Regulatory Impact Assessment

For the Introduction of a

Flammability Reduction System

David Gibbons, JAA FTS coordinator

Laurent Gruz, PPSG chairman

Contents table

List of acronyms

ACJ	Advisory Circular Joint
AEA	Association of European Airlines
APU	Auxiliary Power Unit
ARAC	Aviation Rulemaking Advisory Committee
ASM	Air Separation Module
ATA	Air Transport Association
CAA	Civil Aviation Authority
CAST	Commercial Aviation Safety Team
CS	Certification Specification
CWT	Centre Wing Tank
DGAC	Direction Générale de l'Aviation Civile
EASA	European Aviation Safety Agency
ECAC	European Civil Aviation Conference
ECS	Environmental Control System
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation
FRS	Flammability Reduction System
FTHWG	Fuel Tank Harmonization Working Group
FTIHWG	Fuel Tank Inerting Harmonization Working Group
FTS	Fuel Tank Safety
GFI	Ground Fault Interrupter
IACA	International Air Carrier Association
INT/POL	Interim Policy
JAA	Joint Aviation Authorities
JSSI	Joint Safety Strategic Initiative
MMEL	Master Minimum Equipment List
NEA	Nitrogen-Enriched Air
NPA	Notice for Proposed Amendment
NPV	Net Present Value
NTSB	National Transport Safety Board
OEA	Oxygen-Enriched Air
OEM	Original Equipment Manufacturer
PPSG	Powerplant Study Group
RIA	Regulatory Impact Assessment
SB	Service Bulletin
SFAR	Special FAR
SFC	Specific Fuel Consumption
STC	Supplemental Type Certificate
TC	Type Certificate

Executive Summary

The purpose of this Regulatory Impact Assessment (RIA) is to evaluate, from a European perspective, the potential consequences of introducing Flammability Reduction System (FRS) on large transport airplanes featuring high flammability exposure fuel tanks. JAA/EASA tasked this RIA following the FAA Administrator press announcement made on 17th of February 2004 regarding the mandatory retrofit of a FRS. This would affect centre tanks on most of Airbus and Boeing products.

The Flammability Reduction System is based upon a concept proposed by the FAA, it derived from proposals made by an ARAC working group, the 2001 FTIHWG. It uses an Air Separation Module fed with engine bleed air to obtain nitrogen-enriched air, which is discharged into the fuel tank, thus reducing flammability.

The RIA was conducted according to the guidelines of NPA 11-2. The group was chaired by CAA-UK and DGAC-France personnel working on behalf of EASA. Technical information was provided by participants from both affected manufacturers as well as representatives of the airline industry and the FAA. Draft copies of the RIA were provided to the participants for their comments; however, the RIA text, conclusions and recommendations are those of the JAA/EASA team and are not necessarily shared by the other RIA participants.

Out of six options identified at the beginning of the process, two were reviewed in detail: a production cut-in (from 2008 all new production airframes would be required to be delivered with FRS) and a full retrofit starting in 2008 (in conjunction with a production cut-in) and ending in 2015.

Both options are in addition to ignition prevention measures already being adopted following JAA Recommendation 04/00/02/07/03-L024 or SFAR 88 reviews, for which it is estimated around 600 Million Euros will be required to be spent by the industry.

The period studied is 2004-2030. There are 11,000 affected aircraft in service today in the world, and assuming an annual fleet growth of 4%, there will be 13,000 aircraft in service in 2008 and 30,500 in 2030. A retrofit would address 11,600 airframes. Approximately one third of the world fleet is in Europe.

The safety benefit has been assessed using three scenarios: no action beyond ignition prevention measures, production cut-in, and full retrofit. With application of ignition prevention measures only, depending upon their effectiveness (25% to 75%), there will be between 4 and 12 accidents. With ignition prevention measures complemented by an FRS 2008 production cut-in, the number of accidents is reduced by between 2 and 5. Ignition prevention measures complemented by an FRS 2008 production cut-in combined with a full retrofit completed by 2015, the accidents are reduced by a further 1 to 4. Current predictions indicate there could be between 500 and 600 accidents due to other causes in the same period.

The cost of introducing a FRS has been evaluated from data provided by both manufacturers. For some figures (cost of installation and retrofit) there is a factor of up to 4 between them. Some attempt has been made to identify the reasons for the discrepancy but it is not possible to identify a definitive value for the real cost. It has therefore been decided to present calculations using both sets of data, giving a range of the potential costs. Non-recurring, production/retrofit and ownership costs have been taken into account, some other cost elements have been identified but could not be estimated accurately.

The production cut -in costs range from 11 Billion Euros to 25.7 Billion Euros (or a 2004 Net Present Value with a 10% discount of 1.9 Billion Euros to 4.7 Billion Euros). It should be noted that this cost is driven directly by the number of aircraft produced in the period under consideration. A shorter study period reduces the cost dramatically and vice versa. It should also be noted that much of the cost will be accounted into the price of a new aircraft, and is likely to be inseparable from that price in the later years of the study. A significant part of the production cut-in cost will, therefore, be amortised over the life of the airframe. In addition, the actual cost of an FRS may be slightly reduced, because no credit has been taken for improved FRS technologies or airplane configuration changes.

The retrofit costing ranges from 7.5 Billion Euros to 13.6 Billion Euros (or a 2004 Net Present Value with a 10% discount of 2.2 Billion Euros to 5.1 Billion Euros), to be added to the production cut-in cost.

Other elements of the RIA (sector impacted, harmonisation with FAA, impact on other aviation requirements outside of the EASA scope) have been reviewed. Environmental and social impacts have been identified, but are not significant.

A review of the accident record shows that fuel tank explosions are not a major cause of aviation accidents (statistically the percentage of both accidents and fatalities due to fuel tank explosions is approximately 1.2% over the last 20 years), and it has not been identified as such by either the CAST initiative or JSSI. The question must, therefore, be raised:- ***"Is committing the required level of resource on a single safety intervention justified?".***

On the basis of this RIA, it is considered that a production cut-in is justified, with regard to the safety benefit. It is, therefore, recommended that the necessary rulemaking be initiated, as quickly as possible, to require the introduction of FRS into all new production aircraft with high flammability fuel tanks by 2008. At this time, a full retrofit is not considered justified. The additional costs to industry (in addition to the production cut-in costs of FRS) are high when compared to the additional safety benefit in terms of hull losses prevented. However, in the absence of a case for mandating a full retrofit programme, further consideration could be given to a solution based on each affected manufacturer's position for their individual models.
.

