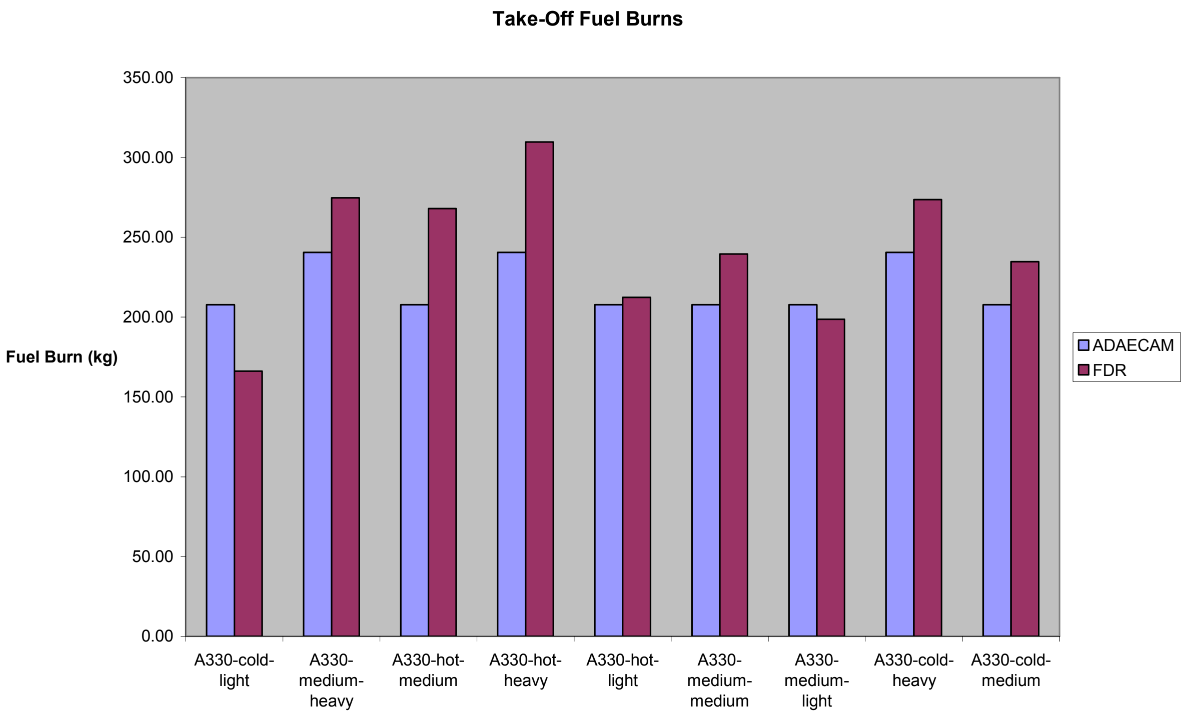


Figure 23: Comparison of take-off fuel burn between ADAECAM and FDR for A330 / PW4168A Floatwall.

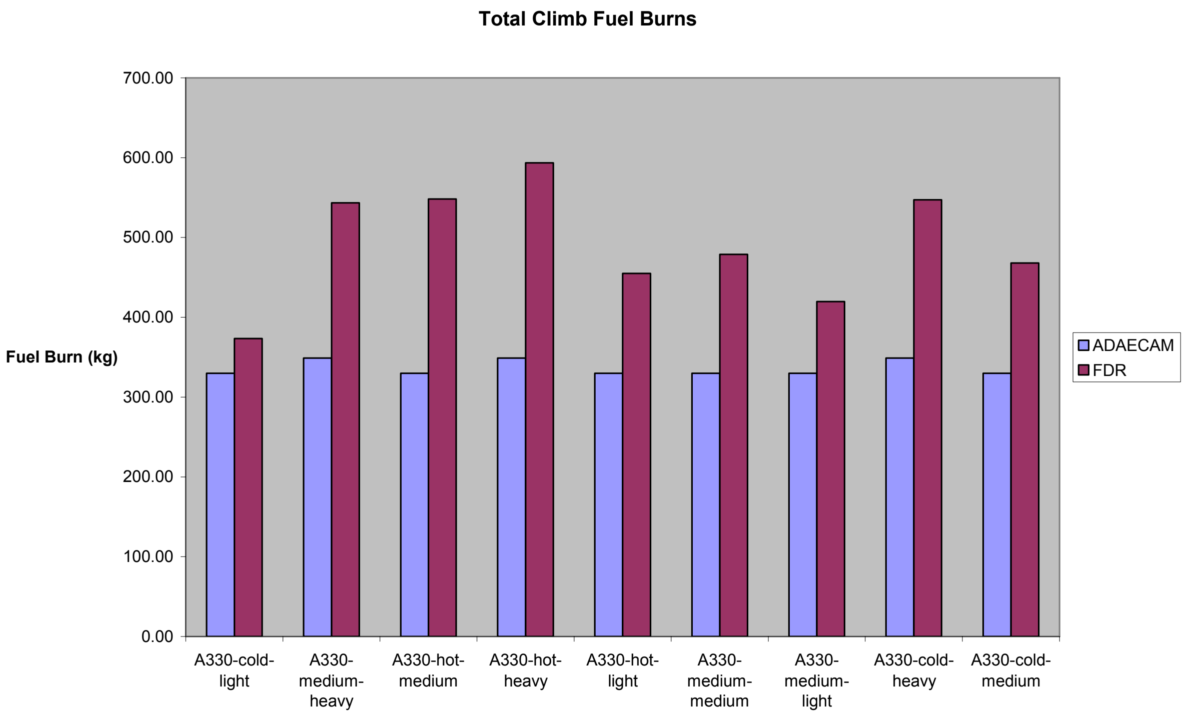


Figure 24: Comparison of climb fuel burn between ADAECAM and FDR for A330 / PW4168A Floatwall.

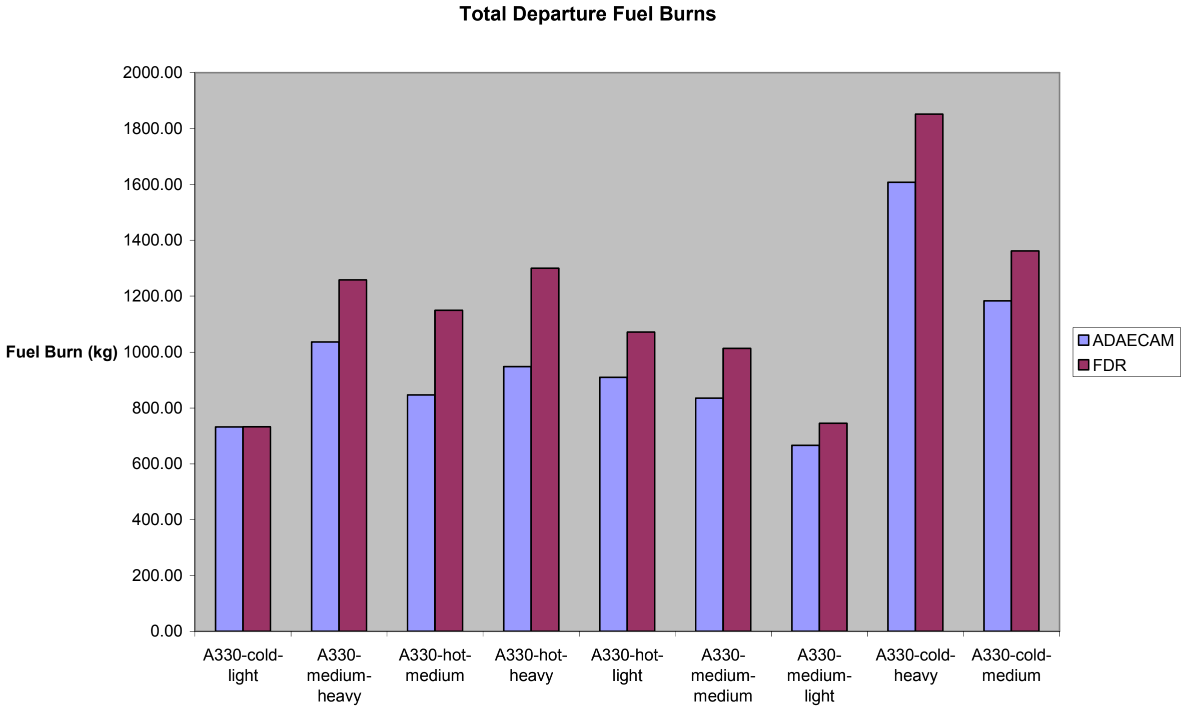


Figure 25: Comparison of departure fuel burn (taxi-out, take-off and climb) between ADAE-CAM and FDR for A330 / PW4168A Floatwall.

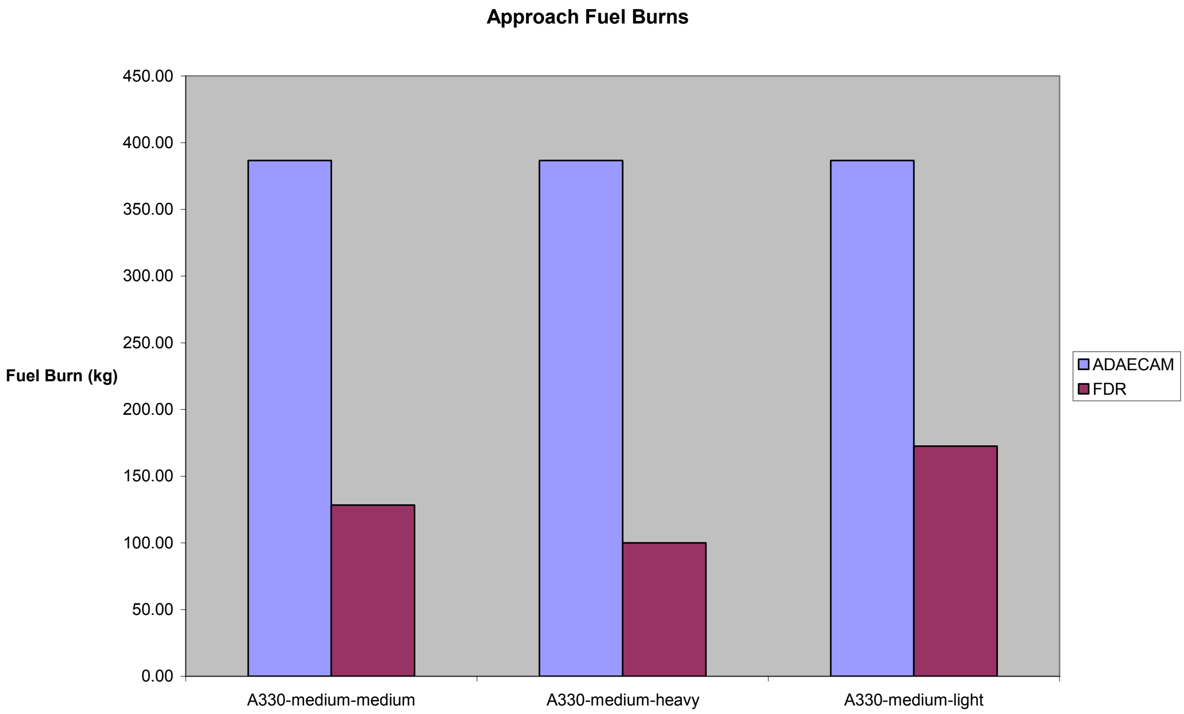


Figure 26: Comparison of approach fuel burn between ADAECAM and FDR for A330 / PW4168A Floatwall.

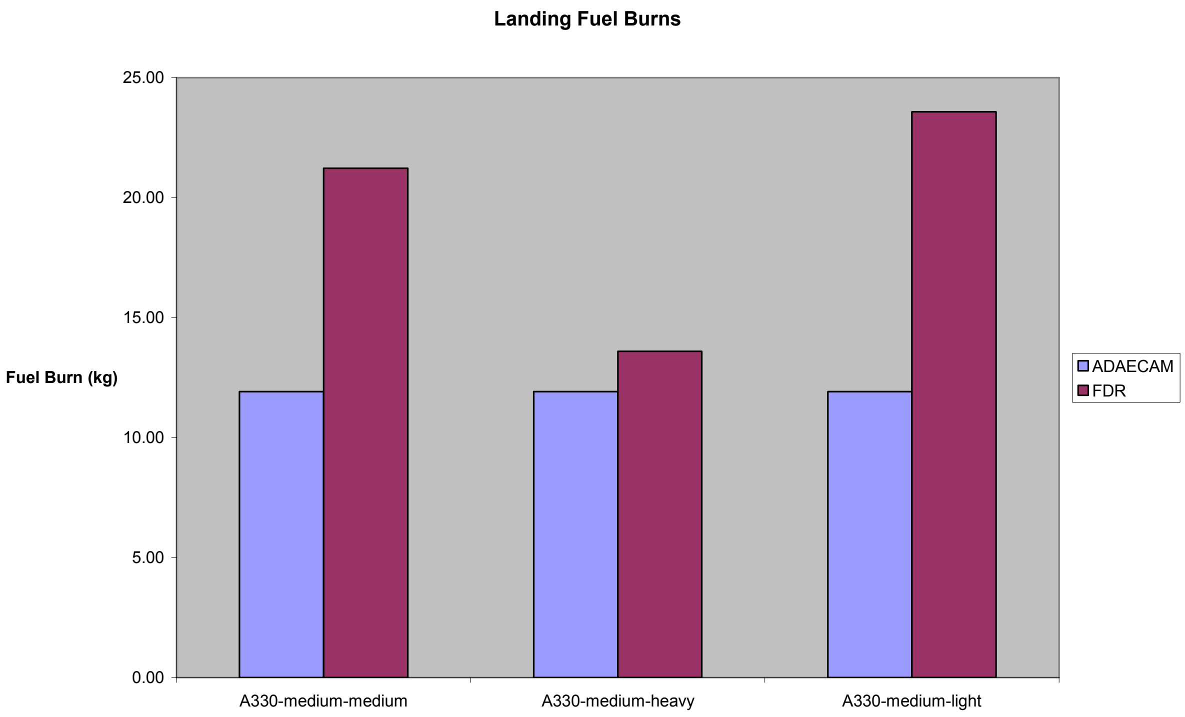


Figure 27: Comparison of landing fuel burn between ADAECAM and FDR for A330 / PW4168A Floatwall.

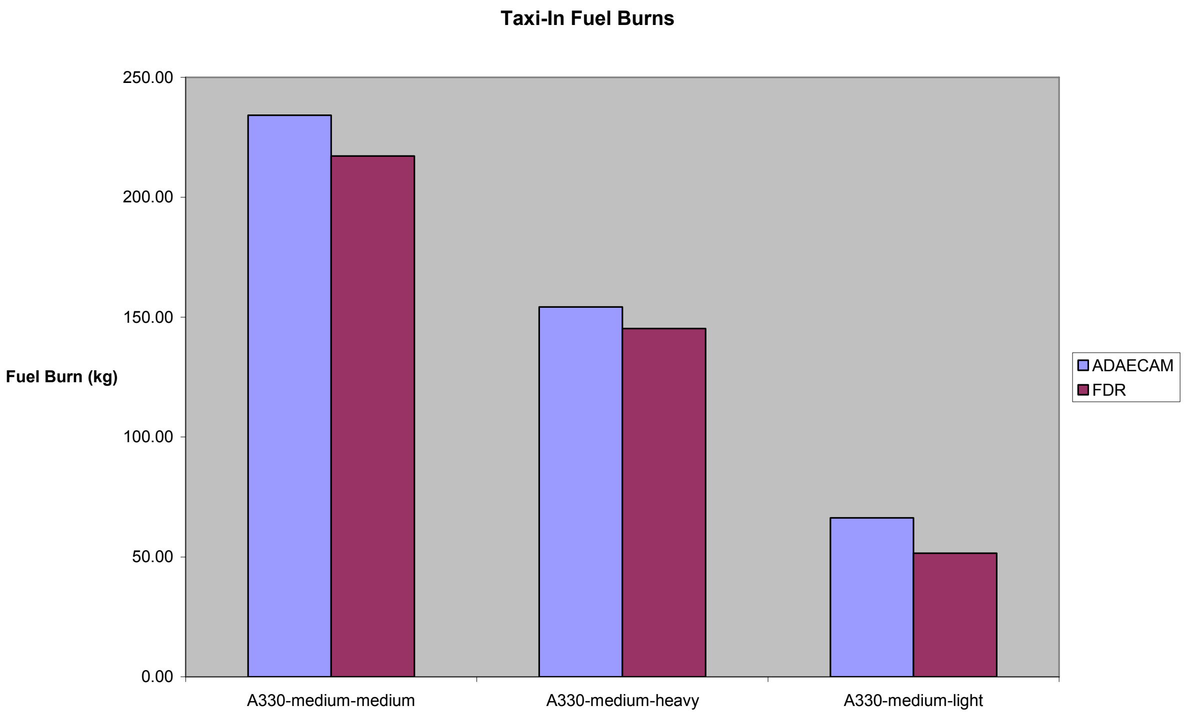


Figure 28: Comparison of taxi-in fuel burn between ADAECAM and FDR for A330 / PW4168A Floatwall.

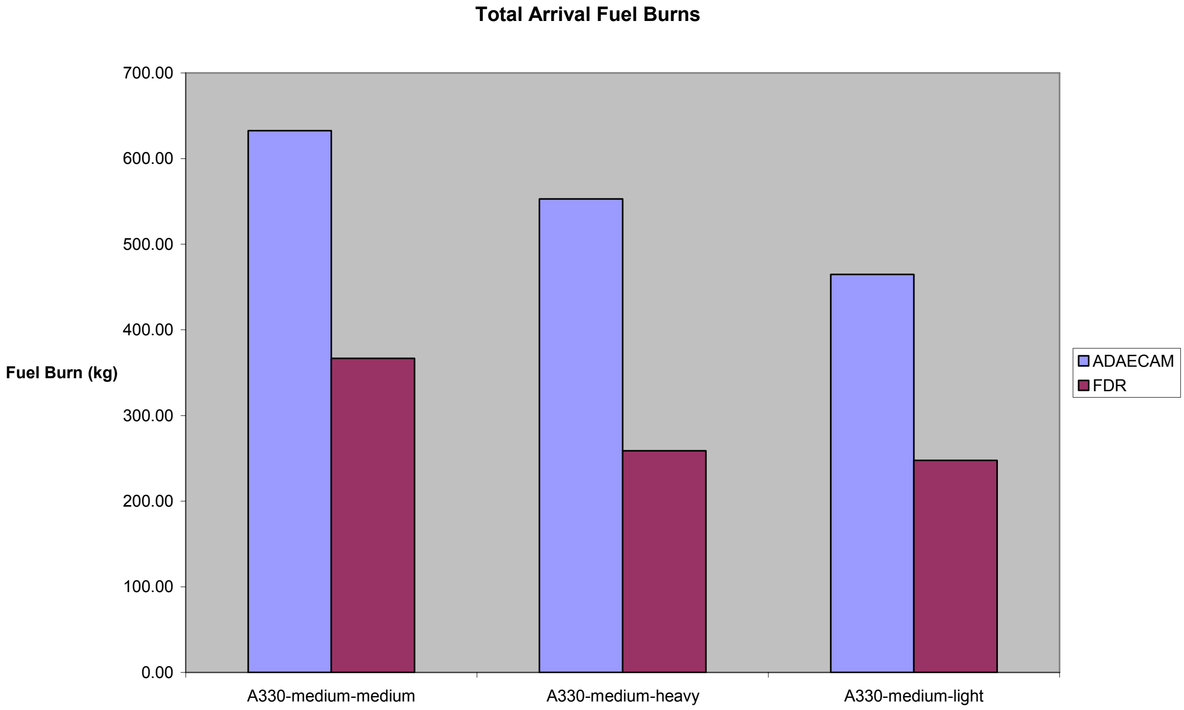


Figure 29: Comparison of arrival fuel burn (approach, landing and taxi-in) between ADAE-CAM and FDR for A330 / PW4168A Floatwall.

3.3 A330-200 / RR Trent 772B

Airport Data for Input in ADAECAM, validation part 2
August 7, 2007

Departures

TYPE OF FLIGHT	IDENT	AC_TYPE	AC_SUBTYPE	ENGINE_UID	ENGINE_NAME	DEPARTURE ARPT_ICAO	DEPARTURE ARPT_IATA	DESTINATION_ICAO	DESTINATION_IATA	TAXI_OUT_TIME_MIN	TEMP_°C	PRESSURE_hPa	REL_HUMIDITY_%
A330-medium-light	DEP71	A332	200	3RR030	RR Trent 772B	OBBI	BAH	OMAA	AUH	5.7	13	1026.8	59
A330-cold-light	DEP72	A332	200	3RR030	RR Trent 772B	OERK	RUH	OMAA	AUH	10.5	5.0	958.1	63
A330-hot-light	DEP73	A332	200	3RR030	RR Trent 772B	OMAA	AUH	OBBI	BAH	5.6	32	1007.8	30
A330-medium-mediu	DEP74	A332	200	3RR030	RR Trent 772B	EDDF	Frau	OMAA	AUH	17.9	10	1005.8	67
A330-hot-medium	DEP75	A332	200	3RR030	RR Trent 772B	OEDF	DMM	OMAA	AUH	8.7	35	998.1	37
A330-cold-medium	DEP76	A332	200	3RR030	RR Trent 772B	EDDM	MUC	OMAA	AUH	27.2	7.0	967.3	84
A330-cold-heavy	DEP77	A332	200	3RR030	RR Trent 772B	EGLL	LHR	OMAA	AUH	9.8	1	1024.1	75
A330-medium-heavy	DEP78	A332	200	3RR030	RR Trent 772B	LFPG	CDG	OMAA	AUH	12.0	12	1001.7	84
A330-hot-heavy	DEP79	A332	200	3RR030	RR Trent 772B	OMAA	AUH	OERK	RUH	6.9	34	1004.3	28

Arrivals

TYPE OF FLIGHT	IDENT	AC_TYPE	AC_SUBTYPE	ENGINE_UID	ENGINE_NAME	ARRIVAL ARPT_ICAO	ARRIVAL ARPT_IATA	ORIGIN_ICAO	ORIGIN__IATA	TAXI_IN_TIME_MIN	TEMP_°C	PRESSURE_hPa	REL_HUMIDITY_%
A330-medium-light	ARR71	A332	200	3RR030	RR Trent 772B	OMAA	AUH	OKBK	KWI	4.8	19.0	1018.1	84
A330-medium-mediu	ARR72	A332	200	3RR030	RR Trent 772B	OMAA	AUH	OPKC	KHI	4.0	14.0	1016.9	100
A330-medium-heavy	ARR73	A332	200	3RR030	RR Trent 772B	OPKC	KHI	OMAA	AUH	6.9	18.0	1009.7	47

Remark: Taxi-out and taxi-in times are matching FDR recorded times

Table 5: Input table for ADAECAM, generated with airport available data.

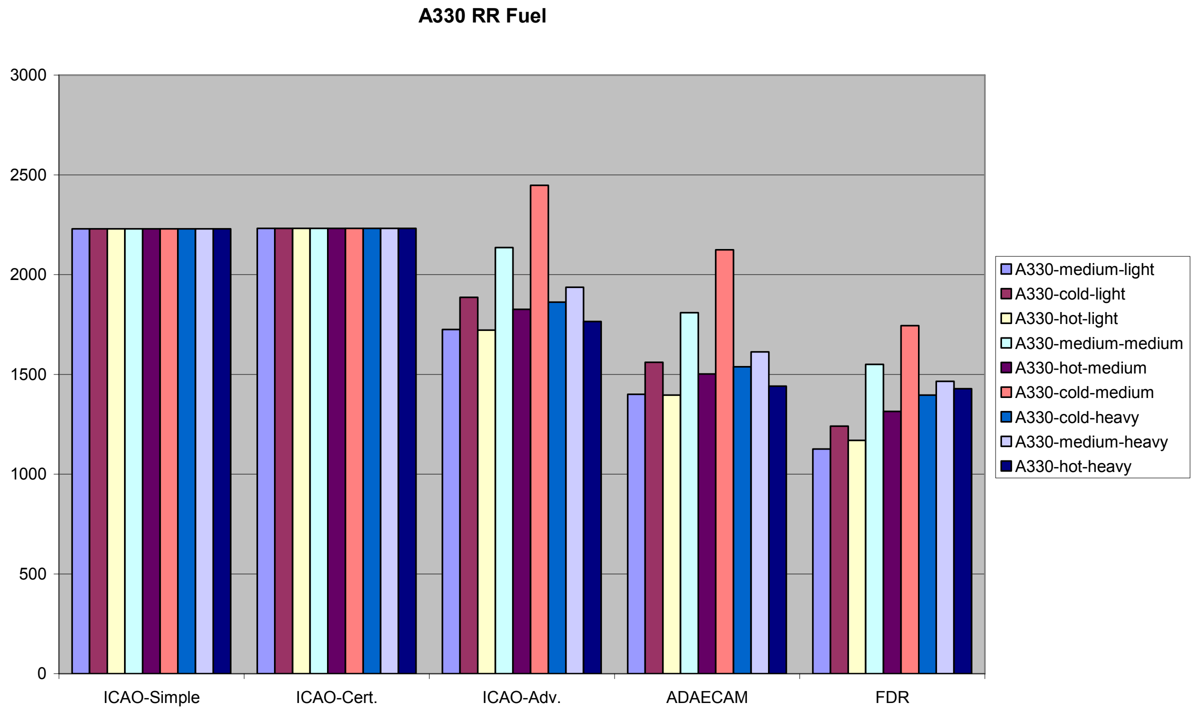


Figure 30: Comparison of LTO fuel use (kg), determined with "ICAO-Simple", "ICAO-Cert.", "ICAO-Adv.", "ADAECAM" and "FDR" (real case) for A330 / RR Trent 772B.

Figures 31 to 38 show the comparison of ADAECAM calculated and FDR measured fuel burn for the seven previously defined LTO segments.

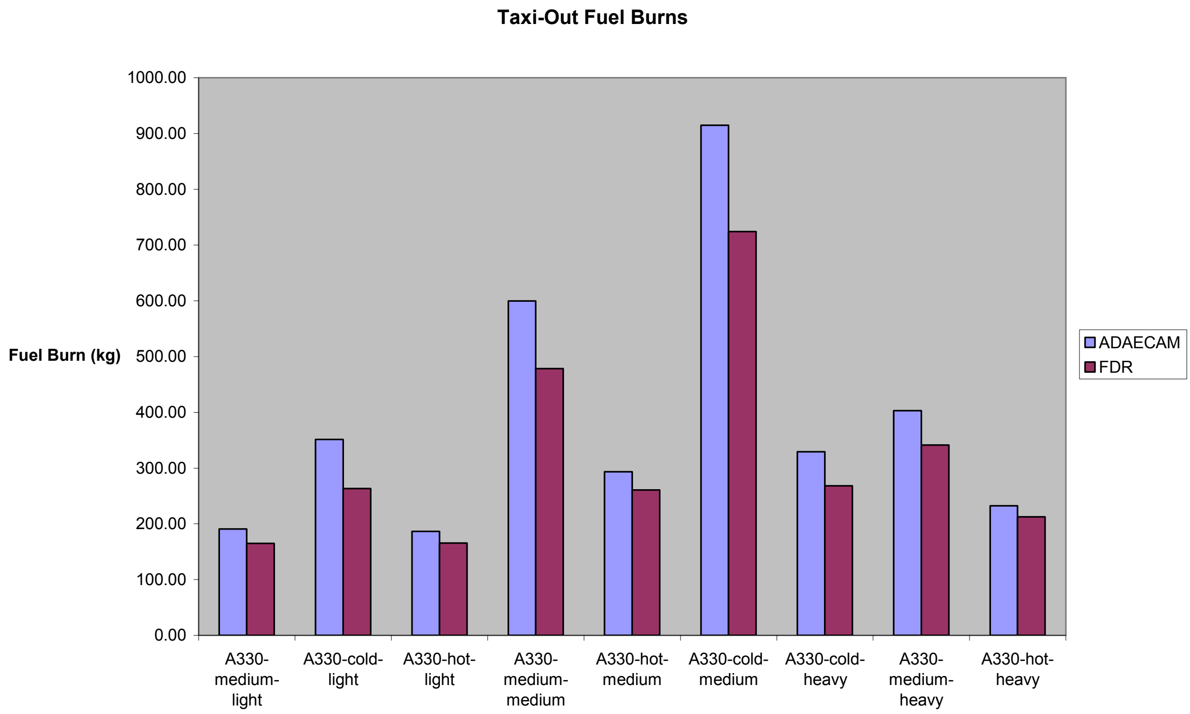


Figure 31: Comparison of taxi-out fuel burn between ADAECAM and FDR for A330 / RR Trent 772B.

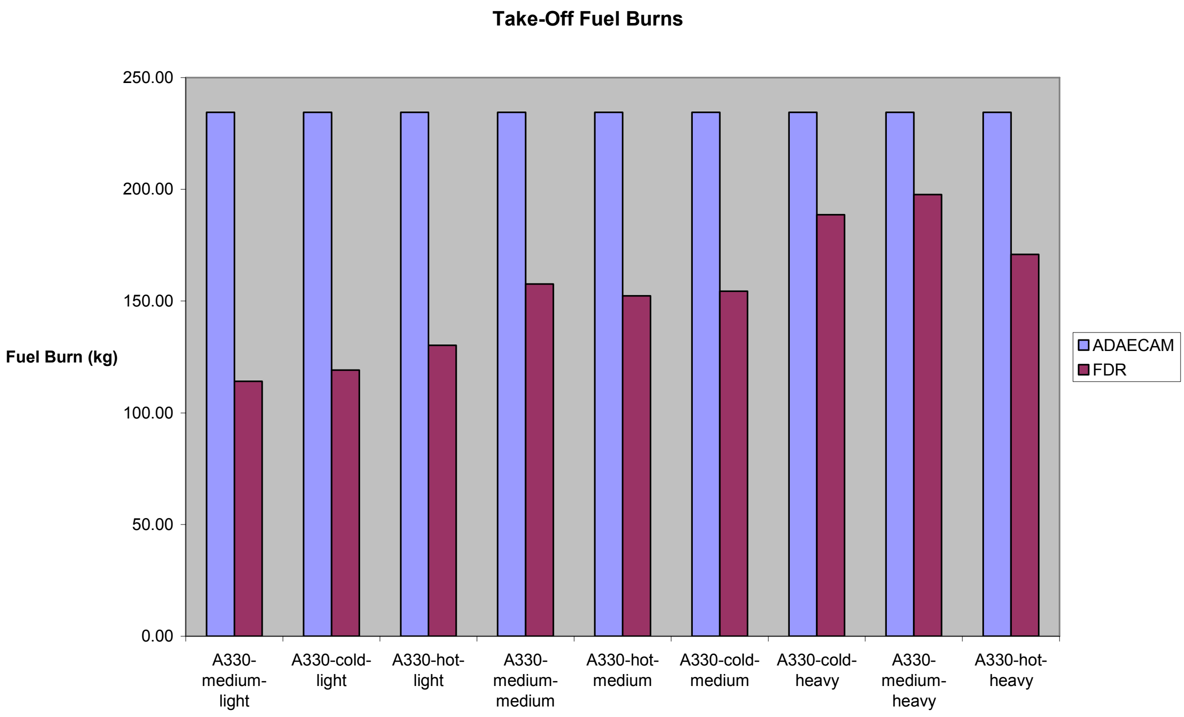


Figure 32: Comparison of take-off fuel burn between ADAECAM and FDR for A330 / RR Trent 772B.

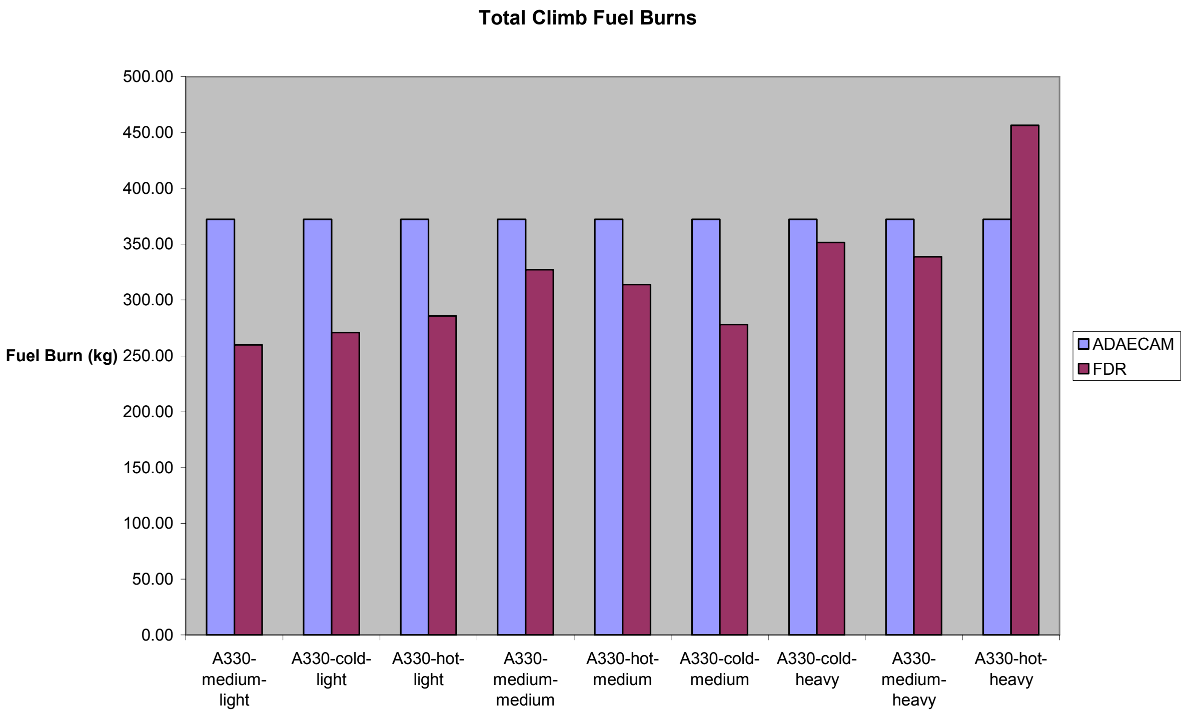


Figure 33: Comparison of climb fuel burn between ADAECAM and FDR for A330 / RR Trent 772B.

