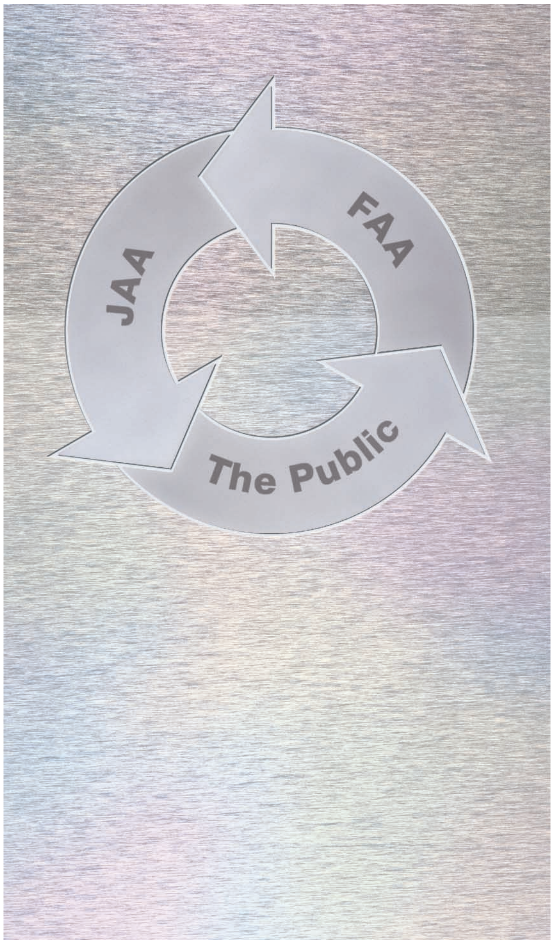

Aviation Rulemaking Advisory Committee

Fuel Tank Inerting Harmonization Working Group

Submitted jointly by:
AEA, AECMA, AIA, ALPA, API, ATA, FAA, IAM, JAA, and NADA/F

Final Report

June 2001

Federal Aviation Administration

alpa

AEA
Association of European Airlines

NATIONAL AIR DISASTER ALLIANCE/FOUNDATION

JAA
Joint Aviation Authorities

International Association of Machinists and Aerospace Workers

American Petroleum Institute

AIA
Aerospace Industries Association

Air Transport Association of America

European Association of Aerospace Industries
AECMA

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GLOSSARY

AC	advisory circular
AD	Airworthiness Directive
AEA	Association of European Airlines
AECMA	European Association of Aerospace Industries
AIA	Aerospace Industries Association
ALPA	Airline Pilots Association
API	American Petroleum Institute
APU	auxiliary power unit
ARAC	Aviation Rulemaking Advisory Committee
ASM	air separator module
ASTM D	an ASTM test designation
ASTM	American Society for Testing and Materials
ATA	Air Transport Association of America
ATB	air turnback
BITE	built-in test equipment
CBT	computer-based training
CFR	Code of Federal Regulations
CMR	certification maintenance requirement
CRC	Coordinating Research Council
CWT	center wing tank
DDG	dispatch deviation guide
DOT	Department of Transportation
EPA	Environmental Protection Agency
ER	extended range
ERA-7	an additive for CO_2-enriched fuel
ETOPS	extended twin operations
FAR	Federal Aviation Regulation
FHA	functional hazard analysis
FTHWG	Fuel Tank Harmonization Working Group
FTIHWG	Fuel Tank Inerting Harmonization Working Group
GBI	ground-based inerting
GBIS	ground-based inerting system
GN_2	gaseous nitrogen
GPM	gallons per minute
HCWT	heated center wing tank
HWG	Harmonization Working Group
IAMAW	International Association of Machinist Aerospace Workers
IATA	International Air Transport Association
JAA	Joint Airworthiness Authorities
JAR	Joint Aviation Requirements

LFL	lower flammability limit
MEL	minimum equipment list
MMEL	master minimum equipment list
MO	modification order
MSG-3	Maintenance Steering Group—Version 3
MTBF	mean time between failures
MTBMA	mean time between maintenance actions
MTBUR	mean time between unscheduled removal
NEA	nitrogen-enriched air
NIOSH	National Institute of Occupational Safety and Health
NPRM	Notice of Proposed Rulemaking
NSF	nitrogen-saturated fuel
NTSB	National Transportation Safety Board
OBGI	onboard ground inerting
OBGIS	onboard ground inerting system
OBI	onboard inerting
OBIGGS	onboard inert gas generating system
OEM	original equipment manufacturer
OSHA	Occupational Safety and Health Administration
p/m	parts per million
PRV	pressure-regulating valve
PSA	pressure-swing adsorption
SB	service bulletin
SCF	standard cubic feet
SCFM	standard cubic feet per minute
SFAR	Special Federal Aviation Regulation
TC	type certificate
TCAS	traffic collision avoidance system
UFL	upper flammability limit
VOC	volatile organic compound

1.0
Executive Summary

1.0 EXECUTIVE SUMMARY

1.1 OVERVIEW

This report presents the findings of the Aviation Rulemaking Advisory Committee (ARAC) Fuel Tank Inerting Harmonization Working Group (FTIHWG). The ARAC and its working groups cooperate to bring the expertise of the aviation industry, regulatory agencies, and public interest groups together to study specific subjects. The primary motivation of the FTIHWG is to save lives by enhancing airplane safety in an effective and practical manner.

The FAA tasked ARAC to provide a report recommending regulatory text and data needed by the FAA to evaluate options for new rulemaking requiring the elimination or significant reduction of flammable vapors through fuel tank inerting of transport-category airplanes. The FTIHWG studied several fuel tank inerting concepts. Fuel tank inerting is a method of reducing the oxygen concentration within fuel tanks to decrease the risk of explosions. Using methodology patterned after accepted FAA economic analysis practices, the FTIHWG found that none of these systems produced benefits, at present technology maturity levels, that were reasonably balanced by their costs.

The requested data is contained in this report. However, the FTIHWG is not recommending proposed regulatory text because this study was unable to identify any practical way of implementing the inerting designs studied.

Consequently, FTIHWG recommends that the FAA, NASA, and aviation industry conduct further research with an objective of developing more viable solutions for reducing fuel tank flammability much sooner than any of the inerting concepts evaluated could be implemented.

1.2 INTRODUCTION

The FTIHWG—the author of this report—has built upon the work of the 1998 Fuel Tank Harmonization Working Group (FTHWG), which assessed a broad range of methods to improve fuel tank safety through reduced flammability exposure. The FTHWG in its 1998 final report recommended that the FAA investigate further the feasibility of what it then identified as the two most promising methods:

- Directed ventilation.
- Fuel tank inerting.

The FAA chose to evaluate directed ventilation internally and tasked the ARAC with evaluating fuel tank inerting, leading to the formation of the FTIHWG. The FAA Tasking Statement requested that this HWG define and evaluate fuel tank inerting design concepts that would eliminate or significantly reduce the development of flammable vapors in fuel tanks. The FTIHWG was given 12 months to complete this assignment and prepare this final report.

Within this report is a comprehensive evaluation of the technical, safety, and economic merits of ground-based and onboard fuel tank inerting systems for in-service, current production, and new type design transport-category airplanes.

This ARAC study includes results of ongoing work being performed by the FAA under its internal fuel tank inerting research program. This FAA research covers the evaluation of the latest-available nitrogen generating technologies, research into fuel flammability, and various methods of inerting fuel tanks. Also covered in this report is the ground and flight-test program completed by the FAA and industry in early 2001, which provided essential data for this report.

1.3 SYSTEMS EVALUATED

The three basic inerting design system concepts addressed by the FTIHWG are

- Ground-Based Inerting (GBI)—a system using ground-based nitrogen gas supply equipment to inert fuel tanks that are located near significant heat sources or that do not cool at a rate equivalent to unheated wing tanks. The affected fuel tanks would be inerted once the airplane reaches the gate and is on the ground between flights.

- Onboard Ground-Inerting (OBGI)—an onboard system that uses nitrogen gas generating equipment to inert fuel tanks that are located near significant heat sources or that do not cool at a rate equivalent to an unheated wing tank. The affected fuel tanks will be inerted while the airplane is on the ground between flights.

- Onboard Inert Gas Generating System (OBIGGS)—a system that uses onboard nitrogen gas generating equipment to inert all the fuel system's tanks so that they remain inert throughout normal ground and typical flight operations.

In addition to these three basic design concepts, derivative combinations of OBGI and OBIGGS were also studied. They are described as "hybrid systems" in this report.

1.4 FTIHWG STRUCTURE

To manage and accomplish the requirements established by the FAA Tasking Statement, the FTIHWG established three primary task teams:

- Ground-Based Inerting Design (GBI).
- Airport Facilities (for GBI).
- Onboard Inerting Design (OBGI, OBIGGS, hybrid systems).

In addition, five support task teams were created:

- Airplane Operations and Maintenance.
- Estimating and Forecasting.
- Safety.
- Rulemaking.
- Integration.

1.5 SCOPE AND ASSUMPTIONS

The overall mission of the FTIHWG has been to determine whether safety enhancement through fuel tank inerting systems is practical. If not, this body was asked to propose research programs that would lead to a practical system.

The task teams included representatives from U.S. and non-U.S. companies from a variety of fields (e.g., commercial airlines, major and general aviation manufacturers, petroleum refiners, industrial gas suppliers, public interest groups). These experts worked closely to devise a practical inerting system.

As defined in the Tasking Statement, the FTIHWG based its work on the assumption that the proposed fuel tank inerting systems are not considered flight critical and, therefore, airplanes may be dispatched with the system inoperative. This assumption is fundamental to the technical and cost conclusions of this report.

For the purposes of this study, it was assumed that the resources would be made available as needed to implement a desirable inerting system. Further studies would be needed to assess the effect of the unavailability of industrial capacity, personnel, or any other resources needed to implement an inerting system.

During the study period, some 70 experts spent more than 50,000 hr evaluating a large number of fuel tank inerting options and design concepts together with the effects these systems would have if implemented in the existing fleet as well as airplanes yet to be designed. Areas specifically evaluated for resultant effects were safety (measured in the anticipated preclusion of future accidents), regulation, airplane configuration, airport infrastructure, and flight and maintenance operations. Underlying this exhaustive effort were a single defined set of *study ground rules* that were used by all participants to ensure that each team worked consistently and was aware of the requirements in all other areas.

When completed, the above efforts yielded a detailed body of knowledge that allowed the FTIHWG to draw informed conclusions based on data and analysis. These conclusions and recommendations specifically address the technical limitations of inerting, its potential benefits and hazards, and the relative costs of implementing inerting versus its projected benefits (i.e., cost-benefit analysis) as described below and in the body of this report.

1.6 TECHNICAL EVALUATIONS

Figure 1-1 summarizes the technical evaluation of each of the inerting system concepts considered by the FTIHWG.

1. Ground-Based Inerting (GBI)
Concept Center wing tanks (heated or unheated) and auxiliary fuel tanks are purged at the gate with nitrogen-enriched air (NEA) from an airport supply. Airplanes are equipped with a dedicated NEA service panel and manifold connected to a series of outlets inside the appropriate tank(s), thereby inerting the ullage (air space above the liquid fuel). Large transports take 30 minutes to inert, medium transports 25 minutes, and small transports 20 minutes. **Advantages** Simple, reliable, lightweight onboard equipment (tubes, etc.). Standard approach: every airplane supplied with NEA 1.7 times the maximum ullage volume. Service technician identifies airplane model and injects prescribed NEA volume. **Disadvantages** Dependent on dedicated airport supply system for NEA. Not inert after landing and until after ground servicing is completed. Ullage oxygen level increases during cruise, and—depending on initial fuel load—can exceed inert limits. Supply pressure varies by airplane type. Poses confined-space hazard to ground service personnel. New worldwide standard would be needed for interface and regulating equipment. Requires vent system changes for large portion of fleet. **Other issues** Dedicated, trained ground personnel needed. Impact on overall ground servicing operations (fuel, catering, baggage, cargo, etc.). Bigger impact will be on the airport infrastructure than on the airplane/airlines. Potential environmental issues from venting tanks overboard.
2. Onboard Ground Inerting (OBGI)
Concept Same as 1 above except airplane uses onboard equipment to generate NEA. Only operates on the ground. Time to inert a large transport: 60 minutes. **Advantages** Airplane is self-sufficient. A better solution for flights into airports with no airport NEA supply. **Disadvantages** Takes longer after landing to reach inert levels and may impact airplane turn time. Provides limited protection during flight cycle depending on flight duration. System is heavy, bulky, and requires external dedicated electrical power supply. System and component reliability is poor. Confined space hazard to ground support personnel. **Other issues** Air inlet and exhaust for compressor and heat exchangers require airplane hull penetrations. Pipes must be shrouded (double-walled pipes where they enter the pressure hull to prevent filling the cabin with nitrogen gas in the event of a leak). Introduces new hazard exposure (very small) to crew and passengers. Insufficient space to retrofit aboard most current in-service and new production airplanes.
3. Onboard Inert Gas Generating Systems (OBIGGS)
Concept Airplane uses onboard equipment to generate NEA. Operates throughout the flight, keeping the fuel tanks inert. **Advantages** Airplane is self-sufficient and thus not dependent on airports for NEA. Fuel tanks are actively inerted throughout ground and flight operations unless system is impacted by reliability. **Disadvantages** Demands more electrical power and high-pressure engine bleed air than is available on most airplanes. Weight and size aboard airplane much greater than for GBI. Draws exhausted cabin air as a source, increasing pressurization system maintenance burden. System and component reliability is poor. Introduces new hazard exposure to crew and passengers (very small). **Other issues** Shrouded pipes in the pressure hull. Mechanically very complex. Insufficient space available for installation aboard most in-service and current production airplanes.
4. Hybrid Systems
Concept These are variations of 2 and 3 that have been simplified in an effort to reduce weight, volume, power demands, and air consumption. Two systems are under consideration: • Hybrid OBGI system. • Hybrid OBIGGS (a scaled-down version of the full system). **Advantages** Smaller, lighter; less expensive than OBGI and OBIGGS. **Disadvantages** More time required to inert the fuel tanks; complex; limited system and component reliability; weight and space requirements for retrofit.

Figure 1-1. Technical Summary of Inerting System Concepts

1.7 TECHNICAL LIMITATIONS

The FTIHWG concluded that several major technical limitations and airport infrastructure obstacles must be overcome before a practical fuel tank inerting system could be implemented.

1. The technical limitations/airport infrastructure obstacles for GBI for in-service, in production, and new type design (i.e., future) airplanes are
   - Development and construction of fixed inerting equipment for large airports and medium-sized airports.
   - Development and production of mobile inerting vehicles.
   - Development of a worldwide industry standard for the nozzle, interface panel configuration, and control system that connects the airplane and inerting equipment to deliver the appropriate amount of nitrogen to the airplane fuel tank.
2. The technical limitations for OBGI and OBIGGS inerting systems on in-service and in-production airplanes are that they
   - Demand more engine/airplane bleed air to operate than is available.
   - May demand more airplane electrical power to operate than is available.
   - Take up more space (volume) than might be available on most airplane types (a problem that increases as airplane size decreases); appropriate locations may not exist.
   - Have components that demonstrate low reliability and high failure rates at current technology levels.
3. Future airplane types can be designed with adequate bleed air, electrical power, and volume for OBGI and OBIGGS systems, so the technical limitation of these inerting systems on future airplane types will be
   - The low-reliability/high failure rate of their current-technology components unless mitigated by the application of future technological breakthroughs.

1.8 BENEFITS

The benefit of a safety enhancement system like inerting is avoided accidents resulting in lives saved and prevention of airplane and property destruction. Analyses performed by the FTIHWG established the estimated levels of this potential benefit that fleetwide inerting would achieve.

For this study, six commercial airplane categories were defined and generic models were created with fuel system characteristics as closely representative as possible of today's in-service fleet and current production models. Figure 1-2 summarizes the fleetwide flammability exposure of these generic-study-category airplanes.

	Large transport, 275 passengers	**Medium transport, 195 passengers**	**Small transport, 117 passengers**	**Regional turbofan, 44 passengers**	**Regional turboprop, 31 passengers**	**Business jet, 7 passengers**
Baseline fuel tank flammability—no inerting system, %						
Unheated CWTs (no adjacent heat sources)	6.8	No unheated CWT	5.1	2.6	No CWT	No CWT
Heated CWT (with adjacent heat sources)	36.2	23.5	30.6	No HCWT	No HCWT	No HCWT
Main wing tanks	3.6	2.4	3.6	1.6	0.7	1.6
Fuel tank flammability—with an operative inerting system, %						
Ground-based inerting (heated CWTs)	4.9	2.0	5.2	No HCWT	No HCWT	No HCWT
Onboard ground inerting (heated CWTs)	7.0	1.4	5.8	No HCWT	No HCWT	No HCWT
Hybrid OBIGGS (heated CWTs)	0.9	0.6	0.3	No HCWT	No HCWT	No HCWT
OBIGGS (all tanks)	~0	~0	~0	NA	NA	NA

*Due to the estimated low reliability of these onboard systems, the fleet exposure when including inoperative systems would be 2% to 3% higher.

Figure 1-2. Flammability Exposure—Generic In-Service and Current Production Airplanes

Fleetwide flammability exposure is a measure of the percentage of the airplane operating hours during which the fuel tank analysis indicates a flammable fuel/air mixture would exist. A Monte Carlo–type simulation was used to estimate these percentages. The figure includes the estimated flammability exposure levels for current unmodified (baseline) and modified flammability percentages.

In estimating accidents avoided, the passenger counts for each of these six generic airplanes were derived based on the average number of passenger and crew seats for actual airplane type in that study category. This value was then factored by load factors (percentage of passenger seats expected to be filled) taken from the *FAA Aviation Forecasts Fiscal Years 2001-2012.*

Figure 1-3 shows the accidents anticipated to be avoided through implementation of each of the three basic inerting system design concepts. Avoided accidents are a function of the flammability exposure values and the number of hours flown by all airplanes in each of the generic airplane categories over the evaluation period. For the purpose of the cost-benefit study described below, a 16-year evaluation period was used. Although a 10-year evaluation period had been used in the 1998 ARAC study and the FAA ground-based inerting study, a 16-year period was chosen for this study because of the significant time that is required to design and achieve full fleet incorporation of these inerting system design concepts.

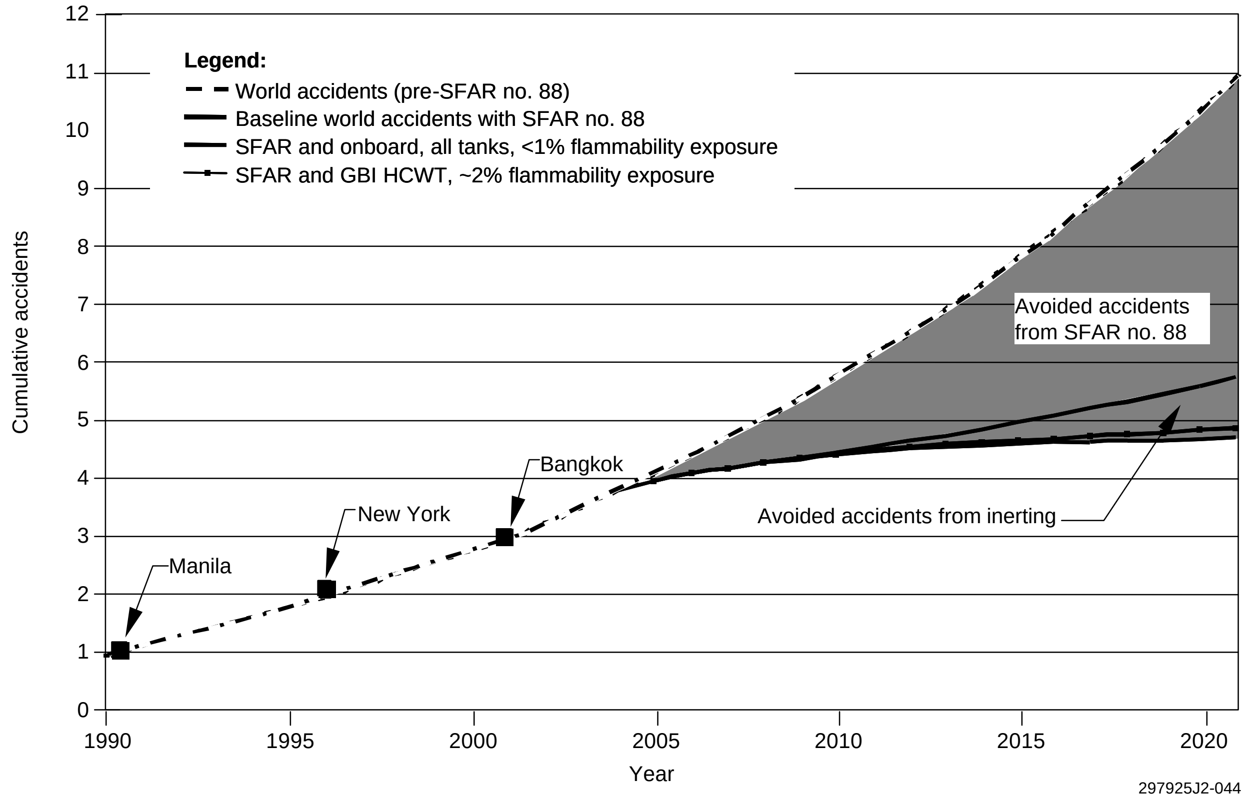


Figure 1-3. Worldwide Forecast Cumulative Accidents

The evaluation period begins in the first quarter of 2005 on the assumption that a rule change requiring fuel tank inerting would be effective at that time. Inerting systems for all applicable airplanes would be designed and certified by the first quarter of 2008 and all applicable airplanes would be modified by the first quarter of 2015. The evaluation period ends in the last quarter of 2020.

In figure 1-3 the avoided accidents analysis takes into account predicted reductions in accident rate of 75% attributable to SFAR no. 88. The 75% reduction had been estimated by the 1998 ARAC FTHWG. In addition, the Safety Team had reviewed the 1998 report and fuel tank safety enhancements as a result of recent AD actions and other improvements. Although consensus was not reached by the FTIHWG, the majority of the HWG considered that using the 75% predicted reduction in fuel tank explosions was reasonable.

The dotted line on figure 1-3 shows the estimated cumulative worldwide fuel tank explosion accident rate for a period 1990 through 2020. The three data points shown in the figure are actual accidents. The first two are confirmed to have resulted from fuel tank explosions while the third is suspected but has not yet been formally confirmed as such.

The estimated reduction in the accident rate resulting from SFAR no. 88 appears as a heavy black line. The third line down shows the further estimated improvement if a GBI system for inerting heated center wing tanks (CWT) were installed in the fleet. The fourth line down shows the estimated improvement if an OBIGGS system inerting all fuel tanks were adopted fleetwide. Thus, the estimated cumulative accident reductions attributable to GBI or OBIGGS are the difference between the SFAR line and those for GBI and OBIGGS.

The team evaluated accidents provided by the 1998 ARAC FTHWG study, plus the 2001 Bangkok accident, and agreed that the three most recent events (Manila 1990, New York 1996, and Bangkok 2001) should form the basis for statistically forecasting future events. These accidents each involved an explosion of the heated CWT, and the ignition source is unknown.

Figure 1-4 shows that the estimated number of avoided accidents with each inerting system design concept is approximately 1 accident (0.77 to 1.03) for the worldwide fleet in the 16-year evaluation period. Statistically, one fuel tank explosion in the 16-year evaluation period would result in approximately 1% of all fatalities from commercial airplane accidents forecast over that period. If these inerting system design concepts are fully implemented, after the implementation a ground-based system would likely prevent one fuel tank explosion in 10 years and an OBIGGS would likely prevent one fuel tank explosion in 8 years for the worldwide fleet.