1. Introduction & background

Following the accident to Flight 800, the influences on fuel tank safety have been widely discussed in recent years, to establish means by which fuel tank explosions can be prevented in future. The National Transportation Safety Board (NTSB) investigation into Trans World Airlines Flight 800 accident on 17th of July 1996, determined that the probable cause of the accident was an explosion of the centre wing fuel tank, resulting from ignition of the flammable fuel/air mixture in the tank. The NTSB recommendations were to eliminate the flammability exposure of the fuel/air mixture and to make improvements to the safety of specific fuel tank designs by reducing the probability of creating an ignition source within the tank.

1.1 Ignition prevention effort

The first step to address fuel tank safety was to reinforce the ignition prevention measures. This is in line with the design and certification approaches used since the early days of commercial aviation. It is taken a step further however by implementing the rigorous safety assessment tools to the ignition sources that may be present within the tanks.

In October 2000, the JAA issued an Interim Policy (INT/POL/25/12) on the subject of Fuel Tank Safety. This Interim Policy confirms that, for new Certification and Validation Projects, a Safety Assessment must be made of the ignition source probability, using the assessment methods of JAR 25.901(c) and JAR 25.1309. This Interim Policy will be used until related amendments are adopted in the relevant JAR or CS codes (for that purpose NPA 25 E-342 has been prepared).

In June 2001, the new FAA regulations related to fuel tank ignition prevention came into force. This requirement package includes new Fuel Tank Safety design requirements. New FAR 25.981(a), Amendment 25-102, includes a requirement for a demonstration that the probability of an ignition source meets specific Safety Objectives. In addition, SFAR No. 88 requires these Safety Objectives to be considered retrospectively by (most of) the current aircraft manufacturers, in performing a review of existing fuel tank system designs. To achieve that aim, the aircraft TC and STC holders are required to conduct a safety review of the airplane fuel tank system, to determine whether the design meets the requirements of FAR 25.901 and (new) 25.981(a) and (b), and to create a new airworthiness limitation section associated to fuel tank ignition prevention (FAR 25 Appendix H, new paragraph H25.4(a)(2). If the design does not meet these requirements, the TC or STC holder must develop design changes to the fuel tank system that are necessary to correct design issues determined by FAA to create unsafe conditions.

On 4th of March 2002 JAA issued a recommendation to National Authorities (JAA letter ref. 04/00/02/07/01-L296) on Fuel Tank Safety. This included a policy that was not harmonised with the SFAR-88 requirements. The Industry, including TC-holders, STC-holders and Operators had major concerns with the implementation of the stringent SFAR-88 requirements. As a result of that, the FAA had requested JAA to co-operate in order to come to a single solution set for the Manufacturers and Operators and to facilitate transfer of aeroplanes from country to country. As a consequence, a revised policy was released on 3rd of February 2003 (JAA letter ref.

04/00/02/07/03-L024). The FAA introduced a similar policy by a spot amendment to SFAR No. 88 and by policy memorandum.

The revised policy introduced a distinction between high and low flammability exposure tanks. For high flammability tanks, the criteria defining the need to introduce corrective actions were more stringent (the JAA interpretation remained JAR 25.1309 based, whereas FAA maintained in addition its 'latent + 1' approach, see FAA memorandum number 2003-112-15, 'SFAR 88 - Mandatory Action Decision Criteria'). The criteria used on other tanks is harmonised between JAA and FAA, and is based on the 'no single failure' concept and in-service findings.
The JAA letter and FAA memorandum included a 3-step criterion to determine the flammability exposure level of a fuel tank.

CS-25 should be modified in 2004 to incorporate the provisions of NPA 25 E-342 (see EASA rulemaking Work Programme for 2004). This NPA features INT/POL/25/12 material as well as considerations related to flammability (but does not address or require FRS introduction).

After reviewing safety assessment performed as per SFAR 88 and the corresponding JAA policy (04/00/02/07/03-L024), both JAA and FAA concluded that for high flammability exposure tanks a further safety enhancement might be needed.

1.2 Suppressing the flammable vapours

NTSB released the following recommendation in 1996:

A-96-174 (FAA) **Issued December 13, 1996** Require the development of and implementation of design or operational changes that will preclude the operation of transport category airplanes with explosive fuel-air mixtures in the fuel tank. Significant consideration should be given to the development of airplane design modifications, such as nitrogen-inerting systems and the modifications should apply to newly certificated airplanes and, where feasible, to existing airplanes. (Source: Letter of recommendation dated December 31, 1996; based on the *Investigation of the Trans World Airlines Flight 800 Crash near East Moriches, New York, on July 17, 1996)*

1.2.1 The Fuel Tank Harmonization Working Group (FTHWG - 'ARAC 1')

In 1998, in order to assess the feasibility of an inerting system on a large transport airplane, FAA tasked an ARAC Working Group, the Fuel Tank Harmonization Working Group, who submitted its final report in July 1998. It recommended, "the FAA/JAA pursue a cost effective approach to enhance fuel tank safety." This ARAC concluded that the technology for a practical and economically viable inerting system was not yet available, and that, at this stage, directed ventilation and ground inerting (filling the tank on the ground with nitrogen generated by airport equipment) "should be pursued to improve their cost effectiveness". The report recommended regulatory text for new design to limit flammability to a level equivalent to unheated wing tanks.

1.2.2 The Fuel Tank Inerting Harmonization Working Group (FTIHWG- 'ARAC 2')

In 2000, this second ARAC group was tasked by FAA to investigate several concepts: Ground Based Inerting, On-board Ground Based Inerting, On Board Inert Gas Generating Systems, and hybrids of those concepts. Its 2001 report concludes that no new regulatory text can be proposed because the working group was unable to identify any practical way of implementing the inerting designs studied. FTIHWG recommended further research should be undertaken by FAA, NASA and the industry in order to develop a practical concept.

1.2.3 FAA research and position

FAA undertook some research with the support of the FAA Atlantic City Technical Center. Initially, research focused on ground based inerting, using a Boeing 737-700 for flight evaluation and a Boeing 747-SP for ground testing.
Then the approach shifted toward On Board Inerting. The intention was to develop a simple system from the existing technology, tailored for civil aviation needs. Some of the FTHWG and FTIHWG work had been based upon military system designed for a zero flammability exposure. By recognizing that a 12% oxygen concentration precludes ignition with a pressure rise sufficient to damage aircraft structure, and minimizing (not eliminating) the exposure time to concentrations greater than 12%, in 2002 the FAA was able to propose a more realistic system concept.