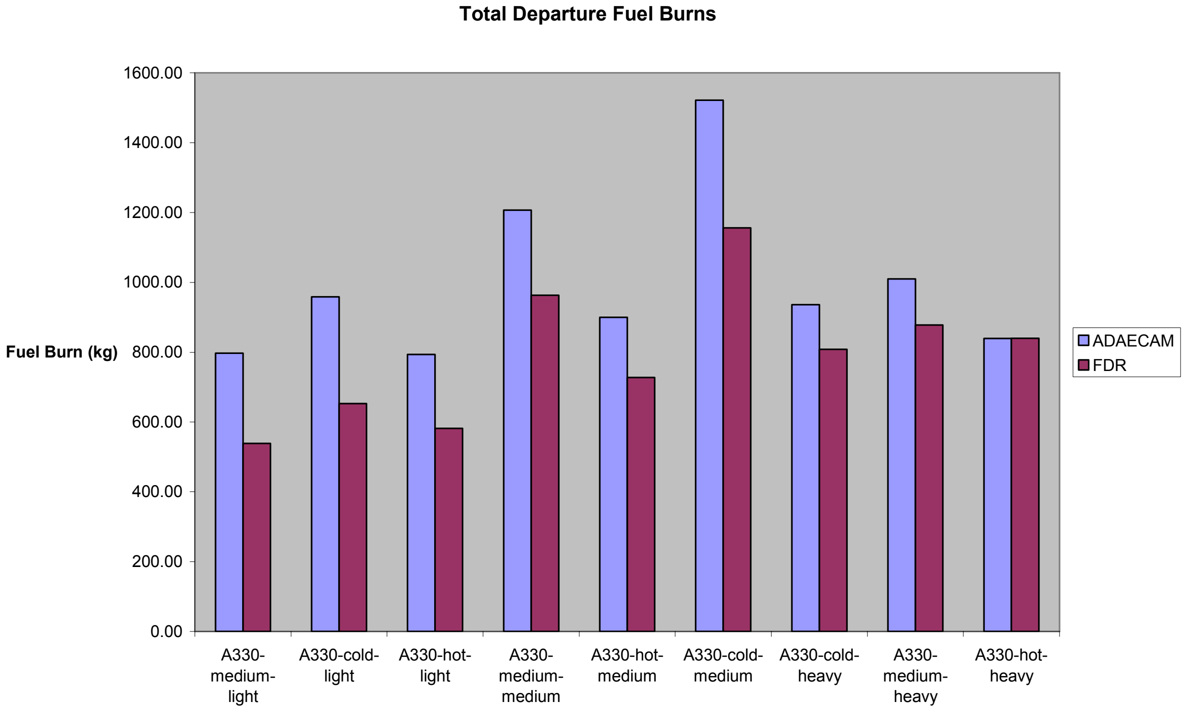


Figure 34: Comparison of departure fuel burn (taxi-out, take-off and climb) between ADAECAM and FDR for A330 / RR Trent 772B.

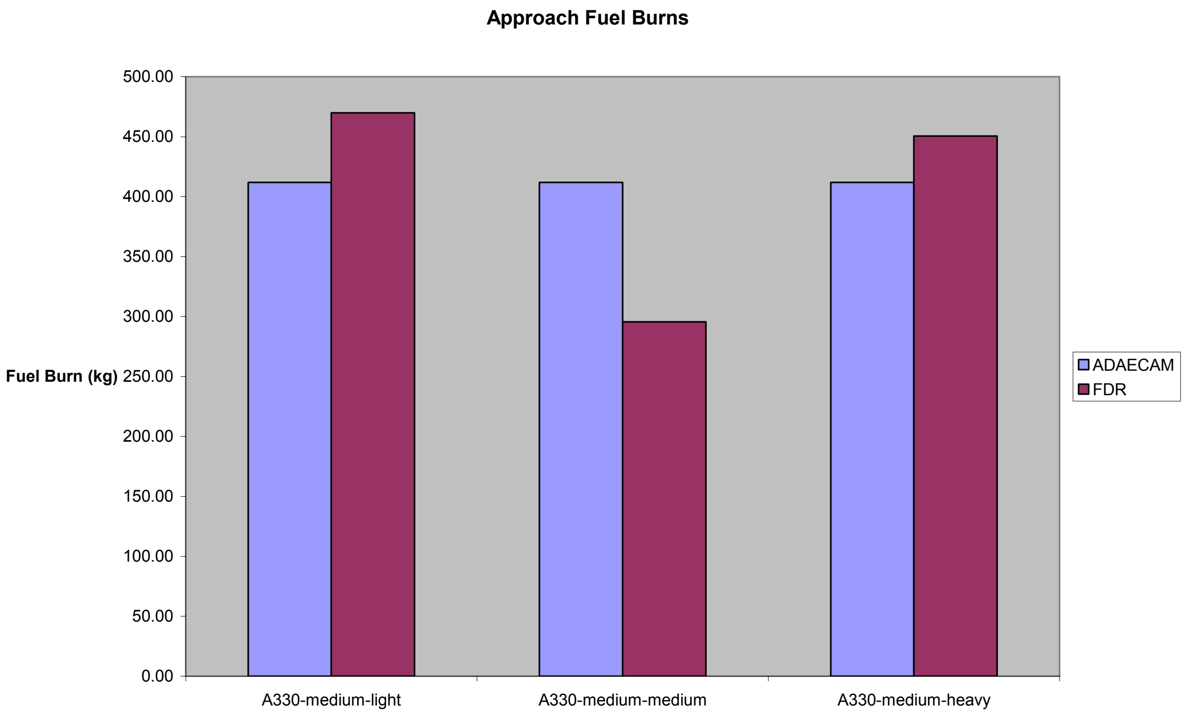


Figure 35: Comparison of approach fuel burn between ADAECAM and FDR for A330 / RR Trent 772B.

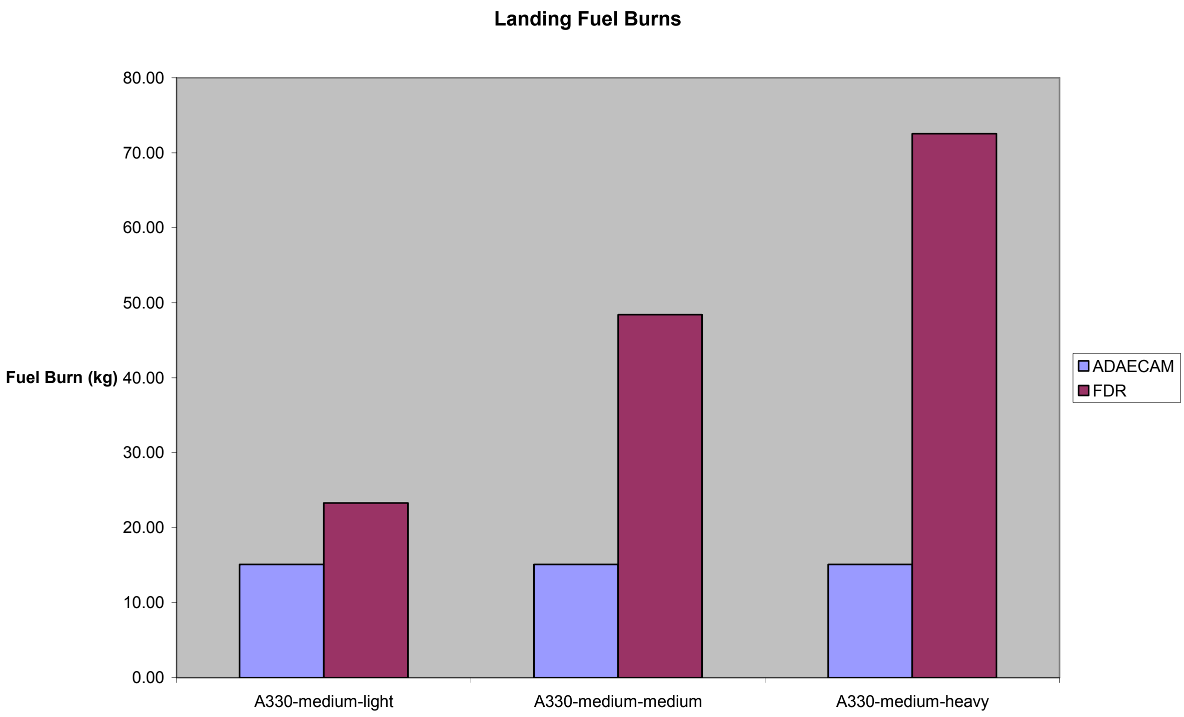


Figure 36: Comparison of landing fuel burn between ADAECAM and FDR for A330 / RR Trent 772B.

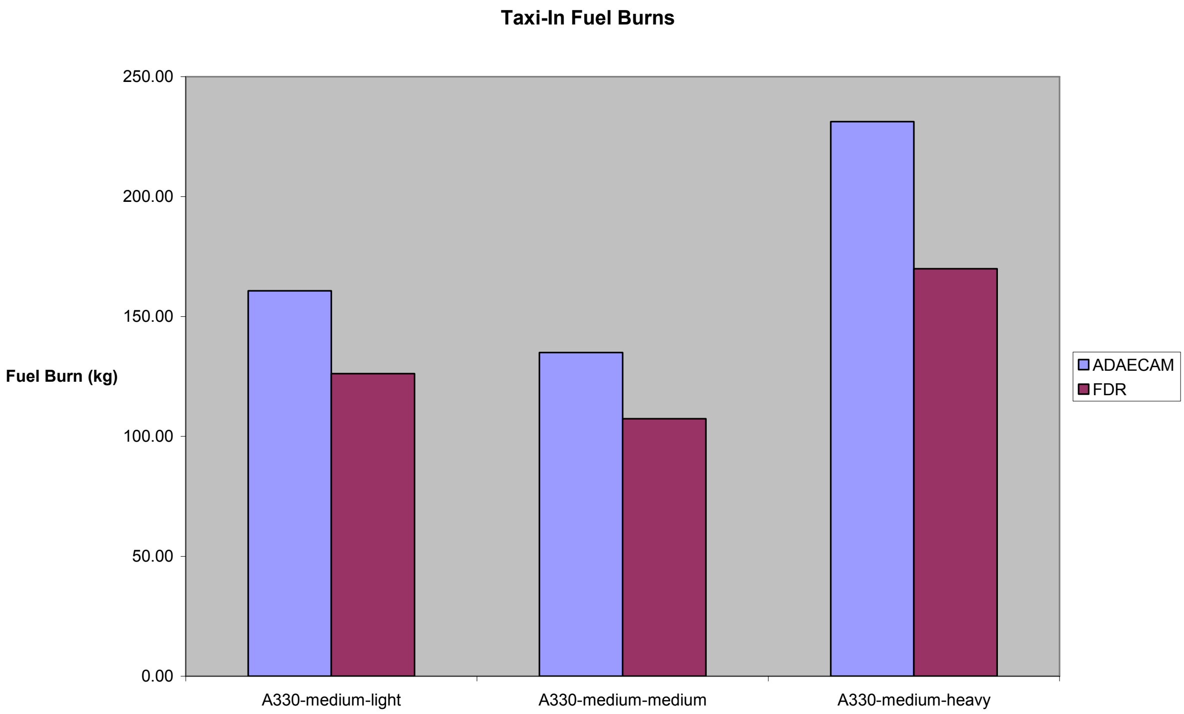


Figure 37: Comparison of taxi-in fuel burn between ADAECAM and FDR for A330 / RR Trent 772B

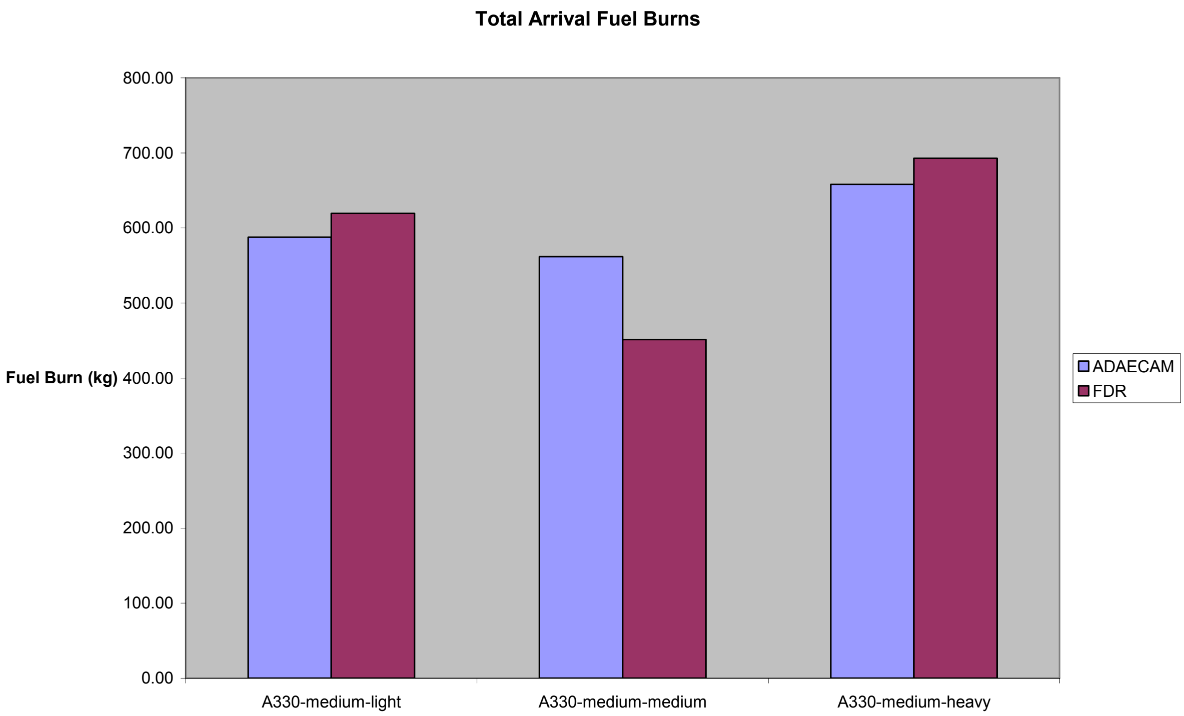


Figure 38: Comparison of arrival fuel burn (approach, landing and taxi-in) between ADAE-CAM and FDR for A330 / RR Trent 772B.

3.4 B757-200 / RR RB211-535E4 (37/44)

Airport Data for Input in ADAECAM, validation part 2
June 25, 2007

Departures

TYPE OF FLIGHT	IDENT	AC_TYPE	AC_SUBTYPE	ENGINE_UID	ENGINE_NAME	DESTINATION_ICAO	DESTINATION_IATA	'AXI_OUT_TIME_MIN	TEMP_°C	PRESSURE_hPa	REL_HUMIDITY_%
B757-cold-high	DEP31	B752	200	5RR038	RB211-535E4	GCLA	TFS	28.9	-0.25	979.3	95.1
B757-cold-low	DEP32	B752	200	5RR038	RB211-535E4	LEPA	PMI	4.0	-3.75	960.8	70
B757-cold-medium	DEP33	B752	200	5RR038	RB211-535E4	OMSJ	SHJ	5.0	2.5	955	51.4
B757-medium-high	DEP34	B752	200	5RR038	RB211-535E4	GCLA	SPC	4.6	12.5	962	55.3
B757-medium-mediu	DEP35	B752	200	5RR038	RB211-535E4	LTAI	AYT	4.4	12	960.4	85.2
B757-high-medium	DEP36	B752	200	5RR038	RB211-535E4	LGKO	KGS	4.7	27.5	966.6	41.6
B757-high-low	DEP37	B752	200	5RR038	RB211-535E4	EDDT	TXL	5.9	28.5	966.6	33.2
B757-hgh-high	DEP38	B752	200	5RR038	RB211-535E4	HESH	SSH	10.4	26.25	967.1	45.1
B757-medium-low	DEP39	B752	200	5RR038	RB211-535E4	LBBG	BOJ	6.2	10.5	961.5	95.9

Arrivals

TYPE OF FLIGHT	IDENT	AC_TYPE	AC_SUBTYPE	ENGINE_UID	ENGINE_NAME	ORIGIN_ICAO	ORIGIN__IATA	TAXI_IN_TIME_MIN	TEMP_°C	PRESSURE_hPa	REL_HUMIDITY_%
B757-medium-high	ARR31	B752	200	5RR038	RB211-535E4	GCLP	LPA	3.6	-6.5	975.2	57.7
B757-medium-low	ARR32	B752	200	5RR038	RB211-535E4	LEJR	XRY	2.9	0	955	55.5
B757-medium-mediu	ARR33	B752	200	5RR038	RB211-535E4	LEPA / PMI	PMI	3.0	9.25	973.3	46.8

Remark: Taxi-out and taxi-in times are matching FDR recorded times

Table 6: Input table for ADAECAM, generated with airport available data.

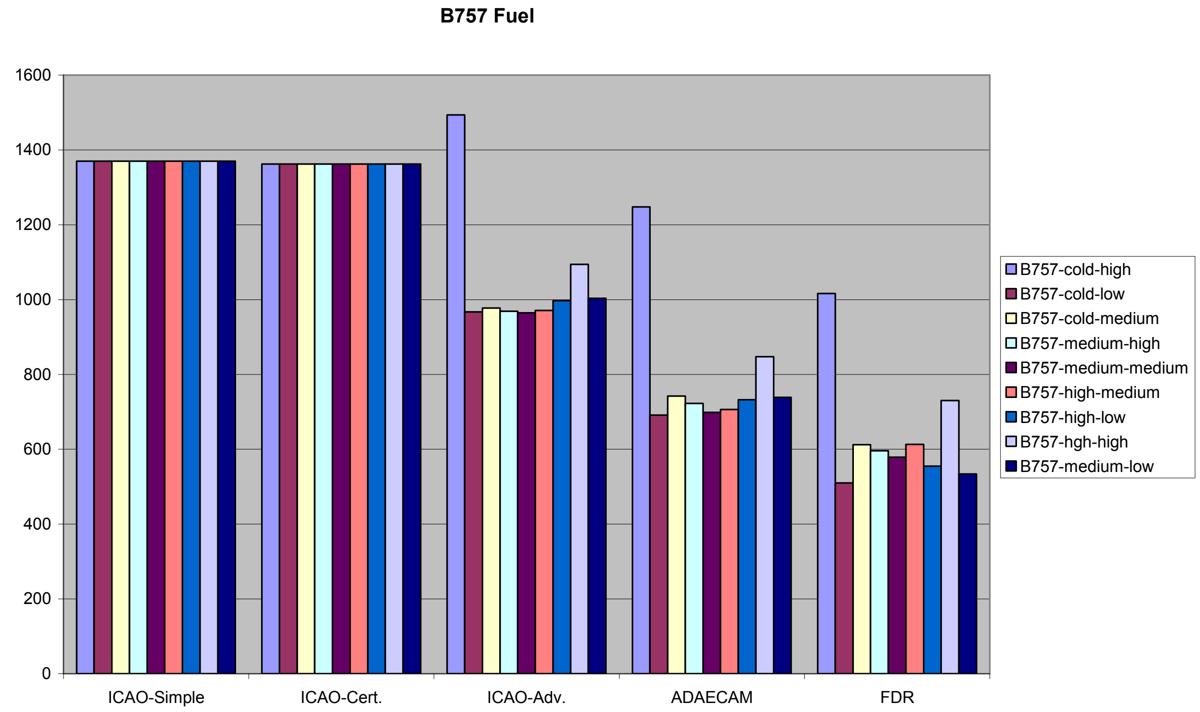


Figure 39: Comparison of LTO fuel use (kg), determined with “ICAO-Simple”, “ICAO-Cert.”, “ICAO-Adv.”, “ADAECAM” and “FDR” (real case) for B757-200 / RR RB211-535E4.

Figures 40 to 47 show the comparison of ADAECAM calculated and FDR measured fuel burn for the seven previously defined LTO segments.

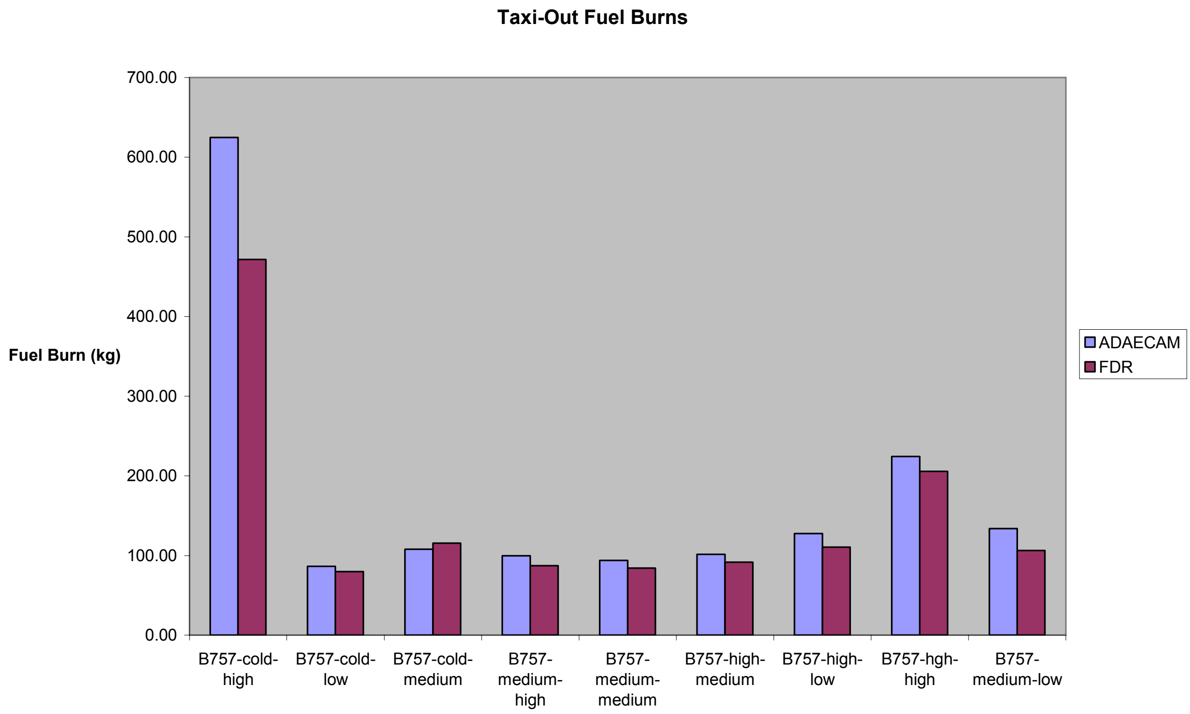


Figure 40: Comparison of taxi-out fuel burn between ADAECAM and FDR for B757-200 / RR RB211-535E4.

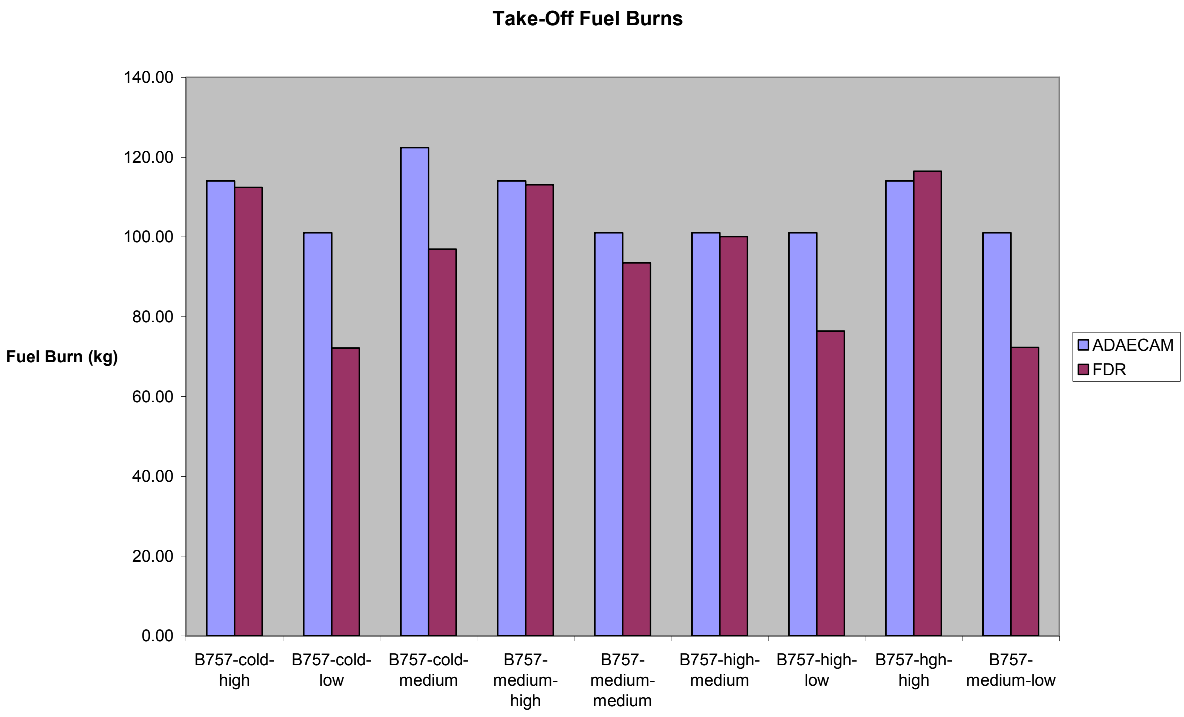


Figure 41: Comparison of take-off fuel burn between ADAECAM and FDR for B757-200 / RR RB211-535E4.

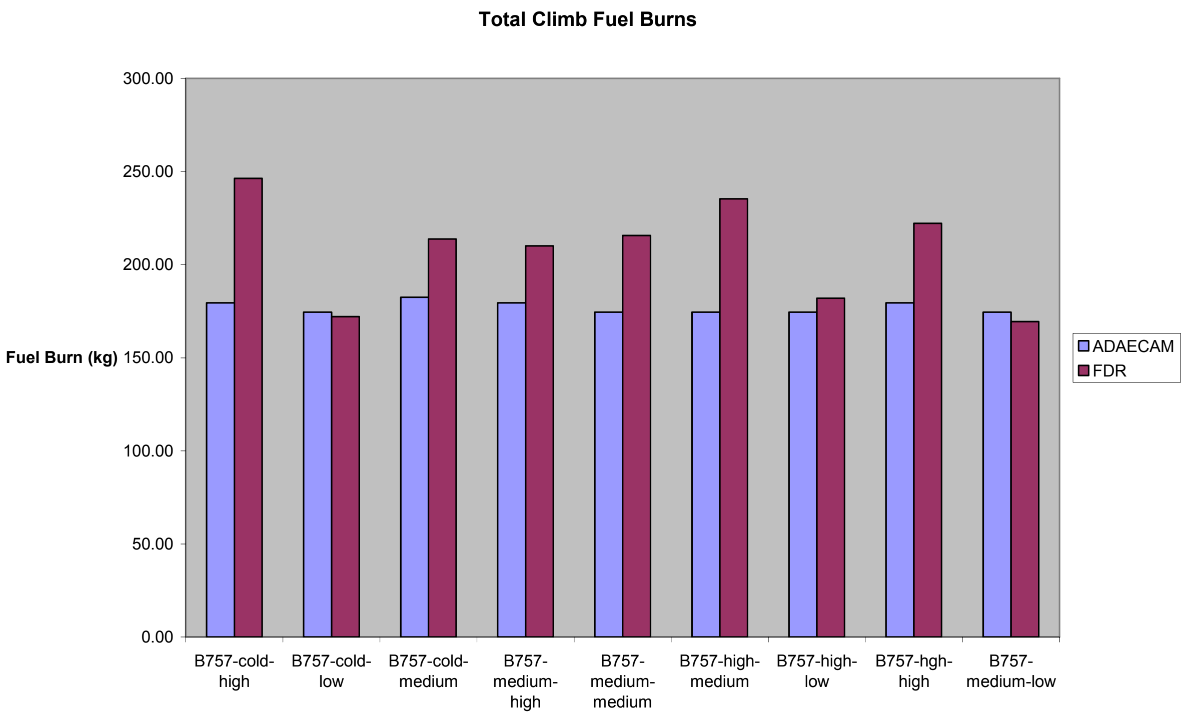


Figure 42: Comparison of climb fuel burn between ADAECAM and FDR for B757-200 / RR RB211-535E4.

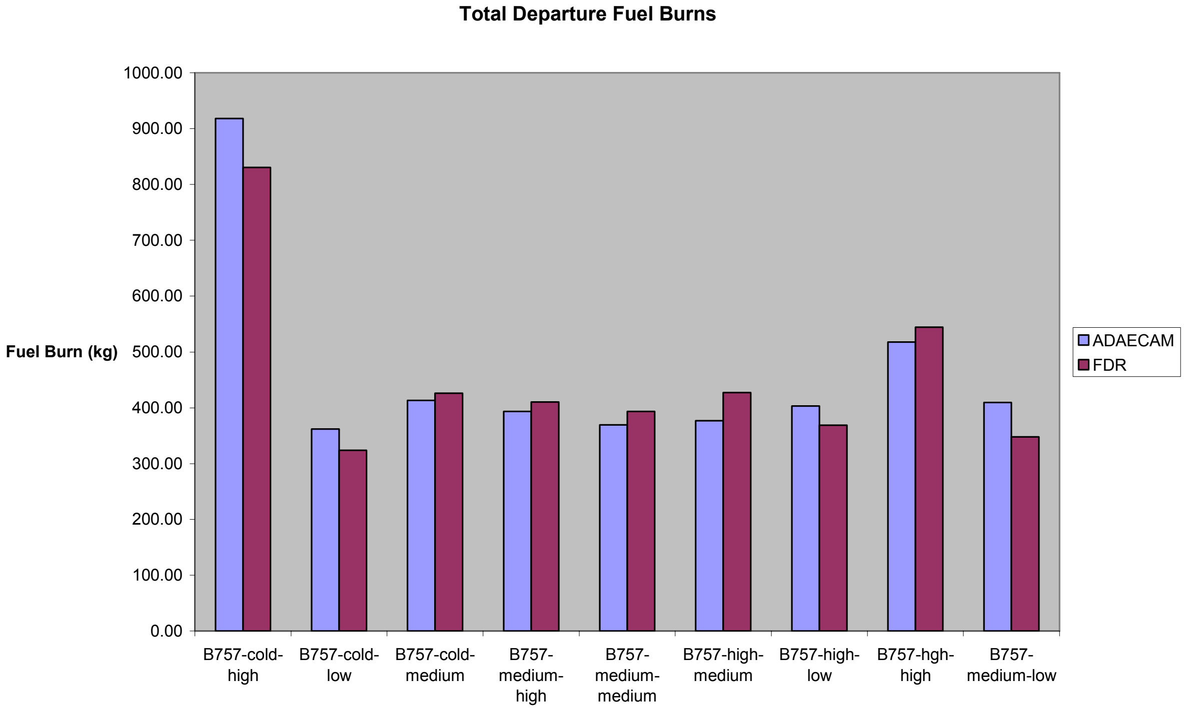


Figure 43: Comparison of departure fuel burn (taxi-out, take-off and climb) between ADAECAM and FDR for B757-200 / RR RB211-535E4.