	Large transport	Medium transport	Small transport	Regional turbofan	Regional turboprop	Business jet	Total
Ground-based inerting (HCWT only)	0.24	0.9	0.54	No HCWT	No HCWT	No HCWT	0.87
Onboard ground inerting (HCWT only)	0.20	0.9	0.48	No HCWT	No HCWT	No HCWT	0.77
Hybrid OBIGGS (HCWT only)	0.24	0.9	0.58	No HCWT	No HCWT	No HCWT	0.91
OBIGGS (all tanks)	0.28	0.12	0.63	NA	NA	NA	1.03

Figure 1-4. Estimated Cumulative Worldwide Avoided Accidents, 2005 Through 2020

The estimated number of avoided accidents for the U.S. fleet (“N” registered airplanes) would be approximately 46% of the projected accidents avoided worldwide. It is estimated that for the same time period a ground-based design system concept would likely prevent one fuel tank explosion in 19 years and the OBIGGS would likely prevent one accident in 16 years for the U.S. fleet.

Based on this analysis, an estimate could be made of the expected number of lives that might be saved through prevented fuel tank explosions and postcrash fires during the evaluation period from 2005 to 2020. Using the above process, it is estimated that once either a GBI or OBIGGS system is fully implemented in the fleet, the accumulated fractional number of prevented fatalities over the 16-year evaluation period would be 132 for GBI and 253 for OBIGGS from in-flight and ground fuel tank explosions and postcrash fires.

1.9 HAZARDS

Nitrogen is a colorless, odorless, nontoxic gas that is impossible for human senses to detect when excessive concentrations displace the oxygen normally present in the air. Depending on the degree of oxygen depletion, the effects of breathing nitrogen-enriched air (NEA) range from decreased ability to perform tasks to loss of consciousness and death. Fuel tank inerting procedures would include stringent measures to minimize these hazards. The risks would exist wherever gaseous or cryogenic nitrogen is handled in the global aviation infrastructure.

The FTIHWG lacks the expertise to assess these risks with confidence. However, a simple extrapolation of available data from the Occupational Safety and Health Administration (OSHA) and National Institute of Occupational Safety and Health (NIOSH) would suggest a rate of 1.4 to 4.7 fatalities per year worldwide. Based on assumed annual fleet growth rates and inerting system implementation assumptions, it is forecast that from 24 to 81 lives may be lost over the 2005–2020 study period as a result of this hazard.

1.10 COST-BENEFIT ANALYSIS

Figure 1-5 shows the present value estimate of inerting system total costs and monetary value of the benefits gained by introducing each of the three basic inerting design system concepts. The benefits were calculated by multiplying the annual number of avoided accidents (presented as fractional values) by the accident cost and then discounting these values by a net discount rate of 7% to the year 2005, which is the beginning of the evaluation period. The accident costs were estimated using established Department of Transportation (DOT) values. The benefits also include the monetary value of lives saved in postcrash fires. They do not include the cost of lives lost due to the hazards of inerting. The total cost for each inerting system includes the cost for in-service, current production, and new type design airplanes. There is little difference in cost between in-service and current production airplanes, except for the 20% to 30% higher installation costs for the retrofit airplanes and the associated airplane downtime. Also, with today's technology, there is little difference in the cost between current production and new type design airplanes.

	Benefits ($US billion)	Cost ($US billion)	Cost-benefit ratio
GBI (HCWT only)	0.245	10.37	42.3:1
OBGI (HCWT only)	0.219	11.60	52.9:1
Hybrid OBIGGS (HCWT only)	0.257	9.90	38.5:1
OBIGGS (all tanks)	0.441	20.78	47.1:1

Figure 1-5. Cost-Benefit Analysis Results, Worldwide Fleet, 2005 Through 2020, Based on Present Value in Year 2005 $US

The benefits shown in figure 1-5 have been calculated on the basis of a 75% reduction in projected fuel tank explosions due to SFAR no. 88. If the actual reduction in fuel tank explosions due to SFAR no. 88 proves to be less than 75%, then the benefits from inerting would be proportionally greater, and vice versa.

1.11 OVERALL CONCLUSION

The FTIHWG has concluded that the current technology of GBI, OBGI, and OBIGGS cannot meet the desired evaluation criteria for a fuel tank inerting system. This conclusion was reached collaboratively by many involved aviation and industry experts who, after intensive efforts, could not devise a practical, timely, and cost-effective method of proposing a fuel tank inerting design concept as a viable solution based on the Tasking Statement guidelines.

The FAA Tasking Statement for this ARAC FTIHWG study requested that this Working Group provide recommended regulatory text for new rulemaking based on the lowest flammability level that could be achieved by an inerting system design concept that would meet the FAA regulatory evaluation requirements. These evaluation requirements include a cost-benefit analysis similar to the analysis performed in this study. Because this study was unable to identify any practical way of implementing the inerting design concepts studied, the FTIHWG concluded that they could not recommend regulatory text based on the flammability level of an inerting system.

The FTIHWG also concluded that if a GBI system is considered for implementation, it will be necessary, before promulgating an airplane requirement, to resolve the current lack of global regulatory authority and industry control over the introduction and construction of new airport inerting supply systems, fixed or mobile.

Consequently, this FTIHWG has also concluded that the FAA, NASA, and the industry must continue to work cooperatively to research methods to reduce fuel tank flammability exposure that can be introduced much sooner than any of the inerting concepts. They should also pursue further basic research into technical breakthroughs in fuel tank inerting system design concepts as well as alternative concepts to improve the fuel tank safety of existing and future airplane designs.

1.12 RECOMMENDATIONS

The ARAC FTIHWG specifically recommends the following actions to be expeditiously carried out by the FAA, NASA, and the industry:

Inerting Systems

- Continue to evaluate and, where appropriate, investigate means to achieve a practical onboard fuel tank inerting system design concept for future new type design airplanes.
- Pursue technological advancements that would result in onboard fuel tank inerting designs having decreased complexity, size, weight, and electrical power requirements, and increased efficiency, reliability, and maintainability.
- Perform NEA membrane research to improve the efficiency and performance of membranes resulting in lower non-recurring costs of NEA membrane air-separation systems. For example, basic polymer research to increase the operational temperature of membranes to a level above 302°F.
- Conduct basic research into high-efficiency, vacuum-jacketed heat exchangers, and lighter, more efficient cryogenic refrigerators for use in inerting systems.
- If a practical means of achieving a cost-beneficial fuel tank inerting system is found, establish a corresponding minimum flammability level and reevaluate and propose regulatory texts and guidance materials accordingly.

Fuel Tank Flammability

- Evaluate means to reduce fuel tank flammability based on existing (e.g., directed ventilation, insulation) or new technology that might be introduced sooner into the in-service fleet and current airplane production.
- Initiate a project to improve and substantiate current flammability and ignitability analyses to better predict when airplane fuel tank ullage mixtures are flammable. This research is needed to support informed design decisions and rulemaking.
- Initiate a project to thoroughly document and substantiate the flammability model used in this study.

2.0
Introduction

2.0 INTRODUCTION

2.1 BACKGROUND

Following the 1996 fuel tank explosion-related accident on a 747 airplane, the FAA initiated rulemaking to re-evaluate the industry's approach to fuel tank safety by precluding ignition sources within the fuel tanks of the transport airplane fleet. The FAA also tasked the Aviation Rulemaking Advisory Committee (ARAC) with a 6-month project to provide specific recommendations and propose regulatory text for rulemaking that would significantly reduce or eliminate the hazards associated with explosive fuel vapors in transport airplanes.

In its July 1998 report, the ARAC provided a detailed evaluation of past accidents and incidents and recommended regulatory text for new rulemaking applicable to future transport airplane certifications. Because of the short time allowed to complete the task, the ARAC was unable to provide the detailed information necessary to recommend regulatory text applicable to existing in-service and current production airplanes. The ARAC did recommend that the FAA further investigate the feasibility of what it determined to be the two most promising methods:

1. **Directed ventilation.** Provides for ventilation of the areas adjacent to certain heated tanks to reduce heating within those tanks.
2. **Ground inerting.** Inerts the fuel tanks during ground operations.

On June 6, 2000, the FAA proposed the formation of an ARAC Fuel Tank Inerting Harmonization Working Group (FTIHWG). The group's purpose was to prepare a report for the FAA that (1) recommended regulatory text for new rulemaking and that (2) provided the necessary data for the FAA to evaluate the options involved in the introduction of fuel tank inerting systems that would significantly reduce or eliminate the development of flammable vapors in transport category airplane fuel tanks.

2.1.1 Scope

The historical approach to fuel system safety has been to control risk by ensuring that ignition sources are not present within the tanks. All current regulation and commercial airplane design is based on this philosophy. Going beyond this philosophy, the ARAC FTIHWG was given the task of recommending new rulemaking that would further enhance safety by eliminating or significantly reducing the presence of flammable fuel-air mixtures in fuel tanks.

As part of the ARAC Tasking Record for "Fuel Tank Inerting for Transport Airplanes," the FAA included the following Tasking Statement. (The complete FAA Tasking Statement for the FTIHWG is shown in appendix A).

2.1.2 Tasking Statement

The ARAC Executive Committee will establish a Fuel Tank Inerting Harmonization Working Group. The Fuel Tank Inerting Harmonization Working Group will prepare a report to the FAA/JAA that provides data needed for the FAA to evaluate the feasibility of implementing regulations that would require eliminating or significantly reducing the development of flammable vapors in fuel tanks on in-service, new-production, and new-type-design transport-category airplanes. This effort is an extension of the previous work performed by the Fuel Tank Harmonization Working Group.

The report should contain a detailed discussion of the technical feasibility of the prevention of, or reduction in, the exposure of fuel tanks to a flammable environment through the use of the following inerting design methods, and any other inerting methods determined by the Working Group, or its individual members, to merit consideration.

Ground-Based Inerting*—The system shall inert fuel tanks that are located near significant heat sources or do not cool at a rate equivalent to an unheated wing tank using ground-based nitrogen gas supply equipment. The affected fuel tanks shall be inerted once the airplane reaches the gate and while the airplane is on the ground between flights.*

Onboard Ground-Inerting*—The system shall inert fuel tanks that are located near significant heat sources or are not cooled at a rate equivalent to an unheated wing tank using onboard nitrogen gas generating equipment. The affected fuel tanks shall be inerted while the airplane is on the ground between flights.*

Onboard Inert Gas Generating System (OBIGGS)*—The system shall inert all fuel tanks with an onboard nitrogen gas generating system such that the tanks remain inert during normal ground and typical flight operations. Non-normal operations are not to be included in the OBIGGS mission requirements. For example, the tanks should remain inert during normal takeoff, climb, cruise, descent, landing, and ground operations (except for ground maintenance operations when the fuel tank must be purged for maintenance access); however, the fuel tanks do not need to remain inert during non-normal operations such as during an emergency descent.*

The report shall provide detailed discussion of technical considerations (both pro and con), as well as comparisons between each of the above design methods for incorporation into the following portion of the large transport airplane fleet: (a) in-service airplanes, (b) new-production airplanes, and (c) new airplane designs. Because the working group may consist of members having differing views regarding the feasibility of inerting fuel tanks, the report should include discussion of such views and any supporting information provided by the membership.

In developing recommendations to the FAA/JAA, the report should also include consideration of the following:

1. *The threat of fuel tank explosions used in the analysis should include explosions due to internal and external tank ignition sources for the major fuel system designs making up the transport fleet, as defined in the July 1998 ARAC Fuel Tank Harmonization Working Group report. The service history in the analysis should be further developed to include incidents involving post-crash fuel tank fires. The FAA awarded a research contract to develop a database that may be useful in this endeavor. This data should be evaluated when determining what benefits may be derived from implementing ground-based or onboard inerting systems. The report is titled, A Benefit Analysis for Nitrogen Inerting of Airplane Fuel Tanks Against Ground Fire Explosion, Report Number DOT/FAA/AR-99/73, dated December 1999.*
2. *The evaluation of ground-based inerting should consider:*
    a. *The benefits and risks of limiting inerting of fuel tanks to only those times when conditions, such as lower fuel quantities or higher temperature days, could create flammable vapors in the fuel tank. This concept would be analogous to deicing of airplane when icing conditions exist.*
    b. *Various means of supplying nitrogen (i.e., liquid, gaseous separation technology; centralized plant and/or storage with pipeline distribution system to each gate, individual trucks to supply each airplane after refueling, individual separation systems at each gate, and so on), and which means would be most effective at supplying the quantity of nitrogen needed at various airports within the United States and, separately, other areas of the world.*
    c. *Methods of introducing the nitrogen gas into the affected fuel tanks that should be considered include displacing the oxygen in fuel tanks with nitrogen gas, saturating the fuel*

with nitrogen in ground storage facilities (for example, in the trucks or central storage tanks), injecting nitrogen directly into the fuel as the fuel is loaded onto the airplane, and combinations of methods.

3. *The evaluation of the cost of an OBIGGS for application to new type designs should assume that the design can be optimized in the initial airplane design phase to minimize the initial and recurring costs of a system.*
4. *Evaluations of all systems should include consideration of methods to minimize the cost of the system. For example, reliable designs with little or no redundancy should be considered, together with recommendations for dispatch relief authorization using the master minimum equipment list (MMEL) in the event of a system failure or malfunction that prevents inerting one or more affected fuel tanks.*
5. *Information regarding the secondary effects of utilizing these systems (i.e., increased extracted engine power, engine bleed air supply, maintenance impact, airplane operational performance detriments, dispatch reliability, and so on) must be analyzed and provided in the report.*
6. *In the event that the working group does not recommend implementing any of the approaches described in this tasking statement, the team must identify all technical limitations for that system and provide an estimate of the type of improvement in the concept (i.e., manufacturing, installation, operation and maintenance cost reduction, and so on; and/or additional safety benefit required) that would be required to make it practical in the future.*
7. *In addition, guidance is sought that will describe analysis and/or testing that should be conducted for certification of all systems recommended.*

Unless the working group produces data that demonstrates otherwise, for the purposes of this study a fuel tank is considered inert when the oxygen content of the ullage (vapor space) is less than 10% by volume.

The ground-based inerting systems shall provide sufficient nitrogen to inert the affected fuel tanks while the airplanes are on the ground after landing and before taking off for the following flight. In addition to the ground equipment requirements and airframe modifications required for the nitrogen distribution system, any airframe modifications required to keep the fuel tank inert during ground operations, takeoff, climb, and cruise, until the fuel tank temperatures fall below the lower flammability range, should be defined.

The onboard ground inerting systems shall be capable of inerting the affected fuel tanks while the airplane is on the ground after touchdown and before taking off for the following flight. As for the ground-based inerting system, in addition to the inert gas supply equipment and distribution system, any airframe modifications required to keep the fuel tank inert during ground operations, takeoff, climb, and cruise, until the time the fuel tank temperatures fall below the lower flammability range, should be defined. Consideration should be given to operating the onboard inert gas generating system during some phases of flight as an option to installing equipment that might otherwise be necessary (e.g., vent system valves) to keep the fuel tank inert during those phases of flight, and as a cost tradeoff that could result in reduced equipment size requirements.

The data in the report will be used by the FAA in evaluating if a practical means of inerting fuel tanks can be found for the in-service fleet, new-production airplanes, and new airplane designs. The FAA may propose regulations to further require reducing the level of flammability in fuel tanks if studies, including this ARAC task and independent FAA research and development programs, *indicate that a means to significantly reduce or eliminate the flammable environment in fuel tanks, beyond that already proposed in Notice of Proposed Rulemaking (NPRM) 99-18, is practical. Such a proposal would be consistent with the recommendations made by the ARAC Fuel Tank Harmonization Working Group in their July 1998 report.*

2.1.3 Charter

The charter of the ARAC FTIHWG has been to

1. Analyze
   - The technical considerations as well as comparisons between the various fuel tank inerting design methods for incorporation into the large transport fleet.
   - The threat of fuel tank explosions due to internal and external tank ignition sources for the major fuel system designs making up the transport fleet.
   - Various design methods of eliminating or significantly reducing exposure to flammable fuel vapors within fuel tanks.
   - Means to eliminate the resultant hazard if ignition does occur.
2. Recommend regulatory text and guidance material for new rulemaking if a practical means of inerting fuel tanks can be found.
3. Assess the cost benefit of those systems.
4. Assess the effect of the new rule on other sections of the industry.
5. Follow the rules for ARAC harmonization working groups.
6. Issue a final report within 12 months after publication of the Tasking Statement.

2.2 WORKING GROUP DEVELOPMENT

On July 13, 2000, the FAA issued a notice in the *Federal Register* in Washington, D.C., establishing the current FTIHWG. This effort is an extension of the previous work performed by the 1998 ARAC Fuel Tank Harmonization Working Group (FTHWG), as reported in July 1998. The FTIHWG will coordinate with other working groups, organizations, and specialists, as necessary.

The FTIHWG addressed the following inerting systems:

- Ground-based inerting (GBI).
- Onboard ground inerting (OBGI).
- OBIGGS.

The FTIHWG addressed the following groups of transport category airplanes:

- In-service airplanes.
- New production airplanes.
- New airplane designs.
- Commuter airplanes.
- Short-range, medium-range, and intercontinental-range airplanes.

2.2.1 Organization

Figure 2-1 shows the organization of the ARAC FTIHWG leadership team.

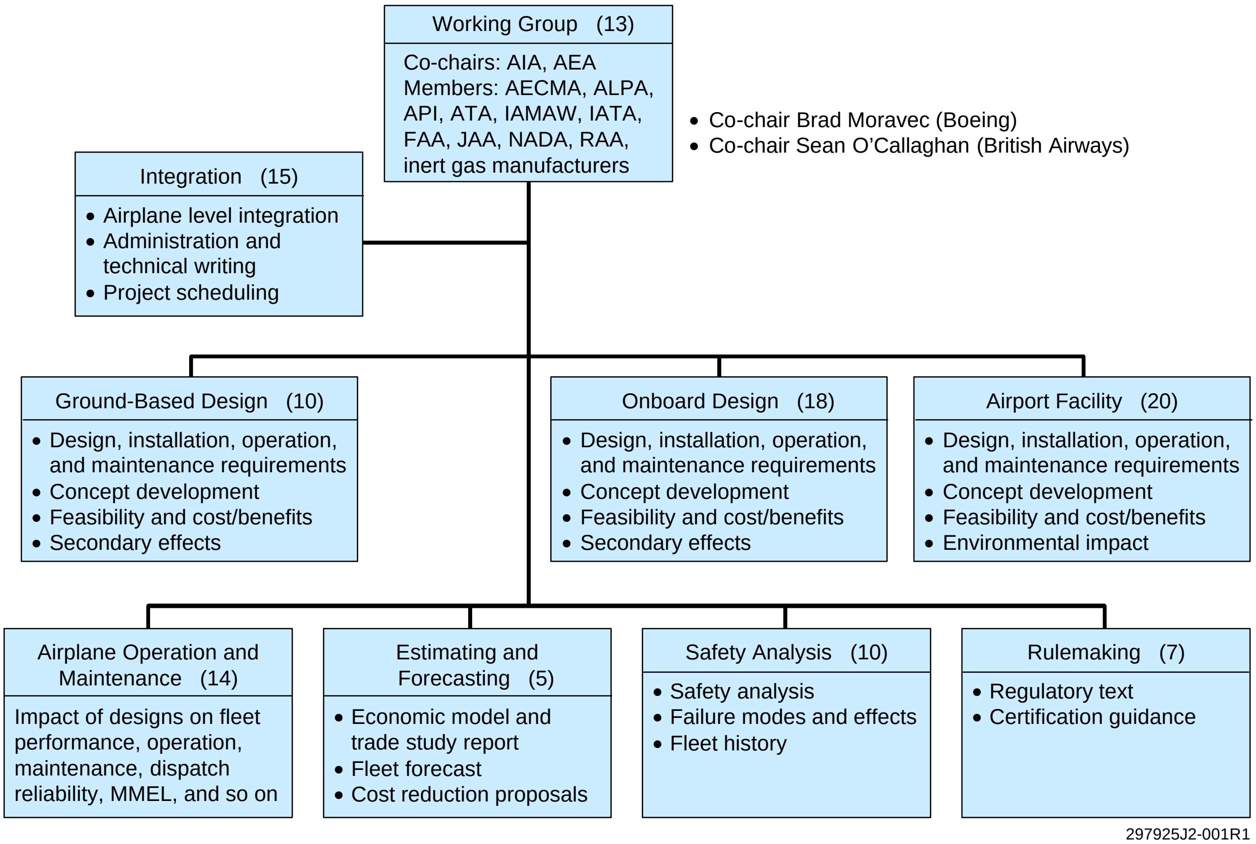


Figure 2-1. Working Group Team Leaders

2.2.2 Task Team Charters and Deliverables

Work Plan Outline

- The FTIHWG will be responsible for overall task management.
- Task management will include overall definition of study ground rules, success criteria, work statements, plans, schedules, resources, and deliverables.
- The FTIHWG will establish task teams to assist in completing the various tasks identified in the Tasking Statement issued in Washington, D.C., by the FAA, dated July 10, 2000.

Task Teams

- Ground-Based Inerting Designs
- Onboard Inerting Designs
- Airplane Operation and Maintenance
- Airport Facility
- Safety Analysis
- Estimating and Forecasting
- Rulemaking
- Integration

Task Team Responsibilities

Ground-Based Inerting Designs

- Review existing data on GBI studies and systems.
- Determine design, installation, operation, and maintenance requirements.
- Develop ground-based conceptual fuel tank inerting system designs.
- Provide a feasibility analysis of proposed designs and inerting methods.
- Prepare a cost-benefit analysis for ground-based system concepts.
- Evaluate the safety, risks, and secondary effects of these systems.
- If the concept is considered impractical, identify all technical limitations and provide an estimate of improvements necessary to make this concept practical in the future.
- Document the results of the GBI design and analysis study.

Onboard Inerting Designs

- Review existing data on onboard inerting studies and systems.
- Evaluate three system concepts consisting of an onboard ground inerting system (OBGIS), an OBIGGS, and a hybrid system.
- Determine design, installation, operation, and maintenance requirements.
- Develop onboard conceptual fuel tank inerting system configurations.
- Provide a feasibility analysis of proposed designs and inerting methods.
- Prepare a cost-benefit analysis for inerting system concepts.
- Evaluate the safety, reliability, risks, and secondary effects of these systems.
- If this concept is considered impractical, identify all the technical limitations and provide an estimate of improvements necessary to make the concept practical.
- Document the results of the onboard inerting design and analysis study.

Airplane Operation and Maintenance

- Review existing data on the impact of fuel tank inerting studies and systems on airplane operation and maintenance activities.
- Evaluate the impact of the proposed ground and onboard inerting system concepts on flight operations (such as dispatch reliability, air turnback [ATB], dispatch deviation guide [DDG], and master minimum equipment list [MMEL]).
- Evaluate the impact of inerting system concepts on maintenance operations and the subsequent effect of these concepts on fleet performance.
- Evaluate the cost impact of the inerting system concepts on flight operations, maintenance operations, fleet planning, and so on.
- Document the results of the Airplane Operation and Maintenance Task Team.

Airport Facility

- Review existing data on the impact of fuel tank inerting studies and systems on airports.
- Determine which airports within the United States and in other geographical areas of the world should be included in the study.
- Define the design, installation, operational, and maintenance requirements for inert gas generation, fuel scrubbing, and ullage washing.
- Develop conceptual system configurations to provide fuel-scrubbing and ullage-washing systems that can be used at airports considered in this study.