This system concept was disclosed to the industry, and both affected OEMs (Airbus and Boeing) in the spring of 2002. The system concept was evaluated it in flight by both Airbus and Boeing during the 2003 summer, respectively on an Airbus A320 and a Boeing 747-400.

In the course of 2003, Boeing decided to propose this system on new production airplanes, and to make a similar system available for retrofit to in-service aircraft.

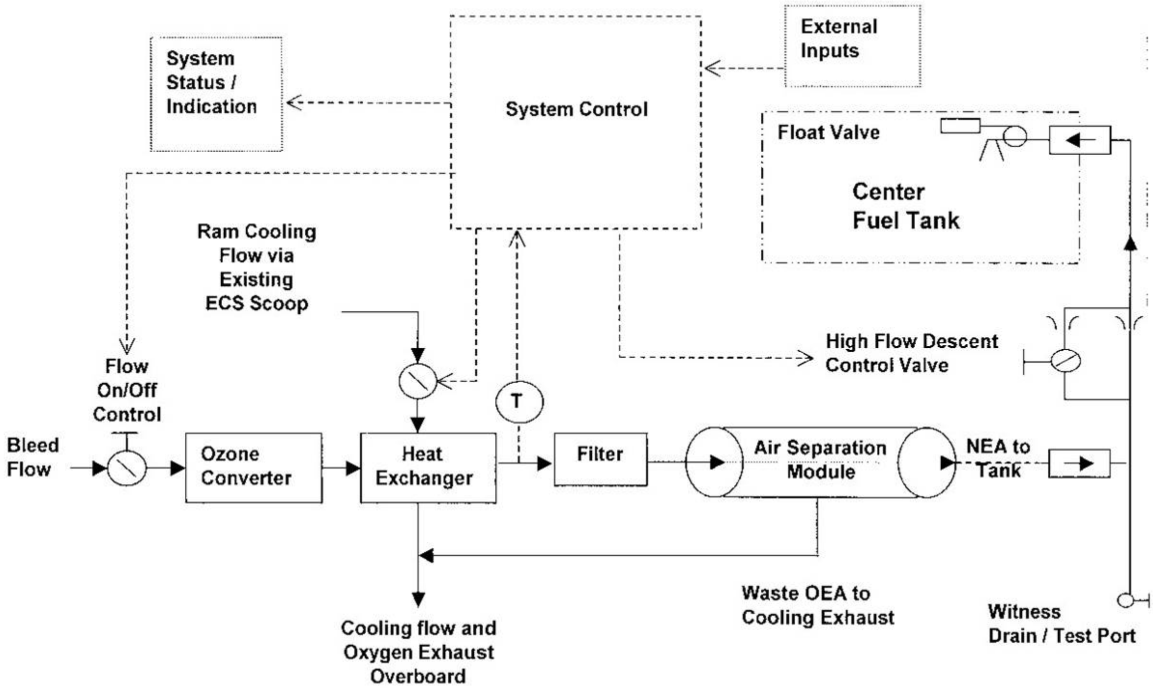

Fig. 1 Schematic of a Flammability Reduction System

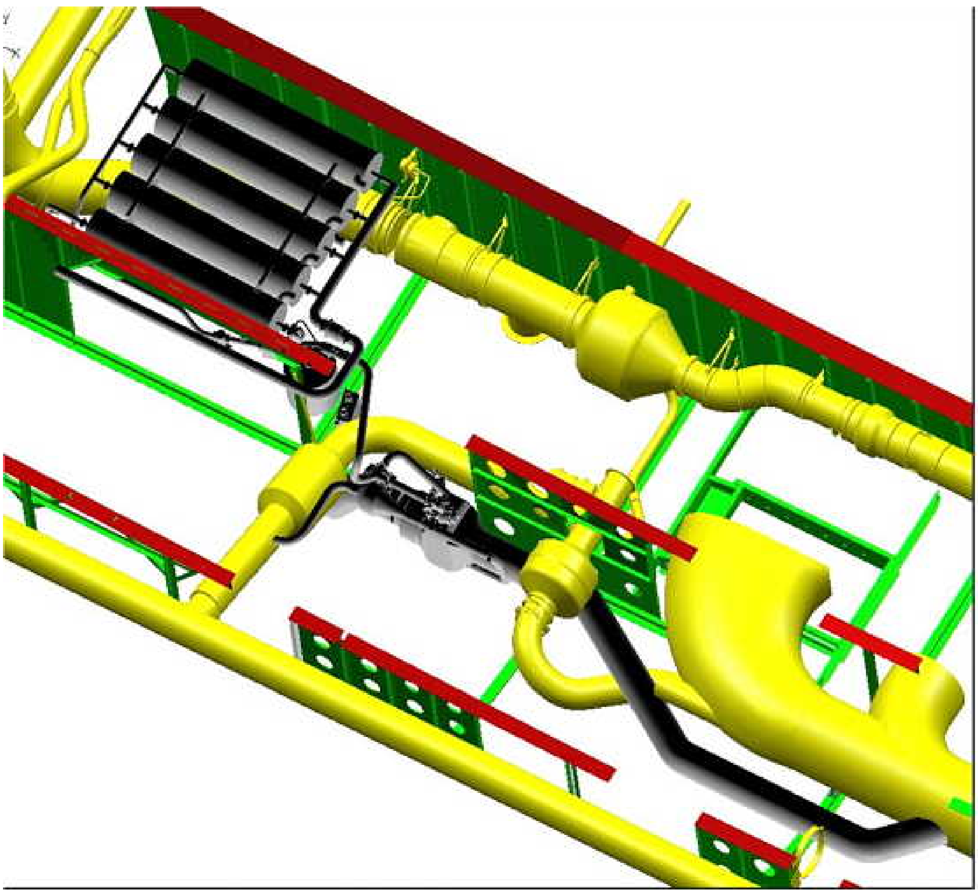

Fig. 2 Installation of a FRS on Boeing 747

Error!

On 17th February 2004, the FAA Administrator announced that the FAA intended to develop rulemaking that would propose requiring the introduction of flammability reduction measures on all affected large transport airplane. The press release also stated that the FAA proposal would also prompt a retrofit of 3,800 Airbus and Boeing airplanes (the US fleet) over 7 years.