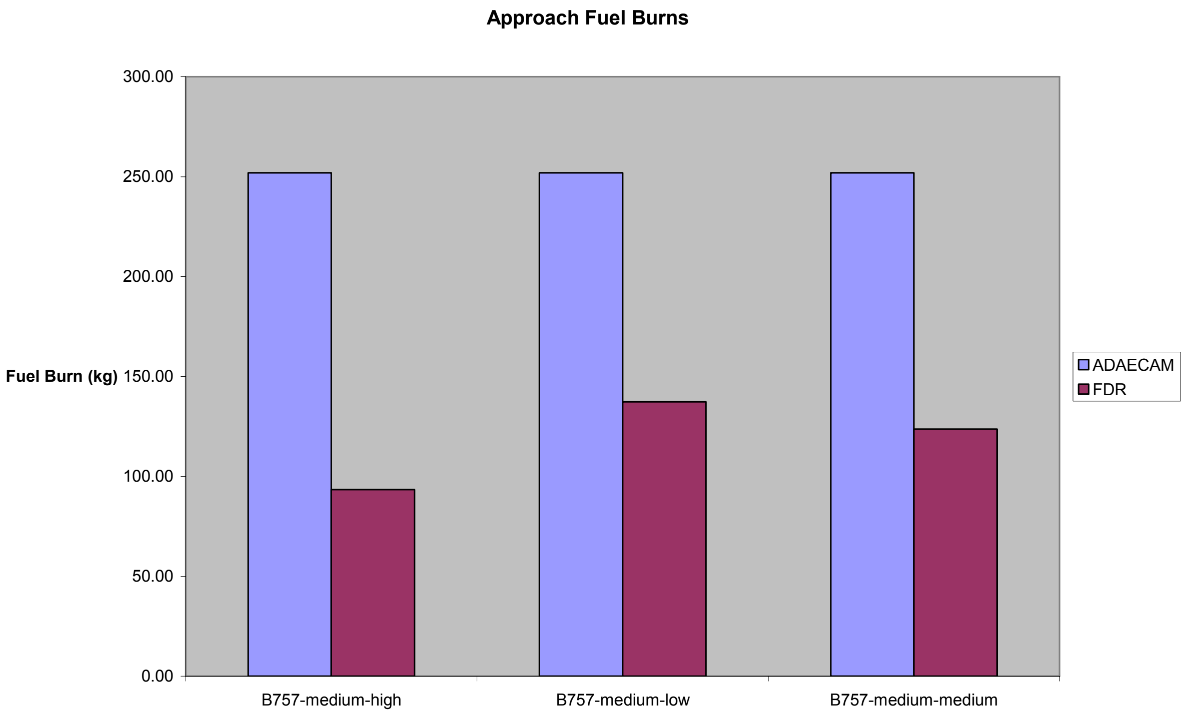


Figure 44: Comparison of approach fuel burn between ADAECAM and FDR for B757-200 / RR RB211-535E4.

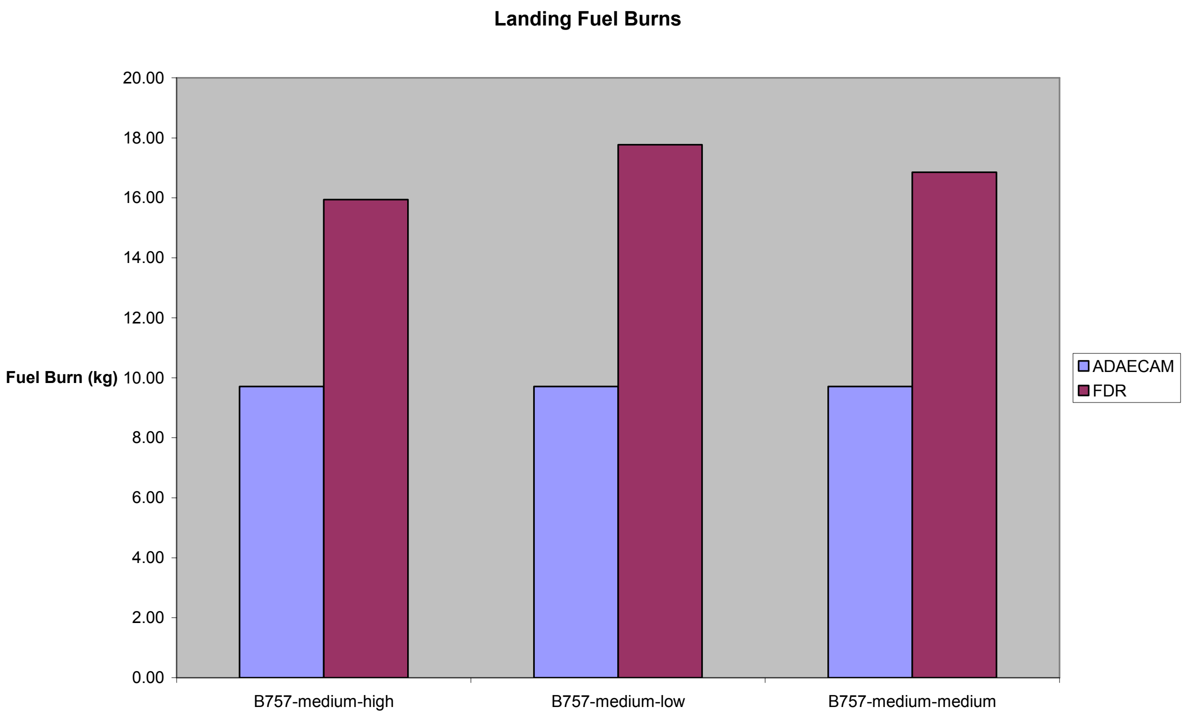


Figure 45: Comparison of landing fuel burn between ADAECAM and FDR for B757-200 / RR RB211-535E4.

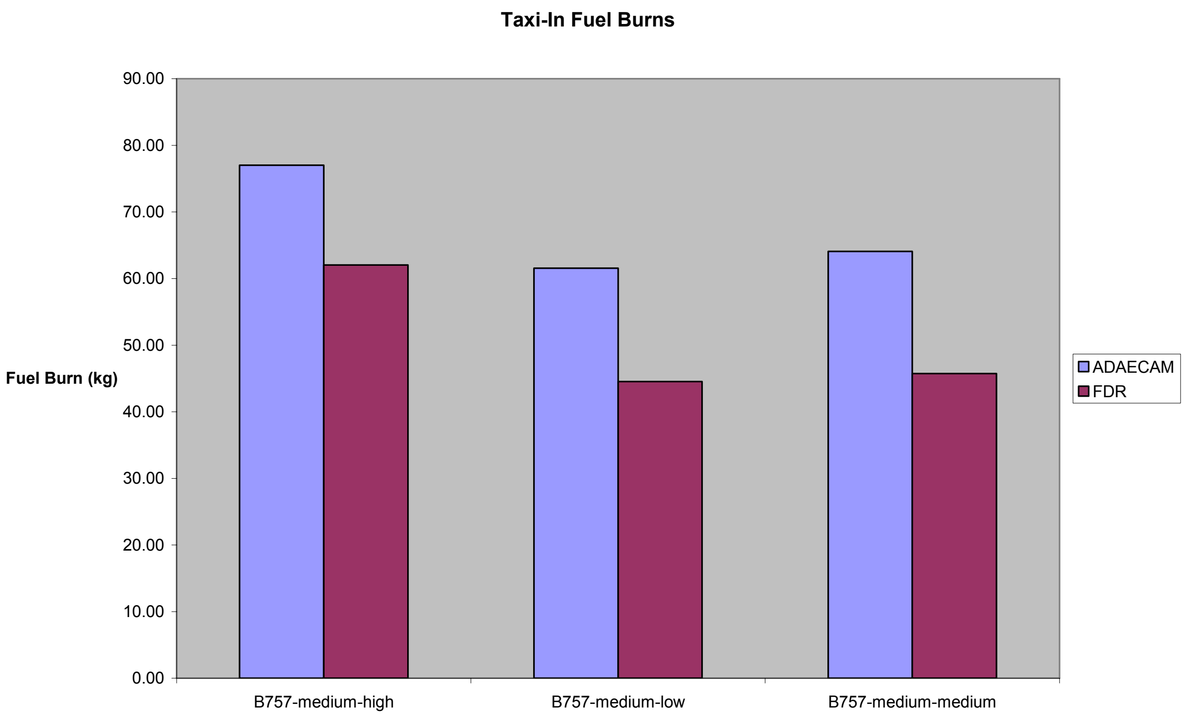


Figure 46: Comparison of taxi-in fuel burn between ADAECAM and FDR for B757-200 / RR RB211-535E4.

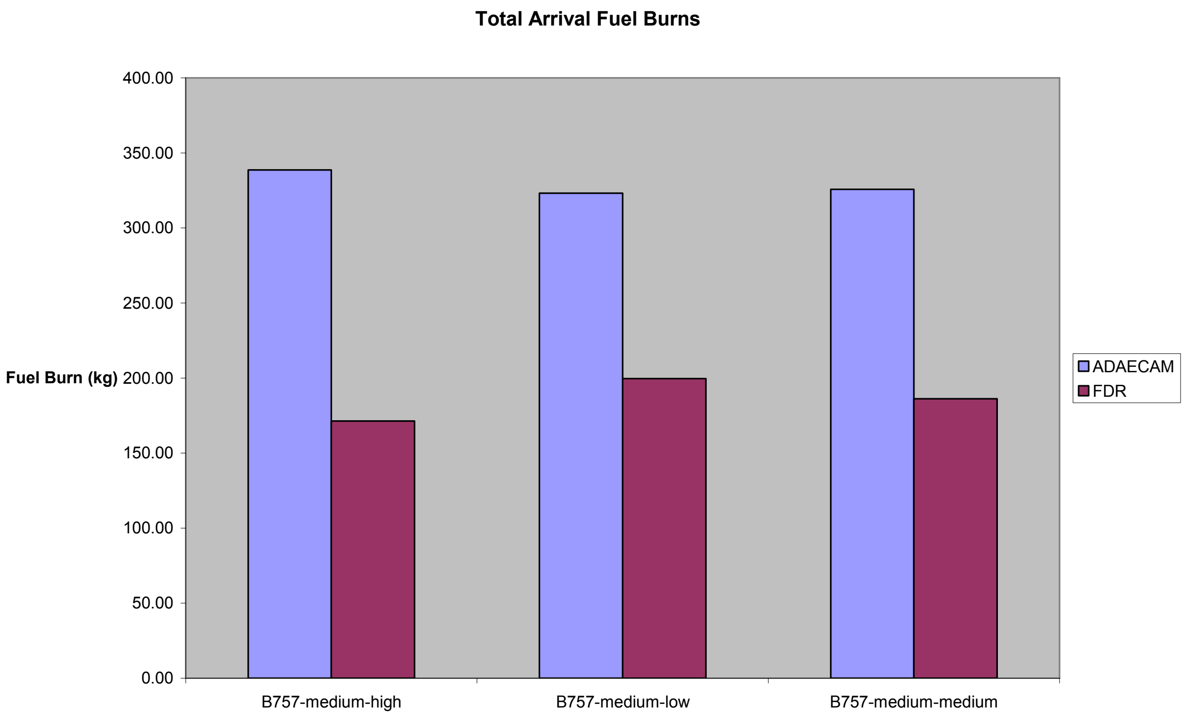


Figure 47: Comparison of arrival fuel burn (approach, landing and taxi-in) between ADAE-CAM and FDR for B757-200 / RR RB211-535E4.

3.5 B767-300 / GE CF6-80C2A3

Airport Data for Input in ADAECAM, validation part 2
August 7, 2007

Departures

TYPE OF FLIGHT	IDENT	AC_TYPE	AC_SUBTYPE	ENGINE_UID	ENGINE_NAME	DEPARTURE ARPT_ICAO	DEPARTURE ARPT_IATA	DESTINATION_ICAO	DESTINATION_IATA	TAXI_OUT_TIME_MIN	TEMP_°C	PRESSURE_hPa	REL_HUMIDITY_%
B767-hot-light	DEP81	B763	300	1GE018	GE CF6-80C2A3	OTBD	DOH	OMAA	AUH	7.6	36	991.4	40
B767-medium-light	DEP82	B763	300	1GE018	GE CF6-80C2A3	OEMA	MED	OMAA	AUH	8.8	14	943.1	50
B767-cold-light	DEP83	B763	300	1GE018	GE CF6-80C2A3	OEDF	DMM	OMAA	AUH	8.3	6	1013.3	50
B767-hot-medium	DEP84	B763	300	1GE018	GE CF6-80C2A3	OMAA	AUH	OPRN	ISB	8.7	35.0	1009.7	26
B767-medium-mediu	DEP85	B763	300	1GE018	GE CF6-80C2A3	OLBA	BEY	OMAA	AUH	7.3	15.0	1011.0	71
B767-cold-medium	DEP86	B763	300	1GE018	GE CF6-80C2A3	OPLA	LHE	OMAA	AUH	8.2	5	992.8	94
B767-cold-heavy	DEP87	B763	300	1GE018	GE CF6-80C2A3	OPRN	ISB	OMAA	AUH	4.2	6	958.2	94
B767-hot-heavy	DEP88	B763	300	1GE018	GE CF6-80C2A3	OMAA	AUH	VABB	BOM	5.6	33	1006.3	53
B767-medium-heavy	DEP89	B763	300	1GE018	GE CF6-80C2A3	OMAA	AUH	OPLA	LHE	6.9	14	1013.3	75

Arrivals

TYPE OF FLIGHT	IDENT	AC_TYPE	AC_SUBTYPE	ENGINE_UID	ENGINE_NAME	ARRIVAL ARPT_ICAO	ARRIVAL ARPT_IATA	ORIGIN_ICAO	ORIGIN__IATA	TAXI_IN_TIME_MIN	TEMP_°C	PRESSURE_hPa	REL_HUMIDITY_%
B767-medium-mediu	ARR81	B763	300	1GE018	GE CF6-80C2A3	OERK	RUH	OMAA	AUH	4.1	12.0	951.3	26
B767-medium-light	ARR82	B763	300	1GE018	GE CF6-80C2A3	OERK	RUH	OMAA	AUH	6.5	18.0	945.9	50
B767-medium-heavy	ARR83	B763	300	1GE018	GE CF6-80C2A3	OPLA	LHE	OMAA	AUH	6.0	11.0	987.1	89

Remark: Taxi-out and taxi-in times are matching FDR recorded times

Table 7: Input table for ADAECAM, generated with airport available data.

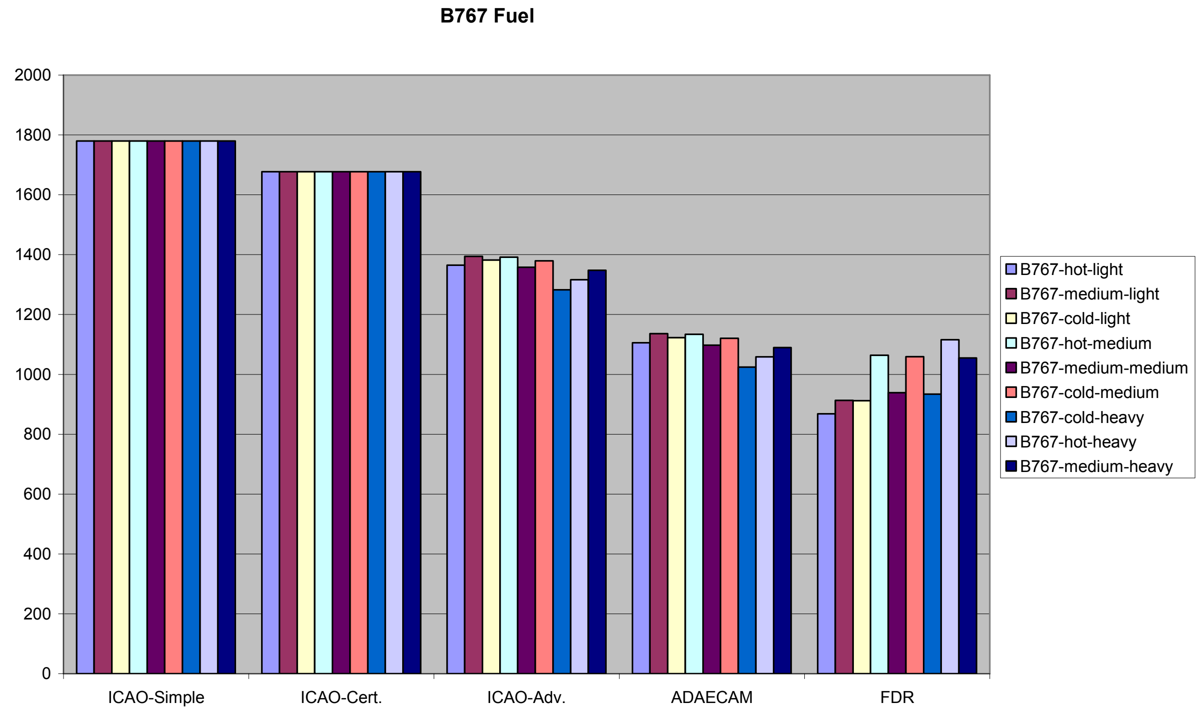


Figure 48: Comparison of LTO fuel use (kg), determined with “ICAO-Simple”, “ICAO-Cert.”, “ICAO-Adv.”, “ADAECAM” and “FDR” (real case) for B767-300 / GE CF6-80C2A3.

Figures 49 to 56 show the comparison of ADAECAM calculated and FDR measured fuel burn for the seven previously defined LTO segments.

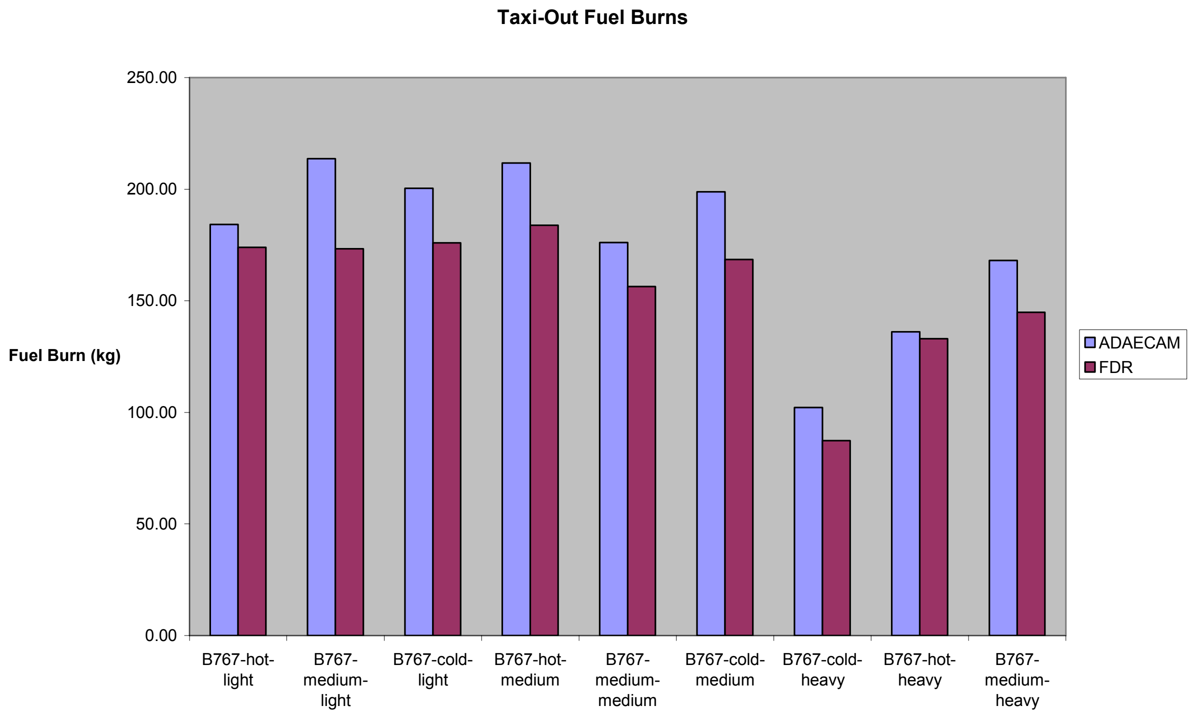


Figure 49: Comparison of taxi-out fuel burn between ADAECAM and FDR for B767-300 / GE CF6-80C2A3.

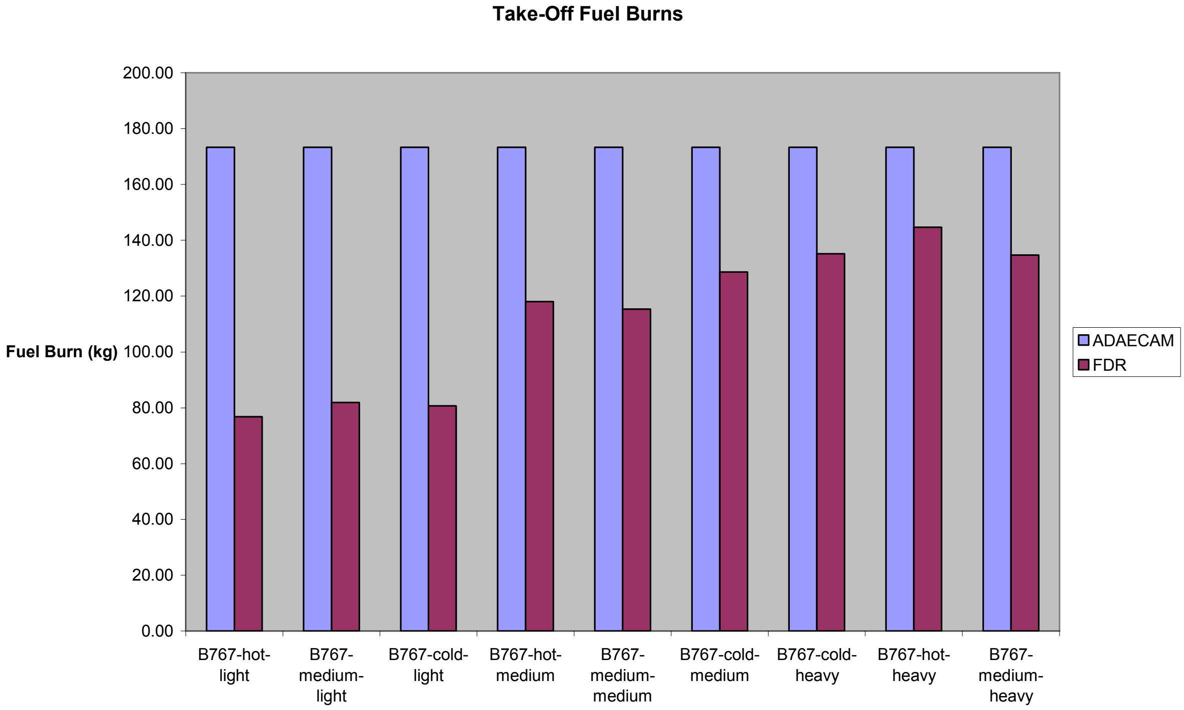


Figure 50: Comparison of take-off fuel burn between ADAECAM and FDR for B767-300 / GE CF6-80C2A3.

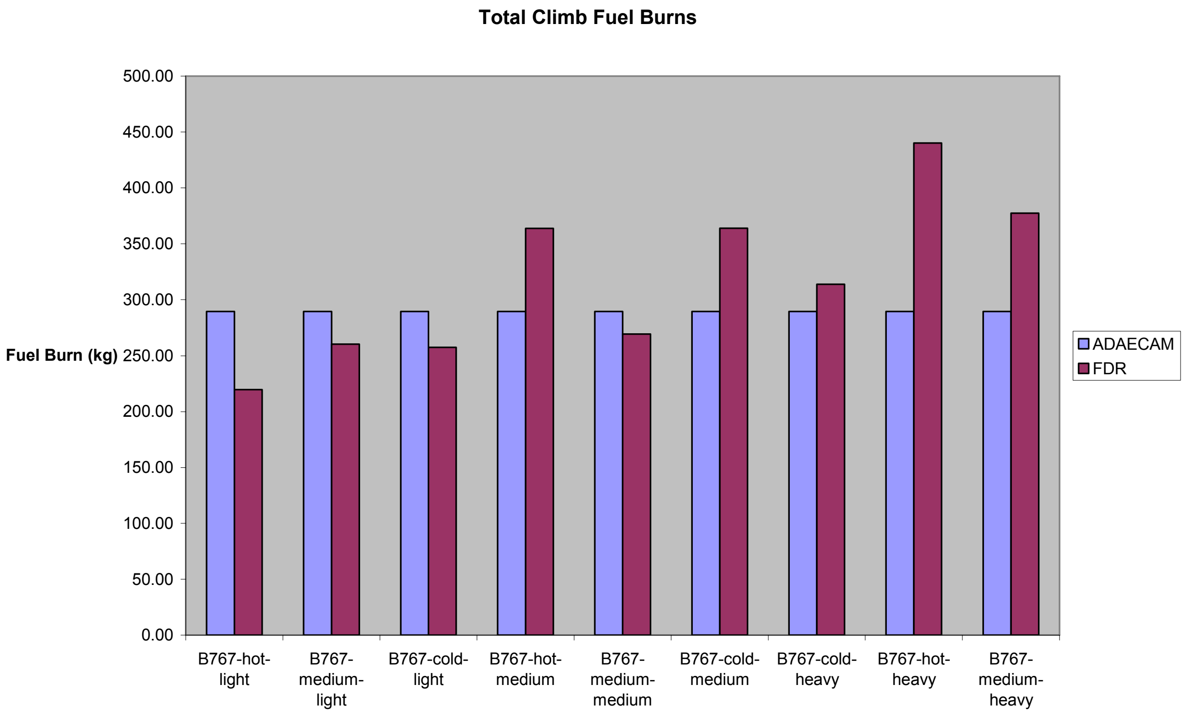


Figure 51: Comparison of climb fuel burn between ADAECAM and FDR for B767-300 / GE CF6-80C2A3.

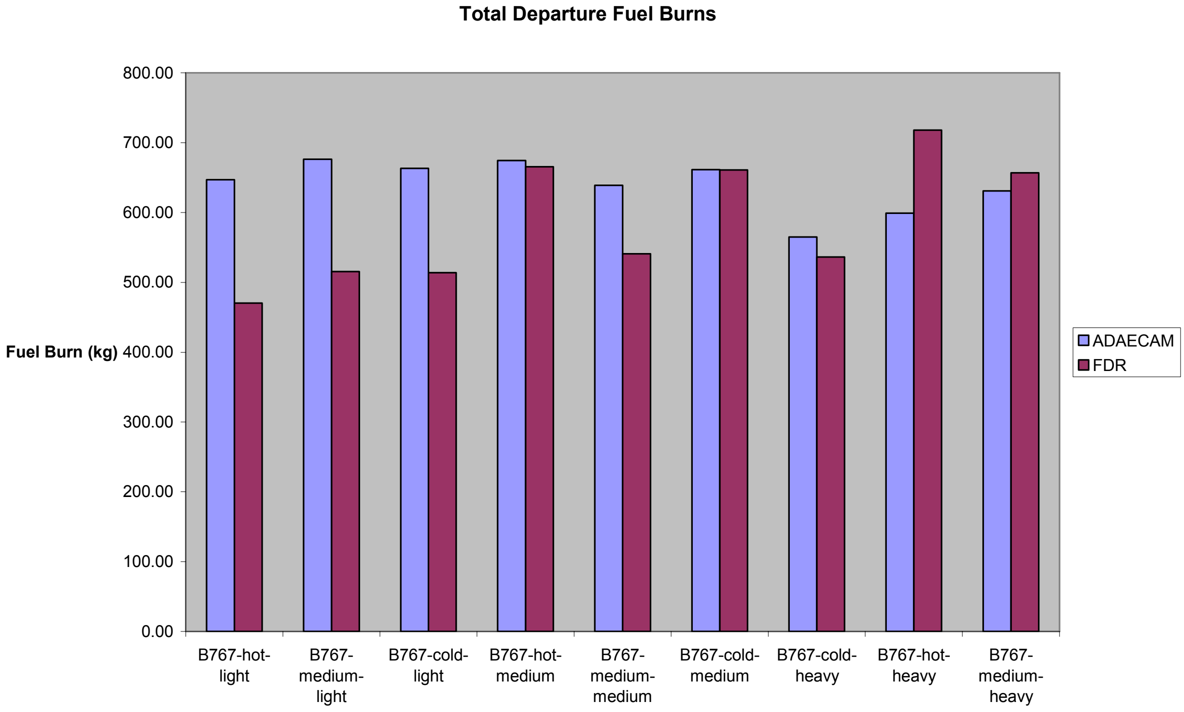


Figure 52: Comparison of departure fuel burn (taxi-out, take-off and climb) between ADAECAM and FDR for B767-300 / GE CF6-80C2A3.

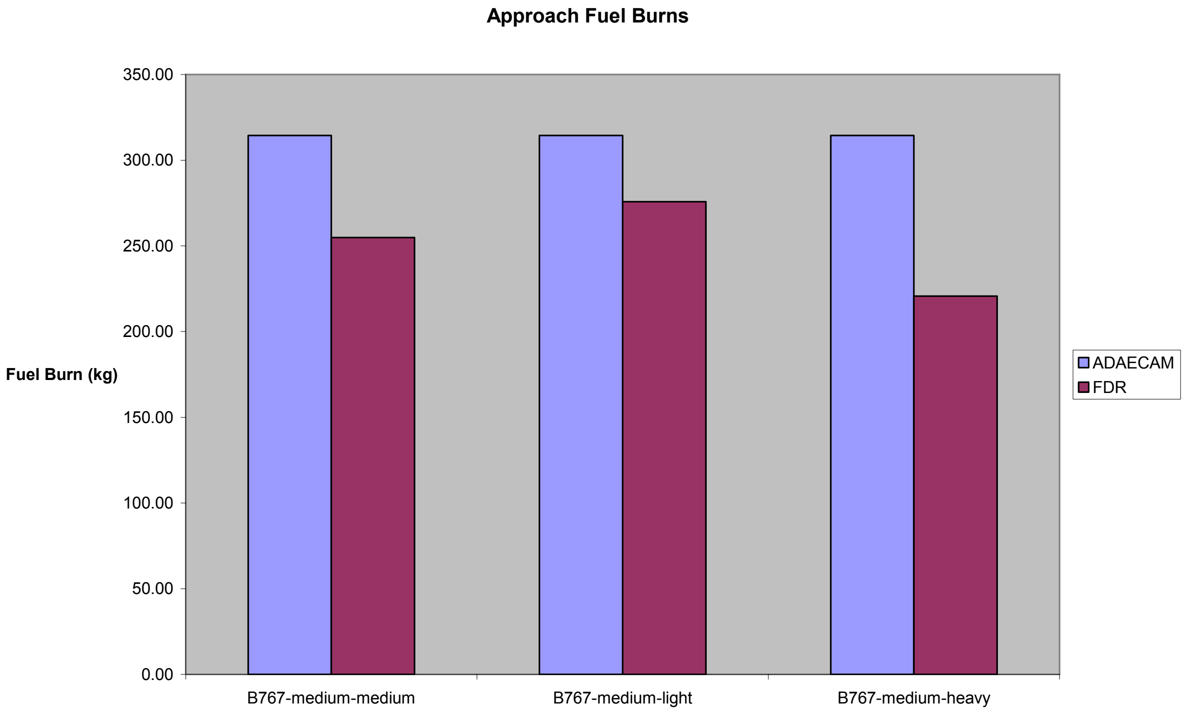


Figure 53: Comparison of approach fuel burn between ADAECAM and FDR for B767-300 / GE CF6-80C2A3.

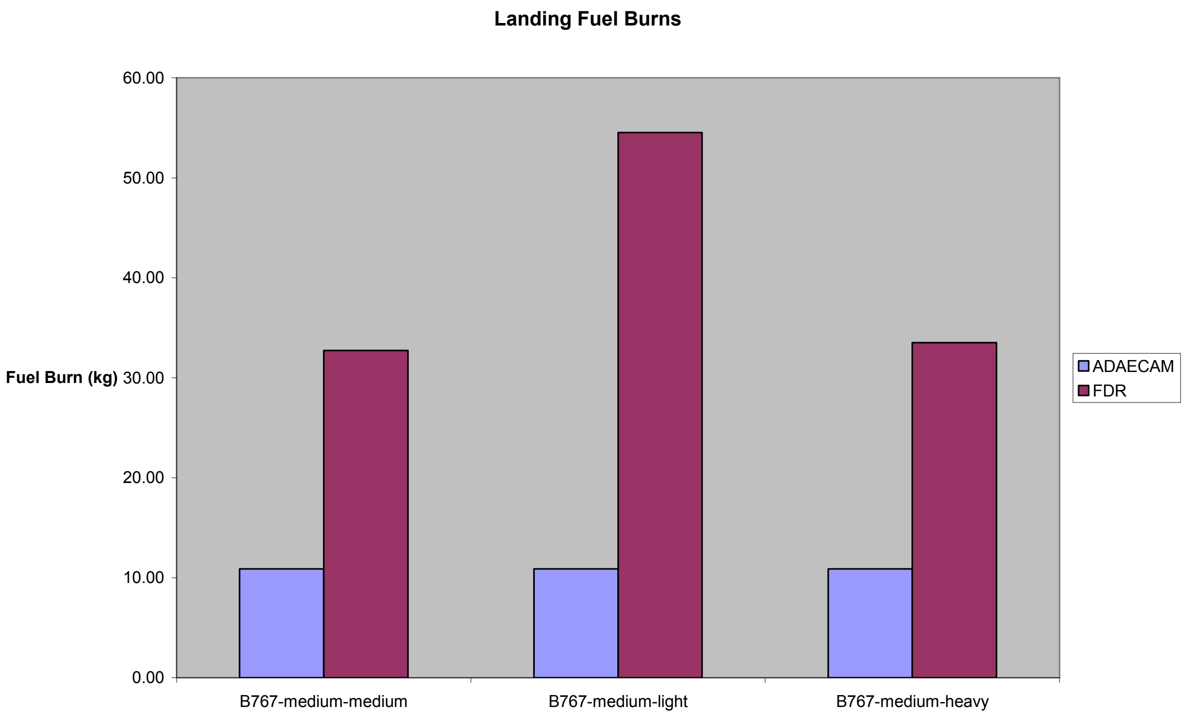


Figure 54: Comparison of landing fuel burn between ADAECAM and FDR for B767-300 / GE CF6-80C2A3.