- Evaluate the impact on airport facilities and infrastructure that would result from the incorporation of the inerting system concepts being considered.
- Determine the most reliable and cost-effective means of providing inerting supplies within the United States and in other areas of the world.
- If system concepts are not practical, identify all technical limitations and estimate what improvements would be necessary to make the concepts practical.
- Document the results of this airport facility and infrastructure study.

Safety Analysis

- Review existing data regarding the safety benefits anticipated from eliminating or significantly reducing the threat of fuel tank explosion.
- Determine the safety benefits resulting from incorporation of the various proposed system concepts to eliminate or significantly reduce the development of flammable vapors in airplane fuel tanks.
- Evaluate the impact of these system concepts on previous service history fuel tank explosion threats resulting from internal and external tank ignition sources.
- Evaluate the risks and benefits of “as required” inerting system concepts.
- Document the results of the safety evaluations.

Estimating and Forecasting

- Review the available existing data regarding the economic impact of airplane fuel tank inerting studies and systems.
- Develop top-level models to assist the other task teams in evaluating the economic impact of the proposed inerting system concepts on airplane and aviation operations, airport facilities and infrastructure, and the general economy.
- Where practical, propose methods to minimize the overall system costs.
- Estimate the economic impact of the recommended systems on airline operations, the transportation industry, airport facilities and infrastructure, and regional and country economy.

Rulemaking

- Review existing regulations, advisory and guidance material, and continued airworthiness instructions regarding the subject of eliminating or reducing the flammable environment in airplane fuel tank systems.
- Prepare and coordinate within the FTIHWG regulatory text for new rulemaking by the FAA that would eliminate or significantly reduce the flammable environment in airplane fuel tank systems.
- For all system concepts recommended, develop and propose guidance material that describes the necessary analysis or testing that may be required to show compliance with the new regulatory text for certification and continued airworthiness.

Integration

- Review existing data from previous fuel tank working groups regarding applicability to the current tasks.
- Coordinate the development of task and system requirements for use by the FTIHWG.
- Coordinate activities within the FTIHWG to ensure that the task teams are using common ground rules, definitions, assumptions, requirements, schedules, and so on.
- Facilitate activities and communication within the FTIHWG to achieve the intermediate and final task assignments in a timely manner.

- Coordinate with other harmonization working groups, organizations, companies, and experts to support FTIHWG activities.
- Develop and implement a review process and integrated task schedule to support the requirements of the ARAC Executive Committee.
- Coordinate preparation of this final report to the ARAC Executive Committee.

Final Deliverables

- Recommend regulatory text for new rulemaking by the FAA that would require eliminating or significantly reducing the development of flammable vapors in fuel tanks on transport category airplanes; and provide compliance guidance material for the proposed regulation.
- Evaluate options for implementing these new regulations on current and future airplanes.
- Identify all technical limitations for those design options that are determined to be currently impractical.
- Provide guidance on testing and analysis for demonstrating certification compliance and continued airworthiness.
- Submit the above by June 29, 2001, for the ARAC Executive Committee to review before forwarding to the FAA.

2.2.3 Schedule

A milestone schedule was developed at the first FTIHWG meeting in September 2000.

The FTIHWG agreed to meet regularly according to a defined schedule. Individual task teams were directed to meet as often as necessary to accomplish the objectives of the FAA Tasking Statement. As stated, the final report is scheduled to be complete and delivered to the ARAC Executive Committee by June 29, 2001.

Figure 2-2 shows the task team schedule.

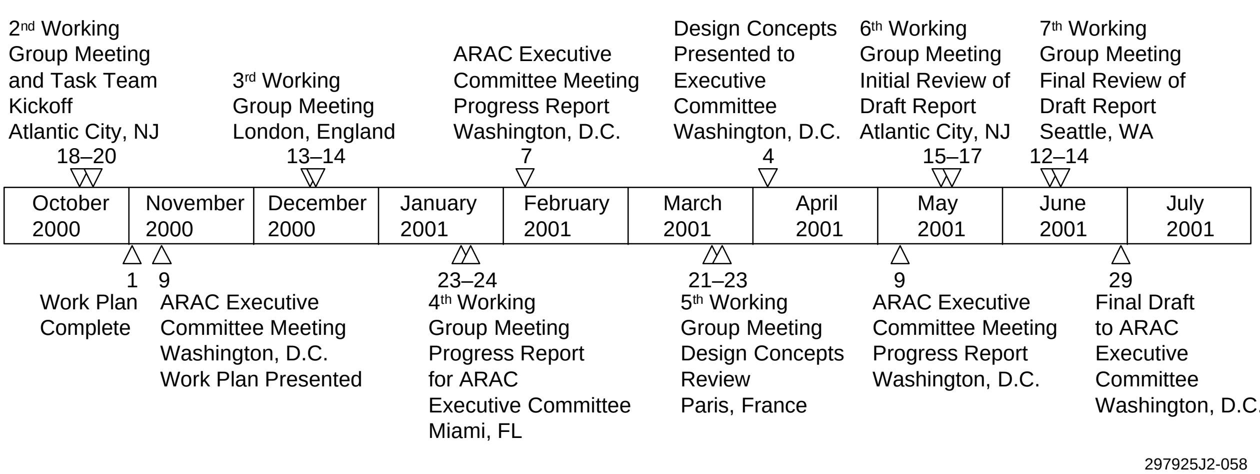


Figure 2-2. ARAC FTIHWG Major Milestones

2.3 STANDARDS

A common set of standards was necessary to achieve consistent results in the development and evaluation of designs and cost-benefit analyses. Therefore, the Integration Task Team developed and provided a common set of definitions for use by all the FTIHWG task teams.

2.3.1 Assumptions

To ensure that the potential methods of inerting were evaluated using consistent data and assumptions, a spreadsheet was created that provided a common source of data for use by the task teams. This spreadsheet included data for six generic airplane types: small, medium, and large jet transports; regional turbofans; regional turboprops; and business jets. The data included summaries for each airplane type, such as fleet size, weights, fuel volumes, and flight distributions. Mission profile data such as weight, altitude, Mach number, fuel remaining in each tank, and body angle as a function of time were included for each generic airplane type. Temperature profiles ranging from cold to extremely hot were also included in the mission profiles.

Performance and cost trade studies were included to allow consistent calculation of performance and cost impacts.

1. A fuel tank is considered inert when the oxygen content of the ullage (vapor space) is less than 10% by volume.
2. An unheated wing tank is defined as a conventional aluminum-structure integral tank of a subsonic wing with minimal heat input from airplane systems or other fuel tanks that are subject to heating.
3. The FTIHWG used the definition of fuel tank explosion threat contained in the July 1998 ARAC FTHWG report.
4. Service history used in this analysis was developed to include postcrash fuel tank fires.
5. Top-level design, reliability, maintenance, and operational study requirements were established to provide guidance for determining practical inerting systems.
6. In accordance with the Tasking Statement, design concepts evaluated had little or no redundancy in order to minimize costs.
7. Fuel tank inerting design concepts evaluated were not considered to be dispatch-critical systems and would therefore be part of the airplanes' MEL.

2.3.2 Ground Rules

The Working Group applied the following ground rules to the design concepts considered, as specified by the FAA Tasking Statement:

1. The FTIHWG evaluated the impact of fuel tank inerting design concepts or designs on transport category airplanes.
2. Within the transport category, the following "generic" study airplanes were evaluated:
   - Large-category airplanes.
   - Medium-category airplanes.
   - Small-category airplanes.
   - Commuter (turboprops and jets).
   - Business jets.
3. Within each airplane category studied, an evaluation was made of the impact on in-service airplanes, current new production, and future new type design airplanes.
4. FTIHWG task teams evaluated the impact of fuel tank inerting on airplanes with heated center wing tanks (CWT).
5. Where practical, the task teams used definitions, including the fuel tank explosion threat, developed for use and contained in the 1998 ARAC FTHWG Final Report.

6. The service history evaluated in FTIHWG studies and evaluations included postcrash fuel tank fires.
7. Fuel tank inerting design concepts considered by the FTIHWG have little or no system redundancy.
8. No fuel tank inerting system concept results in a net negative safety benefit to the airplane study category evaluated.
9. Fuel scrubbing with inert gas did not result in an adverse effect on fuel supply system performance, engine performance, or operational capability.
10. The FTIHWG identified technical and economic limitations of systems evaluated as impractical and estimated the improvements necessary to make these inerting systems practical in the future.
11. Except as noted in the report, the FTIHWG considered systems that would not result in a hazardous condition to personnel, airplanes, or airport facilities resulting from the failure of a fuel tank inerting system component during normal operation, nonnormal operation, or failure conditions.

Ground-Based Design Concepts Ground Rules

12. Each design concept proposed for a particular airplane study category must be capable of providing inert fuel tanks once the airplane reaches the gate and while the airplane is on the ground between flights.
13. It was considered unnecessary to evaluate any conditions within an airplane category's operational and environmental envelopes where a combination of fuel tank temperatures and quantities would not result in flammable vapors being present in any of the fuel tanks.
14. Failure of any fuel tank inerting system component during normal operations, nonnormal operations, and failure conditions will not result in a hazardous condition to any personnel, the airplane, or airport facilities.
15. Nitrogen-enriched air (NEA) that is supplied to the airplane during refueling operations for fuel tank inerting purposes is assumed to be a minimum of 95% purity.
16. The attachment panel or interface and the appropriate interface connections and equipment will not interfere with ingress and egress and the servicing position of ground equipment while the airplane is located at the terminal gate.
17. The location and design characteristics of the installed interface connections and equipment will not result in an additional hazard to the airplane as a result of a wheels-up landing.
18. No special provisions are included in the system design concepts to prevent air from entering the airplane fuel tank or inert gas from being vented from the airplane tank during any change in ground environmental thermal cycling.
19. The time taken by any ground-based design concept to inert the required number of fuel tanks in an airplane study category will not increase the turnaround time of that category.
20. The installation of a ground-based fuel tank inerting system will not result in an adverse effect on fuel supply system performance, engine performance, or engine operational capability.
21. During evaluation of a GBI system, consideration is given to the benefits and risks resulting from inerting only those fuel tanks located near significant heat sources.

Onboard Design Concepts (OBIGGS) Ground Rules

22. The OBGI design concept will be evaluated based on the ground rules defined in the section titled Ground Based Inerting Design Concepts.
23. Each design concept evaluated for a particular airplane study category is capable of providing inert fuel tanks during normal operations, such as takeoff, climb, cruise, descent, landing, and ground operations. However, nonnormal operations are not included in the ground rules in accordance with the Tasking Statement.
24. Each OBIGGS design concept is capable of inerting all fuel tanks in an airplane study category. (Reference: Tasking Statement.)
25. Any OBIGGS design concept installed will inert all fuel tanks throughout the certified airplane operating and environmental envelope during normal operation.

26. Where a combination of fuel tank temperatures and quantities shown within an airplane category's operational and environmental envelopes will not result in flammable vapors being present in any of the airplane fuel tanks, these conditions do not require fuel tank inerting from an onboard system.
27. The installation of an onboard fuel tank inerting system will not result in an adverse effect on the fuel supply system performance, engine performance, or engine operational capability.
28. Any certification maintenance requirements (CMR) or similar periodic maintenance checks required by an OBIGGS are considered to have a minimum frequency equivalent to a C-check.
29. When installed, an OBIGGS will not result in an increase of the schedule interruption rate of 0.05 per 100 departures in an airplane category. (Reference: industry experience.)
30. When installed, an OBIGGS will have an objective mature mean time between unscheduled removal (MTBUR) of any component of 5,000 hr minimum.
31. When installed, an OBIGGS will have a mature mean time between maintenance actions (MTBMA) of 250-hr minimum.

<u>*Airplane Operation and Maintenance Ground Rules*</u>

32. Regardless of the method of fuel tank inerting system used to inert the applicable fuel tanks in an airplane study category, the turnaround time of that particular airplane category will not be increased.
33. The operational and maintenance impact of continued airworthiness requirements of each fuel tank inerting system is estimated.

<u>*Airport Facilities Ground Rules*</u>

34. Any facilities developed to provide NEA for use in inerting airplane fuel tanks, while the airplane is located at the terminal gate, will meet all applicable safety regulations in force as of July 10, 2000.
35. Any system evaluated is capable of providing sufficient NEA to each airplane in a particular study airport so that the current airplane turnaround times are not adversely affected.
36. Any evaluated airport-based system for inerting fuel tanks will have adequate capacity to supply the required volume of nitrogen to each gate position in a period of time that will not result in an increase in the airplane turnaround time for that study-category airplane.
37. The airport-based fuel tank inerting system must be capable of simultaneously providing 100% of the flow requirements for each airport gate, taking into consideration the assumed mix of study-category airplanes at these terminal gates.
38. NEA supplied at the terminal gate for inerting airplane fuel tanks will be 95% minimum.

<u>*Safety Ground Rules*</u>

39. A functional safety hazard assessment will be performed for each ground-based or onboard inerting system evaluated. The basis for this report will be the functional hazard analysis (FHA) published by the 1998 ARAC FTHWG with appropriate changes to reflect the current evaluations.
40. A system reliability prediction will be completed for each ground-based and onboard design concept evaluated.
41. A system reliability prediction will be completed for each airport fuel tank inerting and fuel scrubbing system evaluated.
42. For the purposes of this study, the accident data set defined by the 1998 ARAC FTHWG will be used.
43. Any accident prevention analysis will consider report number DOT/FAA/AR-99/73. (Reference: Tasking Statement.)
44. A study was conducted on any proposed inerting design concept that estimated the accident prevention improvement of implementing that fuel tank inerting design concept. The methodology used for this study will be consistent with that used by the industry's Commercial Aviation Safety Team to evaluate intervention effectiveness.
45. Any fuel tank inerting design concept proposed that does not result in a positive net safety benefit will be considered unacceptable.

Estimating and Forecasting Ground Rules

46. Increases in airplane gate turnaround times will be assessed on an economic value of $150 million/min for U.S. operations and $380 million/min for worldwide operations. (Reference: Air Transport Association of America [ATA].)
47. The cost of fuel per U.S. gallon for this study will be $1.00. (Reference: *Air Transport World*, January 2001.)
48. Any estimated airplane flight delays resulting from operation of either a ground-based or onboard fuel tank inerting system will be assessed an economic value of $24.43/min. (Reference: ATA.)
49. Turnbacks to the departure airport or diversions to unscheduled landings at alternate en route airports will not be required for the system because the system will be eligible for MEL dispatch.
50. For each labor-hour estimated in the study, a burdened rate of $110/hr will be assumed for professionals (e.g., engineers). (Reference: FAA.)
51. For each labor-hour estimated in the study, a burdened rate of $75/hr will be assumed for technicians (e.g., line mechanics). (Reference: FAA.)
52. For each labor-hour estimated in the study, a burdened rate of $25/hr will be assumed for ground support personnel (e.g., refuelers). (Reference: FAA.)
53. The ramp-up time for introducing a certified fuel tank inerting system into the existing and current in-production fleets will be assumed to be 3 years for production models and an additional 7 years for in-service models.
54. The time period to be considered for calculating costs of an inerting scheme will be 16 years (from 2005 to 2020.)
55. The growth forecast assumed for the purposes of this study will be 3.6% per year. (Reference: ATA.)
56. Any increases or decreases in airline operations, direct airplane operating costs, and maintenance costs will be developed to determine the subsequent impact of fuel tank inerting on each study-category airplane and the overall operational impact.
57. For evaluation of costs of an OBIGGS for application to new type designs, it will be assumed that the design can be optimized in the initial design phase to minimize initial and recurring costs. (Reference: Tasking Statement.)

Rulemaking Ground Rules

58. A review of the current 14 CFR will be conducted to consider the changes that may be necessary for the incorporation of ground-based or onboard fuel tank inerting systems.
59. Where changes to the regulations are considered to be required, the FTIHWG will propose regulatory text for each paragraph that would require a change.
60. In support of any proposed regulatory changes, guidance material will be developed to describe analysis or testing that should be conducted for certification of all systems proposed.
61. For each fuel tank inerting design concept proposed, the recurring and nonrecurring costs to achieve complete FAA certification are estimated.

3.0
Service History

3.0 SERVICE HISTORY

The team examined the service history of known instances of fuel tank explosions resulting from internal or external ignition sources in the transport airplane fleet (including turbofan and turboprop airplanes) over the last 40 years.

3.1 METHODOLOGY

Appendix H, Safety Analysis Task Team Final Report, contains a detailed description of each event and the findings of the investigating authority. A description of the mitigating actions taken subsequent to the event to minimize its recurrence is also included in the appendix.

Appendix H summarizes 16 fuel tank explosion events, which are divided into *operational events* (i.e., those occurring on an airplane where passenger-carrying flight was intended) and *refueling and ground maintenance events*. They were grouped by cause (lightning, engine separation, refueling, maintenance, etc.) and then categorized by operational phase, ignition source, type of fuel tank involved, and fuel type.

The team established ground rules to guide this evaluation. First, the team determined that a forecast of future events should be based on the residual risk of recurrence of past events. In addition, the benefits forecast should be based on events that inerting would prevent effectively. As such, the team decided that accidents resulting from external ignition sources that breached the fuel tank would not be used to forecast future events. This ground rule is consistent with that used by the team that developed DOT/FAA/AR-99/73, *A Benefit Analysis for Nitrogen Inerting of Aircraft Fuel Tanks Against Ground Fire Explosion*. The Safety Analysis Task Team notes that inerting may offer some benefit in preventing fuel tank explosions caused by small explosive devices that would not otherwise result in a catastrophe. However, those benefits could not be quantified because of uncertainties related to secondary ignition sources and the loss of nitrogen following breach of the fuel tank.

In addition, the effectiveness of the actions taken subsequent to the event to minimize its recurrence were assessed based on

- Identification of the ignition source.
- Confidence level that mitigating action addressed the ignition source.
- Implementation level of the mitigating action or actions.

Once these data and ground rules were in place, a trend and residual risk analysis was conducted.

3.2 ANALYSIS

The starting point of this analysis was the table of events in the 1998 ARAC FTHWG final report. The events contained in that report were based on the *FAA Notice of Fuel Tank Ignition Prevention Measures* published in the *Federal Register* on April 3, 1997. The data sources used were accident and incident reports provided by investigating organizations, regulatory authorities, and original equipment manufacturers' (OEM) safety-related databases. The level of details reported in the early events was sometimes limited, depending on the event location in the world and the type of event (i.e., whether it involved an internal or external ignition source).

Late in the study period for this ARAC, a fuel tank explosion occurred in Bangkok, Thailand. While it is understood that the accident investigation is ongoing, the NTSB has released information indicating that the wreckage shows evidence that the CWT exploded and that the ignition source for that fuel tank has yet to be determined. This team has not been involved in that investigation and does not wish to publish findings in advance of the investigating authority. However, the event appears to fit the guidelines set forth by the FAA Tasking Statement, and the team decided to include it as a statistical data point on which to base the forecast of future accidents.

3.2.1 Analysis of Previous Tank Explosions

The data indicates a difference in the safety levels of wing tanks and CWTs. The former are force-cooled by air flowing over the wings, whereas the latter, being located in the fuselage between the wings, are cooled less efficiently. Other auxiliary tanks are also housed within the fuselage. Unlike wing tanks, fuselage tanks may be located adjacent to heat sources.

There have been no known internal ignition sources that resulted in a wing tank explosion in 900 million hours of operation by the commercial transport fleet. All wing tank events have been the result of known external ignition sources (e.g., lightning strike, over-wing fire, refueling, or maintenance error). Corrective actions to prevent recurrence of externally initiated wing tank events have been in place for many years and have been demonstrated to be effective. It has also been observed that the use of less volatile fuel (e.g., Jet A versus JP-4) enhances safety.

Over the years, CWTs have accumulated considerably fewer operating hours than wing tanks (e.g., a Boeing 737 has two wing tanks and one center tank, so it accumulates wing tank hours at twice the rate of CWT hours). Because the equipment in wing and center tanks is similar (i.e., equivalent in types and numbers of potential ignition sources), there should be significantly fewer CWT events than wing tank events. In actuality, however, the number of events is approximately equal for two reasons. First, flammable vapors are present in center tanks a greater percentage of the time because they are not as well cooled. Second, potential internal ignition sources in the wing tanks are more often submerged—and thus present less risk—than they are in CWTs, which are not filled unless additional range is required.

With the exception of the three most recent CWT events and the 1989 Bogotá event, the causes of all other CWT events have been addressed by actions designed to prevent or minimize their recurrence. The 1989 Bogotá accident, which involved a breach of the fuel tank because of a high-explosive charge, violated one of the ground rules this team established as the basis for forecasting future events.

For the three most recent CWT events, the exact ignition sources have not been identified. While corrective actions to identify and minimize potential ignition sources are now being put in place, a means to reduce flammability in heated CWTs should be pursued.

The team concluded that the 1990 Manila, 1996 New York, and 2001 Bangkok events should form the basis for forecasting future events.

3.2.2 Postcrash Fuel Tank Fires

As suggested by the Tasking Statement, the Safety Analysis Task Team evaluated the data provided by DOT/FAA/AR-99/73. The Safety Analysis Task Team accepted the findings of this report and chose not to duplicate effort in this area. The report considered 13 survivable accidents worldwide in which a fuel tank explosion occurred but was not the prime cause of the accident. Each of the accidents was analyzed in depth to assess the number of lives that might be saved if nitrogen inerting systems were used. The predicted number of lives saved per year from this analysis were reported as

- Ground nitrogen inerting, center tank only: 0.3
- Ground nitrogen inerting, all fuel tanks: 2.4
- Onboard nitrogen inerting, all fuel tanks: 6.0

The team used this data to determine the forecast number of lives saved over the study period. Based on assumed annual fleet growth rates and the implementation assumptions (discussed in the estimating and forecasting section), the team forecasts that GBI of the CWT would save 5 lives worldwide over the 16-year study period. Similarly, onboard inerting of all fuel tanks would save 101 lives worldwide over the 16-year study period.

The report concludes

> *The predicted potential number of lives saved per year is relatively small compared to other survivability factors. One of the reasons that nitrogen inerting may not be effective, in terms of saving lives in the 13 accidents analyzed, is that in many cases fuel tanks were ruptured when the airplane impacted the ground. Any nitrogen in the fuel tanks is likely to have escaped with the spilled fuel. The system is only effective when the fuel tanks are not significantly ruptured.*

3.3 CONCLUSIONS

The following conclusions from the service history review can be drawn:

- There is a close relationship between the incidence of explosions in wing tanks and the use of "widecut fuel" (e.g., JP-4).
- Wing tanks operating with less volatile Jet A type fuel have demonstrated an acceptable safety record.
- In comparison, heated CWTs are more vulnerable to explosion in the presence of ignition sources.
- The three most recent events (1990 Manila, 1996 New York, 2001 Bangkok) form the basis for forecasting future events.
- Inerting fuel tanks may enhance occupant survival in accidents in which a fuel tank explosion occurs but is not the prime cause of the accident.

4.0
Safety Assessment

4.0 SAFETY ASSESSMENT

4.1 METHODOLOGY

This safety assessment is designed to determine the net safety benefit associated with inerting. Section 4.2 provides an overview of the flammability exposure analysis tool that was used to determine the effectiveness of inerting systems. Sections 4.3 and 4.4 discuss potential new hazards that must be addressed with the implementation of any inerting system design. Section 4.5 describes the approach for calculating safety benefits from inerting. Sections 5.0 through 9.0 discuss the safety benefits for each design concept.

4.2 FLAMMABILITY

Understanding flammability relies on the science of quantifying when a fuel vapor/air mixture will burn upon introduction of an ignition source.