1.2.4 Affected products

The criteria mentioned above and presented in JAA letter ref. 04/00/02/07/03-L024 was used to determine the exposure level of fuel tanks.

The following products have been shown to have fuel tanks, which have a high flammability exposure:

Centre Wing Tanks of the following models are considered high flammability:

- Boeing -707, -737, -747, -757, -767, -777, for their centre wing tanks, *
- Airbus A300/310, A320 family, A330/340, for their centre wing tanks,
- Plus auxiliary tanks on Boeing DC-10 and DC-9/MD-80, and STCs introducing unpressurised auxiliary tanks in cargo compartment.

* Boeing has declared the centre wing tanks on these types to be high flammability without providing the details of the average fleet exposure to high flammability. FAA has accepted this position, whereas EASA is still expecting quantified information. Based on qualitative data available, and knowledge of the main design features of the affected models, it is assumed that the exposure to flammability on Boeing products is likely to be higher than on Airbus products.

The FRS certification criteria have been published as a harmonized Special Condition between FAA and JAA.

2. Regulatory Impact Assessment

2.1 Introduction

The Regulatory Impact Assessment (RIA) is a new tool, which is being introduced into JAR-11 by NPA 11-2.

As per ACJ 11.065(b) NPA explanatory note requires consideration of:

- Sector affected,
- General issues,
- Safety impact,
- Economic impact,
- Harmonisation with FAA,
- Environmental impact,
- Social impact,
- Impact on other aviation requirements outside of the EASA scope.

Each of those items will be reviewed individually in § 2.4.

2.2 Organisation of the process

A Working Group was formed to provide technical information for the RIA, co-chaired by David Gibbons (CAA-UK, chairman of the FTS core group) and Laurent Gruz (DGAC-F, PPSG chairman).

Participation on the RIA Working Group was solicited from Authorities (JAA/EASA, FAA) and from the industry. Airbus, Boeing, the International Air Carrier Association (IACA) and the Association of European Airlines (AEA) attended. The participants provided basic technical and cost information for use in developing the RIA and were fully involved in the development of the RIA. Draft copies of the RIA were provided to the participants for their comments; however, the RIA text, conclusions and recommendations are those of the JAA/EASA team and are not necessarily shared by the other RIA participants.

An initial meeting was held on 7 and 8 April 2004 in Gatwick, JAA regulation director attended the first day to present the RIA methodology, a second and final meeting was held on 3rd of June 2004 in Paris.

2.3 General assumptions

A number of assumptions have been made in order to perform the RIA. These assumptions were agreed during the first meeting held early April in Gatwick and are detailed below.

2.3.1 Level of ignition prevention

The options described in the next paragraph are based on the introduction of the additional ignition prevention measures that have been defined and are in the process of being mandated (SFAR 88 / JAA Policy). This includes (but is not limited to):

- auto-shutdown of dry running pumps,
- GFI on uncovered pumps,
- additional metal conduit protections,
- additional maintenance actions and critical configuration control measures.
- all other type specific unsafe condition prevention measure.

Note 1: In addition to those modifications determined necessary by the JAA/EASA team, FAA have determined the latent plus one failures must be addressed for high flammability fuel tanks, unless flammability reduction means were mandated on both new production and retrofitted on the existing fleet. This would require incorporation of fuel quantity indicating system (FQIS) protection devices (e.g., transient protection devices) on most high flammability fuel tanks. The FAA cost estimate will adjust the cost of mandating flammability reduction means by deducting the cost of mandating FQIS protection devices. JAA INT/POL compliance would not require such devices.

Note 2: Ignition prevention measures are still, even with the incorporation of FRS, a fundamental element of fuel tank safety. Their definition and introduction should not be delayed.

2.3.2 Options available

The group envisaged the following options:

- Option 1: No additional action.
- Option 2: Production cut-in of flammability reduction measures.
- Option 3: Partial retrofit, based upon a model-by-model assessment, depending upon their individual risk exposure and in-service history. Note: Service History of a specific model should include all ignition source potential findings, not simply explosion events. Considering the low failure rate, a zero event history for an individual model would only be significant if the model had accumulated one billion fleet flight hours.
- Option 4: Full retrofit.
- Option 5: Any other solution such as CWT inhibition.
- Option 6: Only new Type Certificates.

Option 1 provides the baseline for the assessment of additional safety benefit. It should be noted that significant costs have already been incurred by the industry to achieve that baseline level of safety. These costs have been identified where appropriate but are considered as 'sunk costs' and have not been included in the economic analysis.

Option 3 may be a way forward but, at this stage, it has not proven possible to establish meaningful criteria on which a model-by-model assessment could be based. Option 3 has not, therefore been studied in detail in this RIA.

Option 5 was not fully evaluated as apart from a small number of installation specific solutions e.g. pressurisation of auxiliary tanks, no alternative solutions have been identified which could be evaluated in a way that would allow detailed consideration in this RIA.

Option 6 provides little improvement in safety level above the baseline over the period of the study, as new designs will represent a negligible fraction of the flight hours that will be accumulated over this timeframe (a situation possibly aggravated by the fact that a final rule has not yet been published to impose changes on any new Type Certificate application).

Options 2 and 4, production cut-in and full retrofit, are those on which this RIA concentrates.

Note 1: it has been considered a retrofit will be, necessarily, coupled with a production cut-in.

Note 2: the production cut-in involves all new airframes having high flammability tanks and manufactured after a given date will be fitted with a FRS. This therefore includes option 6, plus older Type Certificate.

2.3.3 Fleet and period studied

It was decided to limit the period studied to 2004-2030, as it was perceived a longer study period involved too much uncertainty.

The RIA is based on fleet data derived from market forecasts published by Airbus and Boeing. It has been assumed a 4% annual fleet increase, including the annual retirement rate of the fleet of 1.2% (Note: the affected fleet is identified in Para. 1.2.4):

- 11 000 affected aircraft in-service in 2004 (Airclaims database), these are the estimated number of airplanes with "high flammability" centre wing tanks, around 2/3 of the global large transport airplane fleet.
- 12 868 affected aircraft in-service in 2008,
- 30 497 affected aircraft will be in service in 2030,
- the estimated geographical split is approximately 1/3 in each of Europe, North America and the rest of the world,
- Boeing and Airbus market forecasts principally diverge on the fleet composition between single aisle, medium size and large wide body transport airplanes. An average of both manufacturers forecast has been retained: 67.5% of the fleet will be single aisle, 25% medium size, 7.5% large wide body transport,
- for future deliveries, the market is split 50-50 between Airbus and Boeing.