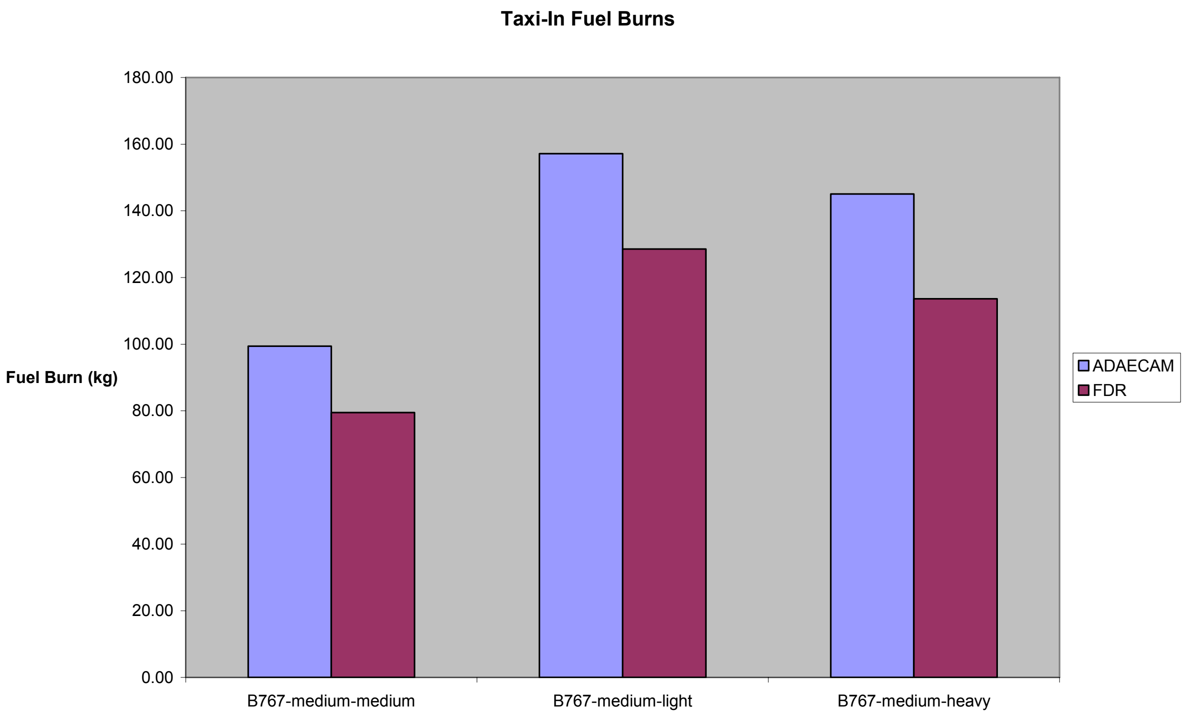


Figure 55: Comparison of taxi-in fuel burn between ADAECAM and FDR for B767-300 / GE CF6-80C2A3.

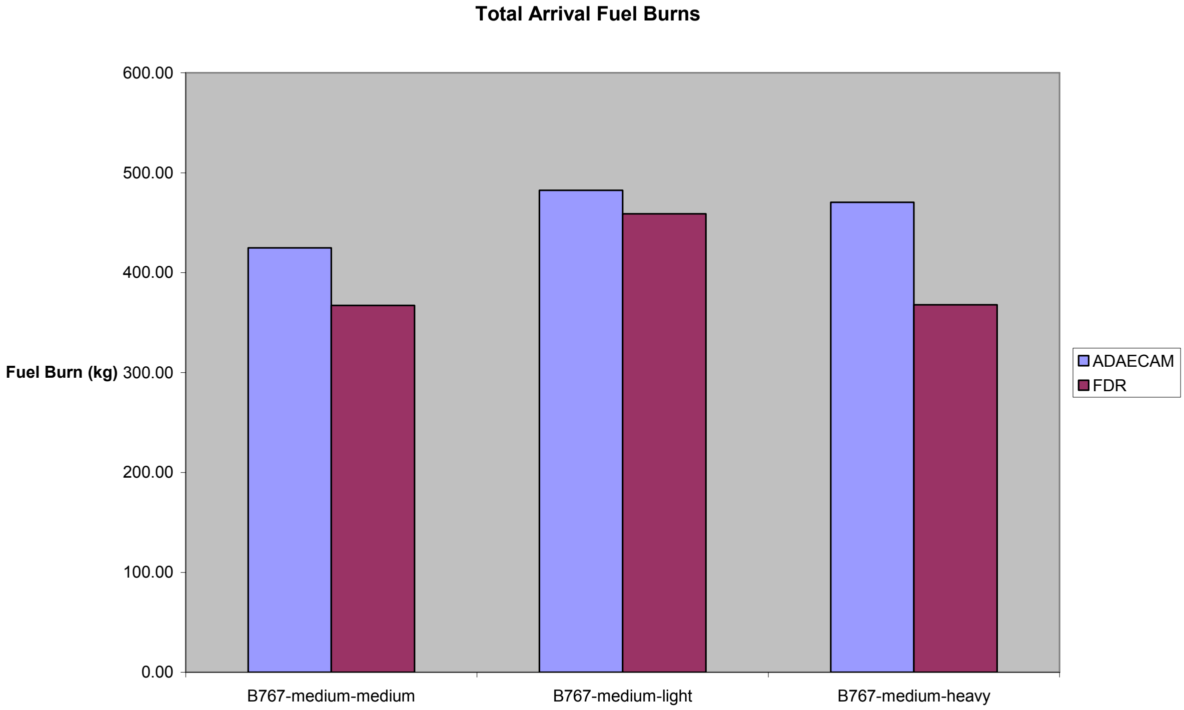


Figure 56: Comparison of arrival fuel burn (approach, landing and taxi-in) between ADAE-CAM and FDR for B767-300 / GE CF6-80C2A3.

3.6 B777-300ER / GE90-110B1

Airport Data for Input in ADAECAM, validation part 2
June 25, 2007

Departures

TYPE OF FLIGHT	IDENT	AC_TYPE	AC_SUBTYPE	ENGINE_UID	ENGINE_NAME	DEPARTURE ARPT_ICAO	DEPARTURE ARPT_IATA	DESTINATION_ICAO	DESTINATION_IATA	TAXI_OUT_TIME_MIN	TEMP_°C	PRESSURE_hPa	REL_HUMIDITY_%
B777-hot-light	DEP41	B773	300ER	7GE097	GE90-110B1	OMAA	AUH	OMRK	RKT	2.4	30.8	1011	28
B777-cold-medium	DEP51	B773	300ER	7GE097	GE90-110B1	EDDF	FRA	OMAA	AUH	12.0	-1.6	992	84
B777-hot-medium	DEP52	B773	300ER	7GE097	GE90-110B1	OMAA	AUH	FAJS	JNB	6.3	30.1	1008	28
B777-hot-heavy	DEP53	B773	300ER	7GE097	GE90-110B1	OMAA	AUH	EGKK	LGW	6.9	27.5	1004	31
B777-medium-mediu	DEP54	B773	300ER	7GE097	GE90-110B1	EGKK	LGW	OMAA	AUH	15.5	15.3	1008	71
B777-medium-heavy	DEP55	B773	300ER	7GE097	GE90-110B1	EGKK	LGW	OMAA	AUH	7.6	15.3	1003	89
B777-medium-light	DEP56	B773	300ER	7GE097	GE90-110B1	OERK	RUH	OMAA	AUH	6.9	15.8	948	67
B777-cold-light	DEP57	B773	300ER	7GE097	GE90-110B1	OIIE	IKA	OMAA	AUH	5.7	-3.8	908	71
B777-cold-heavy	DEP58	B773	300ER	7GE097	GE90-110B1	EGKK	LGW	OMAA	AUH	6.9	-2.4	1031	100

Arrivals

TYPE OF FLIGHT	IDENT	AC_TYPE	AC_SUBTYPE	ENGINE_UID	ENGINE_NAME	ARRIVAL ARPT_ICAO	ARRIVAL ARPT_IATA	ORIGIN_ICAO	ORIGIN__IATA	TAXI_IN_TIME_MIN	TEMP_°C	PRESSURE_hPa	REL_HUMIDITY_%
B777-medium-light	ARR41	B773	300ER	7GE097	GE90-110B1	OMAA	AUH	OERK	RUH	3.7	27	1014	53
B777-medium-mediu	ARR42	B773	300ER	7GE097	GE90-110B1	OMAA	AUH	OERK	RUH	4.1	23	1013	59
B777-medium-heavy	ARR43	B773	300ER	7GE097	GE90-110B1	OLBA	BEY	OJAI	AMM	6.1	16	1015	59

Remark: Taxi-out and taxi-in times are matching FDR recorded times

Table 8: Input table for ADAECAM, generated with airport available data.

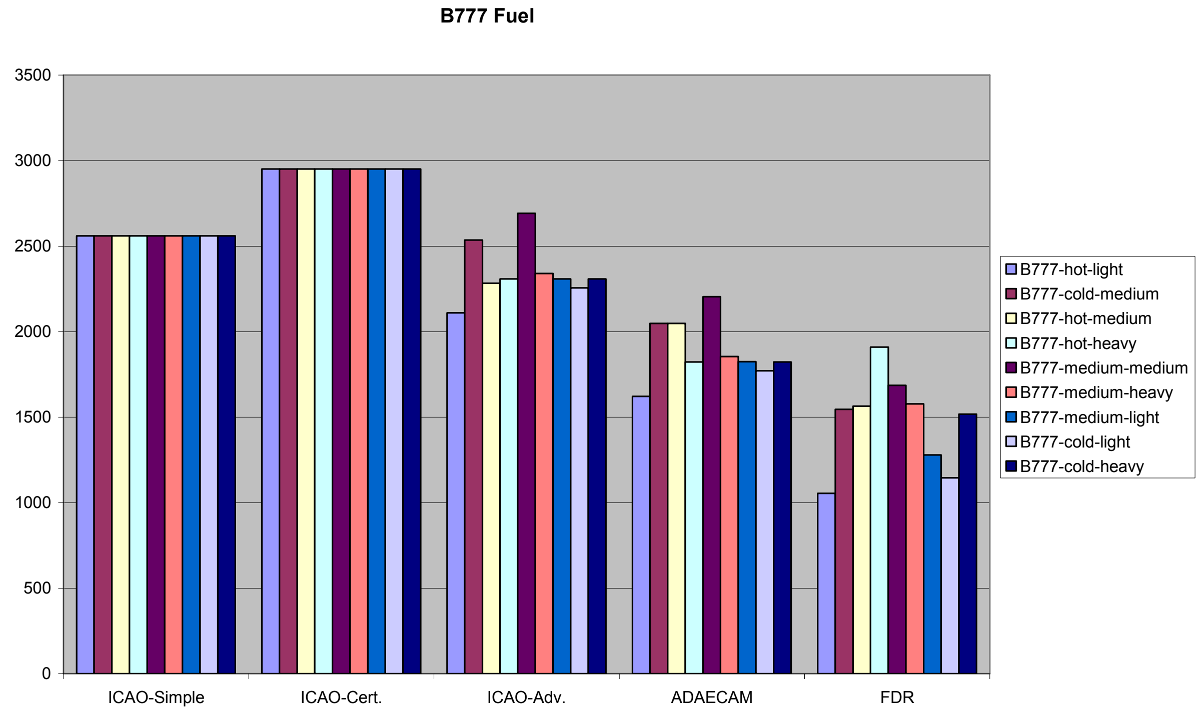


Figure 57: Comparison of LTO fuel use (kg), determined with “ICAO-Simple”, “ICAO-Cert.”, “ICAO-Adv.”, “ADAECAM” and “FDR” (real case) for B777-300ER / GE90-110B1.

Figures 58 to 65 show the comparison of ADAECAM calculated and FDR measured fuel burn for the seven previously defined LTO segments.

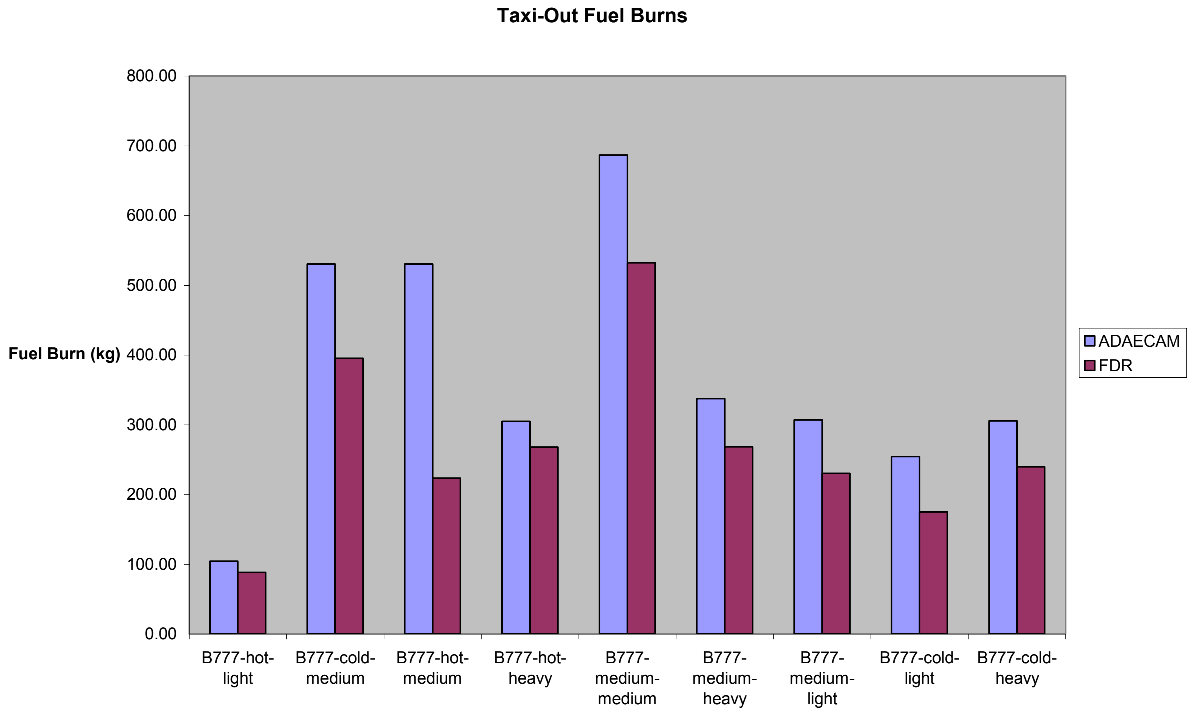


Figure 58: Comparison of taxi-out fuel burn between ADAECAM and FDR for B777-300ER / GE90-110B1.

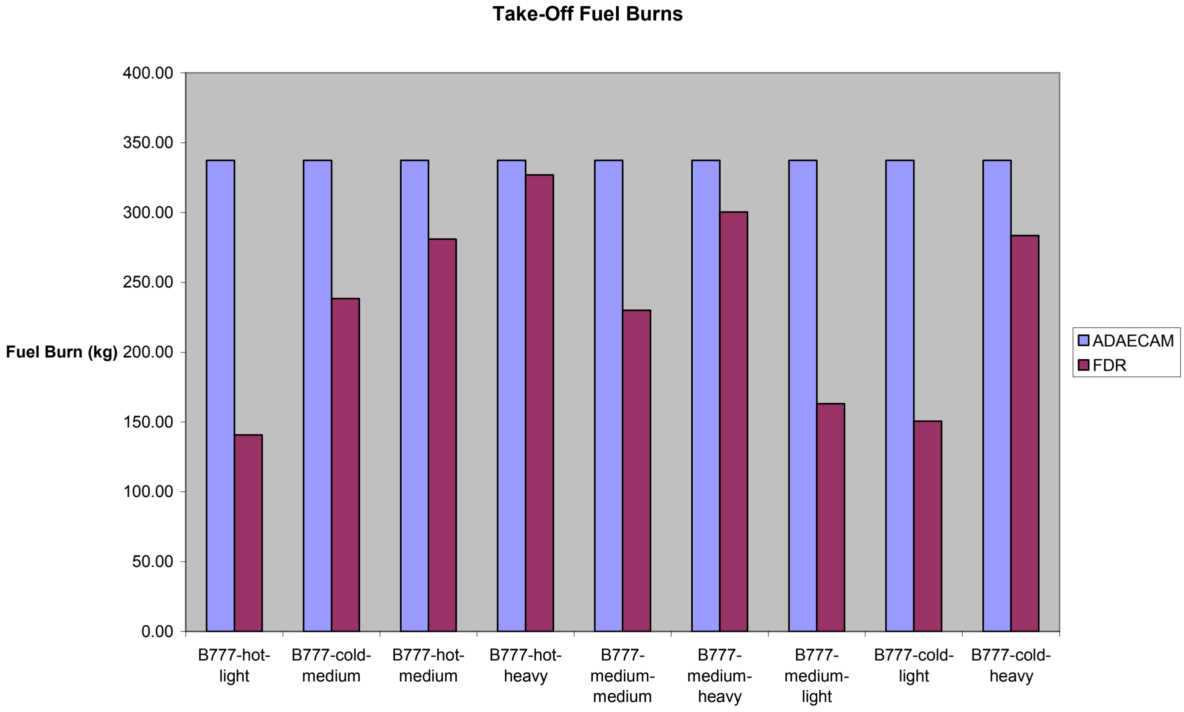


Figure 59: Comparison of take-off fuel burn between ADAECAM and FDR for B777-300ER / GE90-110B1.

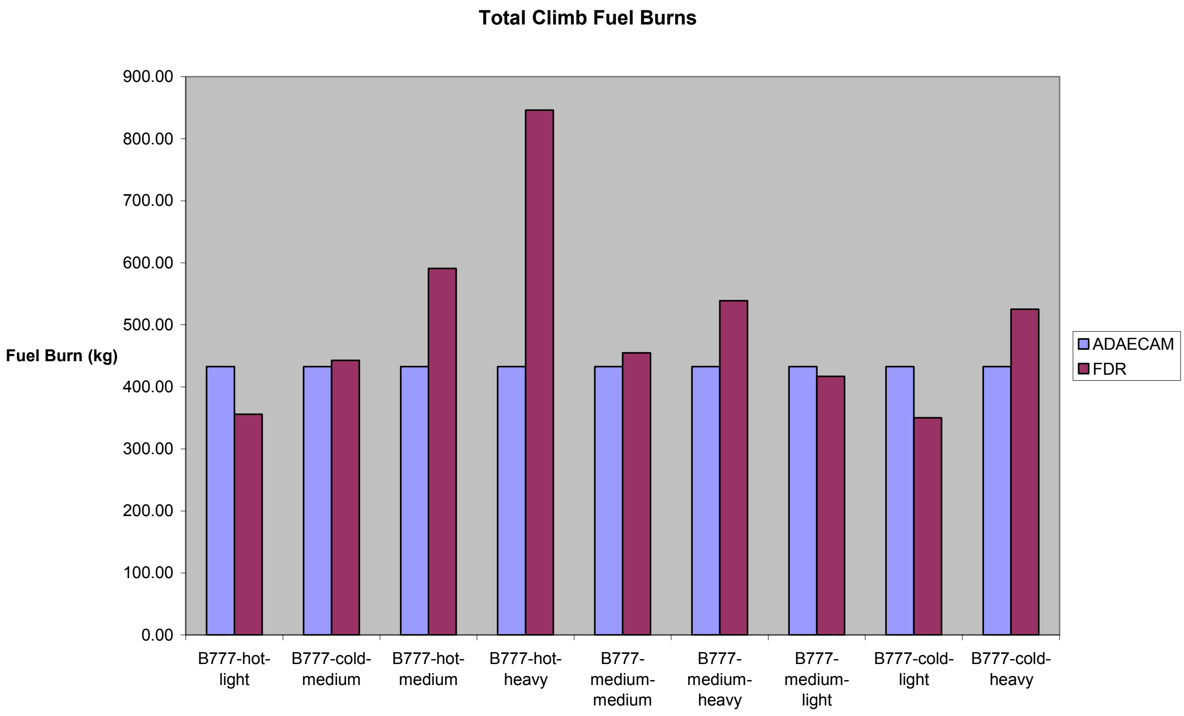


Figure 60: Comparison of climb fuel burn between ADAECAM and FDR for B777-300ER / GE90-110B1.

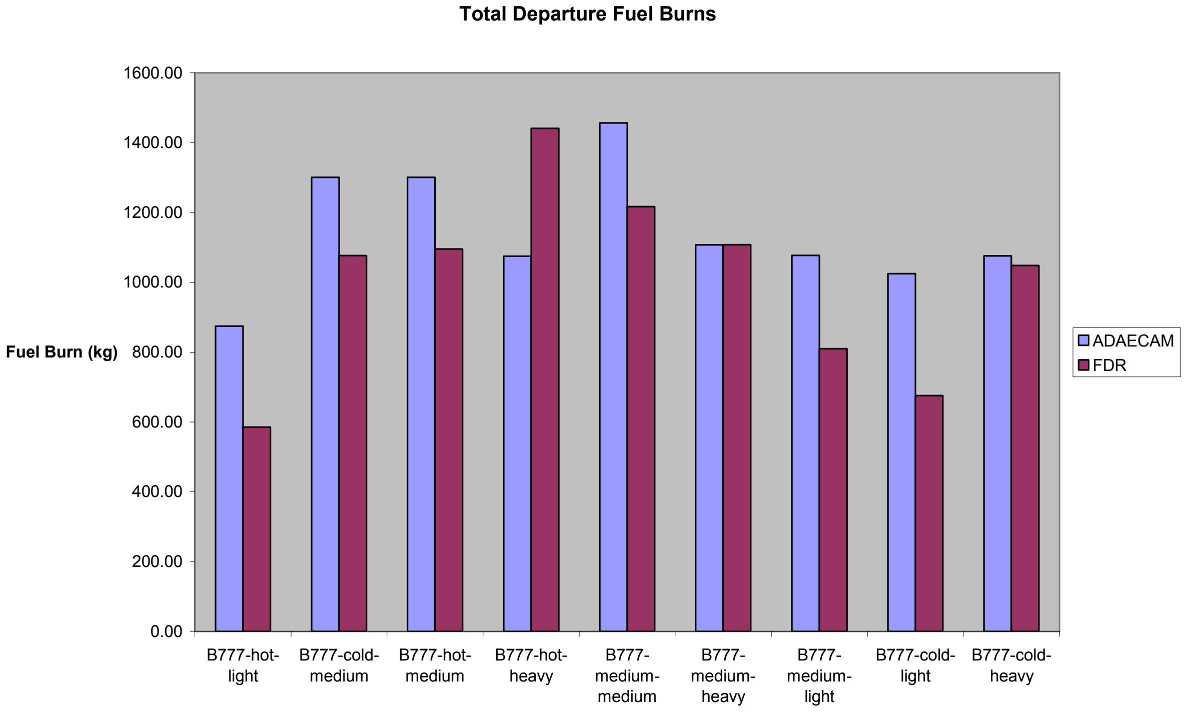


Figure 61: Comparison of departure fuel burn (taxi-out, take-off and climb) between ADAE-CAM and FDR for B777-300ER / GE90-110B1.

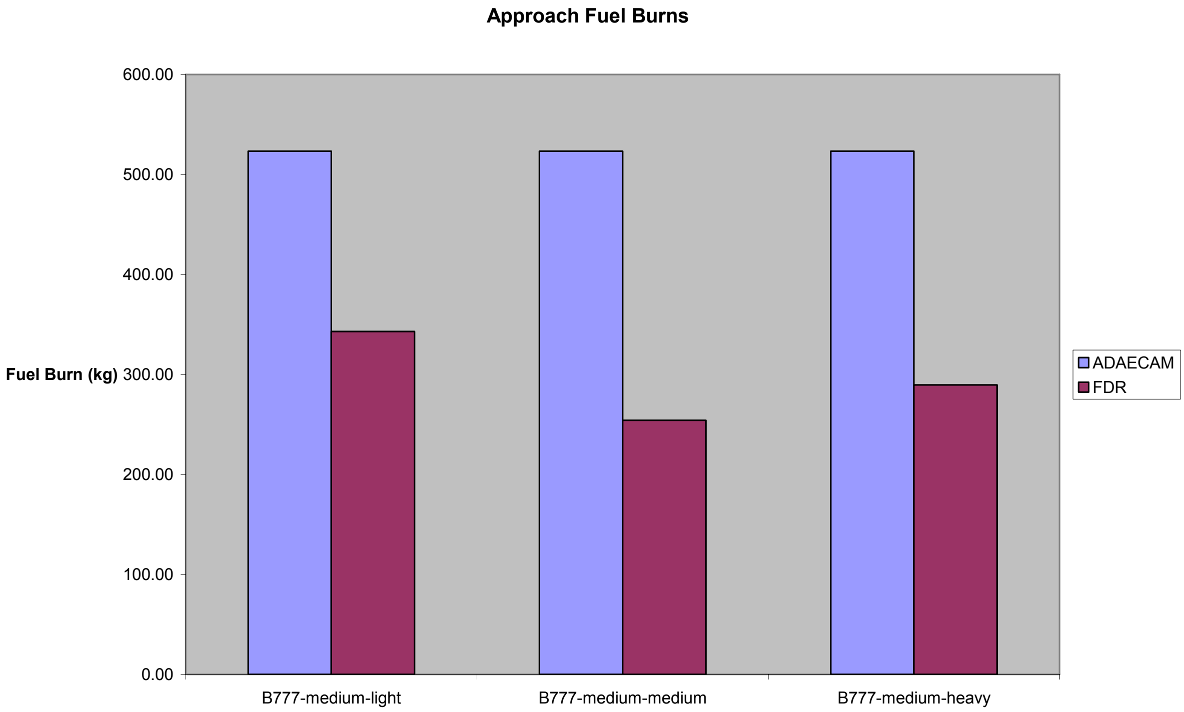


Figure 62: Comparison of approach fuel burn between ADAECAM and FDR for B777-300ER / GE90-110B1.

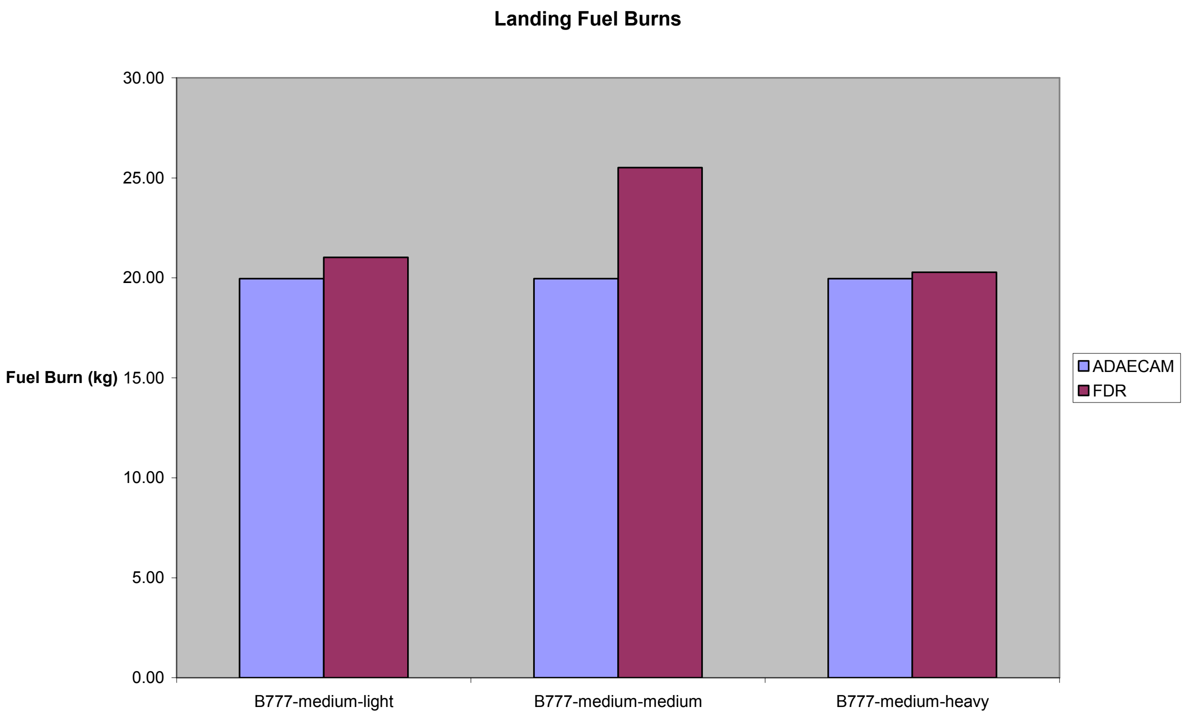


Figure 63: Comparison of landing fuel burn between ADAECAM and FDR for B777-300ER / GE90-110B1.

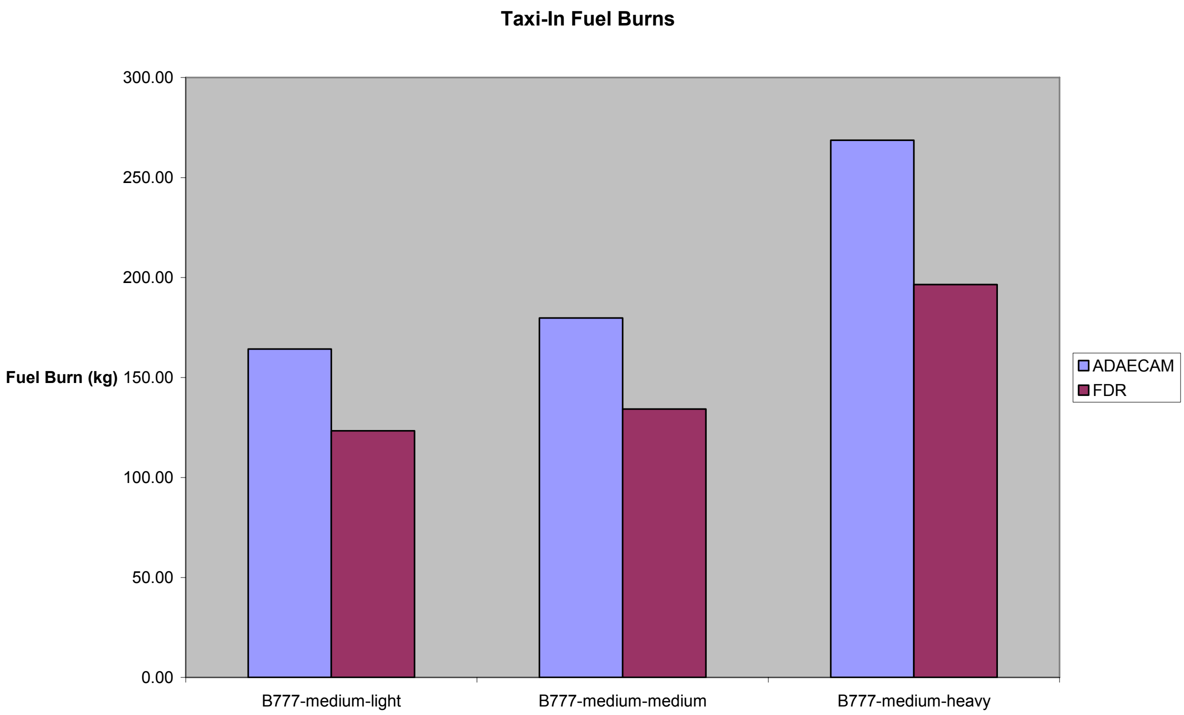


Figure 64: Comparison of taxi-in fuel burn between ADAECAM and FDR for B777-300ER / GE90-110B1.