Jet fuel is a blend of more than 300 different hydrocarbons. When fuel is added to a tank, a certain percentage of the fuel vaporizes, with more of the light hydrocarbons evaporating than the heavy ones. The resulting vapor displaces some of the air in the tank and mixes with the air to create a fuel-to-air mixture in the ullage (i.e., portion of the tank volume not occupied by fuel).

The amount of fuel vapor present in the fuel tank ullage is driven by the vapor pressure of the fuel, which is strongly affected by the fuel temperature. Therefore, the flammability of ullage depends on the fuel temperature while the airplane is on the ground, and on how it cools during the climb and cruise.

This fuel vapor/air mixture can be ignited when the ratio of fuel to air is within a certain range between the lean and rich limits. For jet fuels, this combustible fuel-to-air ratio ranges from a lean limit of around 0.03 (1 lb of fuel vapor to 33.3 lb of air) to a rich limit of around 0.24 (1 lb of fuel vapor to 4.2 lb of air). Within this fuel-to-air ratio range, a spark, arc, hot surface, or other ignition source can ignite the fuel vapor/air mixture. Outside these limits, the fuel is either too lean or too rich to burn.

The energy needed to ignite fuel vapors varies as a function of the fuel-to-air ratio. The lean and rich ends of this ratio require higher spark energy—more than 1,000 mJ. In the middle of the flammable fuel-to-air ratio range, at around 0.08 (1 lb of fuel vapor to 12.5 lb of air), the ignition energy needed drops to 0.25 mJ, or 5,000 times less than is needed at the lean and rich limits. For reference, a jet engine igniter plug has a single-spark discharge of around 5,000 mJ, and a person walking across a carpet in dry weather can create a spark of around 10 mJ. An increase in altitude increases the energy required to ignite the mixture.

Fuel tanks become more flammable as the airplane climbs, as a result of pressure decrease. While the amount of fuel vapor doesn’t change, pressure influences the fuel-to-air ratio because the amount of air in the tank lessens with altitude. At constant temperature, this causes the fuel-to-air ratio to increase. Modeling assumes a lean flammability limit temperature reduction of 1°F for each 808 ft of altitude gained.

The amount of fuel in the tank has an effect on the fuel-to-air ratio because the mixture of different hydrocarbons in fuel evaporates to reach equilibrium. If there is only a small amount of fuel in the tank, the fuel may run out of light hydrocarbon components and a lower fuel-to-air ratio results. This effect exists at low fuel quantities, generally near the unusable quantity of the tank.

A flash point test is a simple test run at sea level to find the temperature at which a small flame will ignite a fuel vapor/air mixture in a small chamber. The flash point is useful for comparing one fuel to another and is about 10˚F above the lean flammability limit for jet fuels. Testing by the University of Nevada at Reno for the FAA has established that the flash point temperature, determined by the American Society for Testing and Materials (ASTM) Standard D 56, gives a fuel-to-air ratio of 0.044 for most Jet A type fuels.

The FAA has developed a computer program to compute the fuel-to-air ratio for a wide range of temperatures, altitudes, and fuel loads for jet fuels. It uses the ASTM D2887 distillation curve to define the fuel in question. This program was made available to and modified by the FTIHWG. The following paragraphs describe the customization of this model for ARAC analysis.

4.2.1 Inerting

Inerting is the process of reducing the amount of oxygen in the tank ullage to reduce or eliminate the ability of an ignition source to ignite the fuel vapor/air mixture. Prior work had established that—even with military threats such as high-explosive shells—reducing the oxygen content of the ullage to less than 10% would eliminate ignitions. The 1998 ARAC FTHWG proposed the concept of using GBI as a means of reducing tank flammability.

The FAA has conducted research on the quantity of nitrogen or NEA needed to inert a simple tank, the cost of providing NEA to the fleet, and—in cooperation with the industry—the use of GBI on a 737 airplane.

To support this research, the FAA has also developed an inerting computer program to assess the oxygen content in the fuel tank ullage over a complete flight. The model can add NEA to the tank ullage at any time and vary both the quantity and quality of the NEA. The model computes the amount of oxygen and nitrogen present in the tank—both in the ullage and dissolved in the fuel—and the fuel vapor in the ullage at 1-min time steps, from the time the airplane arrives at the gate to be fueled, through its fueling, dispatch, flight, landing, and taxi-in at the destination airport.

This model uses Coordinating Research Council (CRC) solubility coefficients (*CRC Aviation Handbook, Fuels and Fuel Systems*, no. Naval Air Systems Command no. 06-5-504, May 1, 1967) to compute the amount of oxygen and nitrogen dissolved in the fuel, and then uses an exponential decay process to transport the gas out of or back into the fuel, depending on the driving partial-pressure differential.

During climb, the exponential time constant is reduced considerably to allow for the more rapid gas evolution seen while climbing. The FAA used data from the 737 flight test to fine-tune the constants used in the model. The model computes ullage gases based on the change in tank pressure and the amount of NEA or air added in the 1-min increments. NEA and existing gases mix instantaneously, but the outflow of oxygen and nitrogen from the fuel needed to reach a pressure balance is assumed to lag the current oxygen content by 4 min, matching the FAA laboratory data.

The FTIHWG has used this model to assess the effectiveness of different inerting systems, including GBI and several forms of onboard NEA generation and delivery systems. The effectiveness of the inerting system can be used to assess tank fleet flammability exposure, as discussed in the following paragraphs.

4.2.2 Flammability Exposure Analysis

The 1998 ARAC FTHWG studies developed a Monte Carlo simulation technique to assess fleet fuel tank flammability exposure.

This method used the thermal characteristics of a fuel tank, the given distribution of missions the airplane would fly, and a model of the range of ambient temperatures experienced to compute the tank temperature for every minute of a large number of flights. Simultaneously, this method compared the fuel tank temperature to the lower and upper flammability limits (LFL and UFL) of the fuel presumed to be loaded for that flight. From this, it was possible to determine the fleet flammability exposure, which is the number of minutes the tank temperature is in the flammable range relative to the total operational time of the airplane. The 1998 ARAC FTHWG showed that CWTs exposed to nearby heating sources would have a flammability exposure of around 30% and unheated wing tanks would have a flammability exposure of around 5%.

The 1998 ARAC FTHWG used proprietary thermal models and Monte Carlo analysis programs developed by participating manufacturers. To conduct its own assessment of flammability exposure, the FAA developed its own Monte Carlo flammability analysis program. The 1998 ARAC FTHWG and FAA made their programs available to the ARAC FTIHWG for use and enhancement as needed to conduct the appropriate studies.

The program follows the original ARAC concept of computing flammability for any number of flights and obtaining a fleet-average exposure.

Because the 1998 ARAC FTHWG was studying a range of generic airplane types, it developed a set of generic tank thermal characteristics. The concept defined an exponential time constant for the tank temperature response to changes in ambient temperature and an equilibrium temperature difference (relative to ambient temperature) to represent the thermal effect of heat input to the tank. A tank will respond to a change in ambient temperature by following an exponential decay curve to the new equilibrium temperature, defined as the new ambient temperature plus the temperature difference from heating. The program used different values for ground and flight cases, and for full and nearly empty tanks. The need to switch from a full to a nearly empty tank is defined by airplane data and the tank in question. Manufacturers' proprietary data determined the specific values for the generic airplanes, which represent an average generic configuration. The constants used do not represent any actual airplane. Figure 4-1 shows these values.

Fuel tank thermal data	**Ground-heated CWT**			**Flight-heated CWT**		
	Equil. temp delta (°F)	**Time constant**		**Equil. temp delta (°F)**	**Time constant**	
Airplane type		**Full (min)**	**Empty (min)**		**Full (min)**	**Empty (min)**
Large transport	60	400	120	60	300	150
Medium transport	30	300	30	50	300	90
Small transport	37	300	25	50	300	90

Figure 4-1. Generic Tank Thermal Characteristics

A randomly selected ground temperature defines the atmospheric conditions for each flight by using a set of Gaussian distributions to define the range of temperatures and a randomly selected tropospheric temperature. The distribution of ground temperatures was based on 16 years of hourly temperature observations (7 a.m. to 11 p.m., local times) for 533 airports worldwide. The data was weighted based on the passenger volume for each specific airport. The climb period uses an interpolation scheme that computes the altitude of the tropopause and includes a temperature inversion on cold days.

A random value based on a distribution of flight lengths from fleet airline statistics determines the mission length for each flight, which is then scaled to match the maximum flight length of the generic airplanes.

Time on the ground is a random variable consisting of taxi-in time (set at 5 min), time before refueling (set at 5 min), refueling time (based on flight length and generic refueling rates), time at gate after refueling (based on a probability distribution from airline fleet statistics), and taxi-out time (set at 5 min). The approximate time on the ground for the generic large airplane is a minimum of 60 min, with 80% of the ground times shorter than 105 min and the maximum lasting 225 min. The approximate time on the ground for the small generic airplane is a minimum of 20 min (10% of flights), with 50% taking less than 50 min, 80% less than 75 min, and the longest taking 210 min.

Fuel flammability properties are defined by a randomly selected flash point for each flight and the effect of flammability temperature range computed as a function of altitude. The flash-point range is a normal Gaussian distribution, with a mean temperature of 120°F, and a standard deviation of 8°F. Generally, this results in a flash-point range of 100 to 140°F.

The model can compute a single flight and present the flight profile and resulting flammability information as a plot, or compute the fleet flammability exposure for a given airplane type and tank for a Monte Carlo run of any number of flights. The ARAC analysis used computer runs of 5,000 flight cases.

Inerting systems such as GBI can be examined in the flammability model by creating a set of rules for the system using the inerting program discussed above. These rules compute when an increment of the flight is not flammable because the tank is inert, resulting in reduced fleet flammability exposure.

The team uses the results of the flammability exposure analyses for the generic airplane types and tanks to compute the effectiveness of candidate systems at preventing potential future accidents.

4.2.3 GBI Analysis

GBI was analyzed by adding a set of rules that inerted the center tanks with the volume of 95% NEA necessary to reach 8% with an empty tank. The inerting is a step function inserted at 50% of the time at gate after refueling. Had additional modeling time been available, the team would have evaluated actual inerting flow time and varied time at the gate, though this rule seemed likely to represent the average airline operations. Section 5, Ground-Based Inerting System, presents the results of the GBI analysis.

4.2.4 OBGI Analysis

OBGI was analyzed to ensure that the ullage contained 10% or less oxygen concentration. This concentration had to be achieved while the airplane was parked at the terminal gate. The NEA purity depended on the technology being analyzed. The size of the system was highly dependent on the time available at the gate to inert the fuel tanks. A flammability exposure analysis was then performed to compare the OBGI system to the other technologies.

Hybrid OBGI was analyzed in exactly the same way except that it was able to take advantage of an additional 5 min during taxi-in, after landing, to inert the fuel tanks. This slightly decreased the system size compared to OBGI, while maintaining the same flammability exposure.

4.2.5 OBIGGS Analysis

OBIGGS was analyzed to ensure that the ullage contained 10% oxygen or less during all phases of flight. The NEA purity depended on the technology being analyzed. Based on the 737 flight testing conducted by the FAA, where the tanks remained inert for several hours after receiving nitrogen, it was assumed that OBIGGS would not operate on the ground.

Hybrid OBIGGS was designed to provide the same flammability exposure as the GBI, OBGI, and hybrid OBGI systems. The focus was on ensuring that the flammability exposure during ground operations, taxi, takeoff, and climb were consistent with the other systems.

4.3 FUNCTIONAL HAZARD ANALYSIS

Because some of the inerting concepts involve technologies not currently fully mature or proven in a commercial airline environment, rigorous and detailed safety analyses could not be performed down to the component level with confidence. However, the team did perform a top-level FHA, which is included in appendix H, Safety Analysis Task Team Final Report.

4.4 PERSONNEL HAZARDS

4.4.1 General

Nitrogen and other inert gases are not normally dangerous, but when used in confined spaces they can create oxygen-deficient atmospheres that can be deadly. Nitrogen is especially hazardous, because it cannot be detected by human senses and can cause injury or death within minutes. In the United States, at least 21 people have died in 18 separate incidents involving the use of nitrogen in confined spaces between 1990—when more stringent requirements were adopted—and 1996. Every year in the United Kingdom, work in confined spaces kills an average of 15 people across a wide range of industries, from those involving complex plants to those using simple storage vessels. Fatalities include not only people working in confined spaces, but also those who try to rescue them without proper training or equipment. Still more people are seriously injured.

The health risk to ground and maintenance personnel servicing airplanes that use nitrogen inerting technology is present not only in the fuel tanks themselves, but also in the location of the nitrogen-generating equipment. Wherever possible, such equipment should be located outside the airplane pressure hull. However, this is not possible on all airplanes. Therefore, it will be necessary to ensure that safety systems and procedures are in place to protect the airplanes and personnel working in and around them.

The following sections highlight some of the hazards associated with operating fuel tank inerting systems on commercial transports and the risks they pose to the airplane, its occupants, and maintenance personnel.

4.4.2 Confined Spaces

The Occupational Safety and Health Administration (OSHA) defines a confined space as a space that by design

- Has limited openings for entry and exit.
- Has unfavorable natural ventilation.
- Is not intended for continuous employee occupancy.

OSHA further defines a permit-required confined space as a confined space with

- Hazardous atmosphere potential.
- Potential for engulfment.
- Inwardly converging walls.
- Any other recognized safety hazard.

By this definition, all airplane fuel tanks meet the OSHA definition of a permit-required confined space. If the tanks were to be inerted, the current requirement to ventilate fuel tanks before entering would be critical. In addition, other locations under consideration for housing nitrogen-generating equipment, such as cargo holds, wheelwells, wing-to-body fairings, and APU bays, may also be considered confined spaces. As such, appropriate entry procedures must be in place to minimize the risk to workers entering these spaces. These areas should be clearly marked and workers thoroughly educated regarding both the hazards of confined-space entry and the insidious nature of nitrogen asphyxiation and death.

The costs associated with implementing these additional confined-space entry procedures worldwide are estimated at $39.8 million for safety equipment and an additional $28.3 million per year in labor (see addendum F.E.1 in appendix F). Even with these procedures in place, accidents will continue to happen as a result of people bypassing or simply ignoring the procedures, as is proven annually by the current record of injuries and fatalities.

4.4.3 Gaseous Nitrogen

The most significant hazard associated with exposure to nitrogen is breathing the resulting oxygen-deficient atmosphere. Normal atmosphere is made up of approximately 21% oxygen, 78% nitrogen, and 1% argon, with smaller amounts of other gases. Nitrogen, which is colorless, odorless, and generally imperceptible to normal human senses, requires the use of oxygen-monitoring equipment to detect oxygen-deficient atmospheres. Despite its nontoxic profile, nitrogen can be quite deadly if not properly handled.

It is not necessary for nitrogen to displace all the 21% of oxygen normally found in air to become harmful to people. OSHA requires that oxygen levels be maintained at or above 19.5% to prevent injury to workers. Figure 4-2 summarizes the expected symptoms at various oxygen concentrations for people who are in good health.

Oxygen concentration, % volume	Symptoms	Maximum exposure
19.5	None	NA
14 to 19.5	Labored breathing, particularly at higher workloads	NA
12 to 14	Physical and intellectual performance impaired, increased heart rate	NA
10 to 12	Rapid breathing, dizziness, disorientation, nausea, blue lips	10 min
8 to 10	Loss of control, gasping, white face, vomiting, collapse	• 50% of people will not survive 6 min • 100% of people will not survive 8 min
4 to 8	• Coma • Death	• 40 sec • 2 min
<4	Death	Seconds

Figure 4-2. Personnel Hazards

The very nature of oxygen deficiency is that the victim becomes the poorest judge of when he or she is suffering from its effects. Victims may well not be aware of their condition and could fall unconscious without ever being aware of the danger.

4.4.4 Liquid Nitrogen

For OBIGGS, which uses cryocooling methods, liquid nitrogen presents its own specific hazards. Although relatively safe from the point of view of toxicity, liquid nitrogen—in common with all cryogens—presents the following hazards:

- Cold burns, frostbite, and hypothermia from the intense cold.
- Overpressurization from the large volume expansion.
- Fire from condensation of oxygen.
- Asphyxiation in oxygen-deficient atmospheres.

Skin contact with liquid nitrogen can cause tissue to freeze, resulting in severe burns, which are caused by the extremely low temperature of the cryogenic liquid, not by a chemical reaction. Liquid nitrogen contacting the airplane structure may cause degradation of materials, especially deterioration of composites and stress cracks in aluminum, and could result in structural failure.

The risk of oxygen-deficient atmospheres when using liquid nitrogen arises from the vast expansion of the substance as it boils or vaporizes. Just 1 L of liquid may produce around 700 L of gas at atmospheric pressure, displacing significant quantities of breathable air if the gas is released in a confined space such as an airplane fuel tank or pressure hull. The tendency of cool nitrogen to accumulate at low levels, where it is less easily dispersed than the ambient atmosphere, compounds this problem. Even an apparently small spill could lead to dangerously low oxygen levels, presenting a serious hazard to personnel and other occupants in the area.

Oxygen condensation from the atmosphere as a result of extreme cold is another potential hazard of using cryogens. Liquid oxygen can create highly flammable conditions, and may also create local oxygen-enriched atmospheres, presenting a greatly increased risk of fire or explosion should an ignition source be present.

4.4.5 Gaseous Oxygen

Gaseous oxygen, a byproduct of the nitrogen generation process, presents its own potential hazards. OBIGGS concepts are designed to vent oxygen overboard; however, some form of leak detection would need to be in place. Failure to provide such detection may result in an oxygen-rich atmosphere with associated risk of fire and explosion. Many materials that would normally only smolder in air, such as clothing, will burn vigorously in an oxygen-enriched atmosphere, making it essential that staff members are alerted to high oxygen concentrations so that the risk of fire can be minimized.

4.5 SAFETY BENEFIT ANALYSIS

The safety benefit forecast approach is based on the conclusions drawn from the service history review. Specifically, analysis showed that the tank explosion rate is not the same for all tank types. Further, there are similar types and numbers of potential ignition sources within all tanks, so one can expect the ignition event occurrence rate to be essentially the same for all tanks. It follows that different flammability exposures for the different tank types result in different explosion rates between wing tank and heated CWTs. Furthermore, there are differences in the exposure to potential ignition sources. On average, for example, potential ignition sources in wing tanks are submerged in fuel—and thus incapable of causing an event—more often than they are in CWTs, which are not filled if maximum airplane range is not needed.

The explosion rate for heated CWTs was calculated directly from the three events mentioned earlier. Explosion rates for each of the other tank types were determined based on their exposure to flammable vapors and the likelihood that the potential ignition source would not be submerged. Figure 4-3 shows the three events on which the analysis was based, along with the total worldwide fuel tank accident forecast.

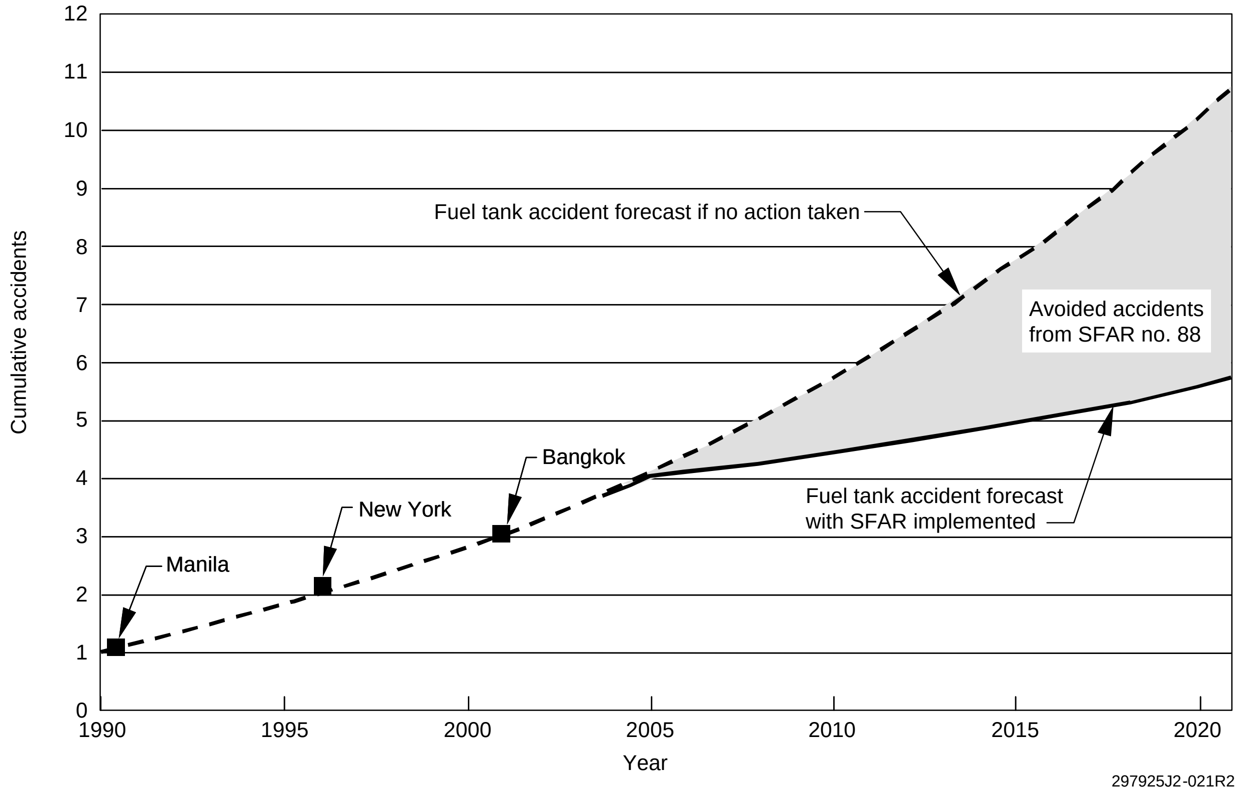


Figure 4-3. Worldwide Unexplained Fuel Tank Explosion Accident History and Forecast

This is the baseline accident forecast if no action is taken to preclude future events. Of the accidents forecast in figure 4-3, approximately 90% are predicted to involve heated CWTs.

In figure 4-3, the avoided accidents analysis takes into account predicted reductions in accident rate of 75% attributable to SFAR no. 88. The 75% reduction had been estimated by the 1998 ARAC FTHWG. In addition, the Safety Team had reviewed the 1998 report and fuel tank safety enhancements as a result of recent AD actions and other improvements. Although consensus was not reached by the FTIHWG, the majority of the HWG considered that using the 75% predicted reduction in fuel tank explosions was reasonable.

In addition, design, implementation, and forecast fleet growth all have a role in the number of forecast accidents that can be avoided. Appendix G, Estimating and Forecasting Task Team Final Report, documents these assumptions.

The number of prevented fatalities from a fuel tank explosion depends on the number of accidents avoided and the number of passengers on board. The number of passengers on board is a function of whether the explosion occurs in flight or on the ground. Based on the flammability exposure after inerting it was estimated that 15% of avoided accidents would have otherwise occurred on the ground, the other 85% in flight. It was also assumed that 10% of the people would die in a ground explosion, while an in-flight explosion would be a complete loss of everyone on board. These two assumptions were based on the historical accident record. The average number of passengers depends on the size of the airplane and the expected load factor.

Using the six generic airplane categories, the FTIHWG estimated that the average number of seats is 350 (plus 12 crew) for a large turbojet, 255 (plus 9 crew) for a medium turbojet, 154.5 (plus 7 crew) for a small turbojet, 65 (plus 5 crew) for a regional jet, 45 (plus 4 crew) for a turboprop, and 11 (plus 3 crew) for a business jet. Based on the FAA Aviation Forecasts Fiscal Years 2001–2012, the load factors are 75% for a large turbojet, 73% for a medium turbojet, 71% for a small turbojet, 60% for a regional jet and turboprop, and 40% for a business jet. Figure 4-4 summarizes the average number of people on board each of the generic airplanes based on these assumptions.

