International Civil Aviation Organization

AFI PLANNING AND IMPLEMENTATION REGIONAL GROUP
SIXTEENTH MEETING (APIRG/16)
(Kigali, Rwanda 19-23 November 2007)

Agenda Item 3: Global and Inter-Regional Activities

3.3: Global Air Navigation Plan

ENVIRONMENTAL BENEFITS OF CNS/ATM SYSTEMS

(Presented by the Secretariat)

SUMMARY

This paper provides an update on the work of ICAO/CAEP and on methodologies for the assessment of the environmental benefits of CNS/ATM systems at the global and regional levels. It also discusses options for estimating environmental benefits of CNS/ATM systems at the national level.

Action by the APIRG/16 is in paragraph 5.

1. INTRODUCTION

1.1 General

1.1.1 The fourth meeting of the ALLPIRG Advisory Group (ALLPIRG/4) was presented with a working paper on the importance of taking environmental aspects into account while defining the CNS/ATM systems implementation strategies, and on the results of the fifth meeting of the Council Committee on Aviation Environmental Protection (CAEP/5) in this area. In its conclusion, ALLPIRG/4 requested that ICAO Regional Offices and PIRGS support ICAO/CAEP efforts to expand the methodology for quantification of CNS/ATM environmental benefits to other regions, providing the necessary data and that the global plan be updated accordingly.

1.1.2 In response to a request from the ALLPIRG/5 Meeting in March 2006, CAEP experts produced an updated paper on issues concerning environmental benefits of CNS/ATM systems (see Appendix) at the global and regional levels. It set out the possible development of simplified tools and associated guidance for estimating environmental benefits of CNS/ATM systems at the national level and provided initial “rules of thumb” for the conversion of saving in fuel into environmental benefits and estimates of savings accrue from the implementation of specific measures such as reduced vertical separation minimum (RVSM).

1.1.3 This paper reflects the information provided to ALLPIRG/5. in particular regarding the modelling activities and general “rules of thumb” for the estimate of environment savings related to fuel burn at the State level.

1.2 Environmental Background

1.2.1 Emissions from aviation come from the combustion of aviation gasoline and jet fuel. Like any device powered by a hydrocarbon-based fuel, aircraft emit carbon dioxide (CO_2) in direct proportion to fuel burn. Based upon our knowledge today an alternative fuel is not likely in the foreseeable future.

1.2.2 In the last few centuries, the activities of humans have directly or indirectly caused the concentration of the major greenhouse gases to increase. Scientists predict that this increase will enhance the greenhouse effect making the planet warmer. Of the number of gases involved in this process, CO_2 is believed to be the single most important as it accounts for about 55% of the change in the intensity of the Earth's greenhouse effect.

1.2.3 Although when compared to all sources, aviation is a relatively small direct contributor to greenhouse gas (GHG) emissions, attention is focused on aviation because of its historic growth rate and the projected future growth. In addition, as the majority of aviation emissions occur at higher altitudes (10-12 km), their relative contributions to climate change are commensurately increased due to other ensuing radioactive effects from, for example, contrails and enhanced cirrus clouds.

1.3 CAEP

1.3.1 The ICAO Committee on Aviation Environmental Protection (CAEP), is a Technical Committee of the Council. It is the international forum for the study and development of proposals to minimize aviation’s effect on the environment. The last Assembly declared that “ICAO is conscious of and will continue to take into account the adverse environmental impacts that may be related to civil aviation activity…. In carrying out its responsibilities ICAO will strive to… limit or reduce the impact of aviation greenhouse gas emissions on the global climate.” The Assembly also directed the Council to “regularly assess the present and future impact of aircraft noise and aircraft engine emissions…” and “disseminate information on the present and future impact of aircraft noise and aircraft engine emissions…”. Specifically with regard to aircraft communications, navigation, surveillance and air traffic management (CNS/ATM) systems, the Assembly recognized “that substantial fuel savings and emissions reductions can be achieved through improvements in Air Traffic Management (ATM)” and directed the Council “to continue to study policy options to limit or reduce the environmental impact of aircraft engine emissions and to develop concrete proposals…, placing special emphasis on the use of technical solutions….” (Assembly Resolution A35-5).