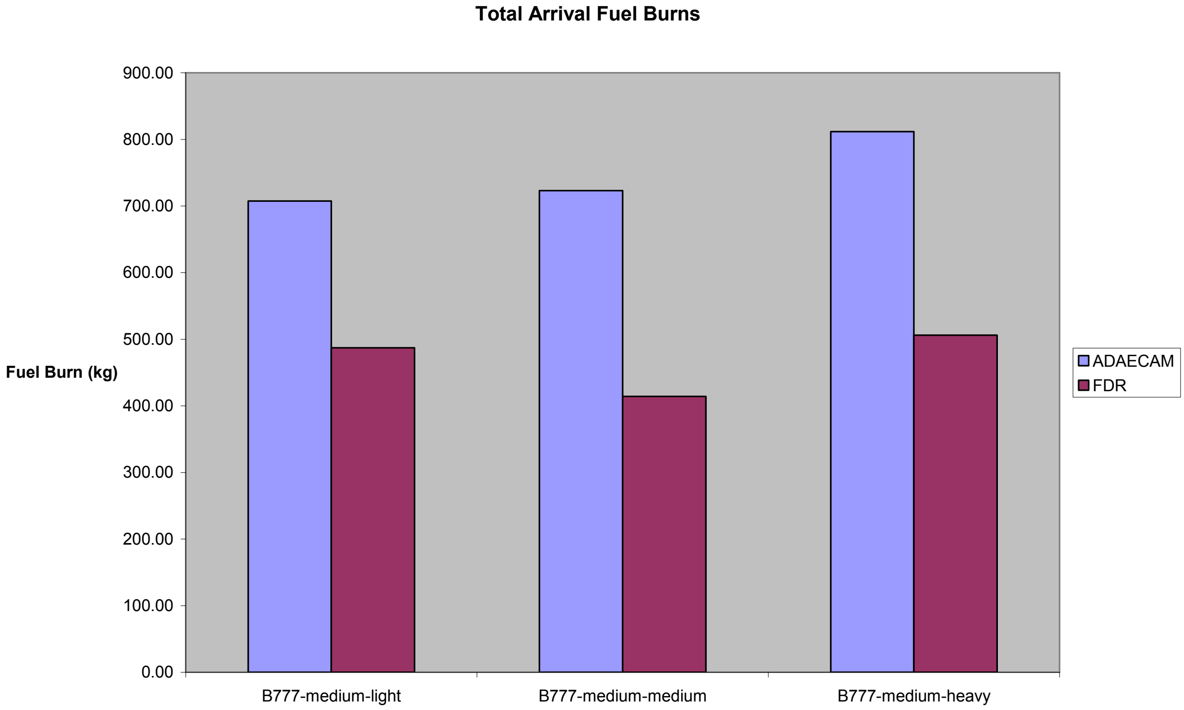


Figure 65: Comparison of arrival fuel burn (approach, landing and taxi-in) between ADAE-CAM and FDR for B777-300ER / GE90-110B1.

3.7 Discussion

- The findings for the **total LTO fuel burn,** as described in section 2.7 have generally been confirmed with the extended aircraft list.

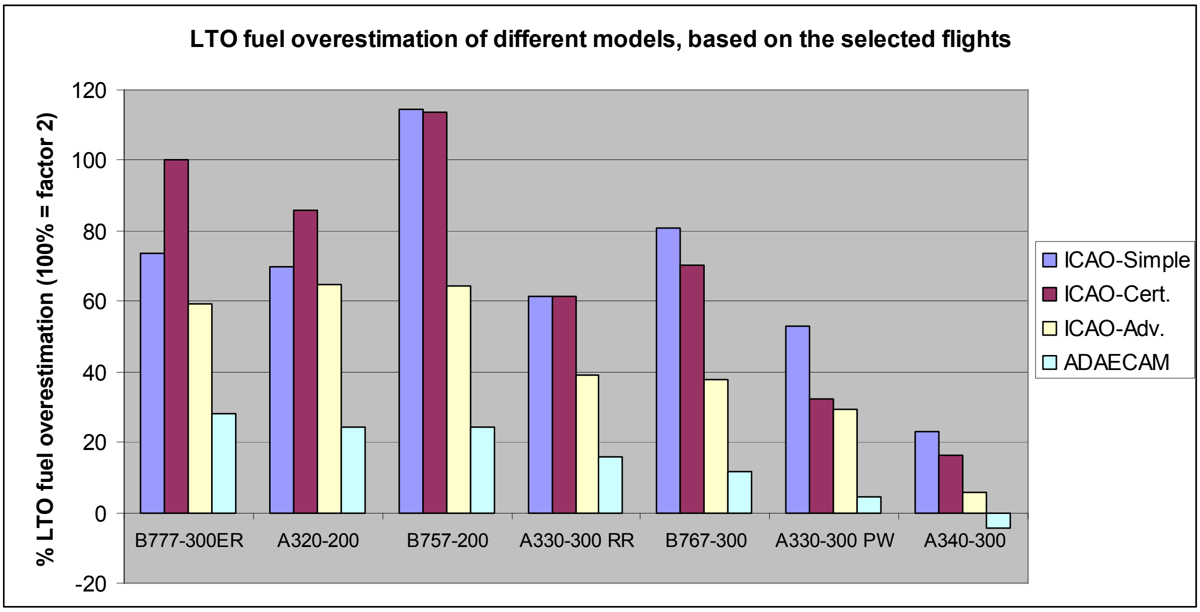


Figure 66: LTO fuel use, overestimation for “ICAO-Simple”, “ICAO-Cert.”, “ICAO-Adv.” and “ADAECAM model”.

For the selected flights, the mean LTO fuel consumption calculated with the ICAO-certification-LTO can be more than 100% (more than a factor of two) above the real LTO fuel. With the “ICAO-advanced” model, an overestimation between 30 and 60% is still possible (figure 66). LTO fuel overestimations with ADAECAM for the selected aircraft and flights vary normally between 5 and 25%.

Compared to the ICAO-advanced model, ADAECAM calculated LTO fuel consumption is significantly lower by 25 to 40% and is still above FDR LTO fuel burn results[5].

- ADAECAM in its present version may only underestimate total LTO fuel burn in case of "hot-heavy" departures.

- ADAECAM **taxi-out fuel** burn is normally slightly higher than FDR fuel burn. An exception is the A330 with PW engine for which ADAECAM taxi-out fuel burn matches or is slightly lower than FDR fuel burn.

- In the **take-off segment**, ADAECAM fuel burn matches FDR fuel burn in different quality, depending on the aircraft type and the airframe/engine combination respectively. Example: ADAECAM tends to underestimate A330 PW take-off fuel burn but significantly overestimates A330 RR take-off fuel burn. In some cases, the model produces constant fuel burn values for all flights (A320, A330 RR, B767, B777)[6]. In the rest of the cases, the calculated fuel consumption is varying and can match FDR quite nicely (e.g. B757).

- In the **climb segment**, ADAECAM fuel burn matches FDR fuel burn in different quality, depending on the aircraft type and the airframe/engine combination respectively. A320 and A330 RR are generally overestimated, with the exception of "hot-heavy" climbs. For A330 PW and B757, the model underestimates the climb fuel burn. For B777, there is a tendency to underestimate the climb fuel consumption.

- In general, there is limited variation during take-off/climb for ADAECAM compared to the real fuel burn.

- The **total departure** ADAECAM fuel burn has a tendency for overestimation in the case of B767 and B777, especially for the "light" departures. Total departure fuel consumption for A320 and A330 RR is overestimated, for A330 PW and A340-300 it is underestimated and for B757 it matches quite nicely.

- ADAECAM is generally high on the **approach fuel burn,** significantly in some cases, with one exception (A330 RR). The ADAECAM approach time is fixed at 4.04 minutes, being based on a 3 degree glide-slope from 3000ft at 140kts. The FDR times normally vary from 3.3 to 5.5 minutes, with extreme values at 2.9 and 7.5 minutes (the latter for one of the selected A330 RR approaches). In general, it looks as though the real mean thrust setting for the approach must be substantially less than the 30% assumed in the model.

- ADAECAM is generally low on **landing fuel burn**, with the exception of the selected A320 and B777 landings. However, the overall amount is an order of magnitude less than for other phases.

- ADAECAM **taxi-in** fuel burn is normally higher than FDR fuel burn.

[5] The A340-300 is excepted from this conclusion. Because of its climb characteristics and Zurich Airspace design, this aircraft is operated very Zurich airport dependent, at exceptionally high thrust during departure. This is the reason, why ICAO-simple, ICAO-cert, ICAO-adv LTO fuel burn are only 5-25% above the FDR fuel burn and ADAECAM is underestimating the fuel consumed by around 4%.

[6] These "constant values" result from all the selected validation flights having route distances much less than the aircraft range. As a consequence, all the aircraft are assumed to fall into the "light" category for calculation of take off fuel.

4. Conclusions

ADAECAM total LTO fuel burn calculations show a substantial improvement towards more realistic calculated LTO fuel burn Although ADAECAM fuel burn is considerably lower than in the models which are generally used today, the results for the total fuel use are still conservative and can be considered rather on the safe side.

The development and availability of ADAECAM is considered an important step forward into the direction of real world related modelling, without the need for sensitive, proprietary and non-publicly available data.

As far as fuel burn calculations for individual segments are concerned, the validation has shown two main areas of the model where a potential further development might be worth considering:

- Increase the variation of take-off and climb fuel consumption according to input information and prevent an underestimation of take-off and climb fuel burn.

- Adjust the approach fuel consumption modelling in order to reduce systematic overestimation of approach fuel use.

Appendix A: FDR parameter distribution for flight selection

1) A320-200 / CFM56-5B4

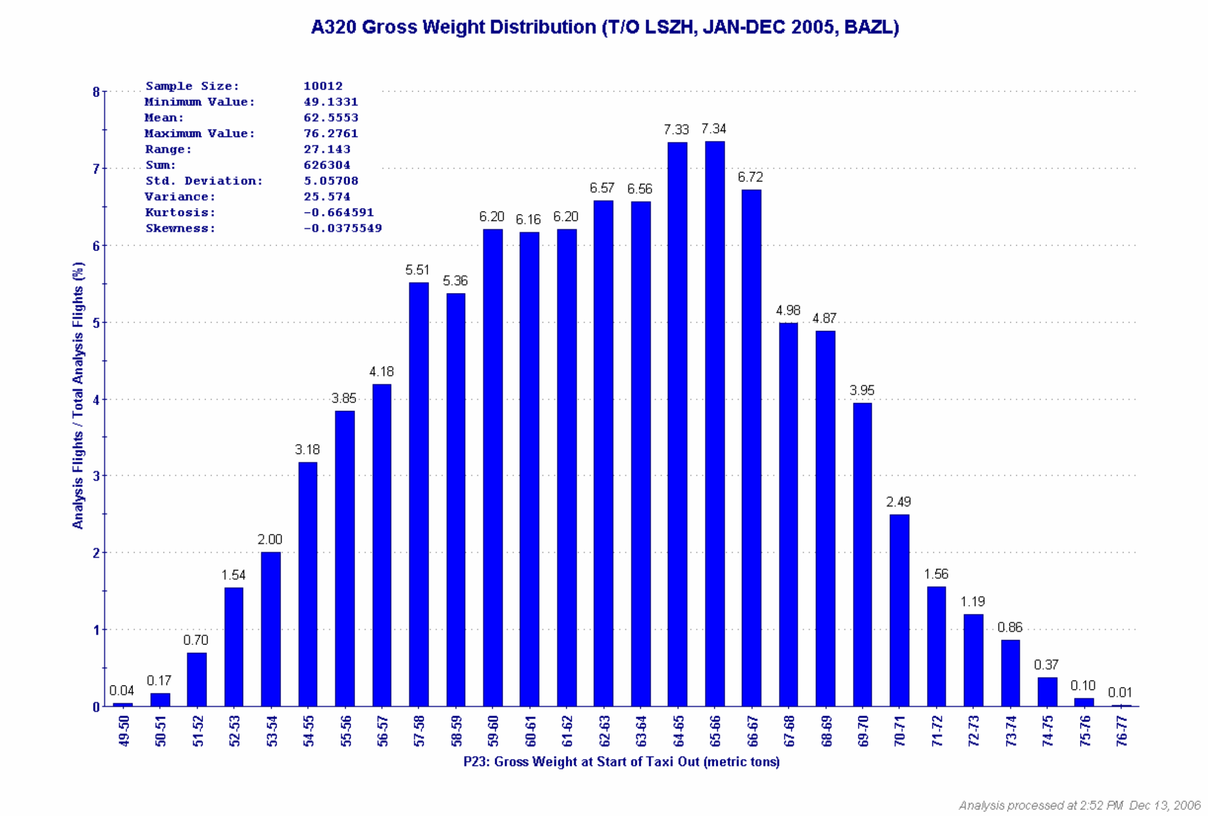


Figure 67: Example of FDR gross weight distribution at start of taxi-out during a one year operation of all aircraft of the selected A320-200 / CFM56-5B4 type.

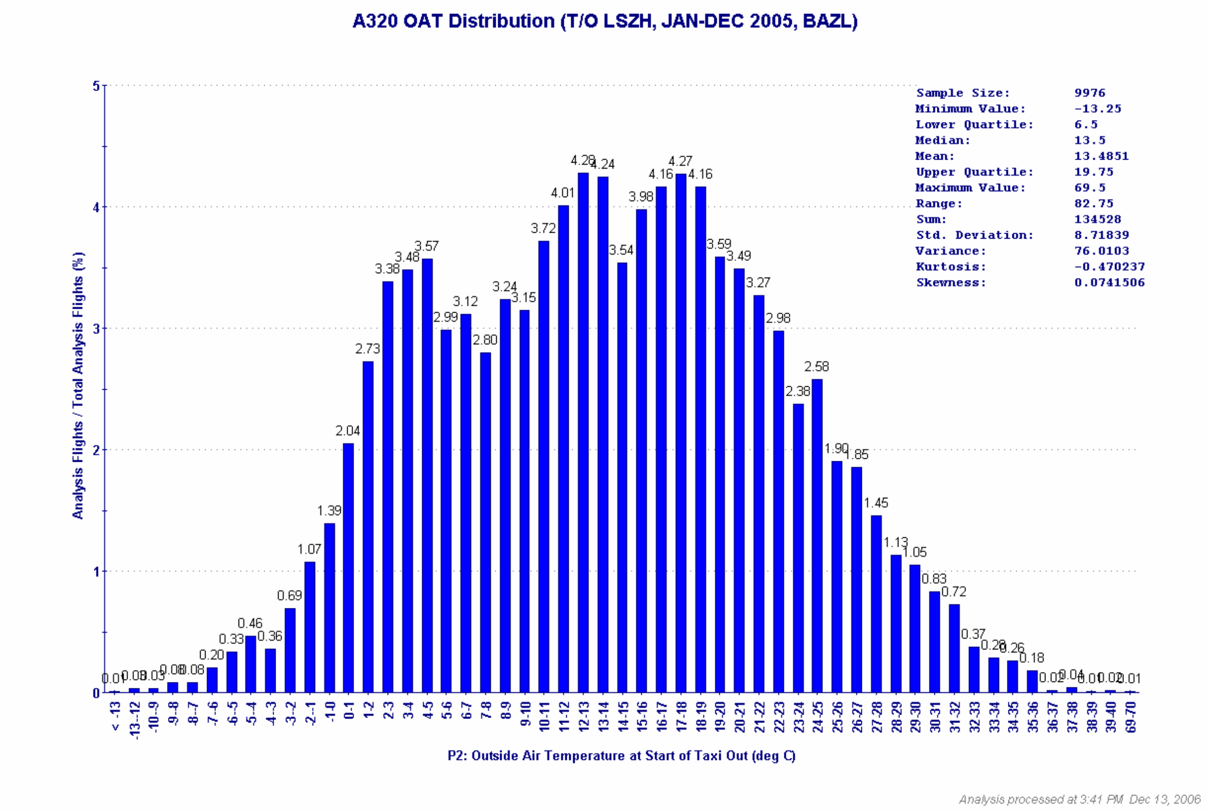


Figure 68: Example of FDR outside air temperature distribution at start of taxi-out during a one year operation of all aircraft of the selected A320-200 / CFM56-5B4 type.

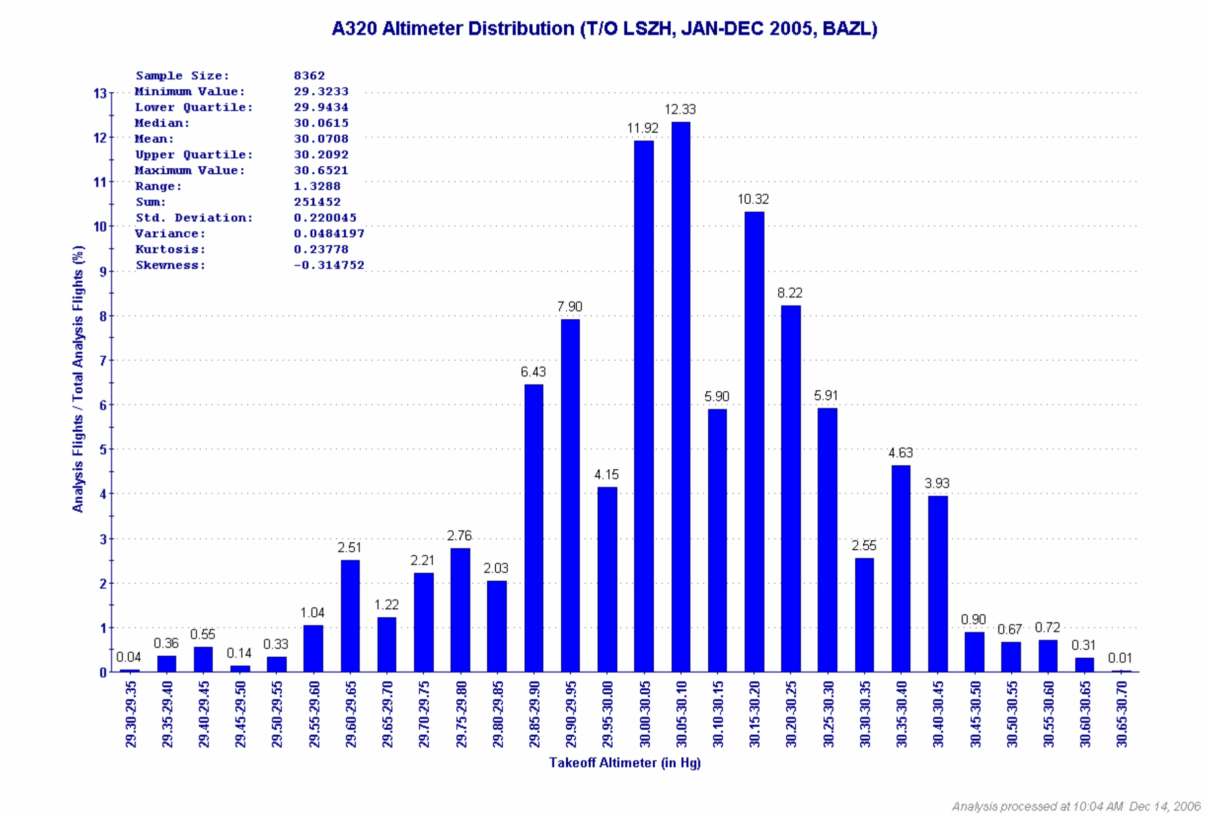


Figure 69: Example of FDR altimeter (QNH) setting distribution at start of taxi-out during a one year operation of all aircraft of the selected A320-200 / CFM56-5B4 type.

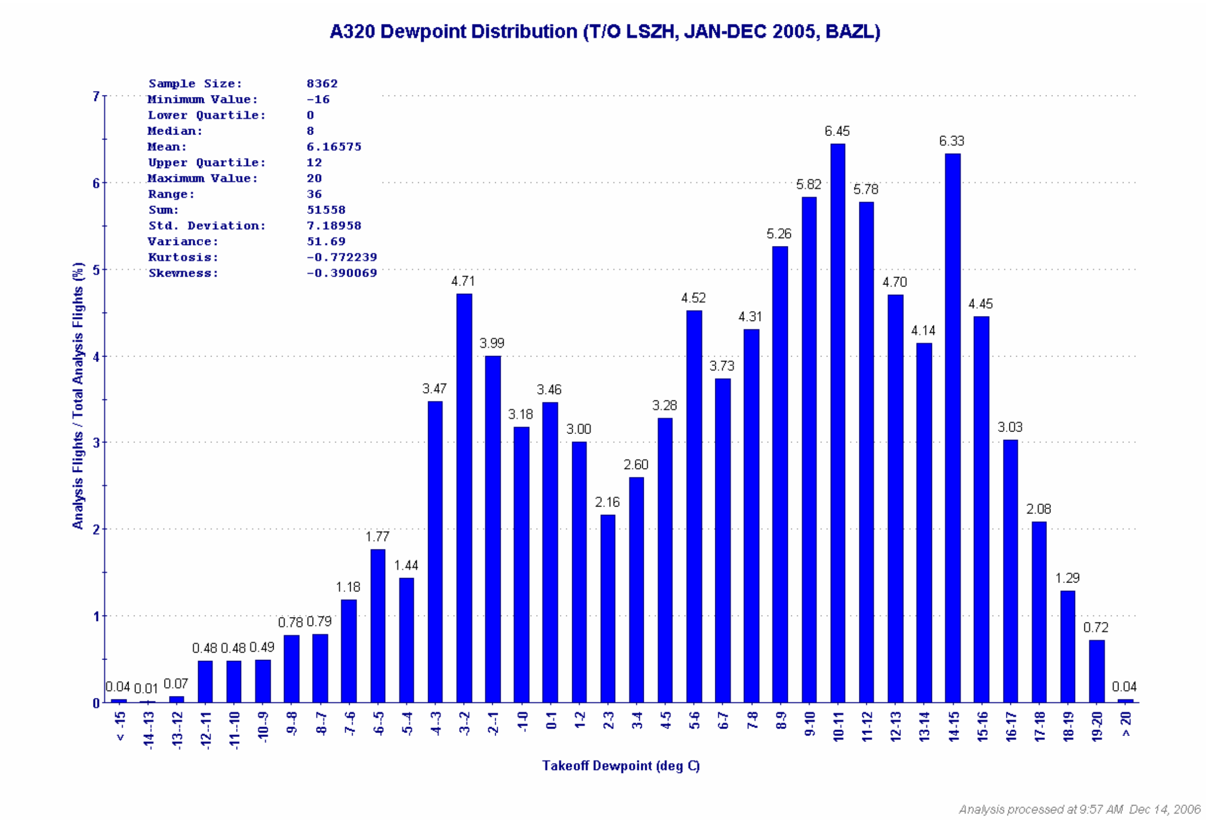


Figure 70: Example of FDR dew point distribution at take-off during a one year operation of all aircraft of the selected A320-200 / CFM56-5B4 type.

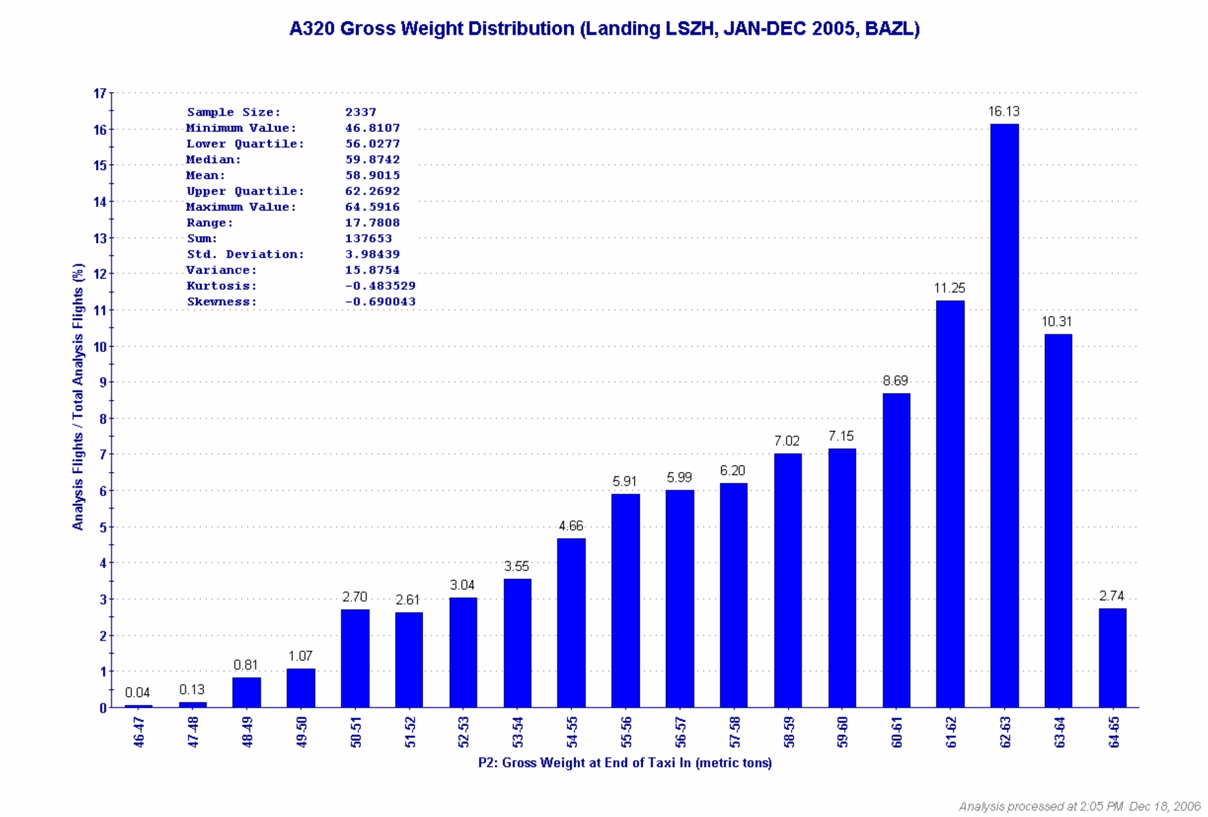


Figure 71: Example of FDR gross weight distribution at end of taxi in during a one year operation of all aircraft of the selected A320-200 / CFM56-5B4 type.

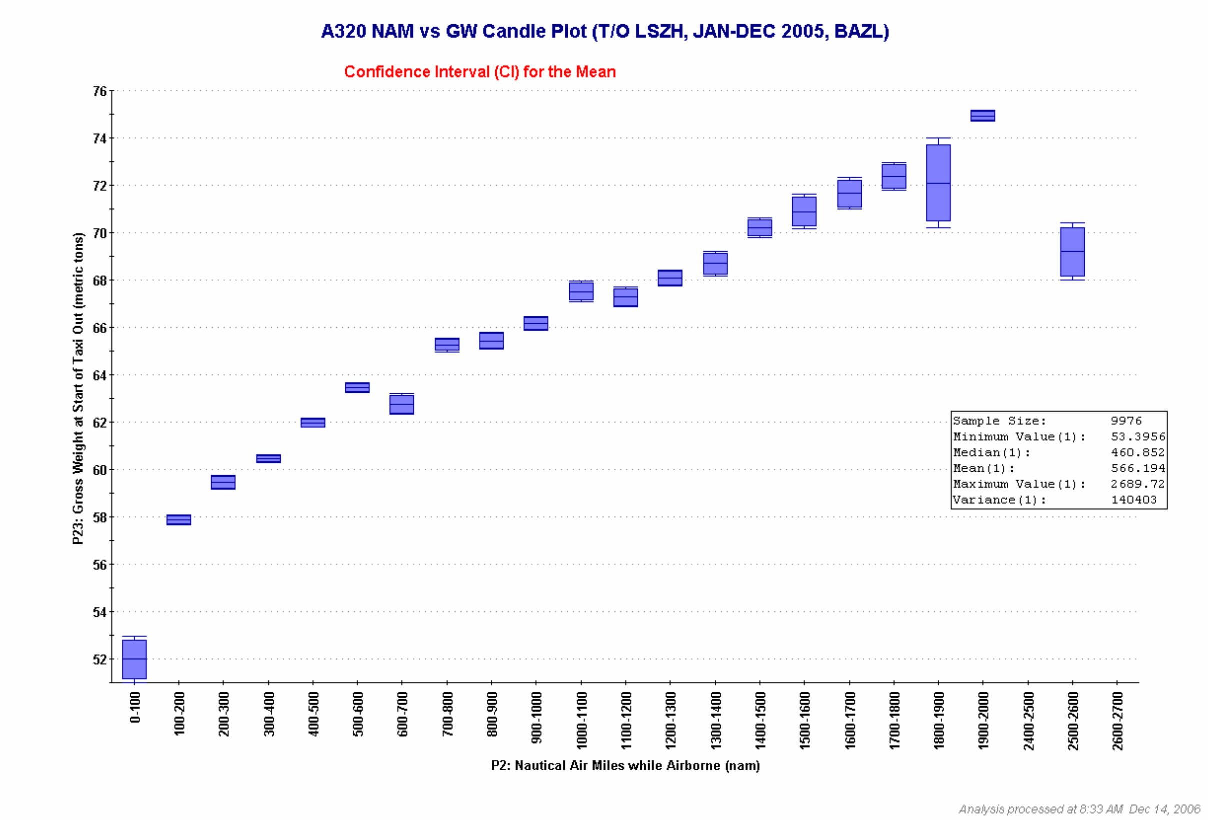


Figure 71: Example of FDR data in a candle plot, showing the gross weight at take-off in function of the nautical air miles of all aircraft (A320-200 / CFM56-5B4 type).

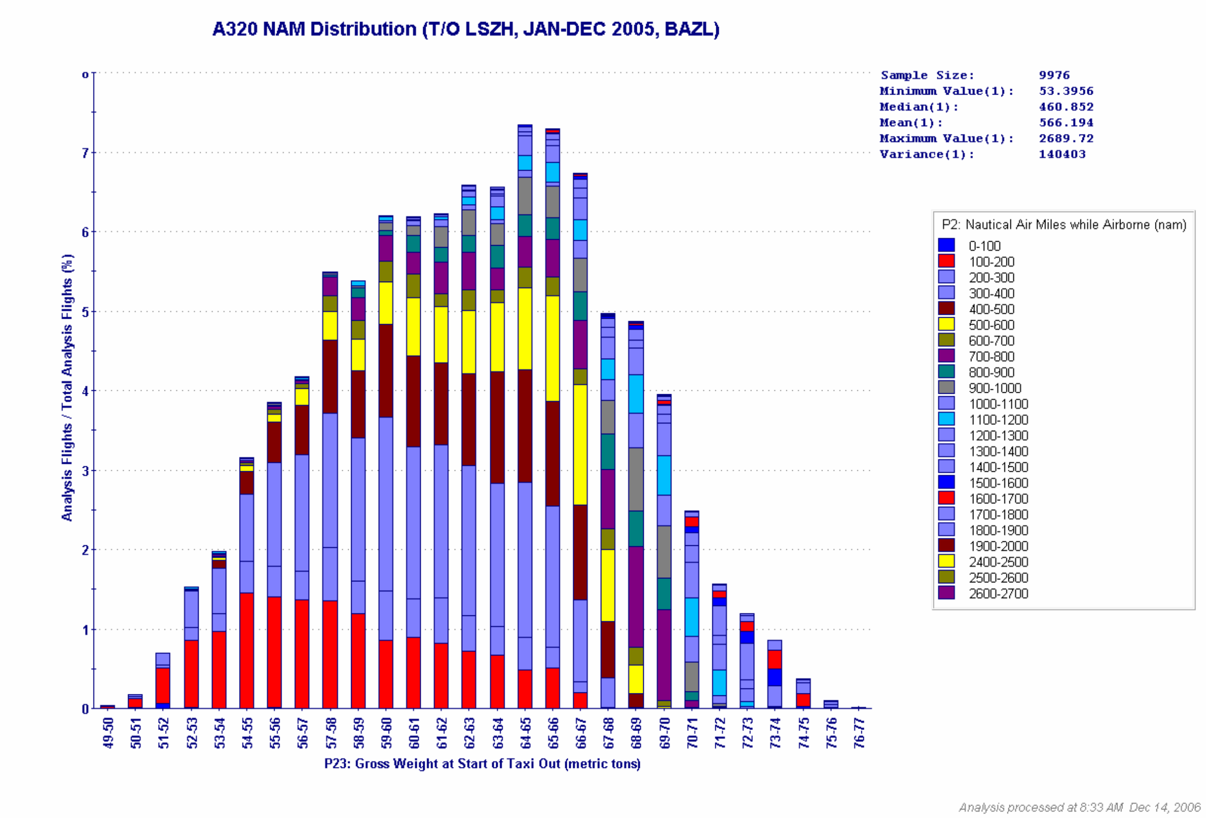


Figure 72: Distribution of flights with a certain gross weight at take-off, in function of nautical air miles of all aircraft (A320-200 / CFM56-5B4 type).