	Large transport	Medium transport	Small transport	Regional turbofan	Regional turboprop	Business jet
Passengers and crew onboard	275	195	117	44	31	7

Figure 4-4. Average Number of People on Board Each Generic Airplane

Figure 4-5 summarizes the number of forecast accidents avoided due to GBI (sec. 5.5), OBGI (sec. 7.6), and OBIGGS (secs. 8.6 and 9.6).

	Large transport	Medium transport	Small transport	Regional turbofan	Regional turboprop	Business jet
Worldwide accidents avoided by applying GBI to HCWT only	0.24	0.09	0.54	No HCWT	No HCWT	No HCWT
Worldwide accidents avoided by applying OBGI to HCWT only	0.20	0.09	0.47	No HCWT	No HCWT	No HCWT
Worldwide accidents avoided by applying OBIGGS to HCWT only	0.25	0.10	0.56	No HCWT	No HCWT	No HCWT
Worldwide accidents avoided by applying OBIGGS to all tanks	0.28	0.12	0.63	N/A	N/A	N/A

Figure 4-5. Worldwide Accidents Avoided by GBI and OBIGGS

In addition to preventing in-flight and ground fuel tank explosions, inerting also offers a benefit in enhancing occupant survival in accidents from other causes that result in a postcrash fuel tank fire or explosion. These benefits are discussed in section 3.2.2. It was found that GBI could save 5 lives worldwide over the study period, while OBIGGS could save 101 lives worldwide.

It must be observed that implementing fuel tank inerting on a global scale would introduce new hazards that previously did not exist in commercial aviation. Present wherever nitrogen is handled in the aviation infrastructure, these risks could be mitigated largely through stringent measures, but they could not be entirely eliminated.

Nitrogen is a colorless, odorless, nontoxic gas that is impossible to detect when excessive concentrations displace the oxygen normally present in the atmosphere. Depending on the level of oxygen depletion, the effects on people range from decreased ability to perform tasks to death through asphyxiation.

The adoption of inerting would introduce two types of hazards. The first would be the risk of confined-space asphyxiation from fuel tank entry for maintenance purposes. This risk is well understood and could be mitigated through training and procedures. A second and more insidious risk is the formation of localized oxygen-depleted zones as a result of undetected nitrogen leaks at airline and third-party maintenance facilities, on board airplanes, or—in the case of GBI—in airport ramp and terminal environments. Careful system design and rigorous procedures would be required to mitigate this latter risk scenario.

The FTIHWG lacked the time and expertise to assess these risks with confidence. However, the FTIHWG felt it was important to bound the risk. To do this, a simple extrapolation of available OSHA and National Institute of Occupational Safety and Health (NIOSH) data was used. According to 1980–1989 NIOSH data, the confined-space accident rate is between 0.20 (for the transportation industry) and 0.68 (for the oil and gas industries) per 100,000 employees. Of these, 43% were due to "Hazardous

Atmosphere - O2 deficiency." Assuming that these were all inert-gas related (e.g., argon, nitrogen, and carbon dioxide), this would result in a confined-space asphyxiation rate of 0.086 to 0.292 per 100,000 employees. According to OSHA, there were 1.2431 million U.S. airline employees in 1999. This would suggest the U.S. airline industry could expect 1.07 to 3.6 fatalities per year. In 1993, OSHA implemented more rigorous confined-space permit rules and estimated those rules would reduce fatalities by 85% in the United States. Assuming these rules are as effective as initially estimated, they could reduce U.S. airline industry fatalities to between 0.16 and 0.54 per year. The United States accounts for approximately 46% of worldwide airplane operations, and it was assumed that an OSHA-equivalent confined space regulation did not exist in the rest of the world. That results in a non-U.S. airline industry fatality rate of 1.26 to 4.23. The fatality rate from confined-space asphyxiation from nitrogen for the total worldwide airline industry is 1.42 to 4.77 per year. Based on assumed annual fleet growth rates and inerting system implementation assumptions, it is forecast that between 24 and 81 lives may be lost over the study period. Neither OSHA nor NIOSH participated in the FTIHWG. It is recommended that those agencies evaluate this risk based on current data before implementing inerting on a global scale.

Figure 4-6 summarizes the lives affected worldwide by inerting over the study period.

Lives affected over study period, 2005 through 2020	GBI, HCWT	OBGI, HCWT	OBIGGS, HCWT	OBIGGS, all tanks
Lives saved from fuel tank explosions in flight	125	112	132	149
Lives saved from fuel tank explosions on ground	2	2	2	3
Lives saved from post-crash fires	5	5	5	101
Lives lost due to asphyxiation	24 to 81	24 to 81	24 to 81	24 to 81

Figure 4-6. Summary of Lives Affected Worldwide by Inerting

Based on the last 10 years' accident records, there are approximately 650 fatalities per year worldwide resulting from airplane accidents. Assuming the worldwide accident rate remains constant and applying the unconstrained fleet growth assumption, over 15,000 fatalities could result from airplane accidents—from all causes—that could occur over the study period. The lives saved from inerting represent approximately 1% of that total.

4.6 SAFETY ASSESSMENT SUMMARY AND CONCLUSIONS

Over the past 12 years, the fuel tank explosion rate has remained essentially constant. Based on this observation and the forecast fleet growth, the occurrence of fuel tank explosions will be more frequent in the future. Ignition source reduction associated with SFAR no. 88 will provide a reduction in the fuel tank explosion rate.

Figure 4-7 shows the pre-SFAR no. 88 fuel tank explosion accident rate for each of the generic airplane families. Figure 4-8 shows how the accident rate is reduced by SFAR no. 88, GBI, and OBIGGS.

When evaluating the data in figure 4-7 and figure 4-8, it is important to understand that inerting systems offer little benefit to three of the six generic airplane families (regional turbofan, regional turboprop, and business jet) because none have heated CWTs and flammability of the wing tanks is already low. Furthermore, onboard systems were not found to be practical for these airplanes. One might expect the estimated time to the next accident for the OBIGGS scenario in figure 4-8, for example, to be longer. For airplanes equipped with OBIGGS (large, medium, and small transports) it is much longer still, on the order of 100 years. When forecasting so far into the future (and maintaining the unconstrained fleet growth assumption in att. B), the regional turbofan, regional turboprop, and business jet all contribute to the forecast. As a result, rather than the estimated time to the next accident being on the order of 100 years, it is forecast to be 51 years.

The flammability levels achieved by inerting systems can result in an improvement in the fuel tank explosion rate.

	Large transport	Medium transport	Small transport	Regional turbofan	Regional turboprop	Business jet	Total
Accident rate pre-SFAR no. 88	8×10^{-9}	8×10^{-9}	8×10^{-9}	6×10^{-10}	1×10^{-10}	4×10^{-10}	5×10^{-9} (weighted average)

Figure 4-7. Accident Forecast Summary Information

	Pre-SFAR no. 88	With SFAR no. 88 fully implemented	With SFAR and GBI of heated CWT fully implemented	With SFAR and OBIGGS of all tanks fully implemented
Estimated time to next accident in the United States after full implementation in year 2015	4	16	36	51
Explosion rate per operating hour for entire fleet (weighted average of all six generic airplane families)	5×10^{-9}	1.3×10^{-9}	3×10^{-10}	1.5×10^{-10}

Figure 4-8. Fuel Tank Explosion Accident Rate Comparison

5.0
Ground-Based Inerting

5.0 GROUND-BASED INERTING

The GBIS concept is based on the idea of purging the ullage of a fuel tank with NEA provided from a ground source. This externally supplied NEA will be delivered to the airplane at a given purity and pressure. The NEA is generated through hollow-fiber membrane separation technology, which does not affect the airplane's GBIS design.

Either a fixed installation at the gate or a dedicated truck will supply the NEA. Tests carried out for each applicable airplane model will determine the amount of NEA required to reduce the oxygen concentration in the tank ullage to the inert level. Maintaining the added NEA volume at a fixed amount for each different airplane type—regardless of fuel load—to be specified on a placard directly adjacent to the airplane's servicing interface will simplify operations and reduce the risk of loading incorrect quantities of NEA. This also allows for inerting to be performed before, during, or after fueling, without affecting the volume of nitrogen required.

A dedicated distribution pipe network permanently installed on the airplane will discharge the NEA into the required fuel tank. Dedicated equipment and controls will ensure that no unacceptable hazard is introduced into the airplane. At the end of the inerting procedure, the tank ullage will be at a maximum of 8% oxygen by volume.

After this process has been carried out, the tanks will remain inert on the ground for a minimum of 2 hr. After takeoff and climb, fresh air will be drawn into the tanks as fuel is consumed, which will dilute the concentration of NEA in the tank ullage.

Tests have shown that tanks containing low or only residual fuel quantities may remain inert throughout the cruise portion of the flight, as long as no altitude reductions are made. As a part of the GBI incorporation, testing has shown that it is necessary to modify vent systems of some airplane designs to eliminate crossflow through the tank from multiple-vent outlets.

The Tasking Statement defines tanks required to be inerted as those that do not cool at a rate similar to a wing tank, which includes CWTs—heated or unheated—and fuselage auxiliary tanks.

5.1 CONCEPT DESCRIPTION

The final design of the system will be airplane specific and reflect the basic design philosophies and principles of the manufacturer. This generic study uses a system that incorporates the features likely to be necessary on a typical installation. As illustrated in figure 5-1, this system concept is relatively simple.

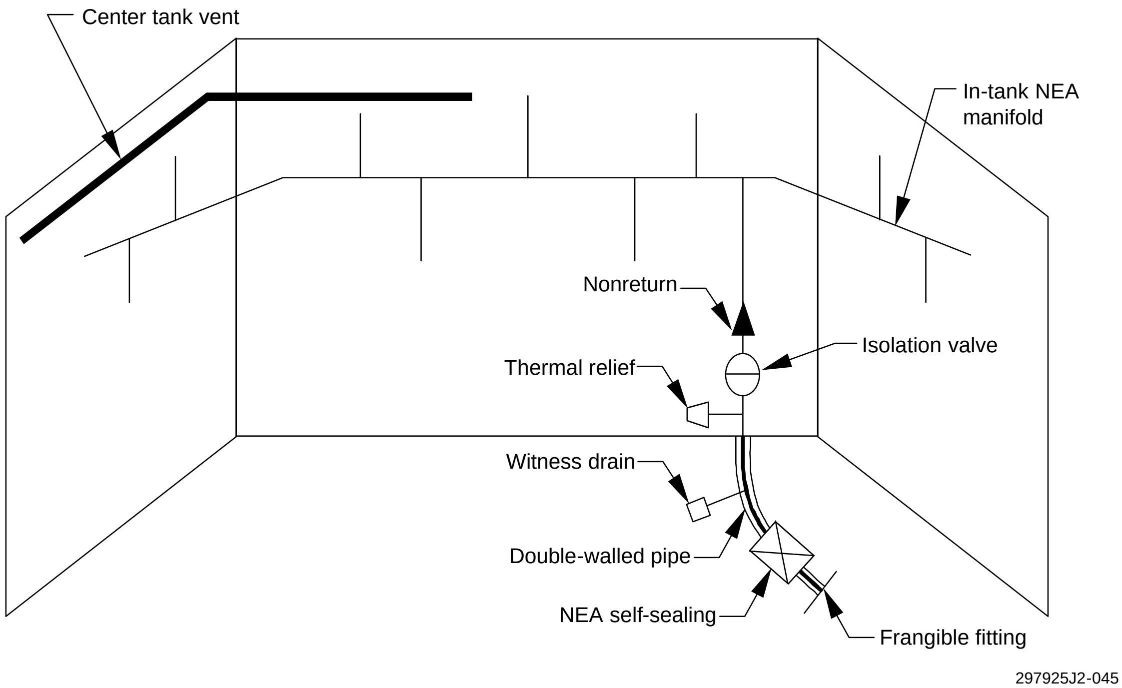


Figure 5-1. Center Tank Installation Concept

A dedicated truck or airport distribution network supplies NEA to the airplane. A new dedicated connection point and service panel will be incorporated into the airplane. The preferred location for this panel is the wing-to-body fairing. The connection point will use a new standard of coupling that ensures that there is no possibility of cross-connection with any other servicing connectors. The service panel will allow all operations associated with inerting the tanks to be carried out. It will comprise a switch to control the isolation valve and a valve position indication lamp.

From the airplane connection point, the NEA will be distributed to the center tank and additional internal or auxiliary tanks if the airplane is so equipped. Where any nitrogen plumbing has to pass within the pressurized compartment or an area of restricted ventilation, the double-walled pipes will minimize the risk of leakage into any confined area.

Within the tank, a dedicated manifold will distribute the NEA. Reviewing the various airplanes included in the study indicated that the type of internal structure could vary between airplane models. On some airplane types, ribs divide the applicable tanks into discrete cells, whereas on other types the tanks are basically open. The detail design of the manifold is airplane specific, but will generally comprise a series of pipes and outlets.

The use of a dedicated manifold allows the inerting operation to be performed before, during, or after the refueling operation. Mounting the manifold close to the top of the tank ensures that maximum mixing occurs and was shown in testing of one model to efficiently purge the ullage of oxygen to 8%, with 1.7 volumes of 95% NEA.

Close to the tank wall, the tank is isolated from the filling manifold. A frangible coupling at the airplane connection point will be provided in case the ground equipment is moved while still attached to the airplane. A self-sealing coupling may be incorporated within the frangible coupling at the connection point. A simple nonreturn valve will prevent the possibility of fuel backflow from the tank.

The generic system also incorporates the following additional equipment:

- A witness drain to detect any leakage in the double-walled pipe.
- A thermal relief valve to prevent pressure buildup in the pipe between the connection point and isolation valve.

Connecting the NEA supply to the airplane and opening the isolation valve is all that will be required to inert the tanks. When the appropriate quantity of NEA has been added, the isolation valve will be shut and the NEA supply disconnected.

To confirm that the inerting operation has been carried out, the person responsible must record the volume of NEA supplied to the airplane and provide this record to the flight crew, who will compare it to the volume contained in the flight manual or on the load sheet.

5.1.1 Auxiliary Tanks

A number of auxiliary tank configurations were reviewed, comprising installations in which the tanks are located in either or both the forward and rear cargo compartments. This review led to the conclusion that, for airplanes fitted with auxiliary tanks, a similar system arrangement and operation to that proposed for CWTs would be used.

A single NEA connection point with the previously described features will supply both the CWT and any auxiliary tanks installed.

From the connection point, the pipe will branch to the center tank and to the auxiliary tanks. The final layout will be airplane specific. The auxiliary tanks will include the same features as the CWT design (i.e., a means of isolating the tank, a nonreturn valve, and a dedicated manifold to distribute the NEA), as shown in figure 5-2.

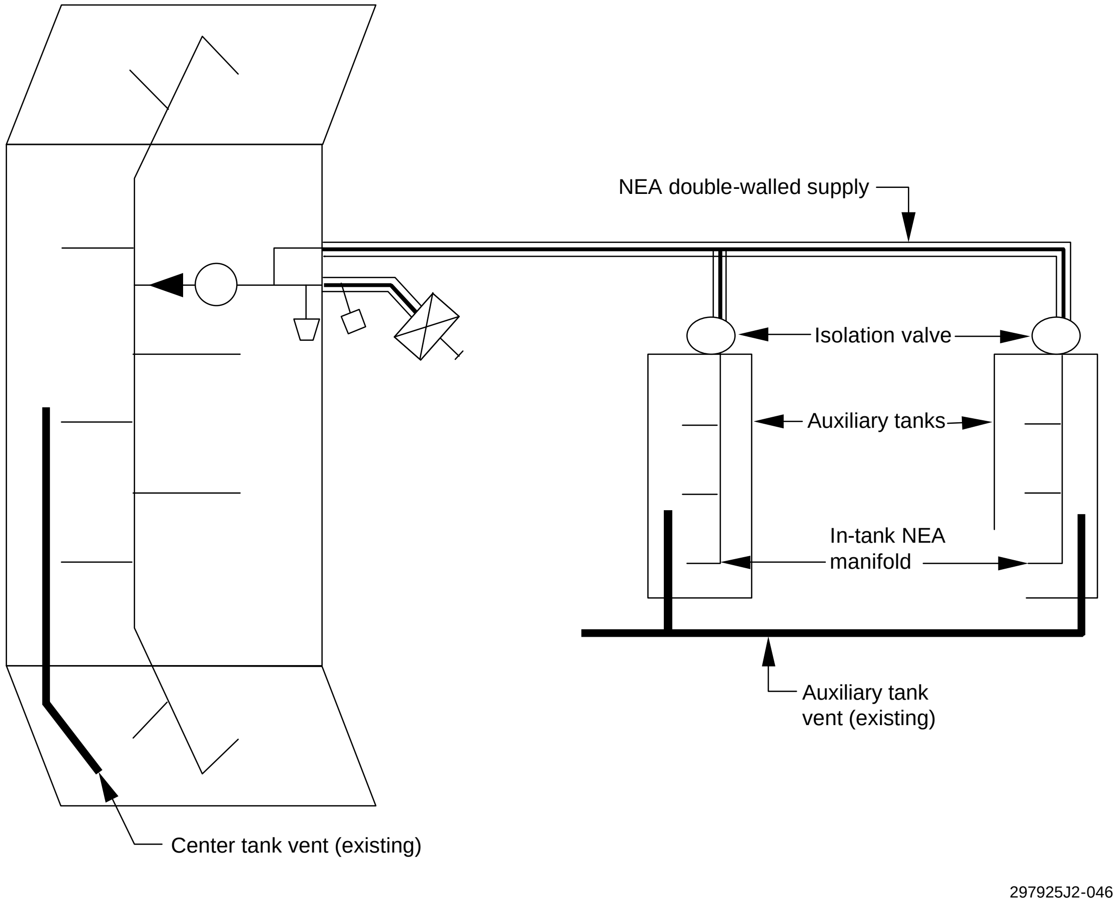


Figure 5-2. Center and Auxiliary Tank Installation Concept

Inerting the auxiliary tanks at the same time as the CWT will minimize any impact on turnaround times. The procedure for the auxiliary tanks will be the same as for the CWT, in that a fixed volume of NEA will be introduced into the tank.

Ensuring that each tank receives the appropriate quantity of NEA may require creating orifices or providing some additional control of the NEA tank isolation valve on the auxiliary and CWTs, depending on the final geometry of the installation and the supply pressure.

Auxiliary tank installation will require a weight increase of approximately 45 lb for each ARAC generic airplane, regardless of size. The system weights are driven primarily by the weight of the double-walled pipework between the connection point and the tank inlet. The weight for the smaller airplane also reflects the installation of auxiliary fuel tanks in both the forward and aft cargo bays.

5.2 APPLICABILITY TO STUDY-CATEGORY AIRPLANES

In compliance with the FAA Tasking Statement, the proposed system design, control, and operation are applicable to all airplane fuel tank types that do not cool at a rate similar to a wing tank. New airplane types will incorporate the requirements during the initial design phase. In-production airplanes will be redesigned for incorporation during the production cycle. Service bulletin (SB) action will cover in-service airplanes within the time prescribed by the regulation.

5.3 AIRPORT RESOURCES SYSTEM REQUIRED

The GBIS is designed to accept airport-supplied NEA from either a fixed installation or a mobile truck. The system design ensures that the fuel tank is inerted within 10 to 20 min. Inerting times have been selected to eliminate or minimize any gate delays.

Ground equipment will control the NEA supply to a maximum acceptable pressure value. For most airplanes, this study shows that the supply pressure must be limited to a maximum of 5 psig. Even at this pressure, a small number of airplane types will still require the installation of additional onboard equipment to further reduce the pressure to an acceptable level.

The purity level of NEA supplied will need to be agreed and standardized for the worldwide airplane fleet, because this value will be used to determine the amount of NEA required during each airplane type certification.

For this study, we have assumed that the amount of NEA required to inert an aircraft fuel tank is 1.7 times the tank volume. This assumes that 95% pure NEA is supplied, achieving a final oxygen concentration within the tank of 8%. This value has been selected as a base on a limited number of tests performed on a Boeing Next-Generation 737 airplane. It should be noted that this factor would vary with each airplane category.

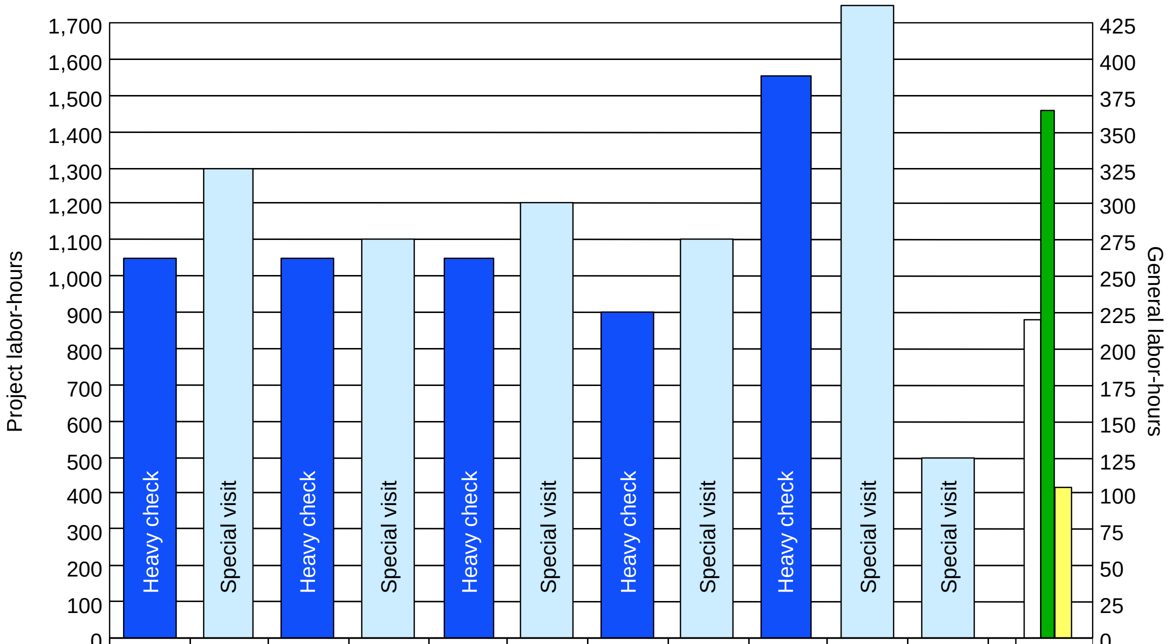
Available data suggests that the discharge of NEA from the airplane vents does not require any special precautions or procedures.

5.4 AIRPORT OPERATIONS AND MAINTENANCE IMPACT

This section discusses the modification of in-service airplanes to install a GBIS and the overall effect of GBI systems on airplane operations and maintenance requirements.

5.4.1 Modification

Figure 5-3 shows the modification estimates for the GBIS. For all airplane categories, estimates are shown for both a regular heavy maintenance visit and a special visit. For corporate and business airplanes (FAR Part 91 operators), the modifications would likely be accomplished during special visits to factory service centers. Consequently, the figure shows special-visit estimates only for corporate and business airplanes.