1.4 CNS/ATM

1.4.1 After labour, fuel represents the largest cost component in airlines’ operations. An effective and efficient way of reducing costs is to use less fuel, which has the added benefit of making a difference to the environment. For operational measures, emissions savings come from improvements in air traffic management and other operational procedures. The large majority of these reductions come from CNS/ATM systems implementation, which will allow more direct routings and more efficient conditions, such as optimum altitude and speed. Specifically, fuel consumption and emissions can be reduced by route improvements, altitude optimisation (drawing upon reduced vertical separation minimum (RVSM)), gate to gate efficiency in ground/air management, approach and departure procedures and other factors. Information on these measures has been disseminated through workshops and is explained in ICAO Circular 303, *Operational Opportunities to Minimize Fuel Use and Reduce Emissions*.

1.4.2 Building on Circular 303, an elementary theoretical calculation was made (ICCAIA[1]-February 2006) broadly comparing ATM improvements, which would benefit the entire fleet, versus aircraft technology improvements applied to part of the fleet. The analysis found that the shorter lead-time for introduction of ATM improvements and quicker penetration to benefit all operations resulted in a clear advantage for ATM system improvements. Assuming the same percentage (purely hypothetical) reduction in fuel consumption from both ATM and aircraft technology changes, the study found that between a given improvement in aircraft technology and one of the same magnitude in ATM, there may be a significant difference in cumulative fuel burn reduction effect due to a more rapid deployment potential for the latter (factor higher than three mentioned in ICCAIA-Feb 2006, as a result of a very simplistic simulation). It can be noted that this analysis was not meant to undermine the importance of aircraft technological progress, rather its intent was to increase awareness and encourage advances towards the most efficient systems approaches fostering homogeneous and consistent development of capabilities relative to ATM and aircraft, ground and airborne systems.

2. EMISSIONS CALCULATION

2.1 Calculation of aviation emissions is dependent on: the number and type of aircraft operations; the type and efficiency of the aircraft engines; the type of fuel used; the length of flight; the power setting; the time spent at each stage of flight; and to a relatively lesser degree, the location (altitude) at which exhaust gases are emitted. For CNS/ATM benefit analyses, it is necessary to have data that can reflect the operational changes.

2.2 Depending on the need, there are different levels of analysis possible: order of magnitude, simple consideration of CO_2 based on fuel burn (rules of thumb), detailed modeling of all emissions parameters, and variations in between. However, not all methods of calculating fuel burn and emissions provide the specificity necessary to calculate the benefits from implementing changes to air traffic management systems. The following is a discussion of the various analysis options and their potential usefulness in assessing the benefits of implementing CNS/ATM systems. As with any assessment, before the outputs can be used with confidence, it is necessary to consider documented inputs, assumptions and methodology.

2.3 Various entities have considered the emissions benefits of implementing CNS/ATM systems based on an order of magnitude assessment (rules of thumb). This type of assessment makes assumptions on the scale of improvements that would come from the implementation of specific ATM system changes. One example that includes this type of analysis is the November 2000 NLR report for IATA entitled *"Operational measures to improve aircraft fuel efficiency and reduce emissions"* (NLR-CR-2000-332). The appropriateness of using an order of magnitude assessment is dependant on the quality of the base data and assumptions, as well as consideration of how the results will be used. With accurate based data and appropriately considered assumptions, an order of magnitude assessment can produce results sufficient for many general information purposes.