2) A330-200 / PW4168A Floatwall

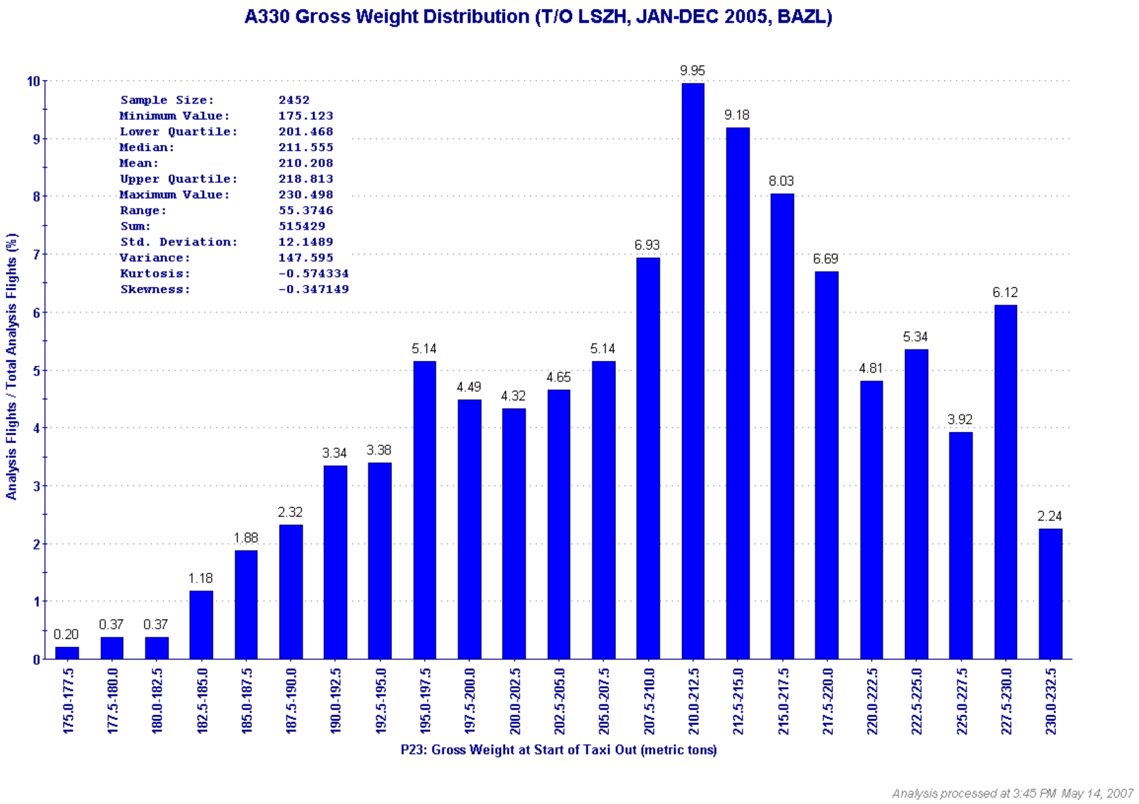


Figure 73: Example of FDR gross weight distribution at start of taxi-out during a one year operation of all aircraft of the selected A330-200 / PW4168A type.

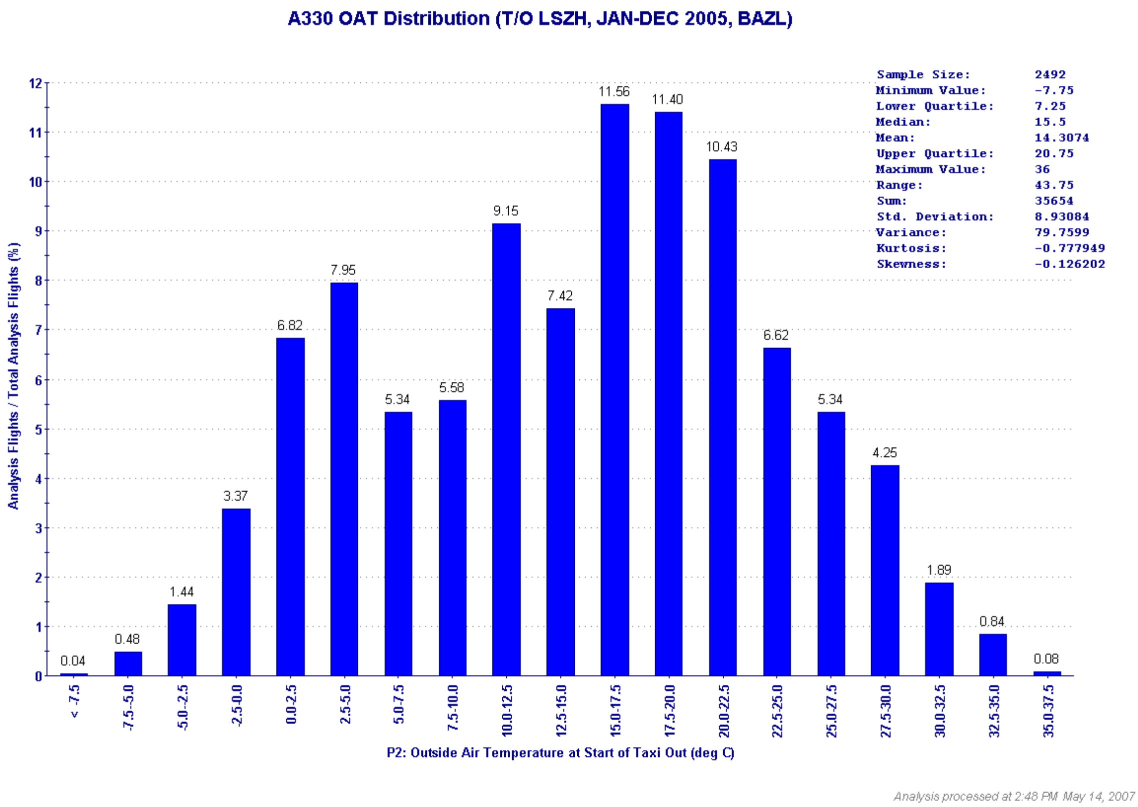


Figure 74: Example of FDR outside air temperature distribution at start of taxi-out during a one year operation of all aircraft of the selected A330-200 / PW4168A Floatwall type.

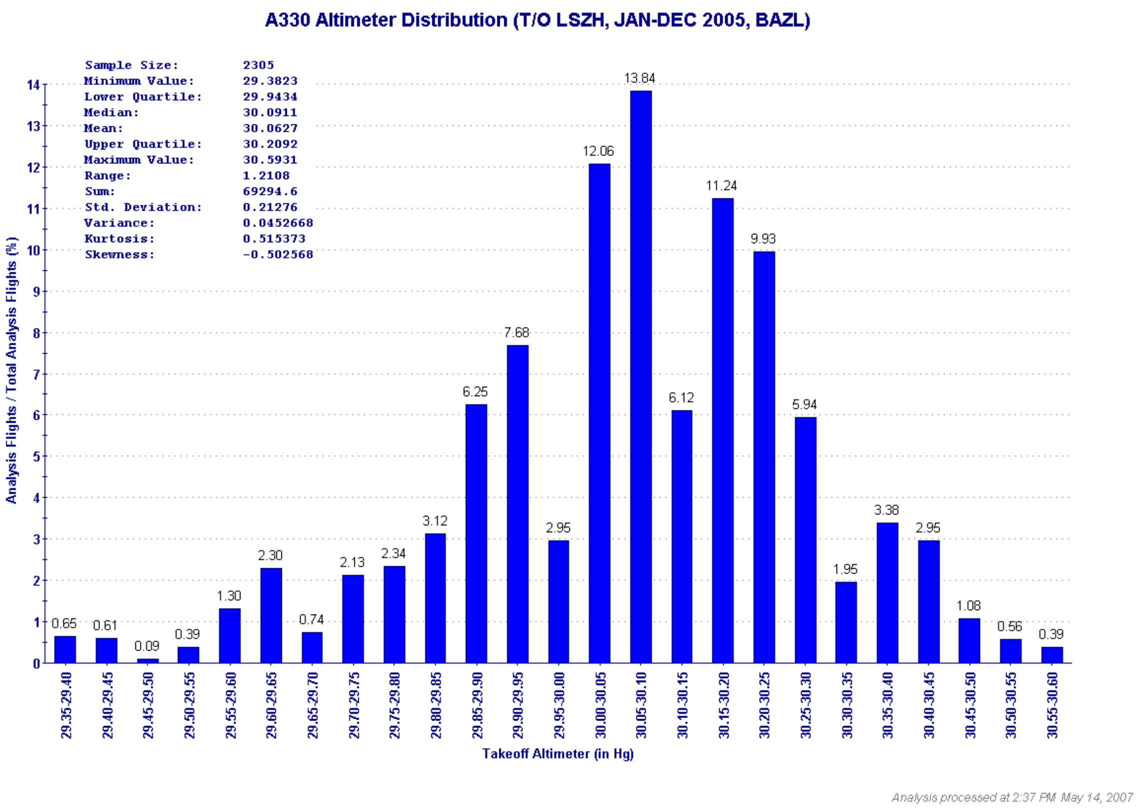


Figure 75: Example of FDR altimeter (QNH) setting distribution at start of taxi-out during a one year operation of all aircraft of the selected A330-200 / PW4168A Floatwall type.

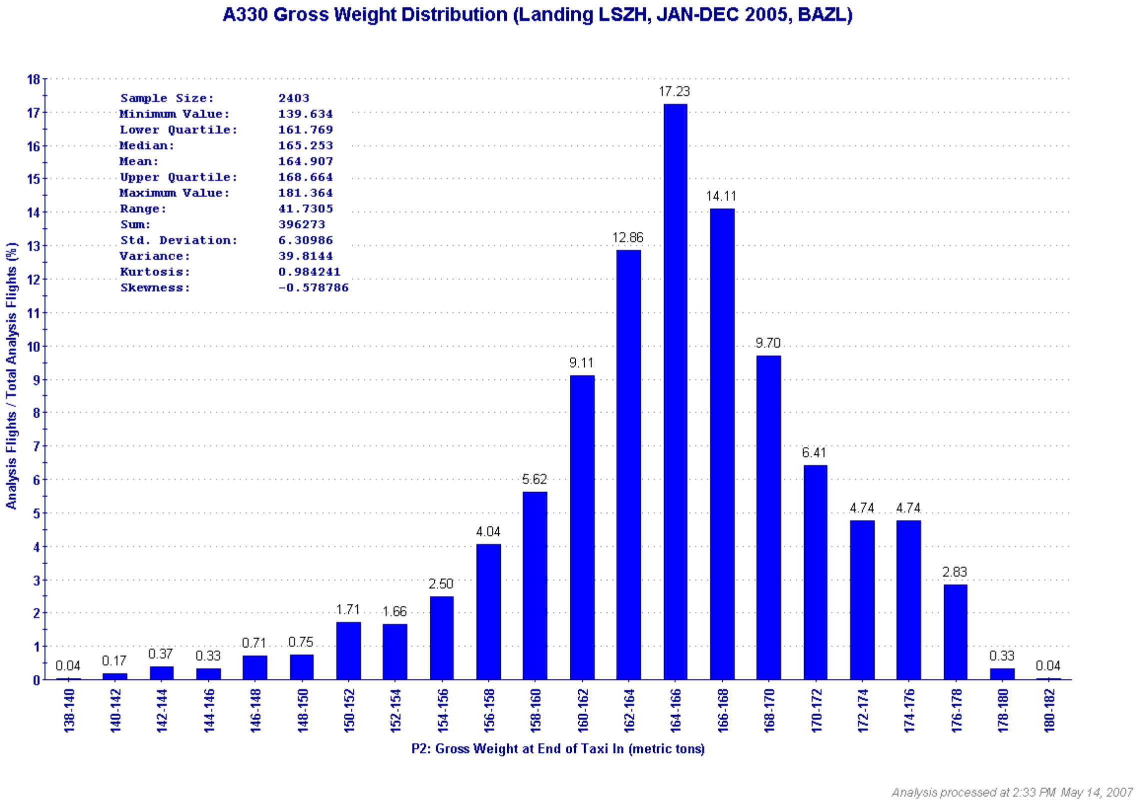


Figure 76: Example of FDR gross weight distribution at end of taxi in during a one year operation of all aircraft of the selected A330-200 / PW4168A Floatwall type.

3) A330-200 / RR Trent 772-B

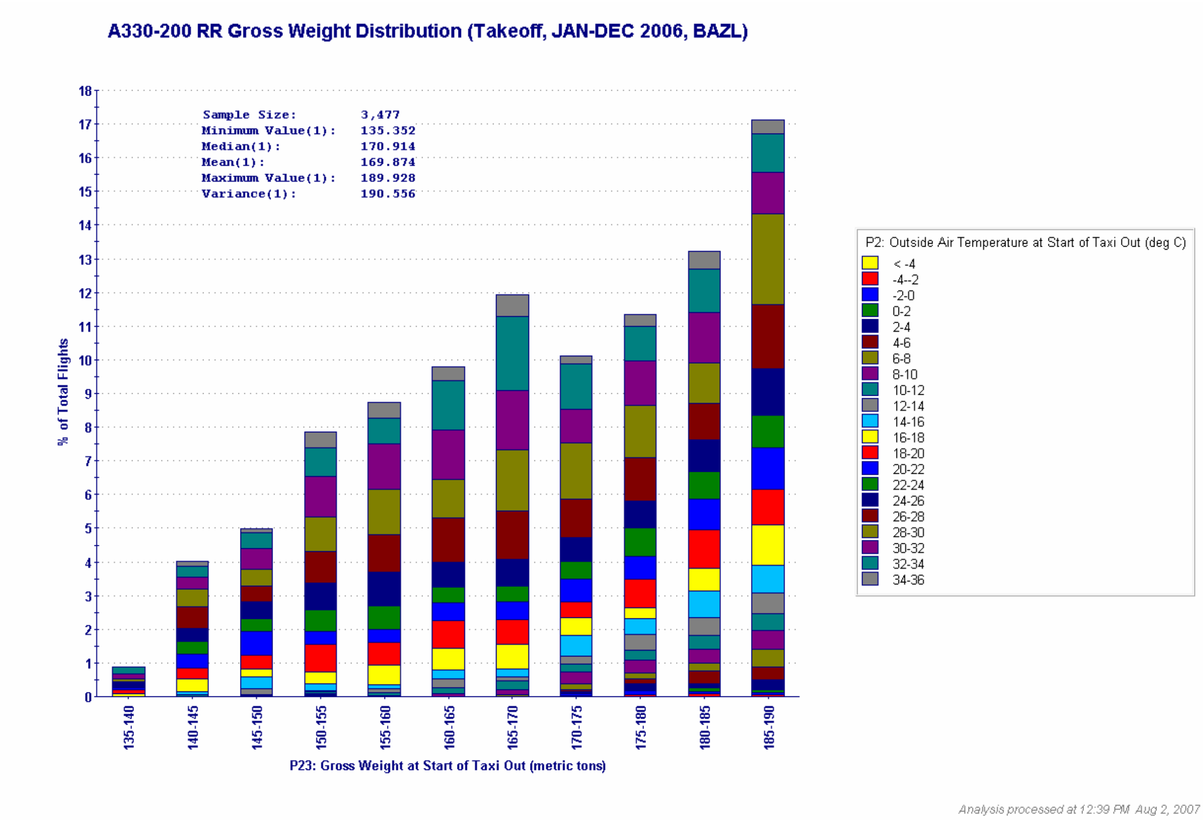


Figure 77: Distribution of flights with a certain gross weight at take-off, in function of outside air temperature at start of taxi out of all aircraft (A330-200 / RR Trent 772-B type).

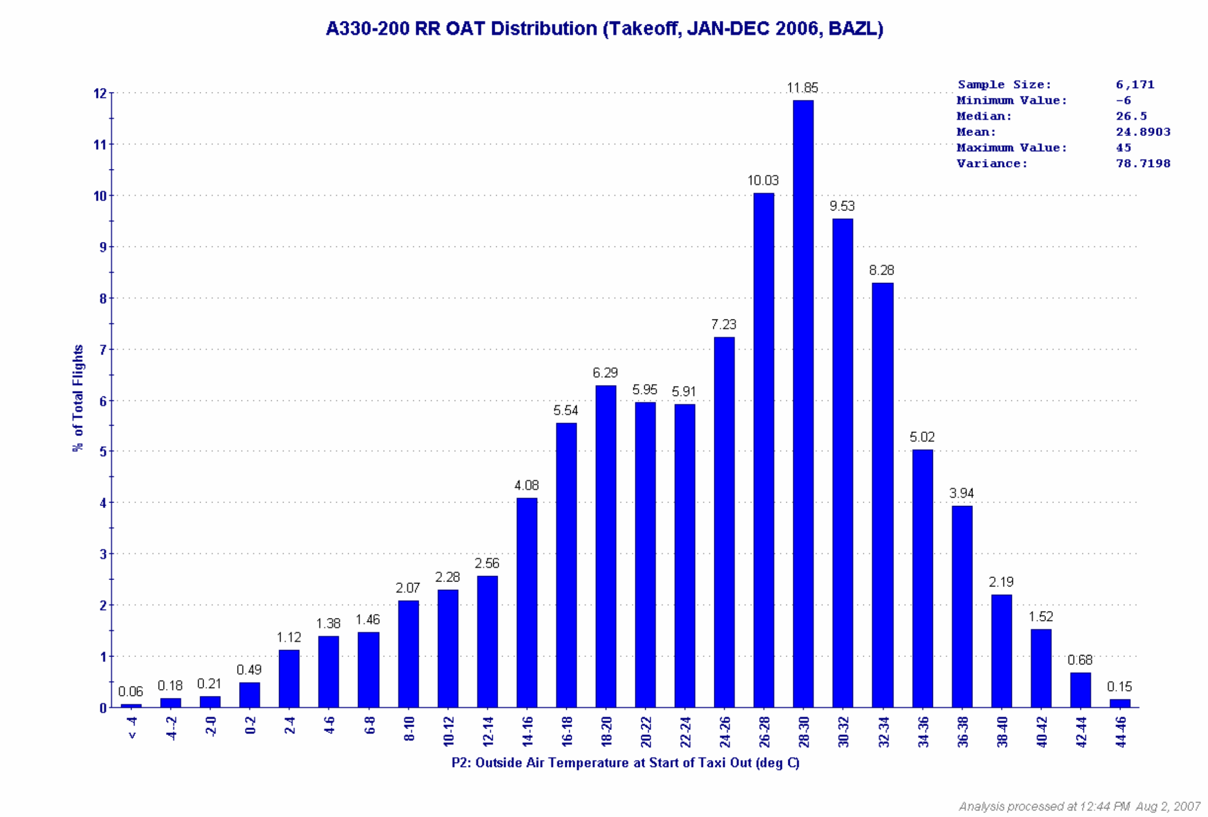


Figure 78: Example of FDR outside air temperature distribution at start of taxi-out during a one year operation of all aircraft of the selected A330-200 / RR Trent 772-B type.

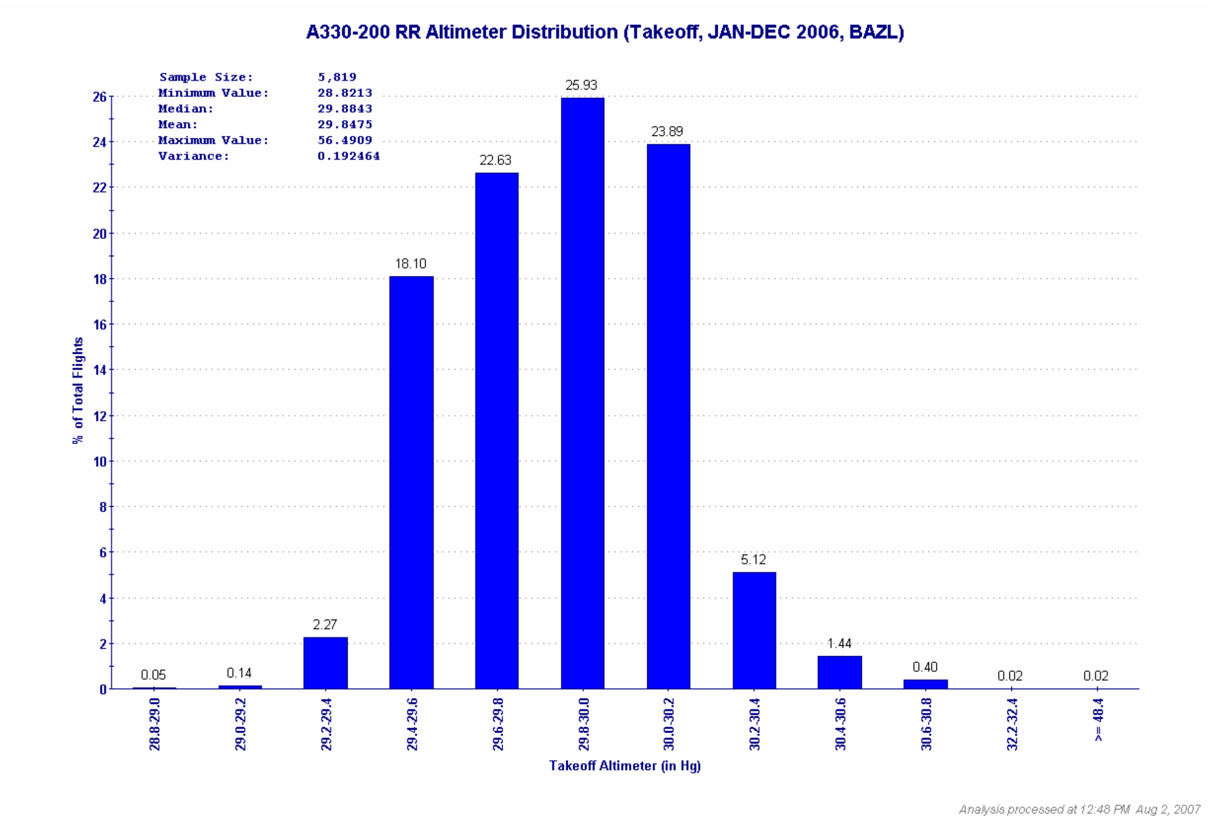


Figure 79: Example of FDR altimeter (QNH) setting distribution at start of taxi-out during a one year operation of all aircraft of the selected A330-200 / RR Trent 772-B type.

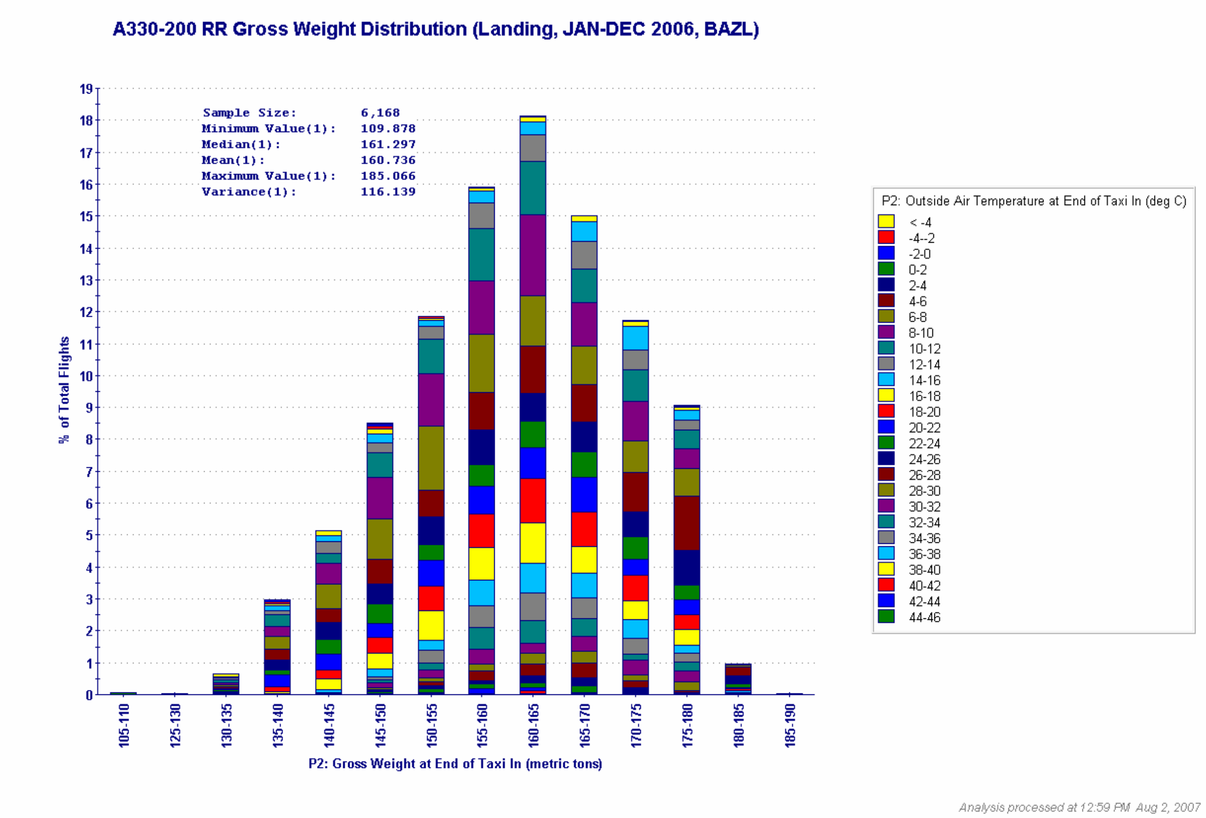


Figure 80: Example of FDR gross weight distribution during one year operation of all aircraft of the selected A330-200 / RR Trent 772-B type, in function of outside air temperature at the end of taxi-in.

4) A340-300 / CFM56-5C4/P

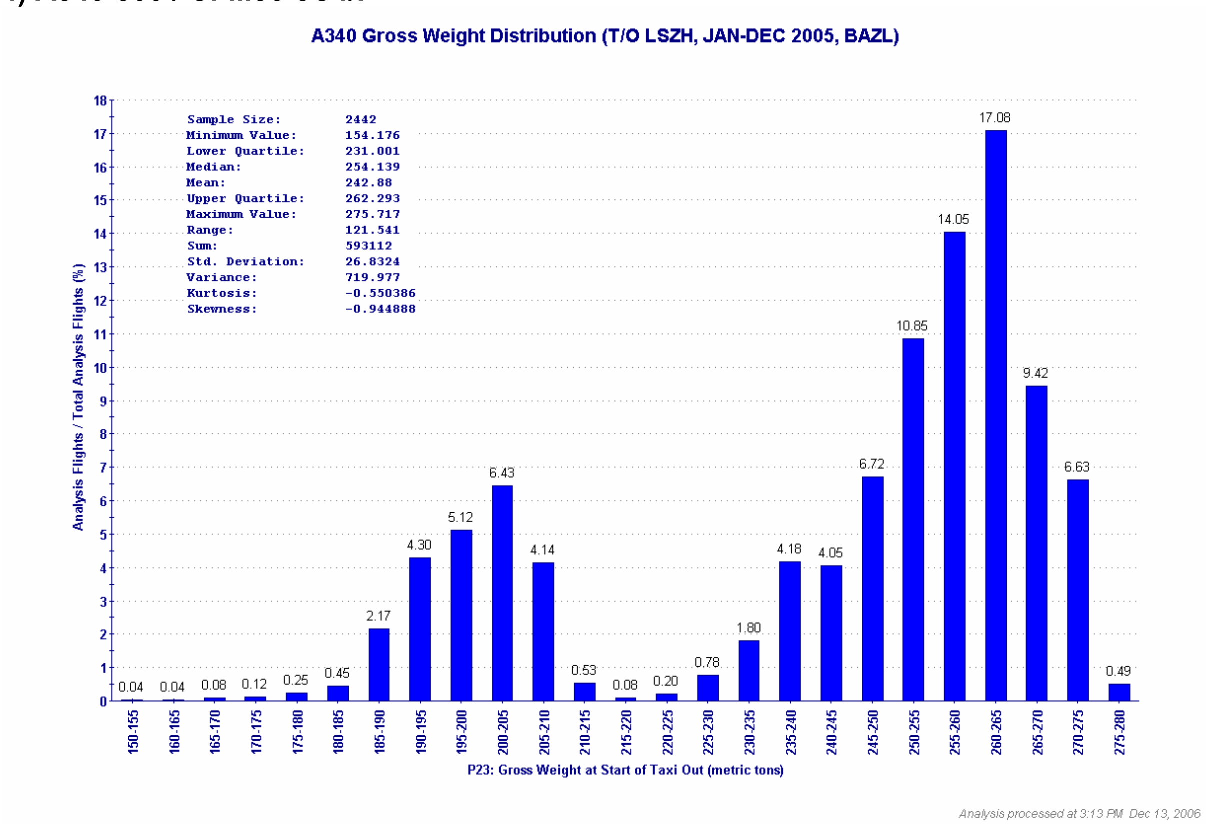


Figure 81: Example of FDR gross weight distribution at start of taxi-out during a one year operation of all aircraft of the selected A340-300 / CFM56-5C4/P type.

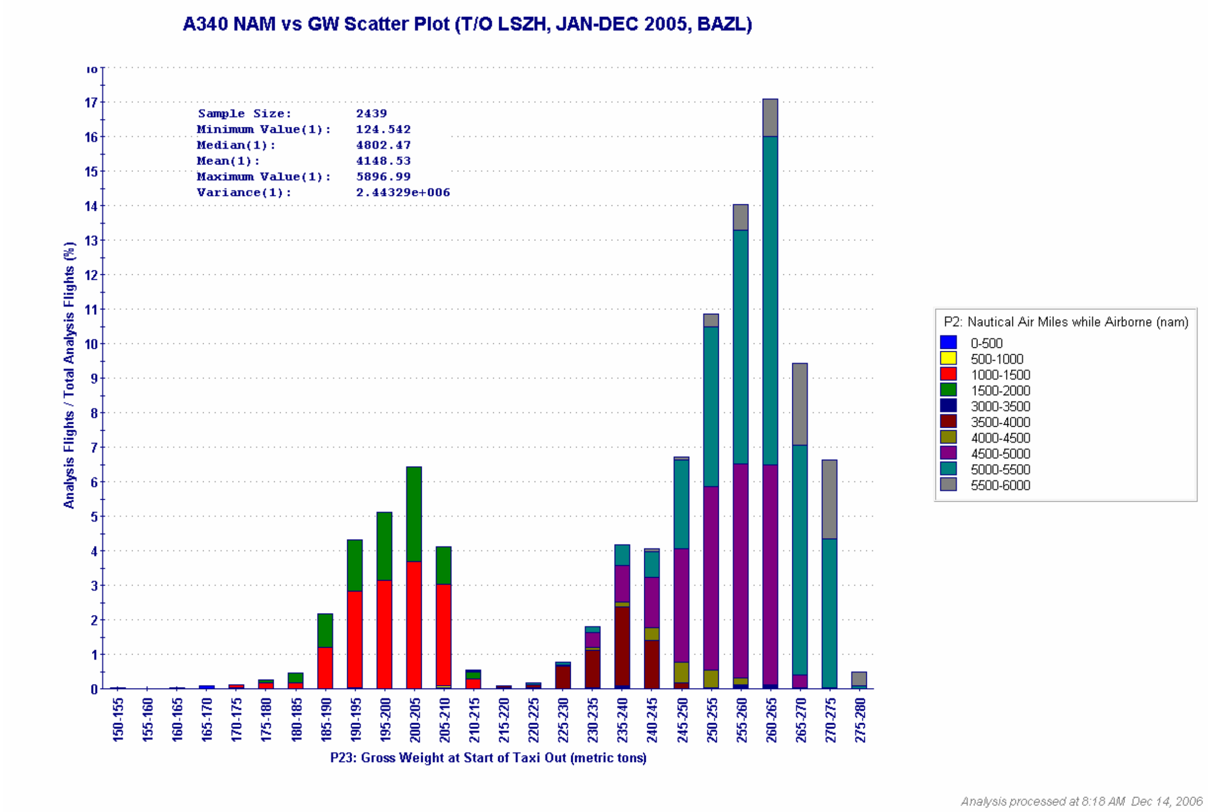


Figure 82: Example of FDR gross weight distribution at start of taxi-out in function of nautical air miles during a one year operation of all aircraft of the selected A340-300 / CFM56-5C4/P type.

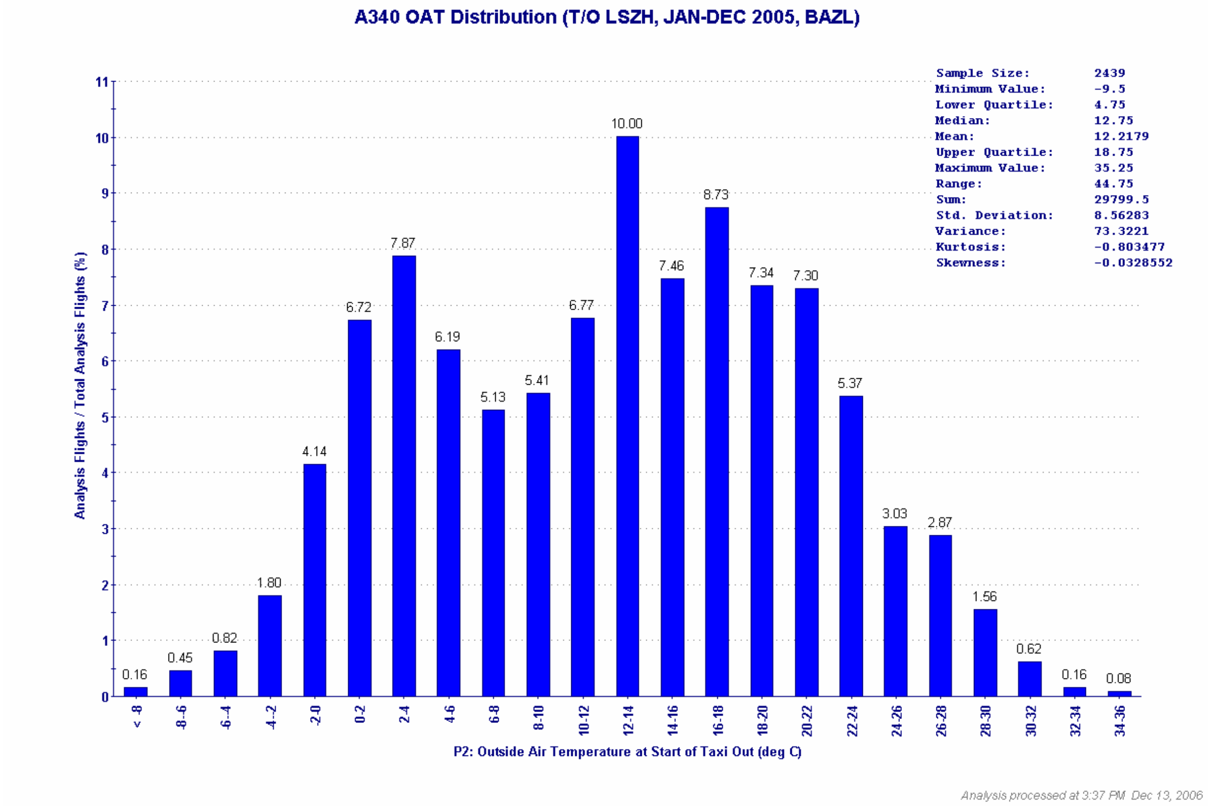


Figure 83: Example of FDR outside air temperature distribution at start of taxi-out during a one year operation of all aircraft of the selected A340-300 / CFM56-5C4/P type.