Legend:	Large	Large	Medium	Medium	Small	Small	Regional fan integral	Regional fan integral	Regional fan bagtank	Regional fan bagtank	Business jets 1e		General
Project time	1,050	1,300	1,050	1,100	1,050	1,200	900	1,100	1,550	1,750	500		
Engineering													220
Tech pubs													365
Material control													104
Training													
Flight ops eng													

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Figure 5-3. Modification Estimates for Ground-Based Inerting Systems

Estimates for regional turbofan airplanes with bladder tanks (rubber cells) are made as well. Previous sections explain that such tanks were not taken into account. However, we felt that this estimate had to be made to obtain an idea of how many extra labor-hours would be required for the project.

No estimates have been made for regional turboprop airplanes, because no company that does the maintenance for turboprop airplanes with a CWT could be located or consulted. According to Fokker Services, who did the estimates for the regional turbofan airplanes, there are very few if any turboprop airplanes that have a CWT.

The left side of figure 5-3 shows estimated project labor-hours for the different airplane categories. General labor-hours are shown on the right. These labor-hours are the same for all airplane categories.

5.4.2 Scheduled Maintenance

Scheduled Maintenance Tasks

A list of scheduled maintenance tasks was developed using the GBIS schematic provided by the Ground-Based Inerting Designs Task Team. Each component illustrated in the schematic was individually evaluated and tasks were written accordingly. These tasks included inspections, replacements, and operational and functional checks of the various components that make up the system. These tasks were assigned to the various scheduled checks (A, C, 2C, and heavy), and labor-hours for each task were estimated. The estimates assume that tasks completed at an A-check would also be completed at a C-check. Similar assumptions were made for the C- and 2C-check tasks (i.e., that they would be accomplished at the 2C- and heavy checks, respectively). Appendix F, addendum F.B.1, lists these tasks.

Additional Maintenance Labor-Hours

Figure 5-4 shows the estimated additional scheduled maintenance labor-hours required at each check to maintain a GBIS.

Airplane category	Additional A-check hours	Additional C-check hours	Additional 2C-check hours	Additional heavy check hours	Average additional labor-hours per year
Business jet	2	5	7	17	16.46
Turboprop	2	5	7	17	16.46
Turbofan	2	5	15	17	17.21
Small	2	5	17	17	34.65
Medium	2	5	21	21	32.93
Large	2	5	25	25	34.74

Figure 5-4. GBI Additional Scheduled Maintenance Hours

5.4.3 Unscheduled Maintenance

In accordance with the Tasking Statement, the design of the GBIS is based on inerting fuel tanks that are near significant heat sources or that do not cool at a rate equivalent to an unheated CWT. The design concept for the GBIS considered only CWTs and auxiliary tanks. In addition, because the GBIS operates only on the ground, the system operation time was based on the minimum turn times discussed later in this report. The basic design of a GBIS for airplanes without auxiliary tanks is relatively simple. The detailed design concept was discussed previously in this report. A reliability and maintainability analysis evaluated the following system components:

- Nonreturn valve.
- Isolation valve with integral thermal relief valve.
- Self-sealing coupling incorporating a frangible fitting.
- Ducting (including distribution manifold and double-walled tubing).
- Wiring.

For airplanes with center wing and auxiliary tanks, the system components include the same components as a CWT-only installation, with the addition of one nonreturn valve and one isolation valve per auxiliary tank plus interconnect ducting. Including auxiliary tanks in the reliability and maintainability analysis will have a minimal effect because it would simply increase the quantity of nonreturn and isolation valves, depending on the number of auxiliary tanks installed. This would affect the component MTBUR for the nonreturn valve and isolation valve. However, the exclusion of the auxiliary tank components is considered well within the margin of error of the total system analysis. Just the CWT components noted above were considered in the analysis.

The system design concept took into consideration the need for a pressure-regulating valve (PRV), which would limit the delivery pressure of the NEA on some business jets and regional airplanes resulting from fuel tank construction. Conceptually, the PRV could be part of either the airplane system or the airport delivery equipment. Because of this and the limited applicability of the PRV, this analysis did not evaluate this component.

As with each of the system design concepts, component reliability was evaluated based on similar components. Once the individual component MTBUR was determined, the system MTBUR was estimated to be 9,783 hr. Because of the system's simplicity, the GBIS had the highest level of reliability and is the only system with reliability levels considered acceptable for commercial airplane operations.

Each of the six study airplane categories used the system MTBUR. There was no attempt to determine whether the system MTBUR would vary between the different airplane categories because of system size or operational differences. Any differences were well within the margin of error used to calculate the system MTBUR.

The system annual failure rate was calculated based on the respective system MTBURs and yearly use rates for the airplane category. Section 10 describes the annual delay time as based on a standard delay rate assumption for each airplane category.

Each airplane category was looked at separately to determine component removal and replacement time, access time, and troubleshooting time. Figure 5-5 shows system maintenance labor-hours per year based on the summation of the individual component removal, replacement, access, and troubleshooting time multiplied by the component annual failure rate.

Category	Large	Medium	Small	Regional turbofan	Regional turboprop	Business
Annual failure rate	0.42	0.29	0.29	0.22	0.3	0.11
Standard delay rate (1 delay = XX min)	30	45	60	60	60	60
Annual delay time (min/year)	13	13	17	13	18	7
Unscheduled maintenance labor (hr/year)	3.13	1.96	2.02	1.35	1.89	0.77

Figure 5-5. GBIS Reliability and Maintainability Analysis

System weights provided by the design team determined the cost-to-carry value for the GBIS. System weights were provided for large, medium, and small airplanes, including weights of the components listed above and other equipment not included in the analysis, such as brackets and ground straps. The calculated cost-to-carry values (fig. 5-6) represent the costs associated with the additional weight of the system over 1 year of operation. Calculated from the system weight and a variable input, cost to carry per pound, per year ($) equates to additional fuel burn.

	Large	Medium	Small
System weight, pounds	54.33	34.10	22.05
Costs per pound per year, dollars*	165.53	131.80	62.00
Cost to carry, dollars per year	8,993.24	4,494.38	1,367.10

*Considered a nominal value; may differ by airline.

Figure 5-6. GBI System Cost to Carry

5.4.4 Flight Operations

GBI has the least impact on flight operations, in that there will be no onboard operating systems to monitor or control. Once the tanks are inerted on the ramp, the maintenance technician will need to inform the operating crew that the inerting has been properly completed. The object has been to design the servicing apparatus so that this function can be accomplished within the average minimum established turn times and thus not create delays, although very short scheduled turn flights could be affected.

Very little flight crew training should be necessary, but dispatch and ramp office personnel as well as the flight crew would have to be familiar with any operational limits or requirements for dispatching with the inerting system inoperative. Dispatch requirements need to be thoroughly defined with regard to conditions of non-availability of NEA supply and the existing conditions of a takeoff and flight from that station. Airport usage for scheduled or alternative operations would have to be evaluated, and route structures could be affected by nonavailability of NEA.

5.4.5 Ground Operations

The GBIS is one of the most labor intensive of all proposed inerting methods researched to date by this group. This results in part from GBI requiring that a dedicated technician be present during the inerting process while the airplane is parked on the ramp or at the gate. The GBIS is also solely dependent on airport infrastructure.

For the purposes of the gate operation, airplanes would undergo servicing procedures similar to the following:

> A technician attaches the inerting hose from a dedicated source, which may come from either the terminal (jetway) or a tanker. After the inerting value is given, the valves are opened to allow the flow of nitrogen into the tank. At the end of the operation, the technician closes the valves and completes the process. When the inerting equipment has been secured, the flight crew receives from the technician an inerting slip that verifies the flight number, date, and quantity of inerting gas loaded, along with the signature of the individual who performed the task. The flight crew then checks the quantities against the flight release. This allows normal servicing and through-flight responsibilities (e.g., logbook items and maintenance checks) to be accomplished while at the gate. Inerting times are proportional to the type of airplane.

Small airports and remote areas of large airports and maintenance facilities will use inerting trucks, which will allow fuel tank inerting when the airplane is away from the gate.

The ground inerting process is unique in that while the inerting system is not flight critical, it is one of the few airplane systems that gives the flight crew no indication or means to verify if the process has been accomplished. The person monitoring the inerting process would be solely responsible for complying with the inerting requirements. Because low-skilled personnel generally hold ground service positions, turnover rates for ground service employees are significantly higher than those for maintenance technicians. Therefore, the team concluded that the inerting would have to be accomplished by a trained maintenance technician.

During several Working Group discussions, the question was raised as to whether the ullage washing task would have to be a dedicated position. After carefully considering the task, the team concluded that, even if the system could be left unattended, it is unlikely that this short period of time could be used efficiently. If the task were to be assigned to a fueler, for example, the inert task would extend the total refueling time per airplane by an equivalent amount of time. To compensate, additional refueling personnel and equipment would have to be added.

The team discussed the reduction in costs for labor. In the early stages of airplane single-point refueling systems, specialized technicians were tasked to this work exclusively. This is still the case in in many countries. As the systems became more automated and reliable, less specialized perrsonnel were able to successfully accomplish this task. The inerting process should mirror this model. The team concluded that in the future, the job function could be reevaluated, but for the initial phase, it is imperative that this is performed by a technician.

GBI Ullage Washing Labor Estimate

The fuel tank ullage washing or inerting process is similar to and accomplished in parallel with the airplane fueling process. The Airplane Operation and Maintenance Task Team reviewed the proposed ullage washing procedure and developed a labor estimate for this process. The labor estimate uses the inerting time developed for each airplane category by the Ground-Based Inerting Designs Task Team. The technician needs 10 min to connect and disconnect the ground service unit to and from the airplane and to complete the paperwork required to approve the inerting process. The estimated time a technician needs to inert an airplane's fuel tank for each airplane category was then multiplied by the number of daily operations for each airplane type and by a 30% lost-labor rate to account for mechanics' unproductive time. Figure 5-7 shows the resulting daily and annual labor estimates for ullage washing.

GBI ullage washing labor						
Aircraft	World daily operations	Inerting time per turn, min	Connect/disconnect time per turn, min	Lost labor rate	Labor- minutes per turn	Daily labor-hours
Business jet		15	10	0.3	36	
Turboprop	20,000	10	10	0.3	29	9,524
Turbofan	10,000	10	10	0.3	29	4,762
Small transport	48,167	10	10	0.3	29	22,937
Medium transport	5,142	15	10	0.3	36	3,061
Large transport	4,599	20	10	0.3	43	3,285
				Total daily labor hours		43,568
				Annual labor hours		15,902,355

Figure 5-7. Annual Labor Estimate for Ullage Washing

Nitrogen inerting stations could be mounted on jetways or in terminal buildings at major airports, similar to the preconditioned air systems currently in use at most major U.S. airports. Airports that currently use preconditioned air systems at the gate must consider the ramifications of placing inerting equipment in the vicinity of these units, to preclude the possibility of nitrogen being vented into the cabin.

If a centralized system is not available (e.g., at regional or smaller airports), tanker trucks or their equivalent would provide nitrogen to operators at these areas. Airplane size and flight schedules would determine the demand for these airports.

Procedures would also have to be established for airplanes that divert into stations that do not have sufficient nitrogen quantities for the inerting process.

The possibility of complications combined with experience requirements should also be considered when determining the long-term effects of both having and not having qualified technicians available to perform the inerting tasks. This may also hold true for the initial MEL process on through-flights.

Potential Future System Improvements

The basic philosophy behind GBI as discussed in this study supplies a standard volume of nitrogen to a fuel tank before each flight. This standard volume is based on an assumption of maximum ullage, or an empty tank. If the tank contains fuel, this would result in more nitrogen being used than is necessary to inert the tank. The excess nitrogen would then be discarded through the tank vent system. This philosophy satisfies the inerting requirement, but results in an increased nitrogen requirement and the release of more volatile organic compound (VOC) fuel-vapor pollutants into the atmosphere. This issue may be problematic in some of the more environmentally sensitive areas of Europe and the United States.

Adjusting the volume of nitrogen used to inert the tank based on the amount of fuel in the tank is one long-range solution. Once the fuel load for a flight is determined, the nitrogen load would also be calculated and included on the fueling sheet. This would require a change to the software used to calculate the fuel load at a one-time cost of $5,000 to $500,000 per operator, depending on the kind of fuel-load program used. Dispatchers would also need to be trained to determine the volume of NEA required. The team considered this solution as a future improvement to the GBI process. These additional costs were not taken into account in the modification estimates.

An onboard inerting computer is one possible future system improvement. The inerting computer would provide the maintenance technician the means to select a specific tank and fuel quantity. Once the information is entered, the computer calculates the proper inerting value for that tank. A monitoring function keeps the technician aware of any inerting anomalies. Sensors automatically close the inerting valves when the process is complete. Once the servicing door is closed, the computer could also provide a signal to the flight deck in case of inerting or system discrepancies. Built-in test equipment at the panel could also allow technicians to test line-replaceable units and perform maintenance checks. Such a system may streamline the inerting process.

5.5 SAFETY ASSESSMENT

5.5.1 Flammability Exposure Analysis of GBI

The methodology of analyzing flammability exposure is explained in section 4.2.2, Flammability Exposure Analysis. Using this modeling approach, the effects of GBI relative to the baseline flammability for the large, medium, and small transport categories are shown in figure 5-8. As noted in the discussion on modeling in section 4, these values do not represent any specific airplane, only a generic configuration selected to represent an airplane in this category. More detail about the analysis is provided in appendix C, Ground-Based Design Task Team Final Report.

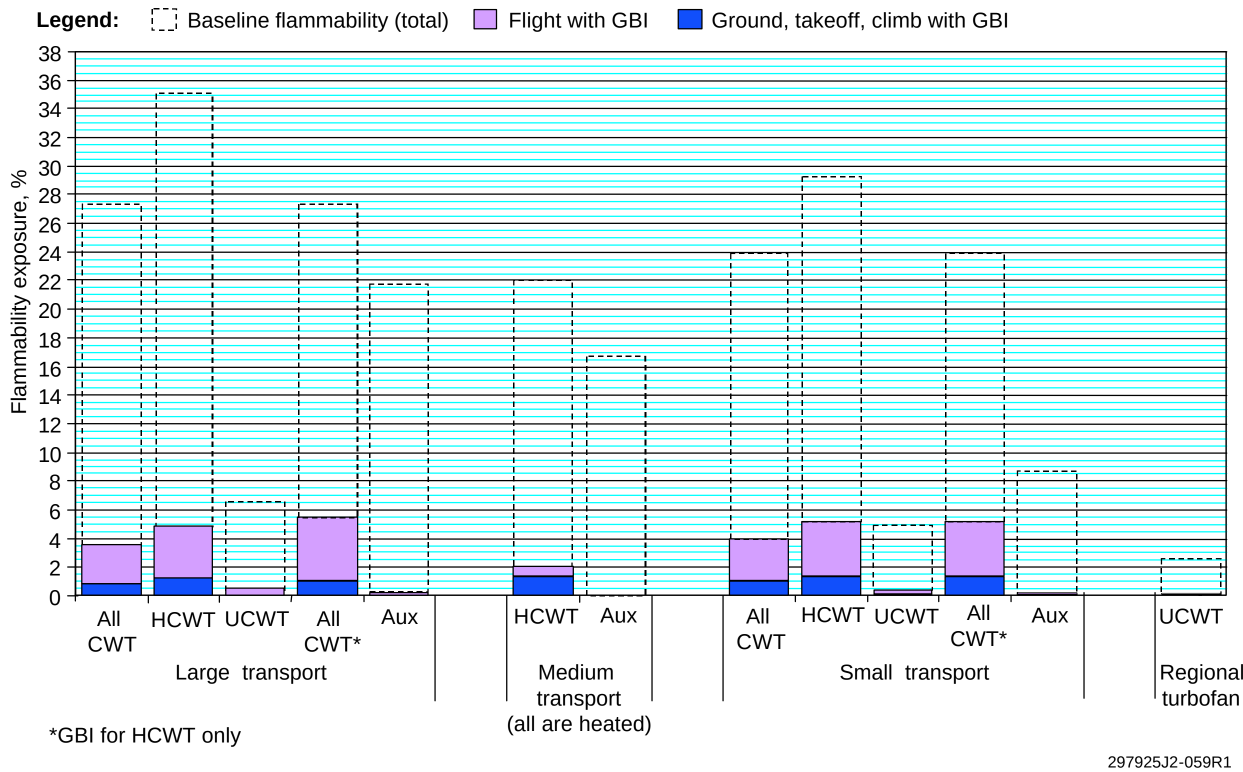


Figure 5-8. Flammability Exposure Results, Ground-Based Inerting System

The “All CWT” values represent a combination (in accordance with the ARAC estimated distribution) of the values for the heated CWTs and the unheated CWTs. Also shown are the individual values for the heated CWT- and the unheated CWT-generic airplanes.

The Tasking Statement also asks for the effect of limiting GBI to airplanes with adjacent heat sources (referred to in this report as heated CWTs) only. As shown in figure 5-8, the largest flammability reduction is for heated CWT airplanes, because the baseline flammability of the unheated CWT airplanes is already similar to the heated CWT with GBI. Therefore, limiting GBI to airplanes with heated CWTs would result in only a modest increase in fleetwide flammability exposure. Note that use of GBI for only heated CWTs is evaluated as scenario 11 and is used in the executive summary information.

Unpressurized auxiliary tanks were also evaluated; the results are shown in figure 5-8. As shown, for airplanes with unpressurized auxiliary tanks, GBI would significantly reduce the flammability. These numbers do not apply to those tanks that use pressure to transfer fuel to other tanks and remain pressurized at altitude. Because auxiliary tanks typically are not exposed to external heat sources, they typically are not flammable on the ground. Maintaining a higher ullage pressure in the auxiliary tank avoids most of the decrease in the LFL that otherwise occurs during climb, and thus most of the auxiliary tank flammability exposure. An analysis of the effects of pressurized auxiliary tanks can be found in the Ground Based Inerting Task Team Report appendix. The analysis shows that use of pressurized auxiliary tanks can result in a reduction in flammability similar to that of GBI.

5.5.2 Safety Assessment of GBI

Figures 5-9 and 5-10 show the potential impact of GBI on reducing future accidents in the United States and worldwide. If GBI is adopted, the forecast assumes that it will be fully implemented by the year 2015. At that time, the forecast indicates the time between accidents in the United States would be 16 years with the SFAR alone, 36 years with SFAR and inerting in heated CWTs, and 38 years with the SFAR and inerting in all fuselage tanks. The corresponding times between accidents for the worldwide fleet would be about half those estimated for the U.S. fleet.

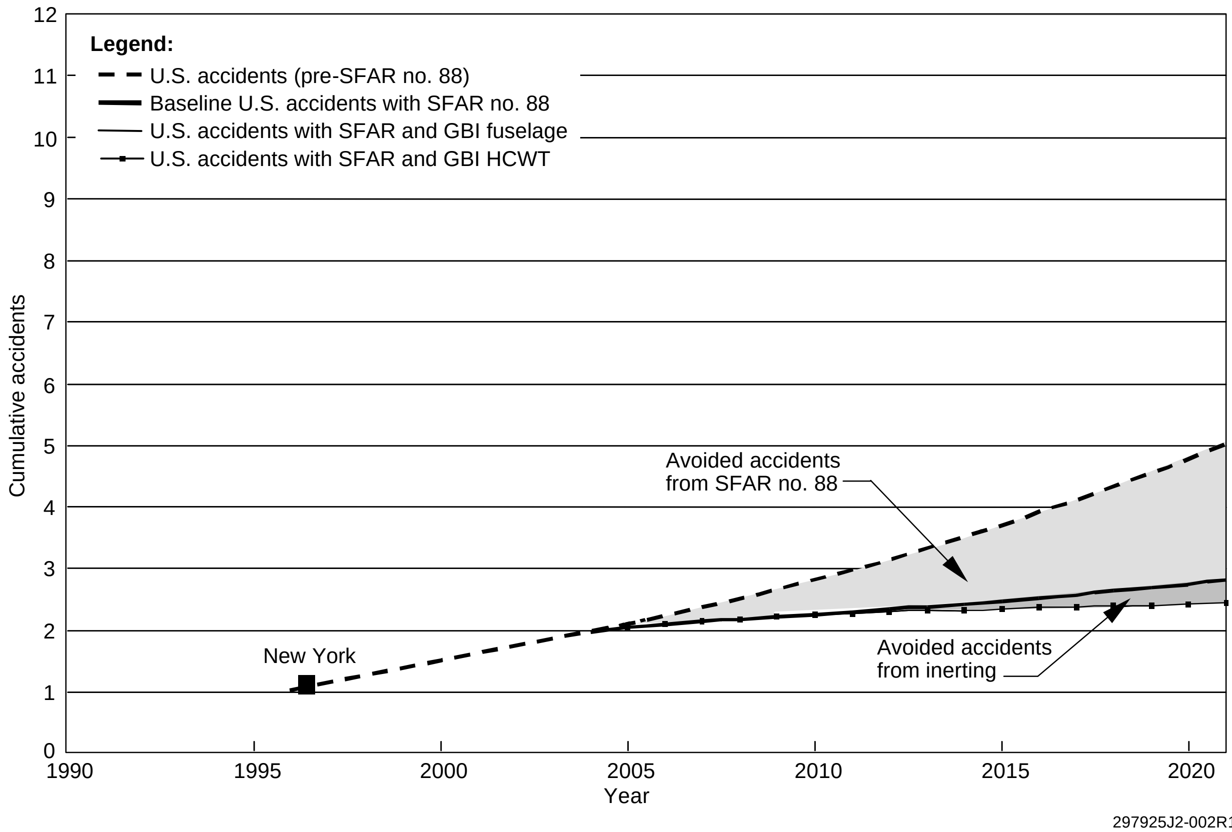


Figure 5-9. U.S. Cumulative Accidents With Ground-Based Inerting

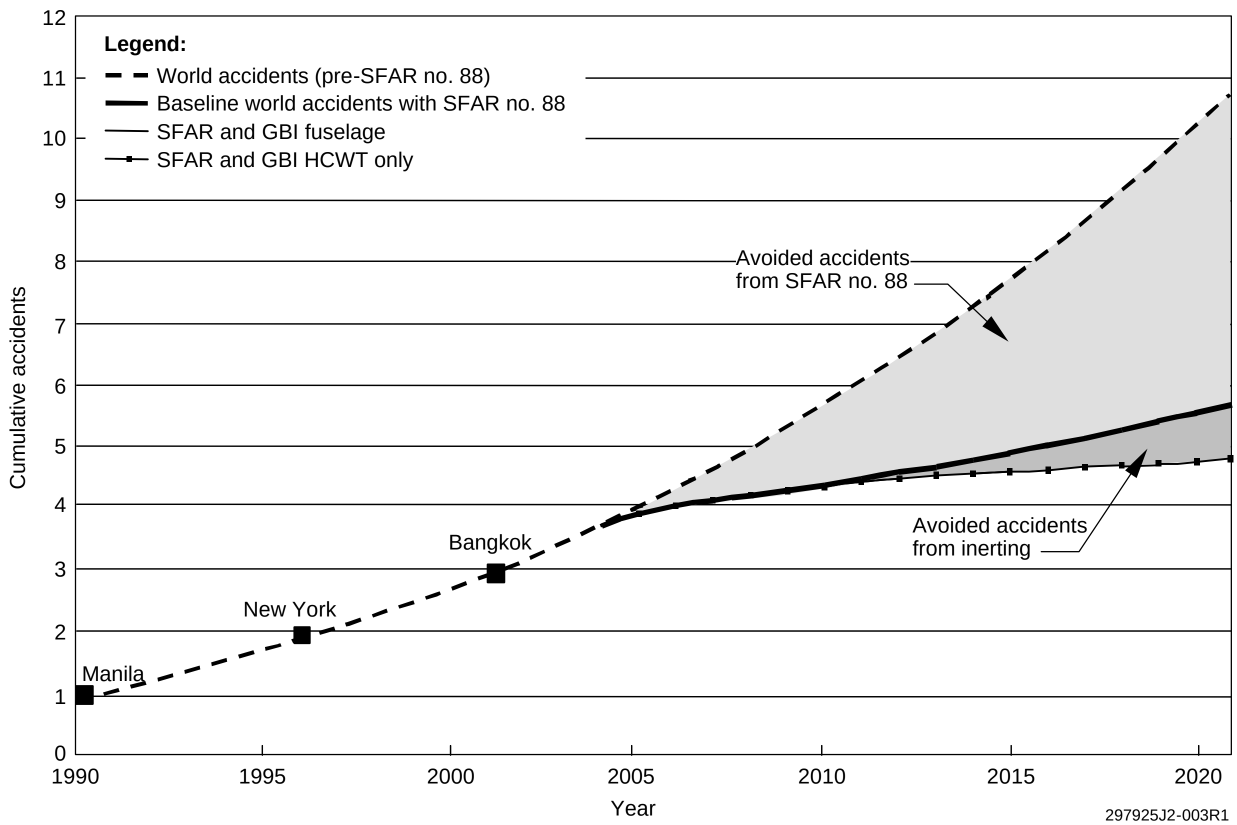


Figure 5-10. Worldwide Cumulative Accidents With Ground-Based Inerting

5.6 COST-BENEFIT ANALYSIS

Figures 5-11 though 5-18 graphically represent the cost-benefit analyses of the scenario combination examined for ground-based fuel tank inerting.