2.4 Initiated in 1999, ICAO CAEP conducted a parametric analysis to estimate the emissions benefits of implementing CNS/ATM systems. The study looked at many types of CNS/ATM systems enhancements, including: route network optimization through reduced separations, airspace management

[1] ICCAIA - International Coordinating Council of Aerospace Industries Associations

and civil/military coordination, collaborative flight planning and re-routing, strategic capacity management, reduced vertical separation minima (RVSM) and wind-optimized direct routes resulting in shorter cruise times. The scope of the initial study covered baseline and optimized scenarios for the years 1999, 2007, 2010 and 2015. A baseline scenario was established that showed the case without CNS/ATM initiatives, but with non CNS/ATM measures such as an additional runway or aircraft engine improvements included. Then, an optimized scenario was developed that incorporated planned CNS/ATM measures as well as the non CNS/ATM measures included in the baseline scenario. Additional information regarding this study and its results can be found in the Global Plan Appendix H, CAEP/5-WP/18 and in: http://www.faa.gov/opsresearch/Emissions/Emissions_121800_Main.pdf.

2.5 Currently CAEP is accessing the use of more sophisticated models for the calculation of aircraft engine emissions throughout the flight path and at global and regional levels. While these models calculate fuel from the entire flight trajectory not all models might be suitable for estimating emissions benefits of implementing CNS/ATM systems. The distinction on usefulness for CNS/ATM analysis typically is the ability to capture the difference in flight trajectory before and after implementation. The three models currently under consideration by CAEP are: AEM, AERO2K and SAGE. Given the appropriate inputs, each of these tools is capable of analyzing the emissions benefits of implementing CNS/ATM systems. Additional information on these tools is available from the following organizations and websites.

a) AEM (Advanced Emission Model) – EUROCONTROL, http://www.eurocontrol.int/eec/public/standard_page/SEE_2004_report_4.html;

b) AERO2K –European Commission, http://www.cate.mmu.ac.uk/aero2k.asp;

c) SAGE – U.S. Federal Aviation Administration, http://www.faa.gov/about/office_org/headquarters_offices/aep/models/sage/.

3. GUIDELINES TO STATES FOR ASSESSING BENEFITS

3.1 While the section above describes an extensive list of aviation emissions calculation methods and studies, this section provides practical information as requested by the PIRGS, on generic “rules of thumb” that can be used by States to estimate the emissions benefits of implementing CNS/ATM systems. Which method to use will depend on the level of detail and accuracy needed for the outputs, and the nature of available input information.

3.2 ***Fuel to emissions conversion*** – When fuel consumption (fuel burn) data are available that show the change from base-case to CNS/ATM system implementation, the most direct assessment of GHG emissions is to use the following CO_2 conversion factor; namely, 3.16 kg CO_2/kg of fuel.

$$CO_2 \text{ Emissions} = \text{Aviation Fuel Consumption} \cdot 3.16$$

Given the global nature of the aviation industry and the tight specification of fuels used, this emissions factor is applicable worldwide and is the basis of the IPCC[2] Tier 1 method (based on total fuel sold). The accuracy of results of using this method is almost entirely dependent on the accuracy of the fuel consumption data.

[2] Intergovernmental Panel on Climate Change.

3.3 ***Rules of thumb*** – To gain a "first-order estimate" of the environmental benefits of potential CNS/ATM changes in order to assess which options to carry forward, a less accurate, rough-and-ready method may be all that is necessary. Statistics relating to fuel burn and emissions are critically dependent on aircraft and engine types, operating procedures, air traffic management constraints, passenger and cargo loading, maintenance procedures, fleet utilisation and other factors. Without more detailed analysis, it is impossible to be specific about the performance of any particular aircraft or airline. **The first order approximation approach used is therefore only intended to provide broad-based information for very general planning and assessment purposes.** The three general estimates provided below are based on common statistics and assumptions and were provided by IATA/ICCAIA. These may be applied more broadly as a "rule of thumb" to obtain order of magnitude estimates[3]:

Average fuel burn per minute of flight = 49 kg

Average fuel burn per nautical mile (NM) of flight = 11 kg

Average additional fuel burn for a change in flight level (FL)[4]: see Table 1

Table 1 – First-order estimates of average fuel burn penalties for changes in flight level compared to an assumed optimum altitude

FL change	Average S.R.* penalty	Average fuel burn penalty	Average fuel burn penalty per hour**	Average fuel burn penalty per 100 NM
ft	%	%	kg	kg
-6000	9,1	10,0	301	110
-5000	6,5	7,0	209	77
-4000	4,5	4,7	141	52
-3000	3,0	3,1	92	34
-2000	1,5	1,5	45	17
-1000	0,5	0,5	15	6
0	0,0	0,0	0	0
1000	0,5	0,5	15	6
2000	1,6	1,6	47	18

*S.R. = Specific Range = distance flown per unit weight of fuel burned ** time-corrected

The average range in fuel burn increase mentioned in ICAO Circular 303[5] is generally in line with the estimated percentages shown in Table 1. It must be noted that the numbers in Table 1 are based on the approximate assumption that the cruise phase of the flight is on average representative of the entire flight, when making fuel burn penalty estimations.

3.4 ***Detailed modeling*** – This method is appropriate when accuracy is essential; however, it is resource intensive and relatively complex. This methodology is distinguished by the calculation of fuel burn and emissions throughout the full trajectory of each flight segment using aircraft and engine-specific aerodynamic performance information. To use this methodology (IPCC Tier 3B), sophisticated computer models are required to address all the equipment, performance and trajectory variables and calculations for all flights in a given year. Models used for Tier 3B level can generally specify output in terms of aircraft, engine, airport, region, and global totals, as well as by latitude, longitude, altitude and time, for fuel burn and emissions of carbon dioxide (CO_2), carbon monoxide (CO), unburned hydrocarbons (HC),

[3] Please see Attachment 1 for more details about how these estimates were derived
[4] In order to minimise fuel burn, an aircraft should be flown at its optimum altitude. In reality, the optimum altitude changes during flight. In this table, the flight level change is relative to the optimum altitude (referred to as zero ("0"))
[5] *Operational Opportunities to Minimize Fuel Use and Reduce Emissions* (February 2004), page 78, paragraph 10.4.

nitrogen oxides (NO_x), water (H_2O), and sulfur oxides (SO_x calculated as sulfur dioxide, SO_2). Examples of these tools are listed in section 2.5 above.

4. NEXT STEPS

4.1 Regional planning groups are asked to take environmental factors into consideration when developing CNS/ATM systems implementation plans.

4.2 The results of environmental analysis can be useful in providing national decision-makers within the various regions with information upon which to base airspace architecture decisions and in providing information on what the aviation industry is doing now to protect the environment in the future.

4.3 Whether CAEP undertakes assessments will be dependant on availability of data and resources. CAEP continues to be open to the receipt of the necessary operational data to support the assessment of the environmental benefits of CNS/ATM, in all of ICAO's regions, while utilizing available modeling tools harmonized data sets and methodologies for assessing CNS/ATM. In order to expand prior analysis work to represent a worldwide result, CAEP issued State letter AN 1/17-03/86 (29-August-2003), *Data Collection for a Study on the Environmental Benefits of CNS/ATM*, initiating an effort to gather information on CNS/ATM systems initiatives in other regions of the world. Unfortunately, very little data resulted from this request and, thus, the planned global analysis could not be performed.

4.4 ICAO is exploring the necessary steps for the inclusion of environmental considerations in the business cases. Valuable information on the environmental benefits of operational measures including ATM were provided in the Colloquium on Aviation Emissions, held in Montreal from 14 to16 May 2006. The presentations and videos of the various sessions of the Colloquium are available at http://www.icao.int/EnvClq/Clq07/Documentation.htm . Efforts have started in the ICAO Secretariat to develop a programme to establish potential fuel-burn/emissions reduction targets to be achieved in various ICAO regions in the upcoming years. The support of CAEP and the PIRGs will be paramount in progressing in this task.