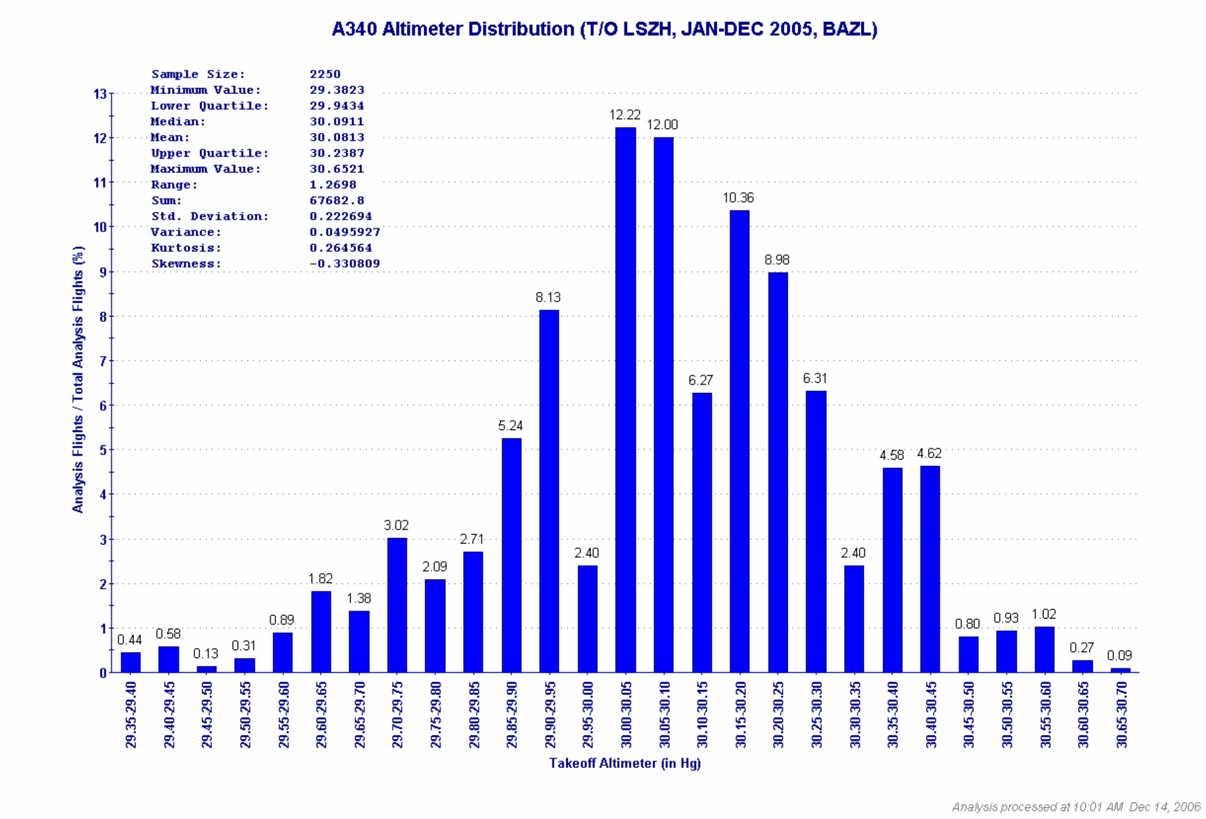


Figure 84: Example of FDR altimeter (QNH) setting distribution at start of taxi-out during a one year operation of all aircraft of the selected A340-300 / CFM56-5C4/P type.

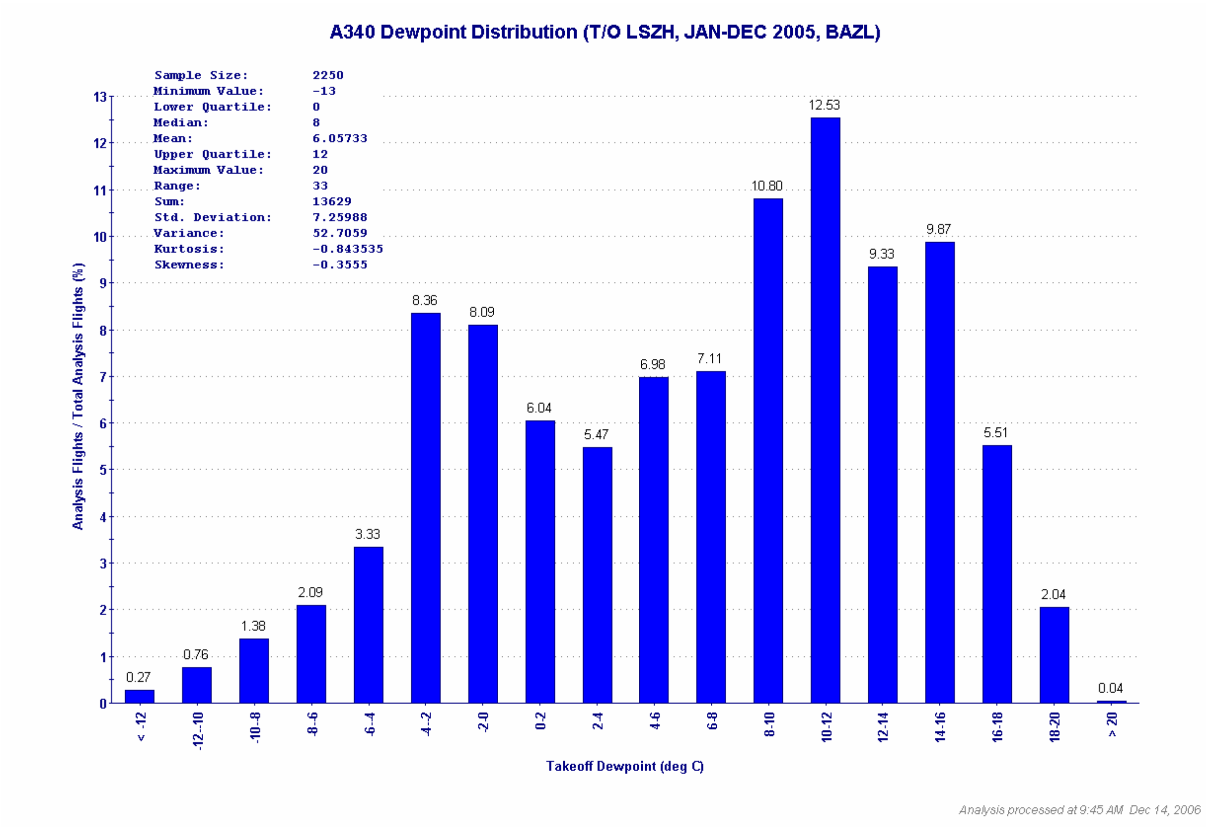


Figure 85: Example of FDR dew point distribution at start of taxi-out during a one year operation of all aircraft of the selected A340-300 / CFM56-5C4/P type.

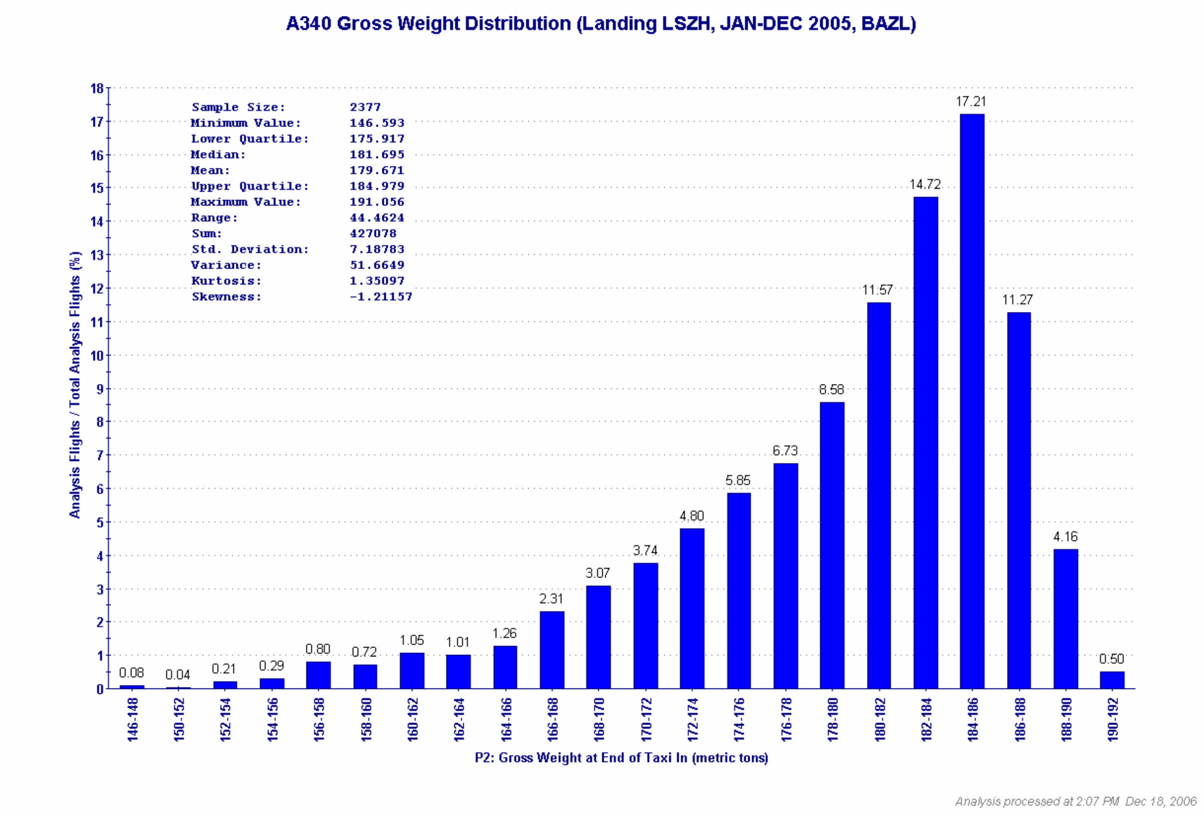


Figure 86: Example of FDR gross weight distribution at end of taxi-in during a one year operation of all aircraft of the selected A340-300 / CFM56-5C4/P type.

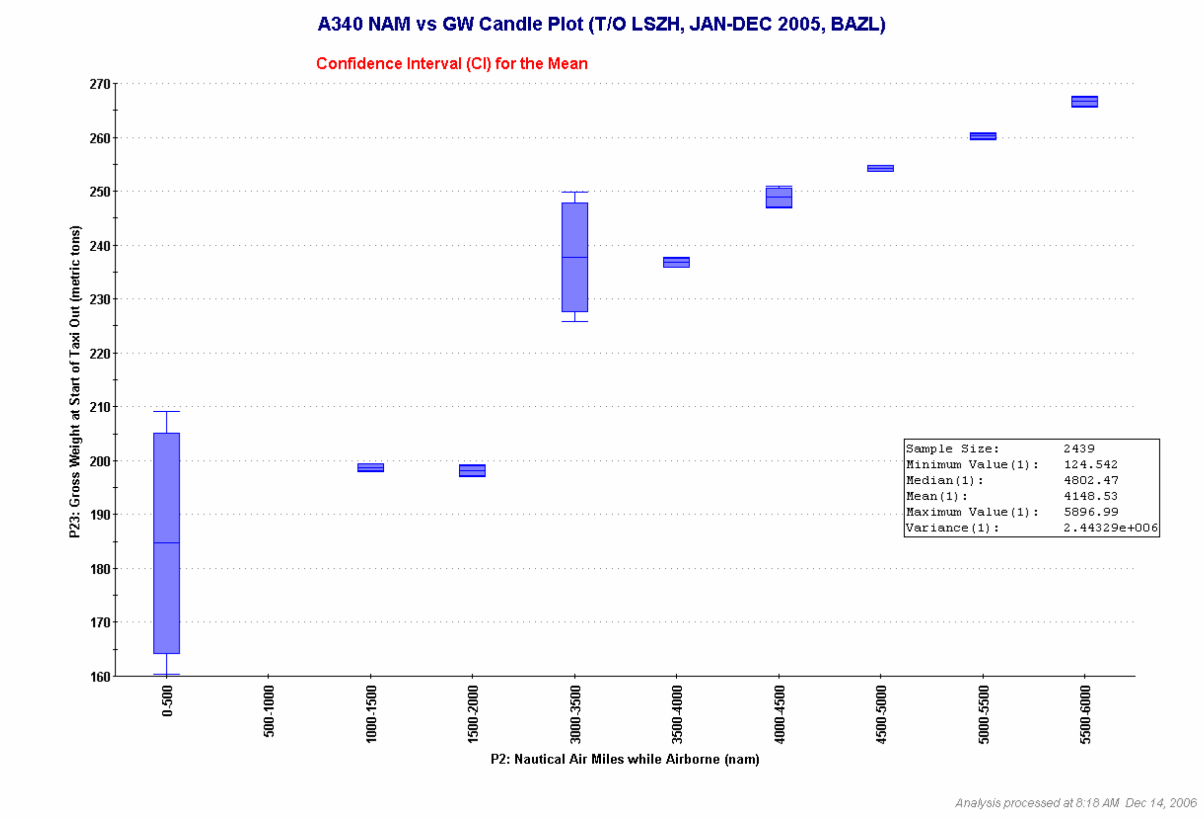


Figure 87: Example of a candle plot, showing FDR gross weight distribution in function of nautical air miles during a one year operation of all aircraft of the selected A340-300 / CFM56-5C4/P type.

5) B757-200 / RR RB211-535E4

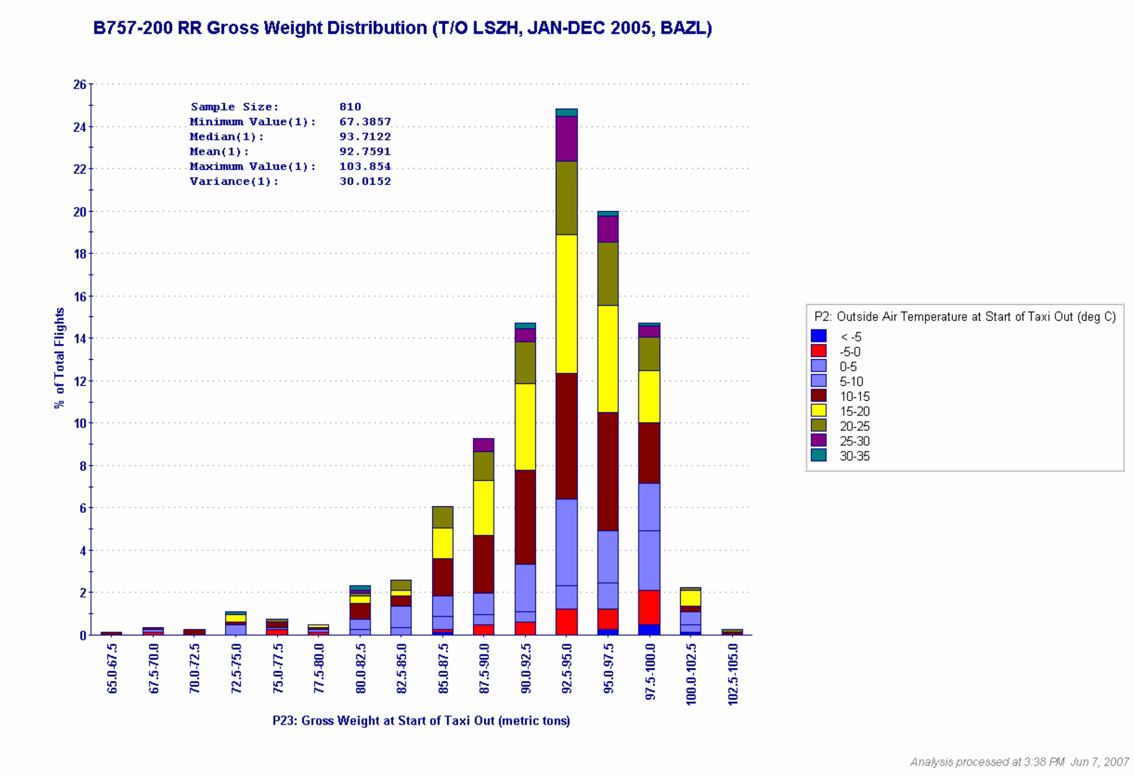


Figure 88: Example for a FDR gross weight distribution at start of taxi-out with information on outside air temperature during a one year operation of all aircraft of the selected B757-200 / RR RB211-535E4 type.

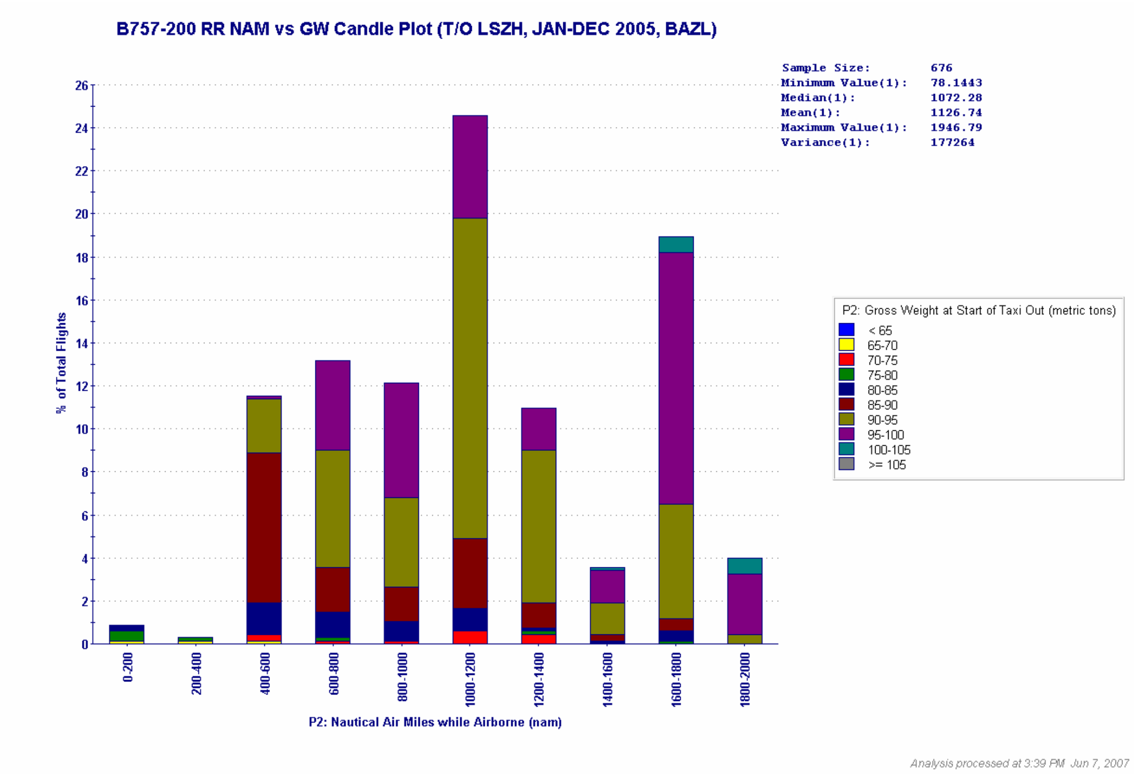


Figure 89: Example for a FDR nautical air miles distribution with information on gross weight at taxi-out during a one year operation of all aircraft of the selected B757-200 / RR RB211-535E4 type.

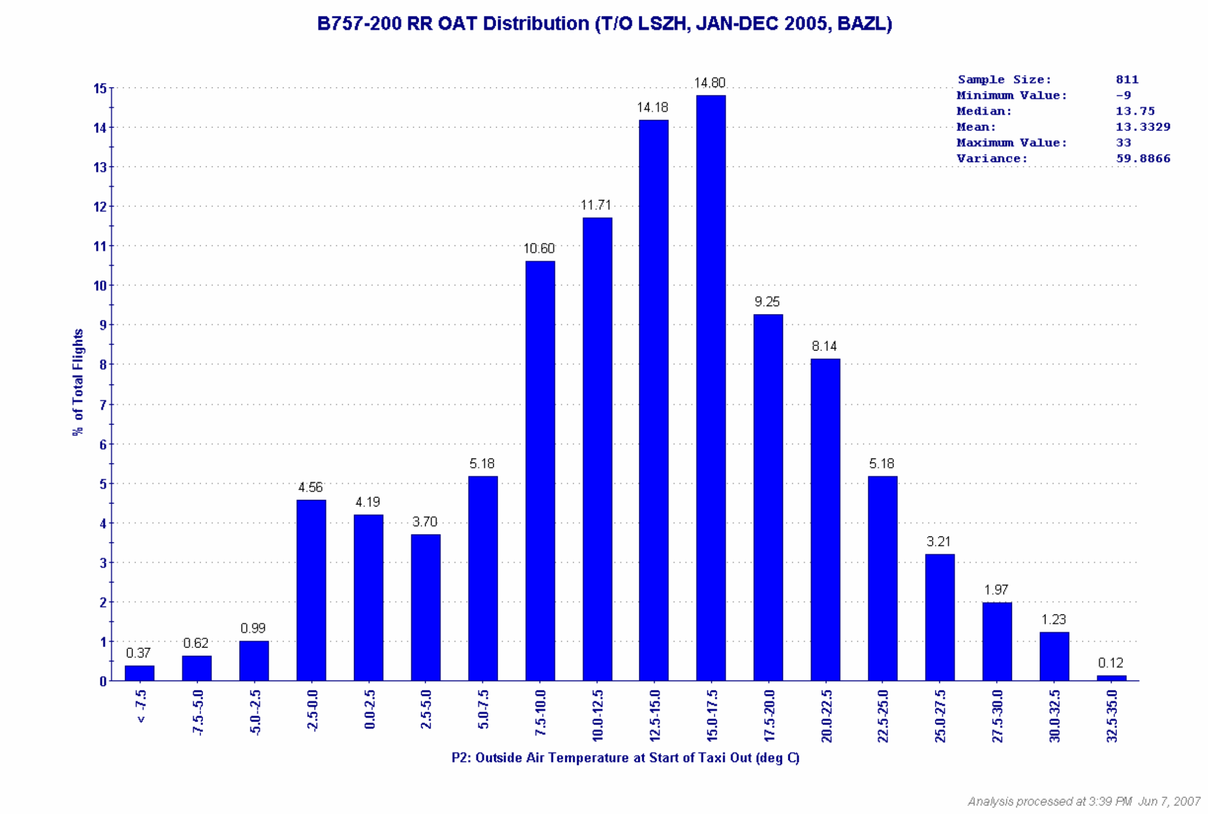


Figure 90: Example for FDR outside air temperature distribution at taxi-out during a one year operation of all aircraft of the selected B757-200 / RR RB211-535E4 type.

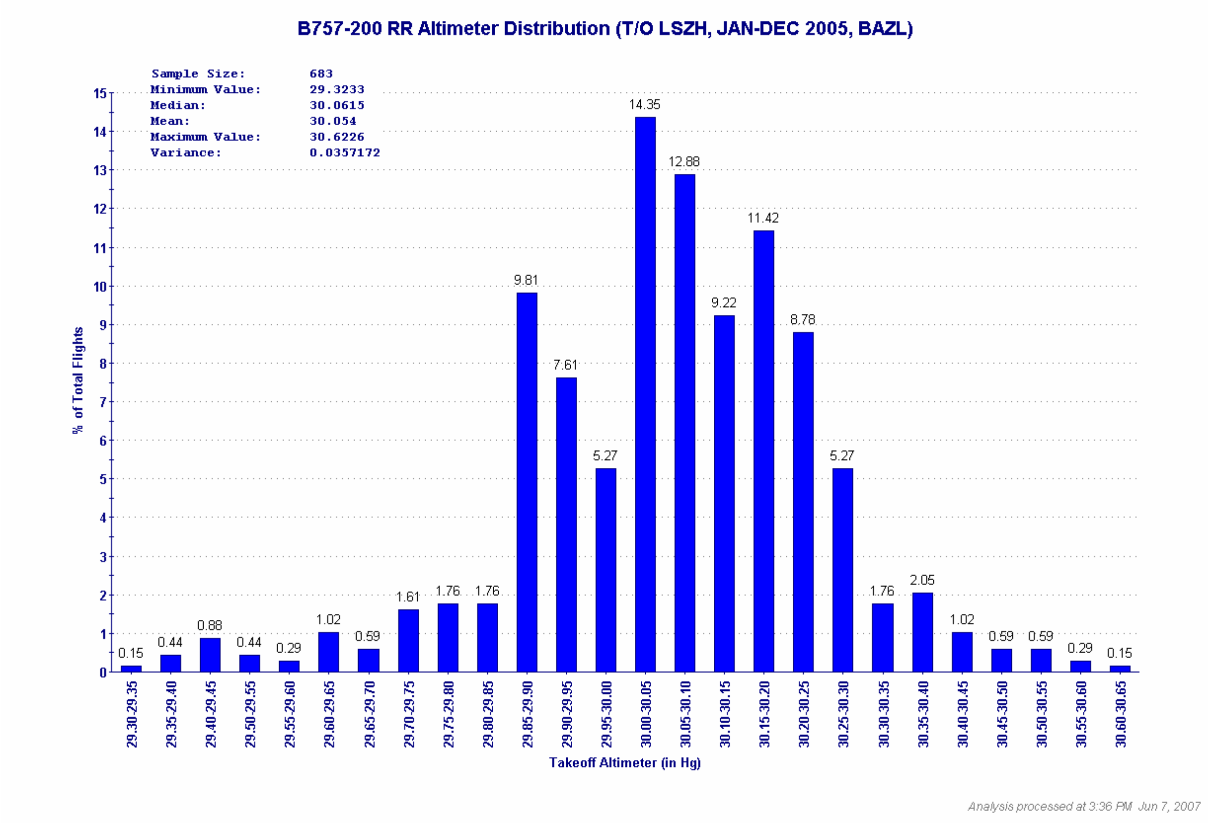


Figure 91: Example for FDR altimeter (QNH) distribution at taxi-out during a one year operation of all aircraft of the selected B757-200 / RR RB211-535E4 type.

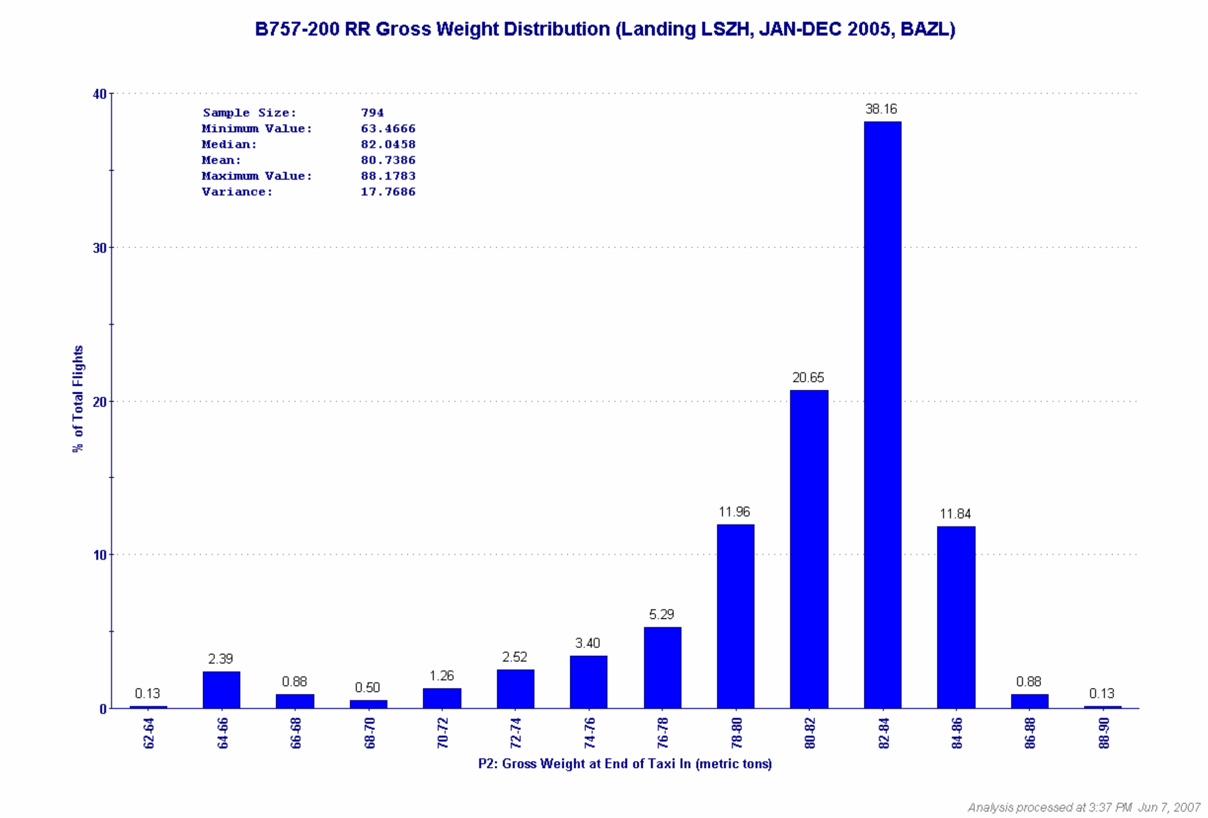


Figure 92: Example for FDR gross weight distribution at end of taxi-in during a one year operation of all aircraft of the selected B757-200 / RR RB211-535E4 type.

6) B767-300 / GE CF6-80C2A3

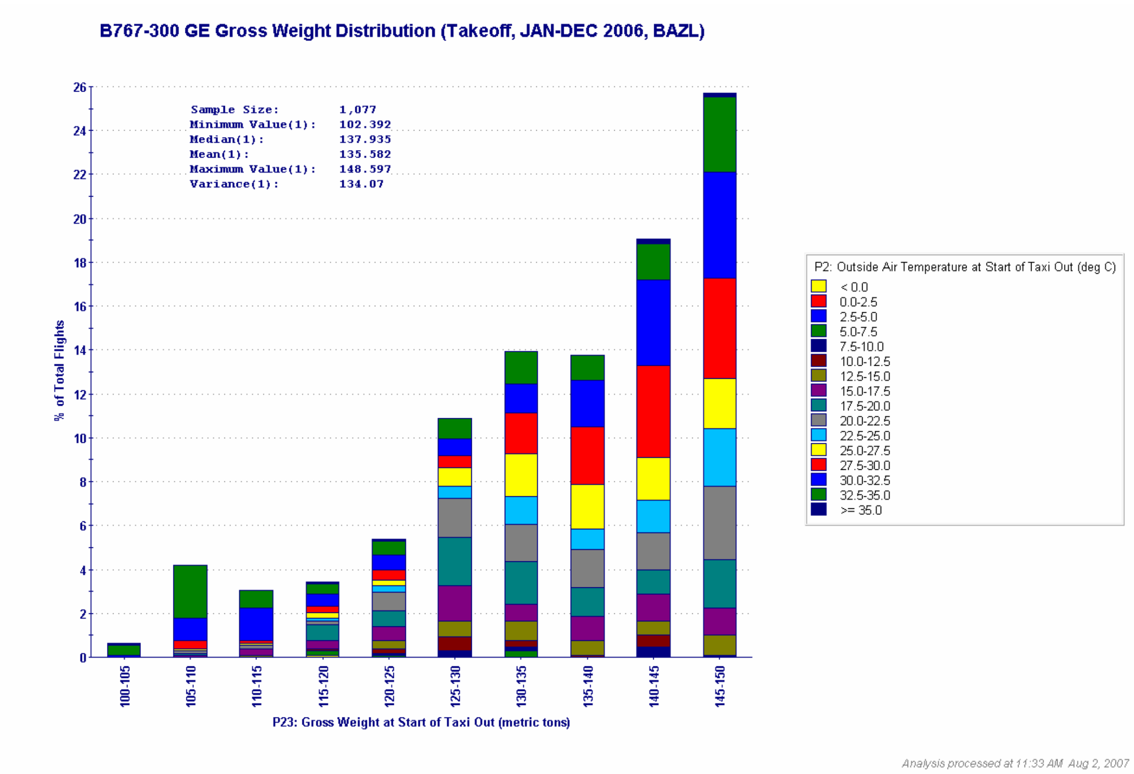


Figure 93: Example for a FDR gross weight distribution at start of taxi-out with information on outside air temperature during a one year operation of all aircraft of the selected B767-300 / GE CF6-80C2A3 type.