For retrofit, this translates into 11,649 in-service airframes to be modified, corresponding to the fleet in service in 2015 less the deliveries between 2008 and 2015 (which will be fitted with FRS on the production line).

The following assumptions have been made:

- Study period until 2030.

- Rule issued early 2005.
- 36 months allowed for design, certified design available in 2008.
- Production cut-in starts and the beginning of 2008
- Retrofit SB's available at the end of 2008
- 7 years retrofit implementation period ending in 2015, with a retrofit equally spread over the seven years (experience indicates that the incorporation of significant modification such as FRS will be skewed towards the end of the compliance period, this will slightly reduce the safety benefit in real terms as less flight hours will be actually performed by aircraft with an FRS installed).
- Retrofit performed for 85% during extended heavy check which already includes fuel tank entry (extended by 1 day for a D check, 5 day for a C check), and 15% during specific downtime (compensated by leasing replacement capacity).
- The available solution will be an active Flammability Reduction System (FRS) based on that developed by the FAA (See Para 1.2.3.).

Changes to some of the above assumptions can have a significant impact on both the safety benefit and the cost of introduction of FRS. For example, extending the period under consideration reduces the relative benefit of retroactive introduction over production cut-in, as the proportion of modified aircraft in the fleet increases the longer the period considered. If the period is shortened the relative benefits will be skewed in the other direction. Ending the study at the year 2030 is considered to be an acceptable compromise and the maximum period that can be considered without unidentified changes in fleet growth predictions or development of new technologies potentially becoming overwhelming.

Note: Whilst this assessment concentrates on the impact on the European industry some of the data, particularly accident data, is worldwide. To protect the validity of the RIA it is clearly stated whether the data is applicable to an identified specific area, such as Europe or North America or is worldwide data. Care has been taken to ensure that comparisons of cost and safety benefit are only made where the data is available on the same basis.

2.4 RIA items

2.4.1 Sectors affected

It has been determined that the following sectors are potentially affected:

- Manufacturers,
- Operators,
- Maintenance organisations,
- Leasing companies,
- STC companies.

2.4.2 General issues

A review of the accident record shows that fuel tank explosions are not a major cause of aviation accidents (statistically the percentage of both accidents and fatalities due to fuel tank explosions is approximately 1.2% over the last 20 years), and it has not been identified as such by either the CAST initiative or JSSI. The question must, therefore, be raised: -

"Is committing the required level of resource on a single safety intervention justified".

It must be recognised that the resources of the industry are finite. The question is raised whether the resource required to introduce FRS to in-service aircraft could be better expended to address other, more common, accident causes.

2.4.3 Safety impact

The safety benefit assessment is based on worldwide data, and has been determined on the basis of number of accidents prevented. It should be noted that an in-flight fuel tank explosion would normally result in high numbers of fatalities. However, several accidents can be expected to occur on the ground where experience indicates that the number of fatalities will be much smaller. It should also be noted that this assessment cannot be made for the European fleet alone, as there is no data on which to base a solely European accident rate.

2.4.3.1 Assumptions:

- Analysis to 2030,
- Fleet growth and utilization from Airbus/Boeing models
- Current (pre SFAR88 or INT/POL) fuel tank explosion rate of one event per 100 million flight hours.
- SFAR88 or INT/POL 25/12 ignition prevention measures introduced in the fleet from 2000 to 2010.
- The analysis was run twice hypothesizing those ignition prevention measures were 25% and 75% efficient (by reducing the number of accidents by those proportions).
- An FRS will be 90% efficient (based upon FAA research data) and will be introduced into the fleet according to the two scenarios detailed in Para 2.3.3; all aircraft fitted with FRS have been assumed to be compliant with ignition prevention measures. It should be noted that the safety benefit achieved, in practice, by the introduction of FRS will be significantly lower than that implied by the 90% efficiency on those specific models where the flammability exposure is markedly lower than the 30% exposure of the most vulnerable types.

2.4.3.2 Results

Preliminary note: the numbers quoted in this paragraph are based upon statistical data, and cannot predict actual accident rate, but only try to quantify the future risk based on past history and forecasting.

Over the period, the fleet will accumulate around 1.5 billion flight hours. For each of the options, the numbers of flight hours that will be accumulated has been predicted according to the scenario given above for the three relevant aircraft conditions: baseline, INT/POL compliant, and INT/POL compliant with a FRS fitted.

Total Fleet Hours – All Airplanes	1 539 536 100
Total 'baseline'	52 117 202
Total INT/POL compliant hours	1 487 418 898
Total FRS hours (Production + retrofit)	1 247 113 499
Production FRS hours	677 134 005
Retrofit FRS Fleet hours	569 979 494

Table 1: accumulative airplane operating hours for study period:

Without any measure, based on the current accident rate of 1 per 100 million flight hours, 15 accidents can be expected.

The expected improvements in accident rates achieved by the introduction of ignition source prevention measures, production cut-in of FRS and full retrofit of FRS are detailed in Table 2, below:

No of events	Baseline conf.	Ignition Prevention conf.	FRS conf.	Total	Events avoided
Probability	$1x10^{-8}$	$7.5x10^{-9}$	$7.5x10^{-10}$	-	-
Baseline	15.4	-	-	15.4	-
Ignition Prevention	0.52	11.16	-	11.68	3.72
Production cut-in	0.52	6.08	0.51	7.11	4.57
Retrofit	0.52	1.76	0.94	3.22	3.89

Table 2: event prediction, ignition prevention measures 25% efficient

No of events	Baseline conf.	Ignition Prevention conf.	FRS conf.	Total	Events avoided
Probability	$1x10^{-8}$	$2.5x10^{-9}$	$2.5x10^{-10}$	-	-
Baseline	15,4	-	-	15,4	-
INT/POL	0,52	3,72	-	4,24	11,16
Production cut-in	0,52	2,03	0,17	2,72	1,52

Retrofit	0,52	0,59	0,31	1,42	1,30

Table 3: event prediction, ignition prevention measures 75% efficient

Note: the analysis has also been run with a basic event rate of 1.5×10^{-8} per flight hour, which has been identified on some specific models. The figures are different, but the general trend is similar.