4.5 Due to the growth of air traffic, increasing public pressure for the reduction of aviation related CO_2 emissions can be expected in the coming years. ICAO has a leading role in promoting the implementation of measures to minimize or reduce the impact of aviation emissions on climate, and needs to ensure that all measures taken to improve the efficiency of air transport are monitored and reported in terms of environmental savings. ICAO is currently taking the necessary steps to facilitate the reporting of voluntary measures to reduce aviation emissions.

5. ACTION BY APIRG/16

5.1 The meeting is invited to:

a) note the information provided in this paper; and

b) invite States to harmonize their assessments by adopting the rules and guidance provided by CAEP, and in particular the CO_2 conversion factor in analyses of environmental benefits of implementing CNS/ATM enhancements;

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APPENDIX

CALCULATIONS BEHIND THE FIRST-ORDER ESTIMATES GIVEN IN SECTION 3.3

1. *Average fuel burn per minute of flight* = 49 kg

This number is derived by dividing the total JET A1 consumption (55 billion USG) by the total of minutes flown (3.4 billion) by all airlines (scheduled and non-scheduled) as per IATA statistics for 2005[1]. For the conversion from USG to kg fuel a factor 3.0265 (3.7831 * 0.8) was used.

2. *Average fuel burn per nautical mile of flight* = 11 kg

This number is derived from dividing the total JET A1 consumption (55 billion USG) by the total of kilometers flown (27.9 billion) by all airlines, (scheduled and non-scheduled) as per IATA statistics for 2005.
For converting km into NM, the definition: 1NM= 1.852 km was used.

3. *Average additional fuel burn for a change in flight level* (FL)

3.1 General approach followed

The fuel penalties resulting from deviations from an assumed optimum altitude are based on average specific range penalties estimations made by Airbus and Boeing, complemented by a short ICCAIA study (ICCAIA-March 2006). The original figures appear in *"Getting to grips with fuel economy"*, issue 3 – July 2004 by Airbus (page 39) and "*Fuel Conservation*" – November 2004 by Boeing (page 41). The principle of the ICCAIA study is outlined in the next two paragraphs. The results are shown in Table 1 and in fig. 1,2 and 3.
It is important to note that all estimations used and corrections made to derive fuel burn penalties, are based on data applicable to the cruise part of the flights and then applied to the overall average fuel consumed over entire flights, which is valid only as a first order approximation, considering that the cruise portion of the flight is the most significant in terms of fuel consumption.

3.2 Derivation of a fuel burn penalty from a specific range penalty

Posing by definition of specific range: $S = D/F$ (D = distance in NM, F = Fuel burn in kg)
For the optimum-altitude case: $So = D/Fo$ hence $Fo = D/So$
For the penalized case (non-optimum-altitude): $Sp = D/Fp$ hence $Fp = D/Sp$
The fuel penalty in % is: $\Delta F/F = 100*(Fp-Fo)/Fo = 100*(D/Sp - D/So)*So/D$
➔ $\Delta F/F = 100*(So - Sp)/Sp$
The specific range penalty by definition is: $\Delta S/S = 100*(So - Sp)/So$
(input in the calculation, coming from the Boeing and Airbus reference data) in %
Hence:

$$\boxed{\Delta F/F = 100*(\Delta S/S)/(100-\Delta S/S)}$$

correctly expressed in algebraic terms: $\boxed{\Delta F/F = -100*(\Delta S/S)/(100+\Delta S/S)}$

[1] Typically, IATA statistics come from in-house analysis using complementary data from ICAO , OAG, IEA, Eurocontrol, FAA, Boeing, Airbus and others.

with ΔS<0 for a penalty.