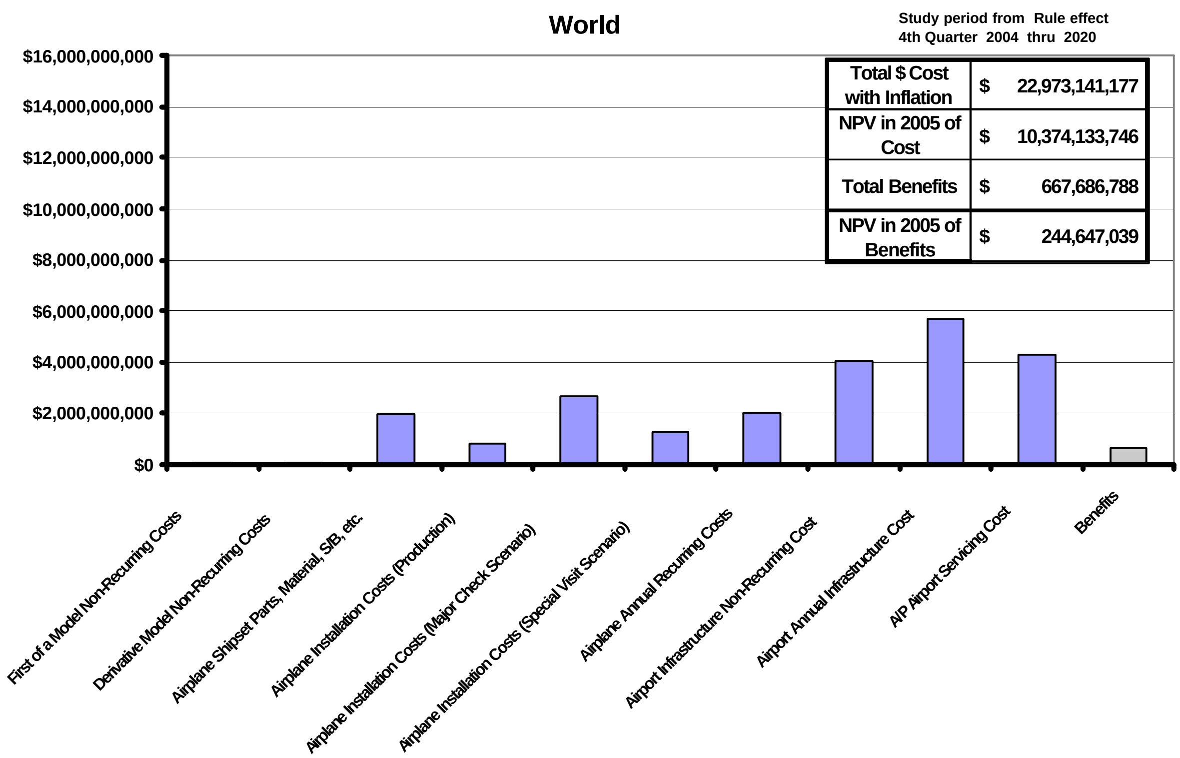


Figure 5-11. Scenario 11—Ground-Based Inerting, HCWT Only, All Transports (World)

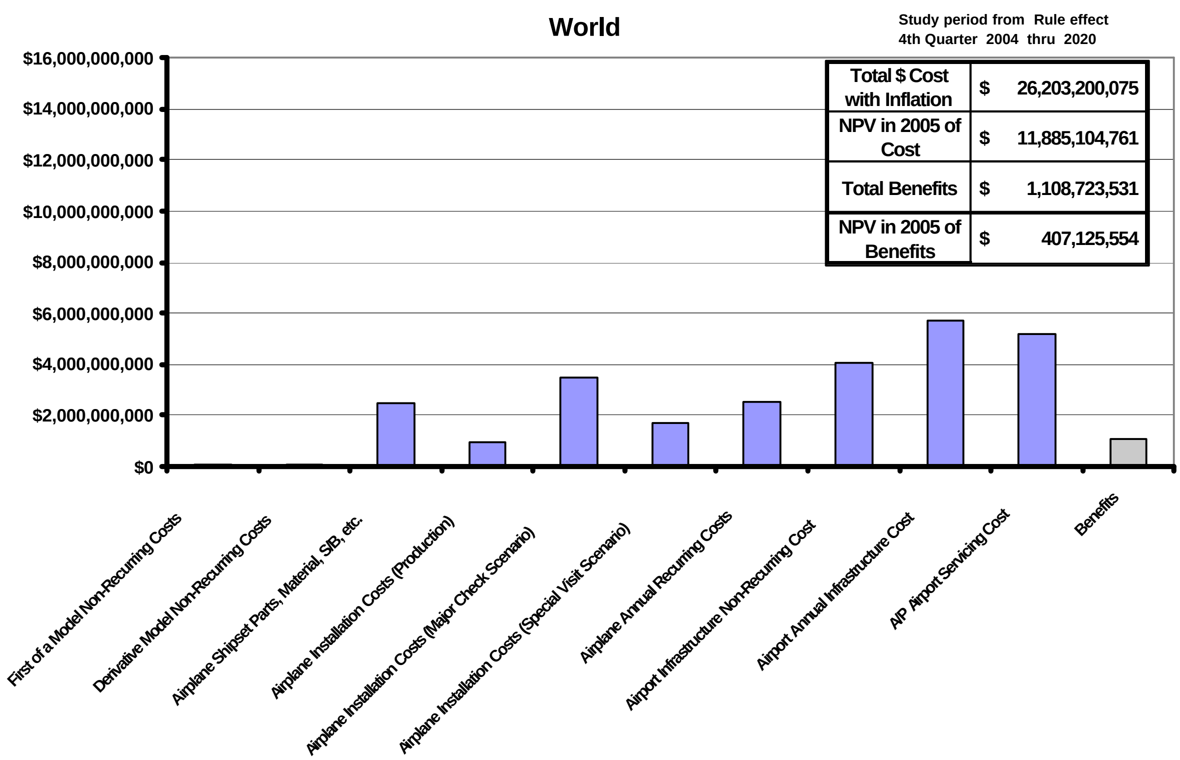


Figure 5-12. Scenario 12—Ground-Based Inerting, All Fuselage Tanks, All Transports (World)

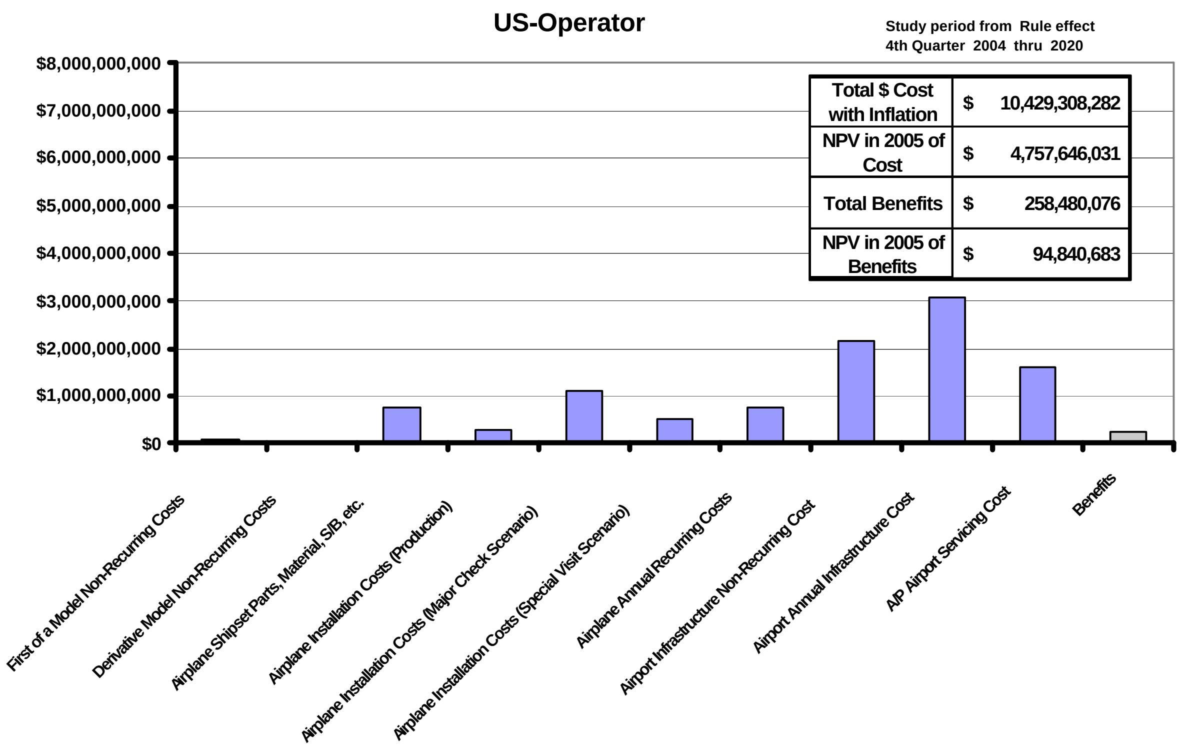


Figure 5-13. Scenario 11—Ground-Based Inerting, HCWT Only, All Transports (U.S.)

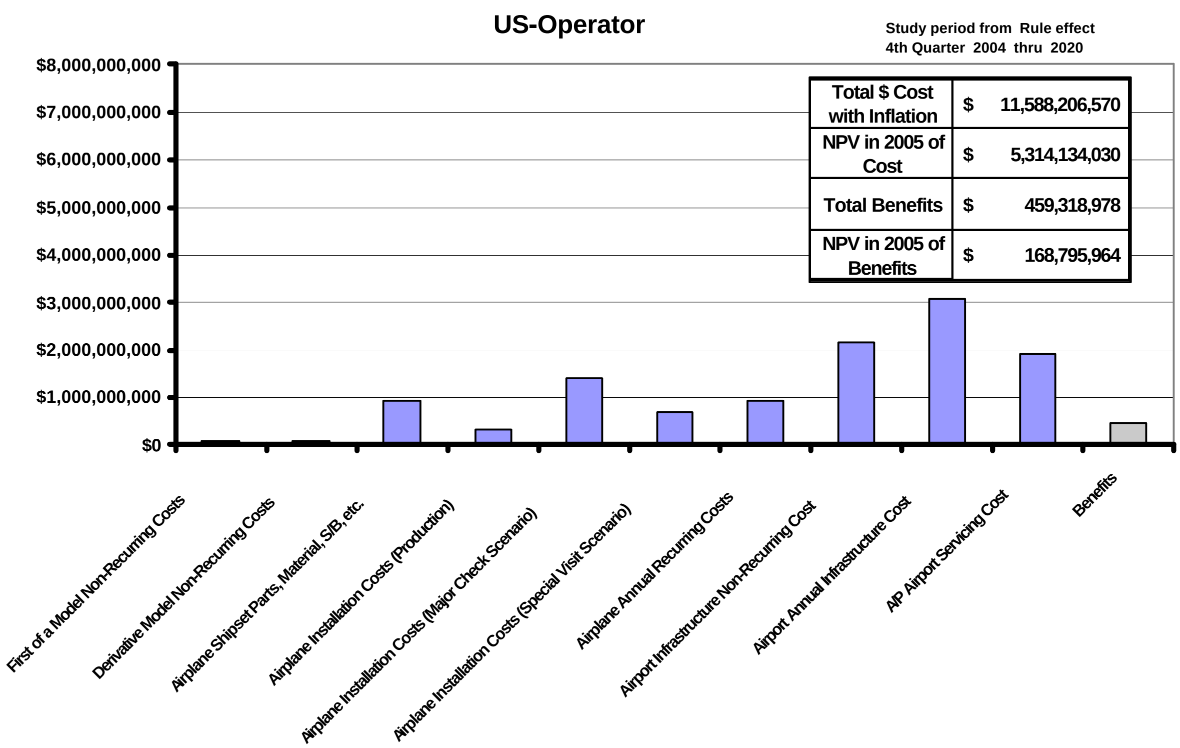


Figure 5-14. Scenario 12—Ground-Based Inerting, All Fuselage Tanks, All Transports (U.S.)

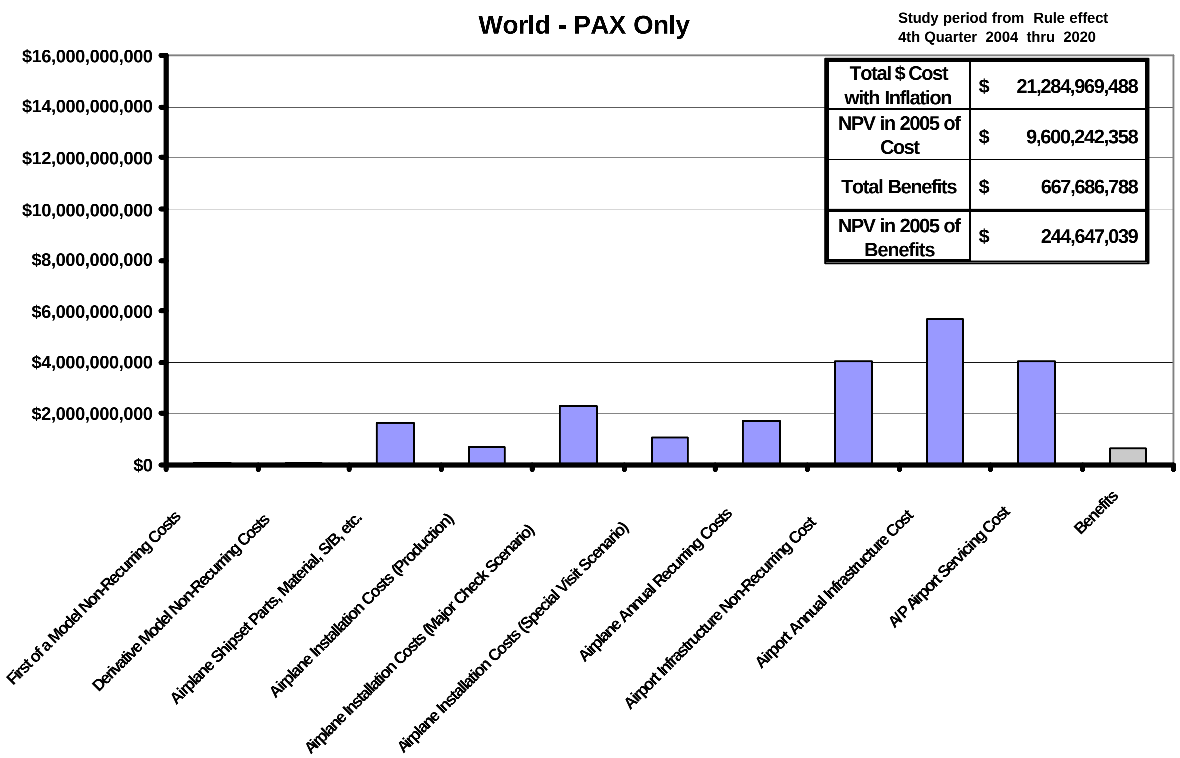


Figure 5-15. Scenario 11—Ground-Based Inerting, HCWT Only,All Transports (World, Passenger Only)

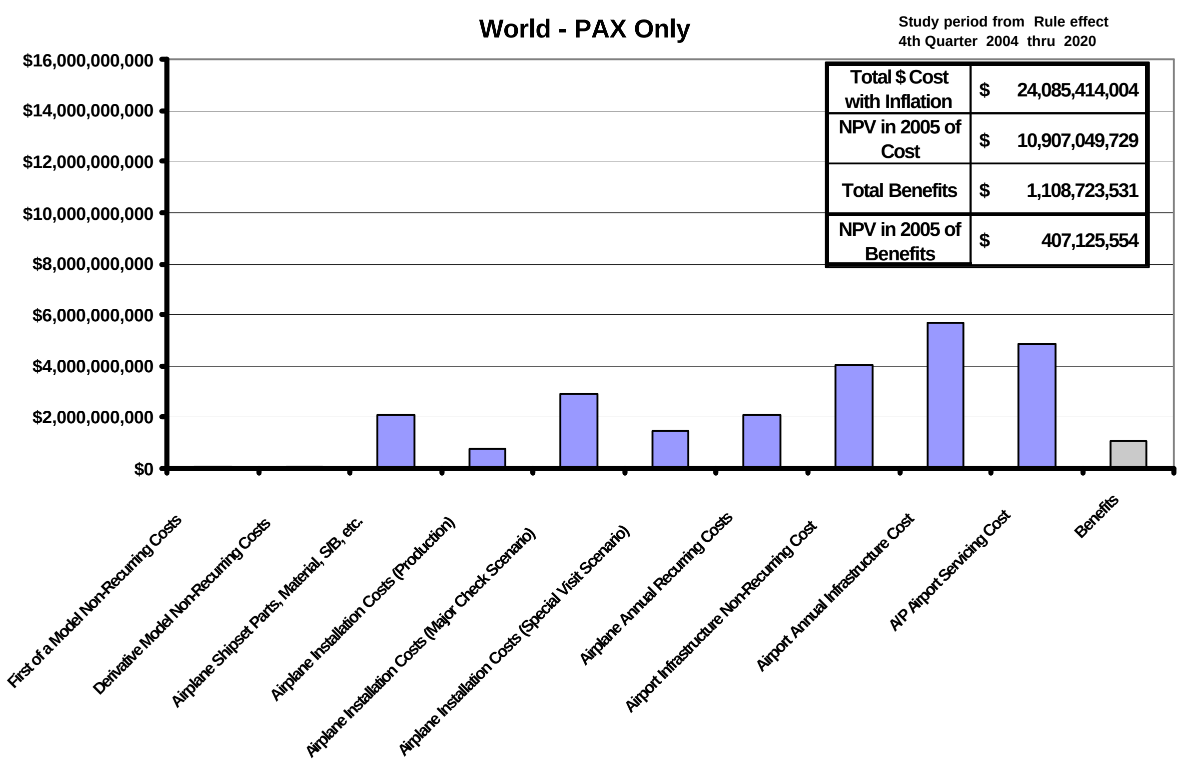


Figure 5-16. Scenario 12—Ground-Based Inerting, All Fuselage Tanks, All Transports (World, Passenger Only)

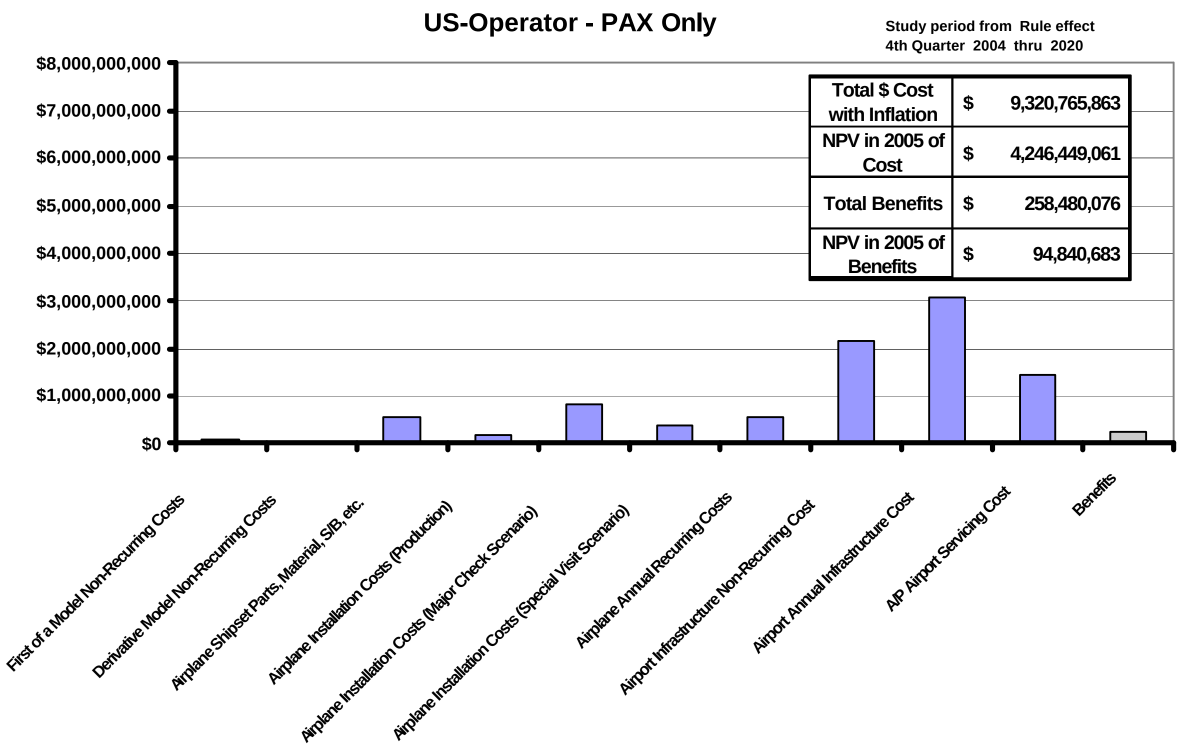


Figure 5-17. Scenario 11—Ground-Based Inerting, HCWT Only, All Transports (U.S., Passenger Only)

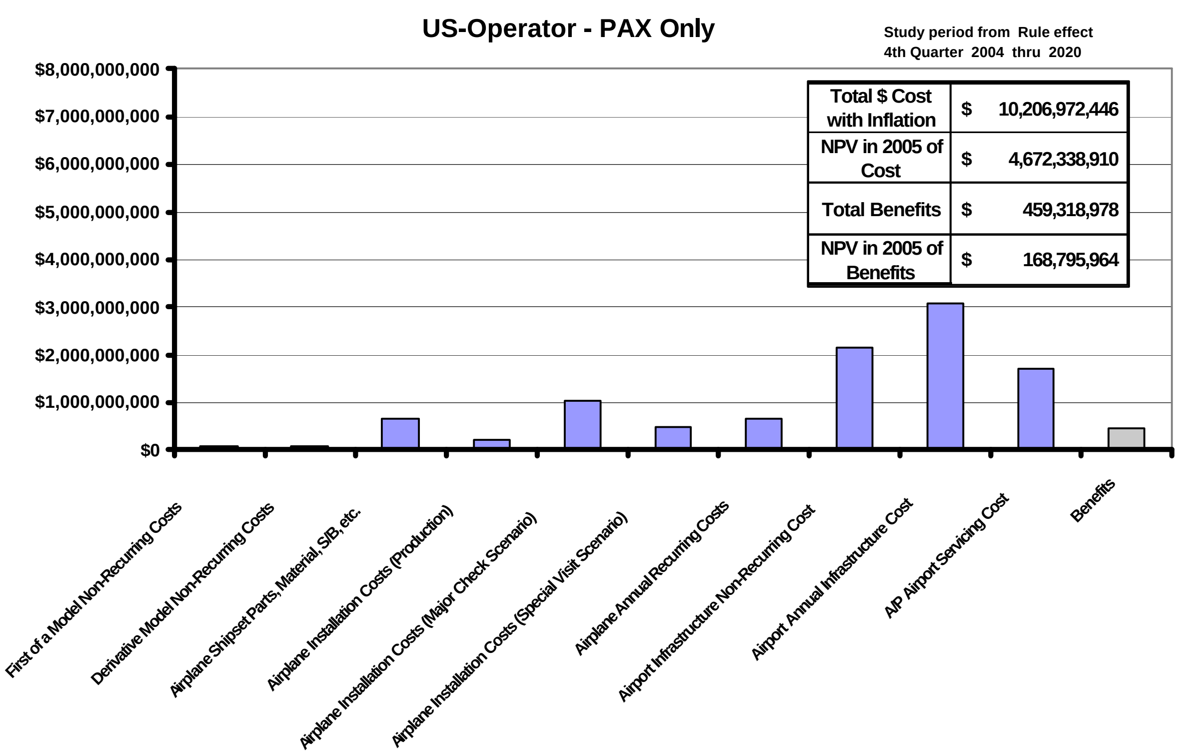


Figure 5-18. Scenario 12—Ground-Based Inerting, All Fuselage Tanks, All Transports (U.S., Passenger Only)

5.7 PROS AND CONS

Pros

- Reduces flammability exposure.
- Simple, with the least impact to the airplane.
- Involves little technical complexity on the airplane.
- Uses current technology components.
- Does not introduce any new installation technology.
- Uses straightforward system operation, in that it is not performed in sequence with the refuel operation and does not require any knowledge of the actual fuel load.