2.4.3.3 Other Safety Considerations

It should be noted that flammability reduction systems might introduce new potentially hazardous or catastrophic failure conditions (for example: over pressurising the fuel tank, contaminating the pressure vessel with nitrogen-enriched air). The manufacturers will be required to show that the probability of such failure conditions is extremely remote or extremely improbable, respectively, but an accident caused by an FRS failure or an installation error during the major retrofit cannot be entirely ruled out.

The potential hazards to maintenance personnel associated with FRS must also be recognised. At least one fatal accident has occurred in the military as a result of inadvertent entry into nitrogen-enriched atmospheres without appropriate protective equipment. Fuel tank entry safety procedure, equipment and training in place today will need to be further emphasised once inerting systems are installed on airplanes.

2.4.4 Economic Impact

It should be noted that it is estimated that the cost of introduction of ignition prevention measures resulting from SFAR 88 or JAA INT/POL reviews is of the order of 600 Million Euros (worldwide fleet, considering the modifications defined at this date, from manufacturer and airlines data). As this cost is not directly related to the FRS introduction, it is not accounted for in the subsequent analysis but it is part of the overall fuel tank safety cost.

The RIA has attempted to identify all elements of cost that contribute to the overall cost of introduction of a Flammability Reduction System. This includes the following:

- Non-recurring costs
  - Design,
    - Development for a model and its derivatives (see ARAC)
    - Certification
  - Production,
  - Retrofit,
    - Installation and functional testing
    - Tooling, ground equipment, training
    - Initial spares provisioning

- Recurring costs
  - Ownership (weight, SFC, payload penalty),
  - Training,
  - Delays,
  - Maintenance (line and heavy check, life limited items, spares)
  - Continued airworthiness.

The RIA has based its cost on the data provide by the manufacturers. Data provided by AEA or the ATA (through FAA) has also been used to check and eventually refine the OEM figures. Where available the detailed break down of the cost figures on which this RIA is based can be provided, if requested.

Both manufacturers provided costing and pricing elements. In some cases (for production and retrofit), those cost estimates vary by a factor of up to four. There are several reasons that may explain this difference:

- One manufacturer based its estimates over the work done by the ARAC FTHWG, adapting it to the system concept proposed by FAA. A team of OEMs, component suppliers, airlines and economists to quantify the cost of several different inerting system proposals developed these ARAC estimates. This manufacturer based its FRS cost estimate on the ARAC inerting system that is most similar to the FRS proposed by the FAA. Adjustments were made to the ARAC cost estimates to reflect the differences.
- The other manufacturer used its own data, and made some provisions for a more complex system considering at this stage the FAA concept as unproven in commercial aviation service,
- Some parameters may have a huge influence on costing, for instance:
  - The decision to mandate or not the FRS can influence the equipment price by a factor potentially exceeding 2, as if FRS is mandated the supplier will be able to recoup its non recurring costs over a much wider basis (both OEMs apparently made a different assumption for that aspect),
  - Similarly, for retrofit, the need to make changes to the structure or to the skin panels has a huge impact on cost. One of the manufacturers is confident there is no need for changing panels (at the cost of a more difficult access), whereas the other, less advanced in the design process, assumed structural and panel adaptation will be necessary. This can be very specific to a model – compared to the basic model which is not requiring panel changes, a shrunk derivative installation may be much more complex due to interferences with a cargo door, despite the fuel system being strictly identical.
- One manufacturer took into account lessons learned from costing and pricing elements from previous retrofit exercises (such as cockpit security) in order to assess the real prices for airlines.
- Generally, the manufacturer who made the decision to install the system took an optimistic view, 'aiming for success', whereas the other one adopted a more conservative approach.

Overall, both estimates have some validity and provide an indication of the likely range of the cost to the industry for an FRS. Therefore, the analysis has been run twice, using each manufacturers data.

The costs are given in Euros. Considering the fluctuation of the exchange rate between the Dollar and the Euro over the last couple of years, an arbitrary rate of one for one has been retained. A 3% annual inflation rate has also been retained over the 2004-2030 period.

2.4.4.1 Design

One manufacturer has identified a non-recurring design cost for the development and certification of an FRS to be 125 Million Euros, the other manufacturer estimates its development cost to 89 Million Euros.

2.4.4.2 Production

The estimated cost is based on separate estimates for the following elements: equipment (supplier hardware: ASM, valves, heat exchangers, etc…), manufacturing (OEM supplied: pipes, structures, wiring, etc…), material, installation and testing.

	Manufacturer A	Manufacturer B
Single aisle	392 000	81 225
Medium size	545 000	101 582
Large wide body	640 000	131 357

Table 4: cost for installing a FRS in production (in € per airframe)

Note 1: the costs given by Manufacturer A include the non-recurring cost. The non-recurring costs of Manufacturer B have been accounted for separately. Manufacturer B costs are based on anticipated production and retrofit incorporation rates.

Note 2: in the analysis, those costs have been used for all deliveries between 2008 and 2030 (with a 3% annual inflation). It could however be reasonably expected that advances in the FRS technologies, including manufacturing techniques, can result in lower prices in the medium term future.

Note 3: it is possible some new designs that will replace types currently in service or in production will not feature any high flammability exposure tank, and thus will not need FRS. This has not been accounted for (a decision supported by the fact the two most recent designs of both manufacturers, the A380-800F and the Boeing 7E7, might both need FRS to meet FAR 25.981 at Amendment 25-102). This is a conservative assumption; the overall price of the production cut-in may actually be lower than presented above.

2.4.4.3 Retrofit

No major differences have been identified in the equipment, manufacturing and material cost between production and retrofit, and therefore the cost for those items which have been presented in the previous paragraph, are also applicable for retrofit.

The retrofit cost will be higher due to several factors: the installation could be more difficult (access difficulty, structural/aircraft panels impacts, configuration variability, etc…) and SB retrofit involves overhead cost. Typically, this increases cost by at least 50 %.

Manufacturers have quoted figures of 350 hours required for installing an FRS At 85 € per hour, this equates to approximately 30 000 € for each airplane. From experience, the airlines have indicated that they normally apply a factor of between 1.7 and 2.0 to manufacturers' estimates for installation hours. A review conducted in the US with the ATA has indicated the installation will probably require around 520 hours.

For one manufacturer, the required tooling has been estimated to cost 10 000 € per set. It is expected that separate tooling will be required for 25% of the fleet. The other manufacturer indicated a similar cost of 3000 € per airframe.