This explains why: |ΔF /F|>|ΔS/S|

Example: deviation altitude -6000ft ➔ ΔS/S = -9.1 (%) ➔ ΔF/F = +10.0 (%) ➔ fuel penalty per hour, not time-corrected: 49*60*0.1 = 294 kg

3.3 Speed / Time correction corresponding to an altitude deviation

A time variation Δt/t can be easily derived from a the speed variation, based on v = D/t, or t = D/v

We find: **Δt/t = - 100 (Δv/v)/(100+(Δv/v))** **in % (1) with Δv/v in %**

The corrected fuel burn penalty in kg per hour is calculated as:

ΔF' = ΔF * t/tc where ΔF is the non-corrected fuel penalty and tc is the corrected time

tc = t * (1+(Δt/t)/100)

➔ **ΔF' = ΔF/(1+(Δt/t)/100)** **(2) with Δt/t in %**

Combining then (1) and (2), we obtain:

ΔF' = ΔF*(1+(Δv/v)/100) **(3) with Δv/v in %**

(All formulae above to be used algebraically)

The speed (v) variation (Δv) corresponding to the ambient static temperature (Tamb) change, from $Tamb_1$ to $Tamb_2$, associated with an altitude Z change from Z_1 to Z_2, is calculated as follows:

By definition, True air speed =v = $M_n\sqrt{}$ (gam*R*Tamb) in $m.s^{-1}$ where: M_n = Mach Number (assumed constant in the estimation of the flight level change effect);
gam and R are thermodynamic constants (gam = 1.4 ; R= 287.053 in SI units)

Δv/v = 100 $(v_2-v_1)/v_1$ = 100 (√ (gam*R*$Tamb_2$ - √ (gam*R*$Tamb_1$))/ √ (gam*R*$Tamb_1$) (in %)

➔ Δv/v = 100 (√(288.15-1.9812*Z_2)/(288.15-1.9812*Z_1)) -1 if Z is the altitude in kft
(standard atmosphere, Z<11000 m or Z<36089 ft)

Example:

- Considering an altitude deviation of –2000ft from an assumed optimum FL 330 (33000 ft) to FL 310 (31000 ft):

For Z_1 = 33kft: $Tamb_1$ =222.77 °K (standard atmosphere) and for Z_2 = 31kft: $Tamb_2$ = 226.73 °K (std. atm.).

Hence: ➔ Δv/v ~ 0.885 % for -2000 ft change
➔ ΔF' = ΔF*(1.00885) = 45*1.00885 = 45 kg (no significant change)

For a -6000 ft deviation from FL330 to FL 270: $Tamb_2$ = 234.66 °K
➔Δv/v = 100 √($Tamb_2$/$Tamb_1$) –1 = 2.63%
➔ ΔF' = ΔF*(1.0263) = 294*1.0263 = 301 kg

Table 1 – First-order estimates of average fuel burn penalties for changes in flight level compared to an assumed optimum altitude				
FL change	**Average S.R.* penalty**	**Average fuel burn penalty**	**Average fuel burn penalty per hour****	**Average fuel burn penalty per 100 NM**
ft	**%**	**%**	**kg**	**kg**
-6000	9,1	10,0	301	110
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-4000	4,5	4,7	141	52
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-2000	1,5	1,5	45	17
-1000	0,5	0,5	15	6
0	0,0	0,0	0	0
1000	0,5	0,5	15	6
2000	1,6	1,6	47	18

*S.R. = Specific Range = distance flown per unit weight of fuel burned ** time-corrected