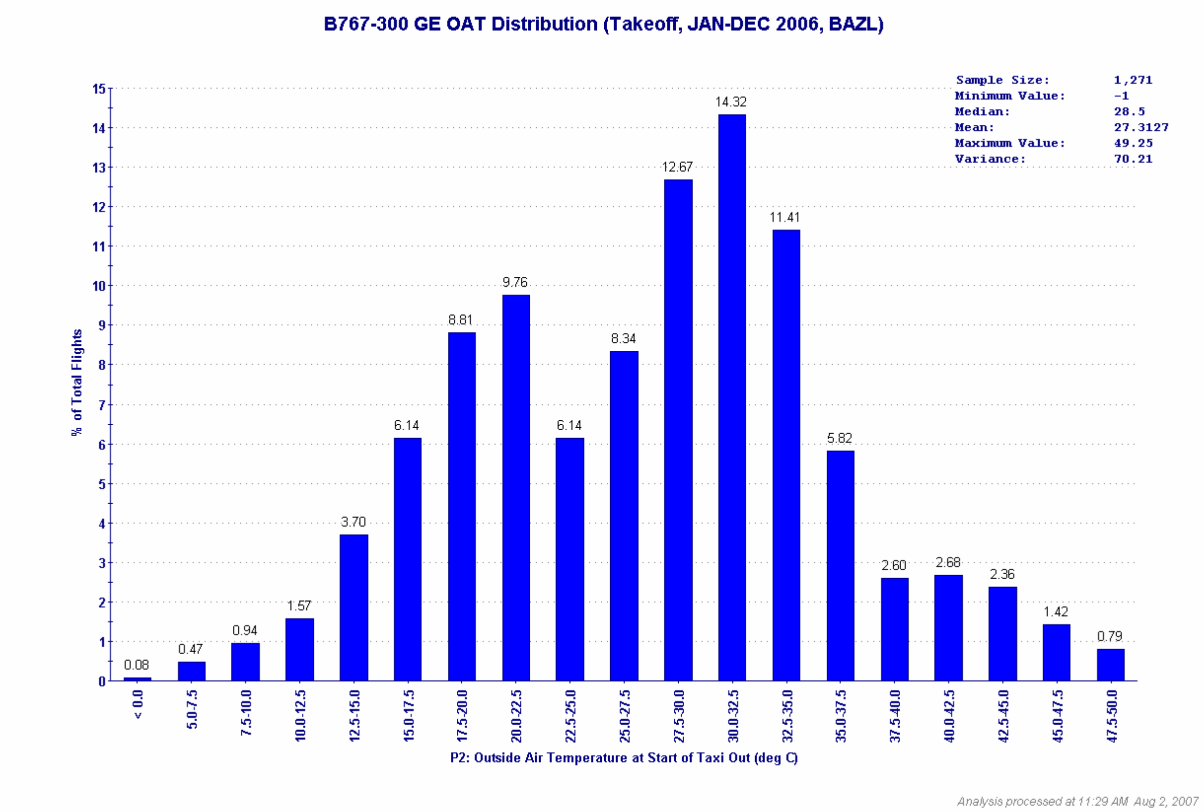


Figure 94: Example for FDR outside air temperature distribution at start of taxi-out during a one year operation of all aircraft of the selected B767-300 / GE CF6-80C2A3 type.

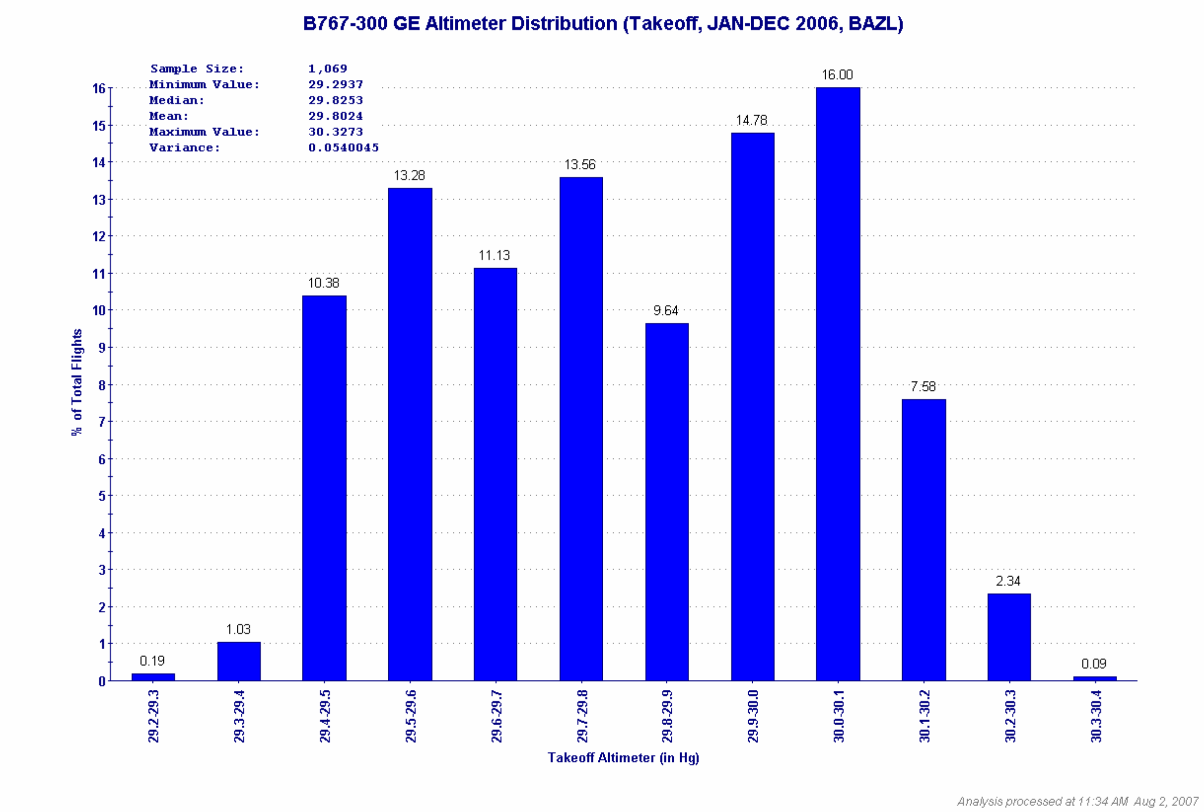


Figure 95: Example for FDR altimeter (QNH) distribution at start of taxi-out during a one year operation of all aircraft of the selected B767-300 / GE CF6-80C2A3 type.

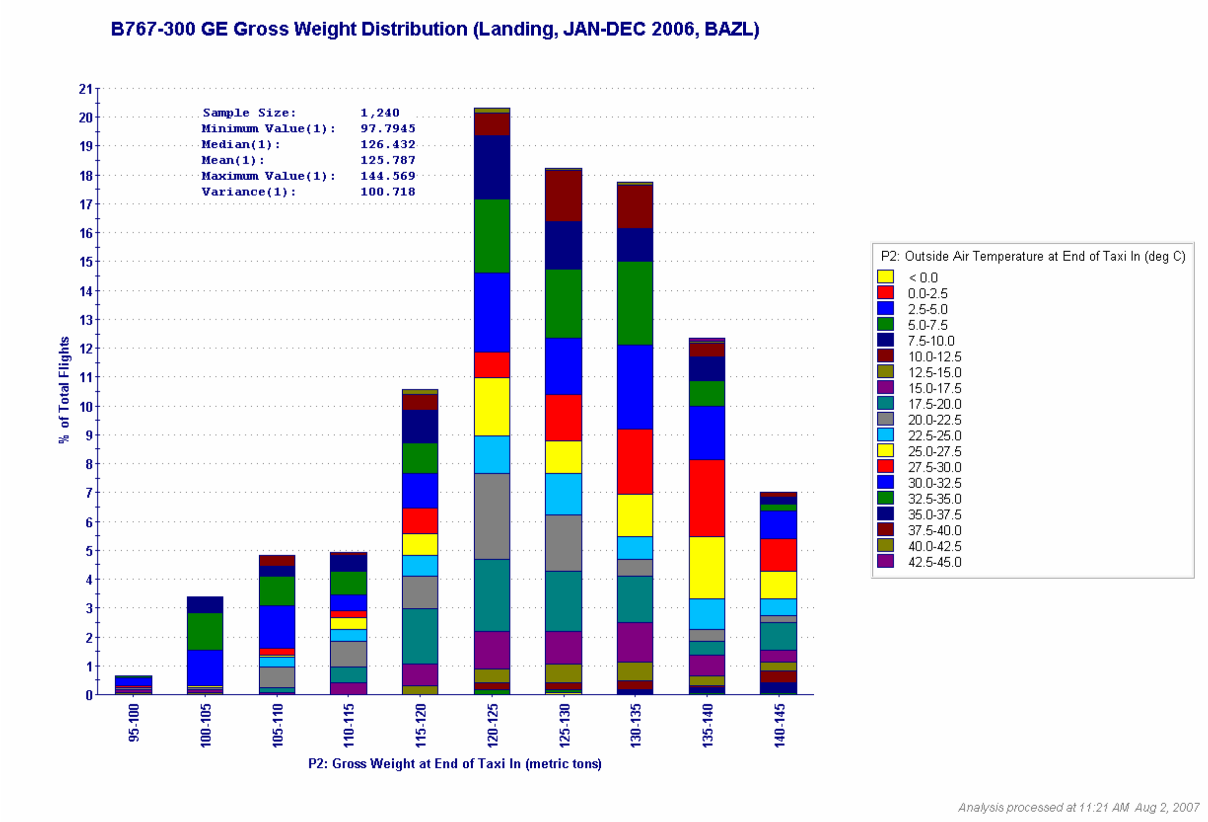


Figure 96: Example for a FDR gross weight distribution at end of taxi-in with information on outside air temperature during a one year operation of all aircraft of the selected B767-300 / GE CF6-80C2A3 type.

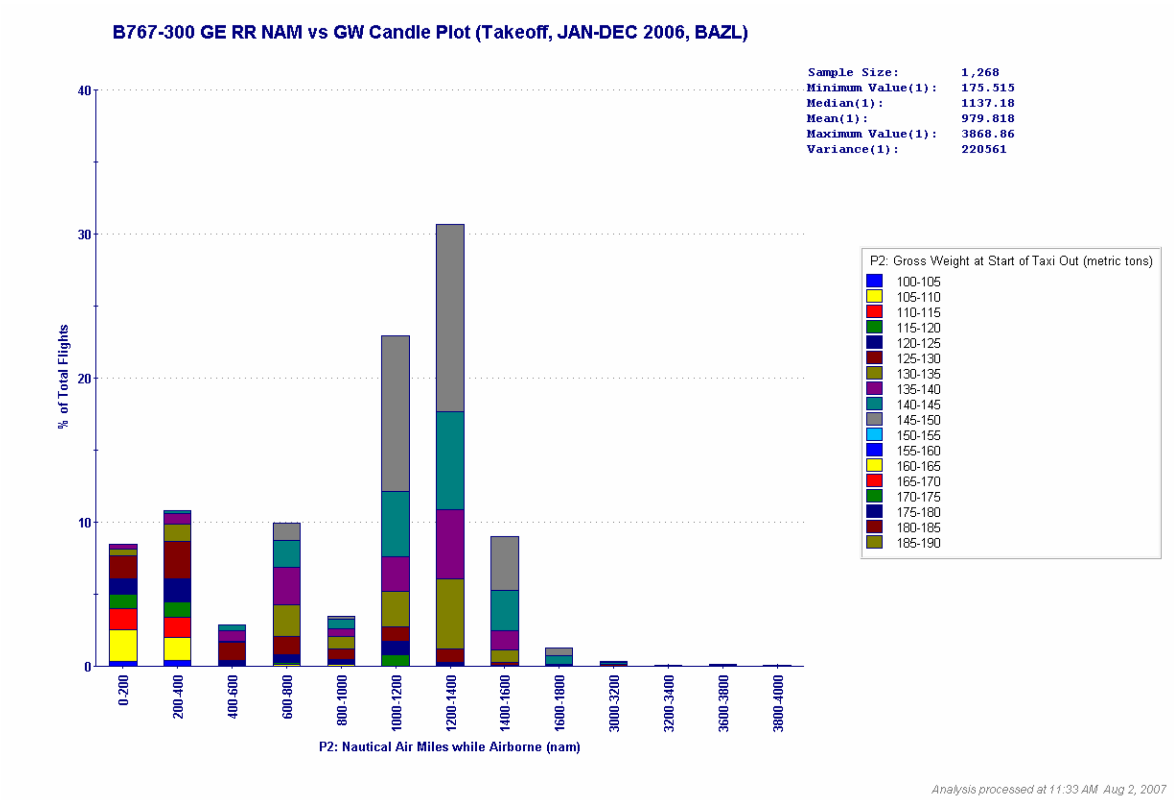


Figure 97: Example for a FDR nautical air miles distribution with information on gross weight at start of taxi-out during a one year operation of all aircraft of the selected B767-300 / GE CF6-80C2A3 type.

7) B777-300ER / GE90-110B1

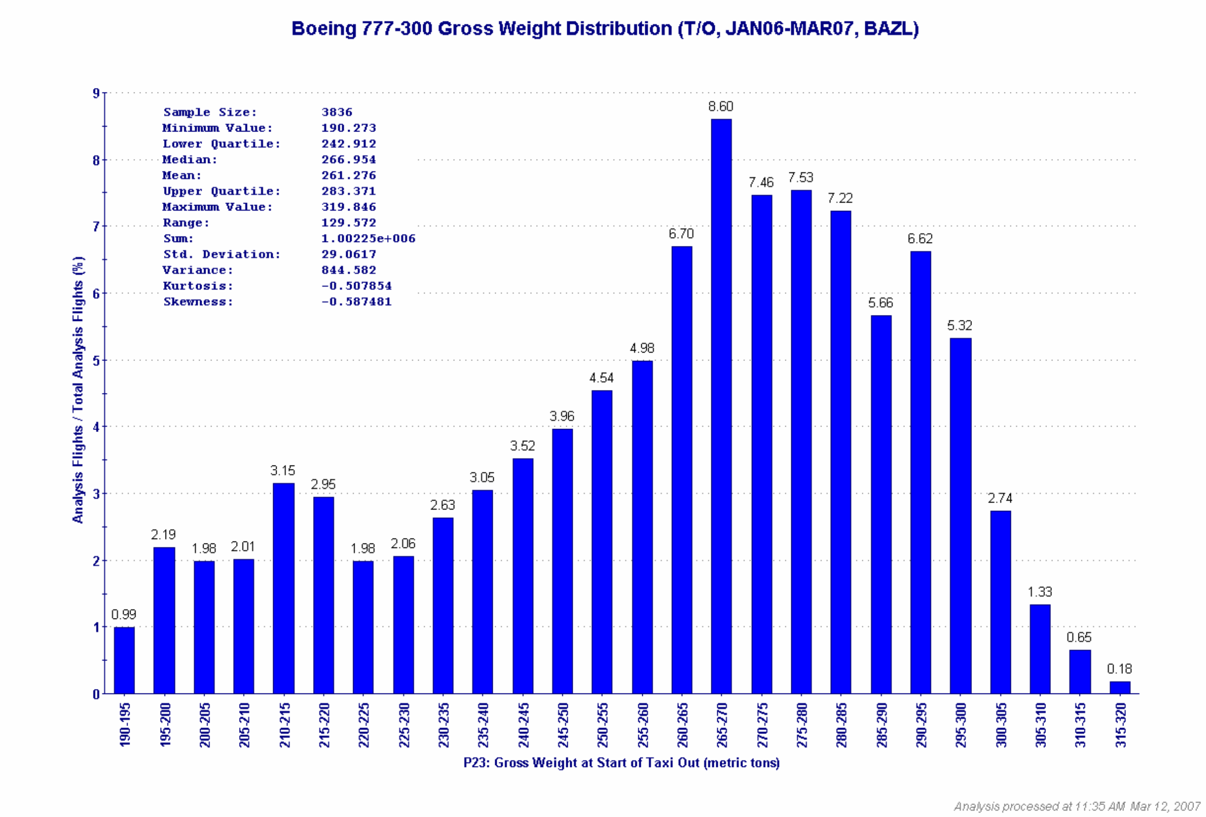


Figure 98: Example of FDR gross weight distribution at start of taxi-out during a one year operation of all aircraft of the selected B777-300ER / GE 90-110B1 type.

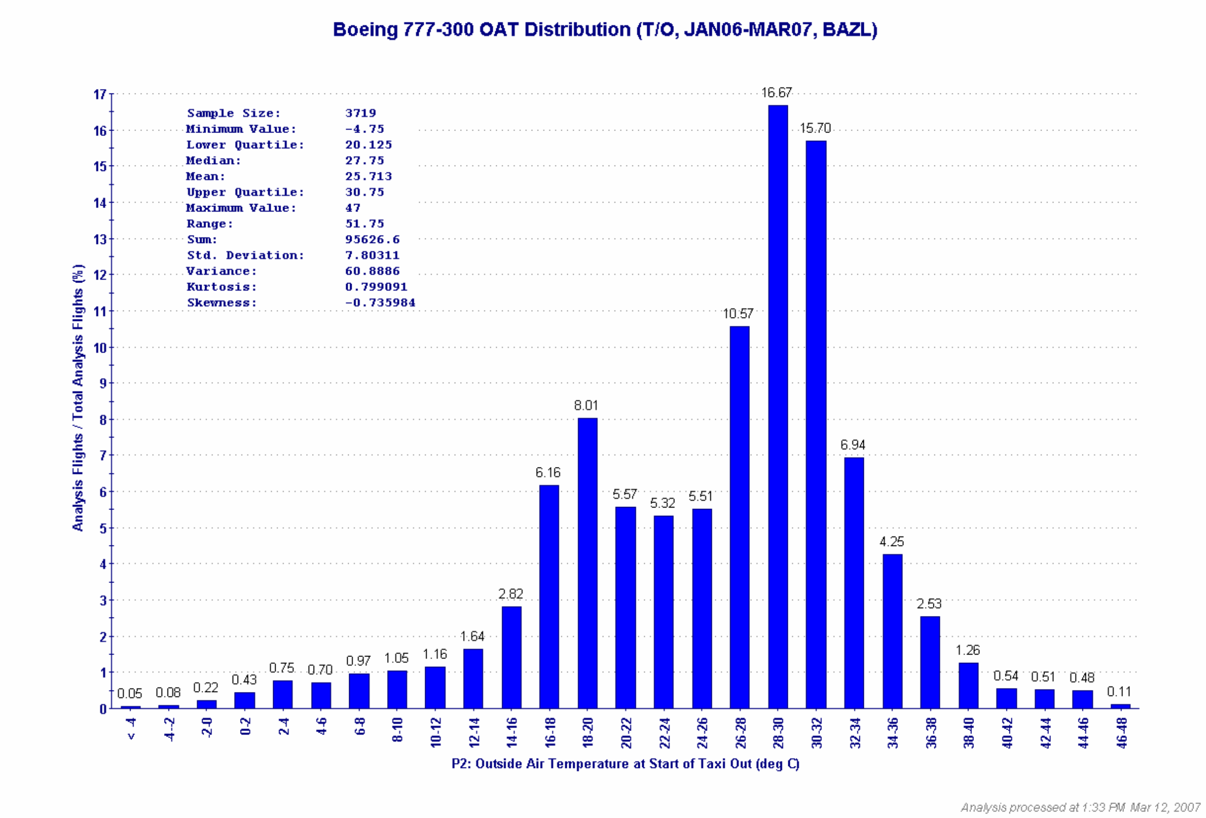


Figure 99: Example of FDR outside air temperature distribution at start of taxi-out during a one year operation of all aircraft of the selected B777-300ER / GE 90-110B1 type.

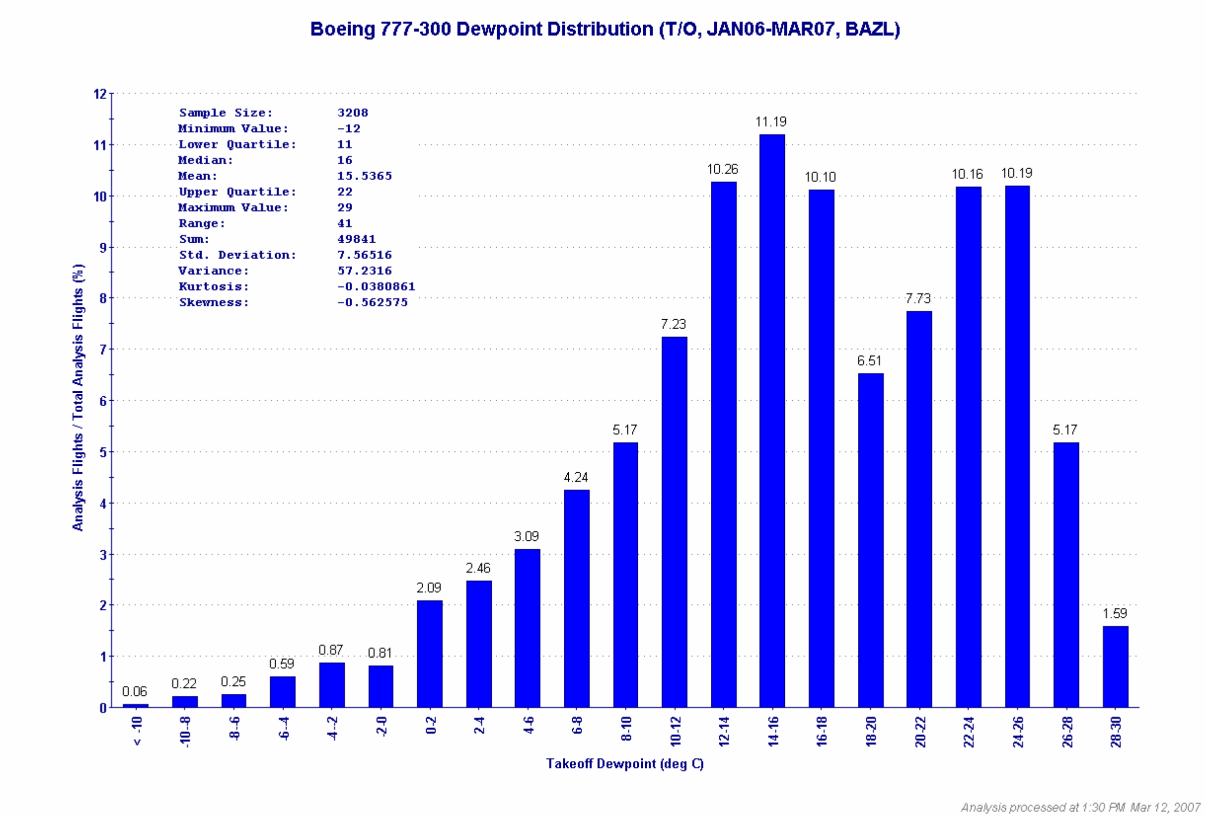


Figure 100: Example of FDR dew point distribution at start of taxi-out during a one year operation of all aircraft of the selected B777-300ER / GE 90-110B1 type.

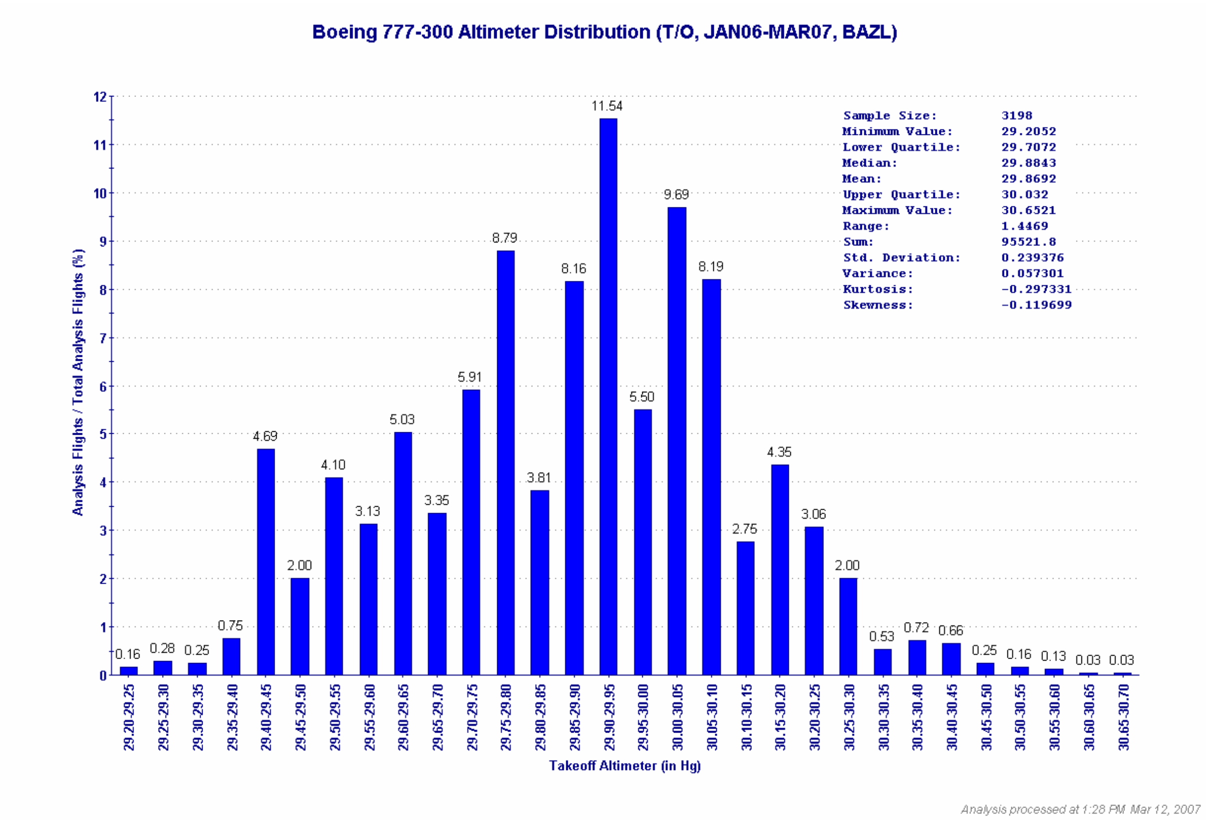


Figure 101: Example of FDR altimeter (QNH) distribution at start of taxi-out during a one year operation of all aircraft of the selected B777-300ER / GE 90-110B1 type.

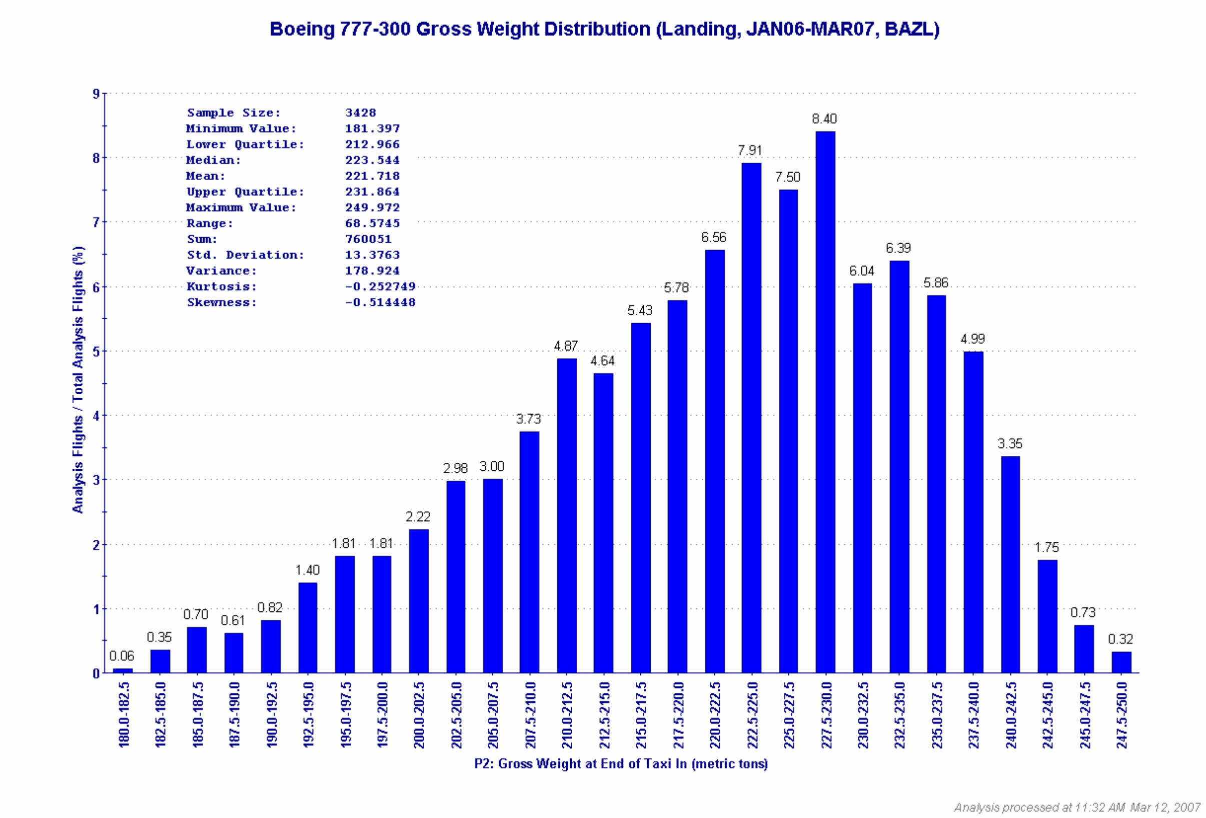


Figure 102: Example of FDR gross weight distribution at end of taxi-in during a one year operation of all aircraft of the selected B777-300ER / GE 90-110B1 type.

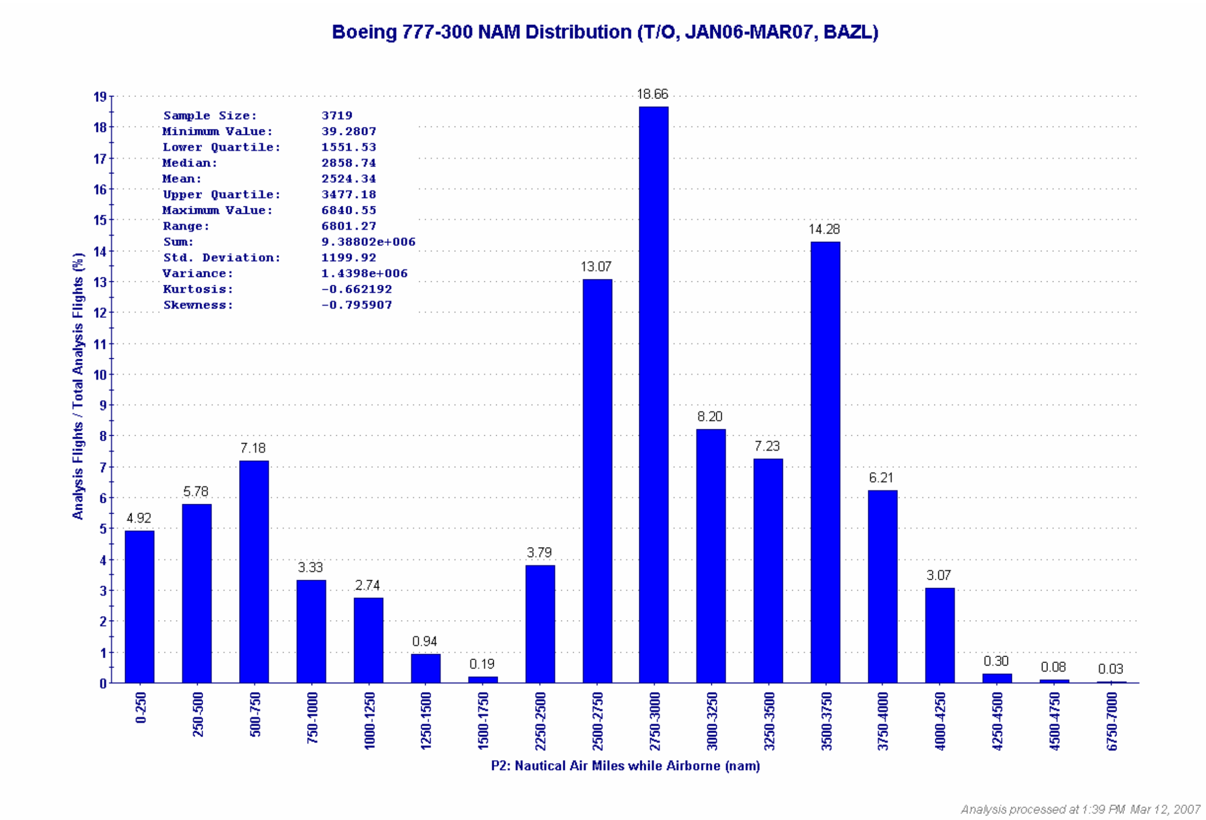


Figure 103: Example of FDR nautical air miles distribution during a one year operation of all aircraft of the selected B777-300ER / GE 90-110B1 type.