For the 85% of aircraft assumed to be modified during an existing check, it is estimated that the additional ground time will be 1 to 3 days. No additional leased capacity is expected to be required to cover this ground time. For those 15% of aircraft modified outside of scheduled maintenance the additional extra ground time is estimated to be 5 to 7 days. For these aircraft additional leased capacity will be required at 80 000 € to 200 000 € a week, depending on the installation complexity of the aircraft to be covered. Note: it is possible manufacturers will be able to define installation proposal including drafting the Service Bulletins in a way that allows airlines to install portions the FRS during over-night shop visits to minimise the amount of time airplanes will be out-of-service, reducing the extra ground time mentioned above down to 2 days.

	Manufacturer A	Manufacturer B
Single aisle	505 000	136 879
Medium size	715 000	179 270
Large wide body	840 000	238 176

Table 5: cost of retrofitting a FRS (in € per airframe)

In addition to the direct costs given above, factors must be included for installation errors. The operating industry estimates, for a relatively complex modification such as FRS, that installation errors will occur on 25% of installations. Assuming two additional days for corrective actions, this equates to an additional cost element per aircraft of 15 000 €. Though noted, these costs have not been included in the study.

In addition to the above, training of the personnel carrying out of the modification will be necessary. The cost cannot be estimated at this time. The manufacturers are expected to provide working parties to help with initial installations.

Also reducing the compliance time for retrospective introduction whilst possibly preventing one outstanding accident disproportionately increases the costs because the majority of aircraft can no longer be modified during existing heavy checks.

Contrary to costs in production, the relatively shorter retrofit period (2008-2015) is unlikely to allow advances in the FRS technologies to have any significant impact on the costs given above.

2.4.4.4 Ownership

Manufacturers have estimated the Specific Fuel Consumption penalty induced by the FRS at around 0.1%.

Included in the cost of maintenance are: line checks, where a daily check is expected, heavy maintenance and component replacement.
For a single aisle aircraft, cost is estimated between 13 000 € and 16 000 € per aircraft, per year. This maintenance cost will increase year on year as more new, modified, aircraft enter the fleet.

The weight of the system itself is estimated to range from 50 kg on a narrow body to 120 kg on a large wide-body, the cost to carry this additional weight has been taken into account.

It should be noted that contrary to production and retrofit costing, both manufacturers estimates are consistent.

	Manufacturer A	Manufacturer B
Single aisle	16 000	17 020
Medium size	21 800	19 141
Large wide body	23 500	21 888

Table 6: annual cost of ownership (in € per airframe)

The additional weight of FRS for the weight limited missions will equate to the loss of 50 kg freight on single aisle airplane and 120 kg on wide body airplane. . Because it is difficult to evaluate its overall effect on the industry, this cost has not been accounted in the analysis.

Although it is the intent of the manufacturers that MMEL relief for the FRS system will be available, it can be expected that there will be some cost to the airlines from delays due to unserviceability of the FRS. The reliability of the FRS system cannot be estimated with any accuracy at this stage. An estimate of the cost of delays has therefore not been included.

In addition to the above, training of the personnel servicing these systems and also entering tanks with inert atmospheres will be required. The cost of this cannot be estimated at this time.

The continued airworthiness of a new and complex system cannot be assured. It is reasonable to expect some additional cost will be incurred with the introduction of corrective actions.

2.4.4.5 Overall Cost

Based on the above figures, the overall cost of FRS installation on the European industry is in the range of (for each cost, the overall cost has been indicated over the 2004-2030 period, as well as the Net Present Value in 2004 Euros with a typical 10% discount):

- For a production cut-in from 2008, which will address all affected airplanes to be delivered by both manufacturers to operators with FRS installed:

	From	To
Production cost (NPV, 2004, 10%)	3 846 735 381 858 840 634	18 347 363 027 3 661 887 325
Ownership cost (NPV, 2004, 10%)	7 360 821 711 1 088 084 859	7 400 737 417 1 093 985 243
Total (NPV, 2004, 10%)	11 207 557 093 1 946 925 494	25 748 100 444 4 755 872 569

Table 7: overall cost in € of a 2008 production cut-in

- for a full retrofit that will address 11,649 affected airplanes in service in the world, the additional cost amounts, in addition to the cost of the production cut-in given above, to:

	From	To
Retrofit cost (NPV, 2004, 10%)	2 225 407 893 1 045 340 780	8 361 028 056 3 927 425 447
Ownership cost (NPV, 2004, 10%)	5 279 035 281 1 187 910 556	5 307 662 033 1 194 352 267
Total (NPV, 2004, 10%)	7 504 443 175 2 233 251 336	13 668 690 089 5 121 777 714

Table 8: cost of retrofit in €

Taking into account the fact the retrofit also implies the production cut-in, the overall cost is therefore:

	From	To
Retrofit cost (NPV, 2004, 10%)	7 504 443 175 2 233 251 336	13 668 690 089 5 121 777 714
Production cost (NPV, 2004, 10%)	11 207 557 093 1 946 925 494	25 748 100 444 4 755 872 569
Total (NPV, 2004, 10%)	18 712 000 267 4 180 176 830	39 416 790 532 9 877 650 282

Table 9: overall cost in € of retrofit and production cut-in

2.4.5 Harmonisation with FAA

The FAA has indicated their intention to proceed with legislation to propose requiring full retrospective introduction of FRS to affected aircraft types.

As a result Airbus would be required to develop a system for their US customers regardless of any European requirement.

The majority of leased aircraft are required by the terms of the lease to be maintained in compliance with FAA requirements. The introduction of FRS, would, therefore, be required during the lease period or, at the latest, on return of the aircraft to the lessor. Where the aircraft is owned, the resale value of the aircraft could be significantly reduced if the resale market could not include the US because FRS was not installed.

2.4.6 Environmental impact

The nitrogen-enriched air supplied to the centre fuel tanks of affected aircraft will displace fuel vapour into the atmosphere. The quantity of fuel vapour displaced into the atmosphere by the airflow into the tank is complex and dependant on many factors. It is not, therefore, possible to quantify the effect, but additional fuel vapour will be vented into the atmosphere as a result of the introduction of FRS.

The increase in fuel burn due to the introduction of FRS is approximately 0.1%. According to fuel burn prediction by Eurocontrol for the ECAC airspace, which predicts for 2015 an annual burn rate of 156 Ktonnes, and assuming slightly less than 75% of large transport airplanes flying in that airspace will be affected, this equates to around an additional fuel burn of 115 tonnes of fuel per annum.