First-order approximation

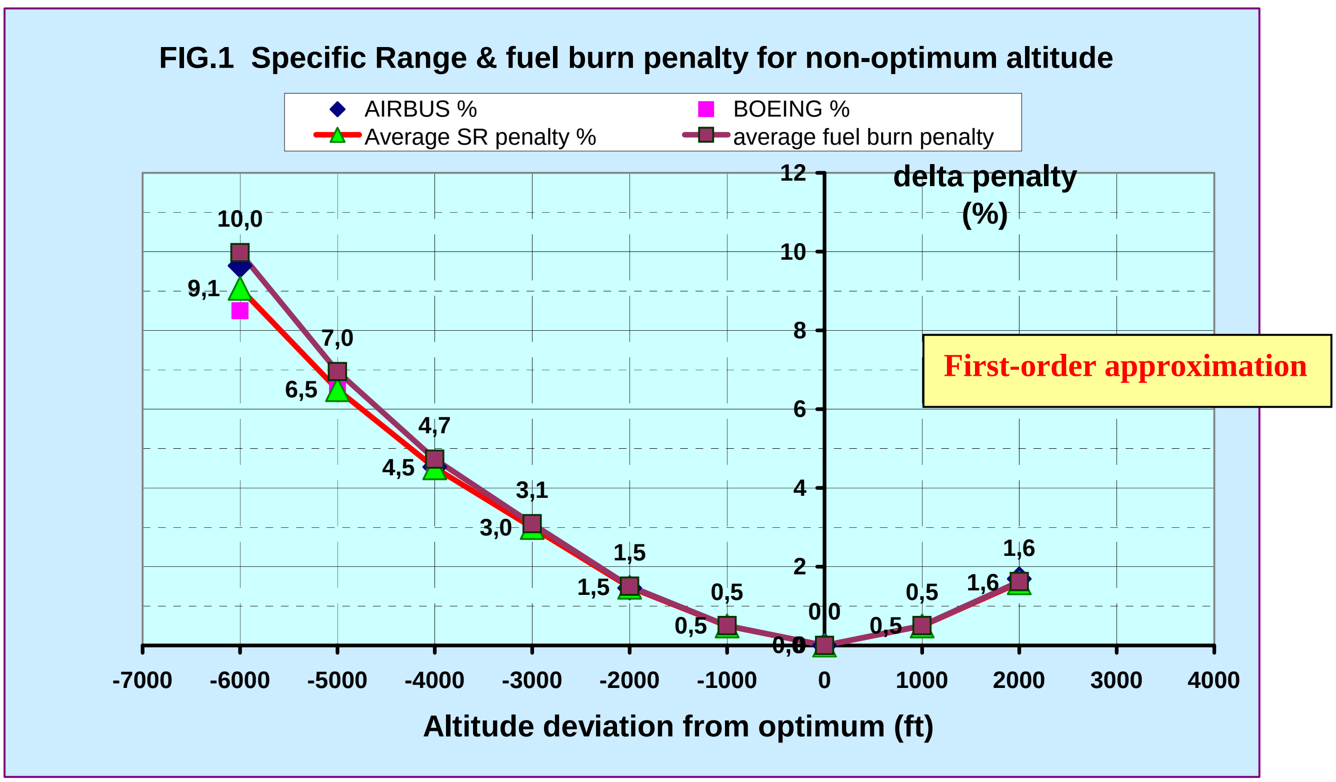


FIG.2 Average fuel burn penalty /hr (kg)

time-corrected

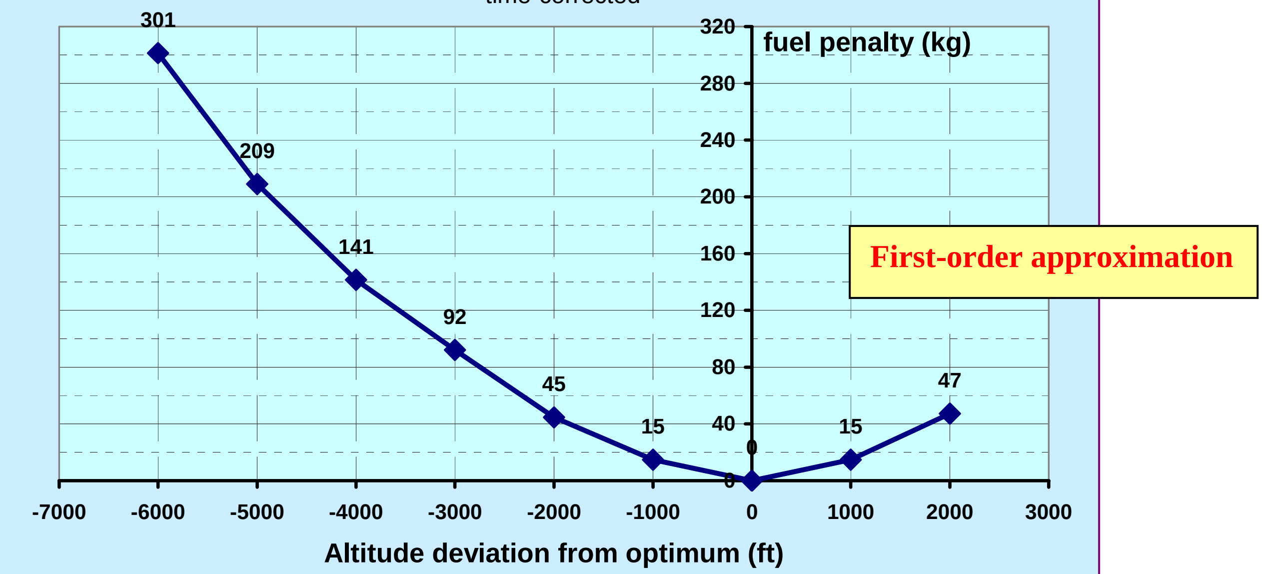
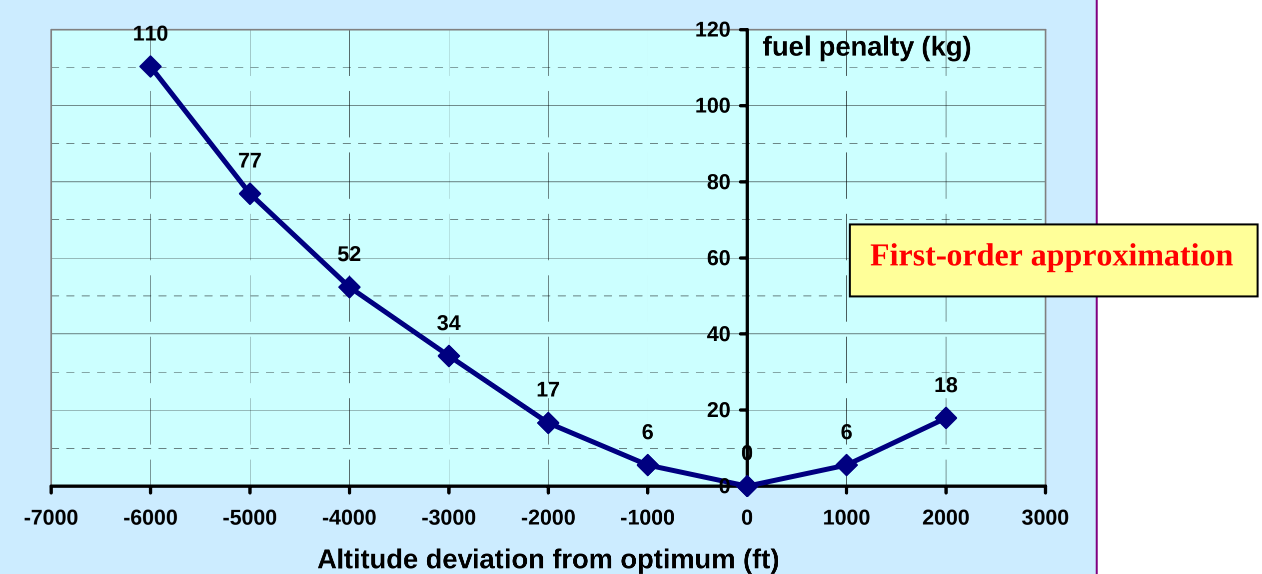


FIG.3 Average fuel burn penalty /100Nm (kg)



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