After maintenance involving fuel tank entry it is likely that some increase in APU or engine running time may be necessary to ensure the FRS is fully recharged before operating the aircraft. Noise issues are increasingly sensitive at many European airports, but the FRS overall effect should be negligible in that respect.

Manufacturing by-products of the FRS should not have any significant impacts.

Generally, it can be concluded that the environmental effects are small.

2.4.7 Social Impact

From data supplied by one of the manufacturer, a major European airline estimates the cost of installation for its fleet to be in the order of 75 Million Euros, with a recurring annual expenditure of 7.5 Million Euros. This could have the following social impacts:

- This equates to between 0.7% and 1% or the airlines gross revenue from sales. Covering this in terms of increased sales or in ticket price might sound simple, but generating a 1% increase in revenue in the current climate is extremely difficult.

- Over a one year period, increasing a single sector fare by 2.25€ or a return sector by 4.5€ would be required to cover this cost. Raising the price would be likely to have an impact on ticket sales by volume (though possibly small).
- In terms of employee costs - 75M€ equates to 1250 employees (based on a figure of 25 staff per 1,5M€). The installation costs would be a capital expense and generally would not impact operating expenditure, so staff cuts alone would be unlikely, but staffing levels would be affected to some degree
- In terms of recurring costs, 7,5M€ equates to approx 125 employees. As this is a recurring operational expenditure, a reduction in employee costs would likely be the primary vehicle in balancing the books.

2.4.8 Impact on other aviation requirements outside EASA scope

In order to require introduction of FRS, either through a production cut-in or retrospectively, the requirements will need to be placed in JAR 26 or possibly JAR-OPS.

It might also be necessary to introduce legislation to control nitrogen on airports and in maintenance facilities.

Considering some regulations are already in place, this should have a minimal impact.

3. Conclusions

The costs associated with the introduction of Flammability Reduction Systems are significant. Comparatively, environmental and social implications are negligible. The detailed costs quoted may be open to challenge due to the number of assumptions that have been made in order to conduct the analysis. However, the order of magnitude of the costs is clear and the relative balance of the costs and safety benefits of the two options under consideration will not be significantly changed by the assumptions.

The safety benefit has been assessed using three scenarios: no action beyond ignition prevention measures, production cut-in, and full retrofit. With application of ignition prevention measures only, depending upon their effectiveness (25% to 75%), there will be between 4 and 12 accidents. The single most significant safety benefit, in terms of preventing accidents, is provided by the production cut-in, which is estimated to save 2 to 5 accidents, worldwide. A full retrofit programme is likely to prevent no more than a further 1 to 4 accidents. This is in the context of between 500 and 600 accidents worldwide, from all causes, excluding terrorism (based on the expected hull loss rate for this class of products if JSSI achieves its objectives), in the period under consideration.

The estimated cost for a production cut-in is 11 to 25.7 Billion Euros, (or a 2004 Net Present Value with a 10% discount of 1.9 Billion Euros to 4.7 Billion Euros), based on the manufacturers estimates of the number of new aircraft, of the affected types, likely to be delivered up to the year 2030. It should be noted that this cost is driven directly by the number of aircraft produced in the period under consideration. A shorter study period reduces the cost dramatically and vice versa. The total cost can be broken down into the cost of designing, manufacturing and installing the systems that account for approximately 3.8 to 18.3 Billion Euros. This cost to the industry is likely to be largely invisible, as it will be absorbed into the price of new aircraft, and is likely to be inseparable from that price in the later years of the study. It is, also, possibly overestimated as new FRS and aircraft technology could lower the long-term costs. The remaining element of 7.5 Billion Euros is the cost of ownership, maintenance costs, operational costs etc. The costs quoted above are for the worldwide fleet and can, therefore, be considered directly against the safety benefits identified. The cost burdens for the individual European, US and the rest of the world fleets are each, approximately, one third of the above.

It must be recognised that it is not practical to consider the retrospective introduction of Flammability Reduction Systems unless similar systems have, already, been introduced into new production aircraft. The cost of retrospective introduction will be 7.5 to 13.6 Billion Euros (or a 2004 Net Present Value with a 10% discount of 2.2 Billion Euros to 5.1 Billion Euros), and is in addition to the cost of introducing such systems into production. The cost of retrospective introduction is largely a capital cost and, as such, represents a direct burden on the industry. In terms of Net Present Value (2004, 10% discount), the production cut-in is has a slightly lower cost, 1.9 to 4.7 Billion Euros compared with 2.1 to 5 Billion Euros than the retrofit cost which is spent before 2015).

The industry generally recognises the benefit of the introduction of flammability reduction measures for certain high flammability fuel tanks and supports, in principle, the proposal for introduction of appropriate measures on new build aircraft. Taking into account the relative costs and safety benefits associated with the two options under consideration in this RIA, and recognising the already identified, associated, costs of 600 Million Euros for ignition source suppression measures, it is considered that a production cut-in is justified, with regard to the safety benefit. It is, therefore, recommended that the necessary rulemaking be initiated, as quickly as possible, to require the introduction of FRS into all new production aircraft with high flammability fuel tanks by 2008. At this time, a full retrofit is not considered justified. The additional costs to industry (in addition to the production cut-in costs of FRS) are high when compared to the additional safety benefit in terms of hull losses prevented. However, in the absence of a case for mandating a full retrofit programme, further consideration could be given to a solution based on each affected manufacturer's position for their individual models.

References

EASA CS-25 Certification Specifications for large aeroplanes

JAA recommendation to National Authorities (JAA letter ref. 04/00/02/07/01-L296)

JAA INT/POL/25/12 issue 1 dated October 1st, 2002.

JAA NPA 25 E-342

JAA NPA 11-2

JAA Special Condition for Flammability Reduction System (Fuel Tank inerting)

NTSB recommendation A96-174

FAA SFAR 88 and FAR 25 at Amendment 102

FAA Memorandum 2003-112-15 SFAR 88 – Mandatory Action Decision Criteria, February 2003

"Limiting oxygen concentration required to inert jet fuel vapours existing at reduced fuel tank pressures", FAA report DOT/FAA/AR-TN 02/79, August 2003

Fuel Tank Harmonization Working Group (FTHWG) executive report, 1998

Fuel Tank Inerting Harmonization Working Group (FTIHWG) executive report, 2002

Current market outlook 2003, Boeing Commercial Aircraft, June 2003.

Global market forecast 2003-2022, Airbus, December 2003.

Forecasting civil aviation fuel burn and emissions in Europe, EEC Note N°8/2001, May 2001.