Cons

- Does not remain inert for 100% of the flight cycle. Introduction of air resulting from fuel consumption may still be flammable during ground time after landing but before inerting on hot days.
- Depends on significant airport infrastructure.
- Requires low NEA supply pressure to avoid overpressurizing the airplane fuel tanks if the overpressure system fails.
- Needs new standard airplane interface coupling.
- Amount of NEA supplied may be in excess of that required to achieve the inert levels when the tank is already partially or completely full.
- Requires unique maintenance practices.
- Increased VOC emissions during the fueling process.

5.8 TECHNICAL FEASIBILITY

5.8.1 New Designs

There are no major concerns with the concept for newly designed airplanes if GBI is integrated early in the design phase. During the design cycle, the system would be subject to design reviews, safety assessment, zonal analysis, and so on. The basic design phase will finalize the manifold design, structural penetrations, wiring, and service-point location. Electrical controls and circuits associated with the inerting system equipment need to be routed so as not to introduce any new hazards. Location of the filling point would take into consideration not just the positioning of the servicing trucks but also their location, so as not to introduce additional hazards in the event of a wheels-up landing. Accessibility of the filling connection would take into consideration the acceptability of servicing steps or a platform, if necessary.

5.8.2 In-Production Airplane Designs

Optimum manifold design in terms of weight and location may not be possible because of other installed systems or limitations on location of structure penetrations. Certain airplane types may require modifications to tank venting arrangements, which would require additional design and certification activity over and above that required to demonstrate the effectiveness of the modification in inerting the tank. Location of the servicing connection point may require redesign of a section of the external airplane body fairing, possibly including the introduction of a dedicated panel granting access to the servicing point. Airline spares will be affected.

5.8.3 In-Service Airplane Retrofit

These same possible redesign concerns apply equally to airplanes already in service needing to be retrofitted with GBI. Modification to the tank installation or areas around the fuel tank made to the airplane since the original delivery may require further additional design work and adaptations.

Auxiliary Tank Installations

Generally, these concerns also apply to auxiliary tanks, as do several additional concerns.

- The need for double-walled tubing in the pressurized areas will further complicate tube routing in areas where space is constrained by other systems.
- More than one auxiliary tank will require a balanced flow of NEA between the tanks. This may require an NEA volume greater than the 1.7 times the total ullage volume currently envisaged, or an additional connection point and control panel.
- Some auxiliary tanks include bladders inside the tanks, which could complicate redesign because of the need for new bladders to accommodate new tubing penetrations and routing in the tank.
- New pipe penetrations will require modification of cargo bay liners.

5.9 MAJOR ISUES AND RESOLUTIONS

A new standard interface coupling, developed and controlled by a recognized authority, would allow the airplane to be purged at any airport location from a ground-based NEA distribution system. The schedule for accepting this standard and the availability of hardware would have to be compatible with the regulatory requirements.

The correct purging of the tank ullage depends on the performance of the ground supply. A specification will be required to control pressure and flow performance and integrity of the ground equipment. The required volume to correctly purge the tank ullage will be defined following airplane tests. Ground equipment will need to be specified before airplane tests can be performed.

Some ground equipment requirements (e.g., delivery pressure) drive the need to consider the demands of retrofitting the system onboard existing airplanes. Ground equipment must be designed so it does not constrain future airplane designs.

5.10 CONCLUSIONS

Installing a GBIS does not require that any new technology be developed, although the low supply pressure of the NEA will require attention to the detailed design of the distribution system. Challenging practical considerations may arise for system retrofit applications (e.g., cutting and reinforcing holes in the tank structure).

The availability of suitable ground equipment, regulatory requirements, airport nitrogen sources, and airport distribution systems will determine the time required to make such a system operational.

Certification will require ground and flight tests on each major airplane model, which in turn will require the availability of airplanes—many of which the original manufacturers do not own—on which to perform the certification tests.

Specific attention must be paid to the special ground equipment and interface connector. Both these items are new and will need to be developed. Development of a new standard will ensure worldwide compatibility. Control of this new standard must be clearly identified.

6.0
Airport Facilities

6.0 AIRPORT FACILITIES

6.1 CONCEPT DESCRIPTION

The FAA tasked the FTIHWG with developing conceptual methods to

- Introduce nitrogen gas into designated airplane fuel tanks to displace the oxygen in the unfilled portion of the tank (i.e., "ullage washing").
- Saturate the jet fuel held in airport storage facilities (i.e., trucks and fuel-farm storage tanks) with nitrogen (i.e., "fuel scrubbing").

In response, the FTIHWG has developed appropriate design concepts to describe the infrastructure necessary to manufacture, store, and distribute the required NEA and nitrogen-saturated fuel (NSF) from permanent airport facilities.

The following sections summarize the various design scenarios that address the on-airport manufacturing and distribution—both fixed and mobile—of NEA and NSF to the wings of airplanes under consideration for inerting.

Sections 6.1.1 and 6.1.2 describe ullage washing and fuel scrubbing. The initiating FAA task requirement can be found in appendix A, Tasking Statement.

6.1.1 Ullage Washing

Ullage washing removes a large portion of the oxygen gas from the air in the fuel tank ullage. Because fuel vapors cannot ignite unless a sufficient amount of oxygen is present to support and propagate the combustion, reducing the oxygen concentration within a tank eliminates or greatly reduces the ability of an ignition source to cause a constant-volume combustion of the tank's fuel vapors.

To reduce oxygen levels, the ullage is flushed or "washed" with a high-purity (97% to 98%) NEA stream that is produced using a membrane gas generator skid and ducted into the fuel tank. This 97% to 98% NEA was chosen as the most cost-effective inerting agent because it is less expensive than higher purity gas but contains half the oxygen content of a 95% inert product. The volume of gas for inerting has been chosen by the Ground-Based Inerting Designs Task Team to be 1.7 times the volume of the airplane tank to be washed, based on an empty tank. These conditions of inerting-agent purity and volume have been shown to reduce oxygen levels within the ullage space of an empty fuel tank to less than 9%. Therefore, no oxygen meter for gas analysis will be needed to verify ullage washing, which helps to minimize complexity. More importantly, in tanks that are even partially full of fuel, the oxygen content is also expected to be reduced to lower than 9% because of the higher actual volume of NEA flowing through the system.

NEA is generated continuously from air using membrane gas separation technology. Essentially, air is compressed, filtered free of solid particles and liquid aerosols, and fed to bundles of hollow-fiber polymeric membranes where the oxygen, carbon dioxide, and water vapor are removed from the nitrogen stream. These gaseous impurities are vented at low pressure while the high-pressure enriched nitrogen product exits the skid at 97% to 98% purity through a surge tank. Backed up by a storage vessel of liquid nitrogen and a vaporizer, a continuous, seamless transfer of NEA will be ensured through the gas supply lines. One large membrane gas generator skid and backup liquid nitrogen tank would be supplied per airport concourse, mainly to minimize the need for long piping runs between terminals. The NEA would then flow through a header located along the roof of each concourse, at a pressure of about 150 psig. The header would be constructed of 2-in-diameter type-K copper tubing. This header would feed an array of metering stations, located one per gate, to supply nitrogen to the airplanes for ullage washing under controlled flow and pressure conditions. A diagram of the membrane gas generator skid at a concourse is shown in figure 6-1.

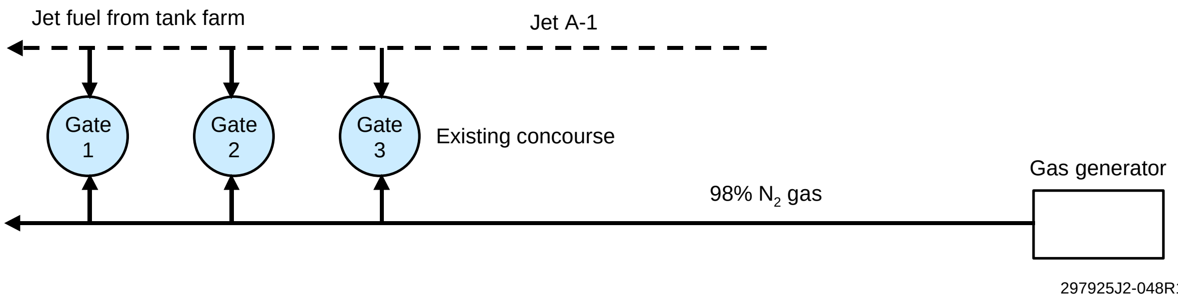


Figure 6-1. Membrane Gas Generator at Concourse for Ullage Washing

At multiple-concourse airports, it would be prudent to consider interconnecting membrane skids between terminals with a larger manifold. While the capital cost of achieving this would be significant, the benefit would be an additional level of redundancy without liquid nitrogen backup if one skid were down for extended maintenance.

The metering stations for injecting NEA gas under flow- and pressure-controlled conditions at each terminal gate are shown in figure 6-2. The station is connected to the concourse NEA header on one end and to a specially designed connector on the airplane at the other end. As stated, this system serves to reduce the oxygen content in the ullage space on airplanes by supplying a given amount of low-pressure NEA to the ullage from a high-pressure source. A solenoid valve and pressure regulator are used to initiate and complete a period of constant-rate gas flow to the airplane. By maintaining this constant flow for a time appropriate to the airplane model, the proper amount of NEA is injected into the ullage. The gas is made available by the regulator at a pressure of just a few pounds per square inch gage. In case of maintenance needs, a shutoff valve would be used to block off the station. The hose reel allows connection to the airplane from a station typically located at the end of the jetway.

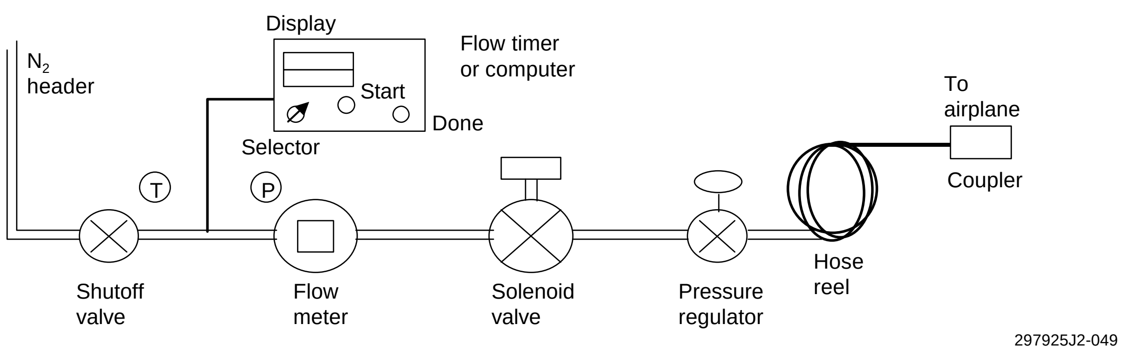


Figure 6-2. Typical Metering Station, Nitrogen Flow, and Pressure Control

The gas metering station would be designed to operate under applicable electrical-safety classifications in an unheated, outdoor service environment where it would be subject to temperature, moisture, and vibration. This station includes a flow meter, flow control terminal, and flow valve. The flow control terminal comprises a lockable, weatherproof housing that contains a flow computer and delivery receipt printer. The flow meter and flow computer deliver a preset quantity of NEA to the airplane's tank ullage. The delivery of this gas to the ullage is measured with reference to standard conditions (i.e., 60°F and 1 atmosphere). Hence, the required preset amount of gas is delivered regardless of the ambient temperature or source-gas pressure.

The flow computer essentially allows gas to flow to the airplane ullage for a given amount of time and then displays the actual volume of gas injected. The flow computer would include a selector to choose the type of airplane being inerted, a start button to control the solenoid valve, an indicator light to show when the job is done, and a dual display to illustrate required and injected gas volumes. In addition, the unit would be configured so that the operator is required to perform a security check (e.g., input an authorization code) to access the system initially. Stored within the flow computer, the appropriate inerting time will produce, at a given constant-rate gas flow, an inert ullage space in the tank above its fuel or within its entire volume if it is empty.

To inert a 737, for example, an operator would connect the coupler to the airplane, select the appropriate position on the selector, and verify the correct pressure on the flow control display. The upper display on the flow computer would show the volume required for ullage washing of a 737 airplane (e.g., 1,360 standard cubic feet [SCF]). The operator would then depress the start button. An NEA flow of 100 standard cubic feet per minute (SCFM) would occur for 13.6 min to produce the recommended volume of NEA for the 737 in this example. Then the indicator light would illuminate (indicating the task is done) and the solenoid valve would shut. The lower display would read 1,360 SCF, reflecting the total of the cumulative gas flow through the metering system at standard conditions. If the value were low, the operator could adjust for more NEA into the ullage to satisfy the requirement. The operator could either verbally inform the flight crew that the airplane has been inerted, or print a written receipt to notify them. This data could also be sent by means of a communications link to a central computer, if preferred.

Maintenance issues related to ullage washing are anticipated to be reasonably light because much of the equipment is passive. In general, the only devices containing moving parts are the solenoids in the flow valves at the metering stations and the air compressors and filters on the membrane gas generator skids. The membrane fibers are passive physical barriers with long lives when adequately protected from chemical attack, liquid impurities, and temperature and pressure excursions. A person skilled in electrical, piping, and instrument issues should be able to handle all routine and breakdown maintenance work on the metering stations at the airport easily.

Ullage washing systems will have to be customized for each airport. Nevertheless, major components required for design of a fixed, ground-based ullage washing system for various classifications (i.e., sizes) of airports may be found in the generic layouts presented in appendix E, Airport Facility Task Team Final Report.

Mobile Ullage Washing

Where it is not practical to supply a land-based source of nitrogen to ullage wash airplane fuel tanks at the loading gate, remote mobile nitrogen-dispensing equipment will be required. This equipment can be either mobile nitrogen-generating equipment, or liquid nitrogen tankers with vaporizers to convert the liquid to a gas.

Two factors have influenced selection of nitrogen-generating equipment over liquid nitrogen and vaporizing equipment for presentation in this report:

- Training and related safety issues associated with handling cryogenic liquids.
- Cost of ongoing purchase of liquid nitrogen compared with costs of generating gaseous nitrogen directly from the air using compressors and high-purity nitrogen membranes.

The design of mobile ullage washing vehicles will emphasize ease of operation by allowing operators to select predetermined automatic cycle times specific to each airplane category. Inerting vehicles will be designed with a high-volume-output, screw-type compressor, appropriate filter, high-purity nitrogen separators, specially designed meter, pressurized nitrogen storage tanks, and a related automated control system. A vehicle brake interlock system is required to ensure that delivery hoses and nozzles are properly stowed before the truck’s brakes are released.

The overall size of mobile NEA-generating equipment could become an issue because of the number of high-purity membranes required. When consideration is given to washing the ullage of the CWTs of large transport airplanes and to possibly providing “makeup” nitrogen to hold refueling tankers inert, size quickly becomes an issue.

Current ramp congestion dictates that mobile ullage washing use the smallest package and vehicle footprint possible to accomplish the task.

It is estimated that to service remotely parked or operated airplanes, especially freighters, and as a backup for land-based systems, mobile ullage washing vehicles will typically represent between 65% and 85% of the number of refueling tankers operating at a particular airport. Adding mobile inerting processes at the terminal gate is certain to exacerbate complications associated with congestion around airplanes. There are a number of existing services associated with airport ground operations, including fueling, baggage handling, catering, and cleaning services. These operations require vehicles to travel to and from the airplane in a very short period of time. Therefore, the inerting process could present an increased risk of accidents during operation. Inerting could also decrease the time available to conduct all other ground operations, further adding to the risk.

At small airports, it may be more cost effective to have all mobile equipment, compared to the fixed infrastructure costs.

Problems generally associated with a significant increase in personnel staffing while operating within the same physical area will be present.

Basic concept designs of both mobile liquid nitrogen conversion and NEA-generating ullage washing vehicles are addressed in appendix E.

6.1.2 Fuel Scrubbing

In the ARAC Tasking Statement, the FTIHWG was asked to provide a concept and design methodology for a system that would saturate and maintain aviation turbine (jet) fuel with nitrogen.

The purpose of delivering NSF into the airplane during normal fueling and refueling operations is to minimize the outgassing of entrained oxygen during the takeoff, climb, and cruise flight envelope to supplement the benefit of GBI. Because of the potential impact on fuel properties, the complexity of the processes required, and the costs, the team concluded that fuel scrubbing was not practical.

The 2001 FAA/Boeing flight test showed that the oxygen evolution from the fuel was not significant to the effectiveness of GBI; therefore, scrubbing the fuel would have very little effect on maintaining an inert atmosphere. It also does nothing to alleviate the concern of empty CWTs.

Three concepts were explored during this study:

- Bulk fuel scrubbing by nitrogen injection.
- Bulk fuel cooling using a proprietary process.
- Bulk fuel saturation with carbon dioxide using a proprietary process.

The three concepts are summarized in sections 6.1.2, 6.1.3, and 6.1.4. The detailed discussion and design concepts covering these fuel modification processes are addressed in appendix E.

Fuel Scrubbing by Nitrogen Injection

In order to prevent the oxygen inherently dissolved in the liquid fuel from coming out of solution and polluting the previously washed fuel tank ullage as the airplane climbs, it may be required to scrub the fuel of oxygen before loading onto the airplane. The logical place to do this job is at the fuel storage facility (fuel farm), where the fuel is inventoried and allowed to settle before being pumped into the hydrant system or loaded on mobile refueling vehicles (refuelers). Because jet fuel can preferentially absorb oxygen from the air, the processing technology at the fuel farm needs to focus on removing oxygen dissolved in the liquid fuel, preventing it from reentering the fuel after treatment, and dealing with environmental issues such as VOC emissions. Because of the more aggressive gas and fuel contact that would occur with implentation of fuel scrubbing technology, we anticipate that VOC emissions would be higher than current levels, causing the need for VOC abatement equipment.

The proposed fuel processing system comprises specialized gas generation and application equipment. The high-purity gas-generating skid (99.999% inert) is used to strip the fuel of dissolved oxygen and to blanket the fuel storage tanks at the farm with nitrogen to prevent reentry of oxygen from the air. The fuel scrubbing unit, which is a gas/liquid fuel contacting system, uses pure nitrogen from the high-purity gas-generating skid to replace the oxygen in the fuel. Tank blanketing management systems control the pressure and oxygen concentration in the headspace above the fuel in the individual large storage tanks. Finally, emissions of fuel vapors from the fuel storage tanks and vent gas from the fuel scrubbing unit will be controlled using an environmental abatement system that uses liquid nitrogen to cryogenically condense the VOC vapors from the vent stream and return them to the fuel tanks. Essentially, all technologies work as separate units at the fuel farm to ensure that the fuel delivered to airplanes has been scrubbed of oxygen.

To more easily understand the integration of these various technologies to achieve fuel scrubbing, it is useful to review the existing fuel farm at a typical airport. The simplest configuration is illustrated with three tanks in figure 6-3. Jet fuel from the pipeline continuously fills the tanks as they supply the hydrant system on an active tank-rotation basis. The maximum fuel flow rates for a large airport (e.g., Chicago O’Hare International) from common carrier supply pipelines and withdrawn by hydrant system from storage may exceed 4,000 and 18,000 GPM, respectively. The supply/withdrawal cycle typically involves a piston of liquid fuel filling one tank as a similar flow rate of VOC-laden air exits the vent to maintain a constant in-tank pressure at or near ambient atmosphere. Elsewhere, another tank is being drawn down, aspirating ambient air into the headspace to break any vacuum that is formed by the retreating liquid. The third tank rests for about 24 hr to settle out any free water and debris that may be present in the fuel.

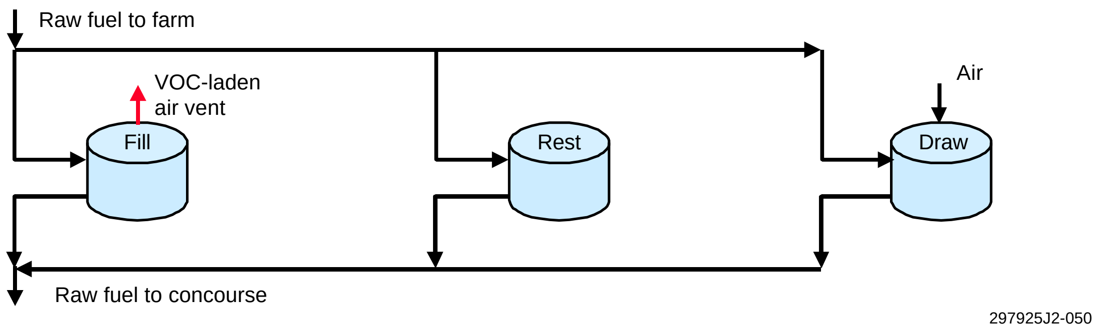


Figure 6-3. Current Tank Farm Configuration

The concept of fuel scrubbing is easily illustrated with some relatively minor additions to the current piping configuration at a fuel farm (fig. 6-4). With this new approach, raw fuel containing 50 to 100 p/m of dissolved oxygen enters the fuel scrubbing unit and is stripped of the oxygen through intimate contact with a stream of high-purity nitrogen gas. The nitrogen replaces the oxygen dissolved in the liquid and dilutes the oxygen gas given off by the fuel. Approximately two volumes of nitrogen gas are required for each volume of fuel processed. The result is a fuel scrubbed of oxygen to about 5 p/m. It has been estimated that the outgas that exits the fuel scrubbing unit contains about 1.5% oxygen and about 0.5% VOC vapors.

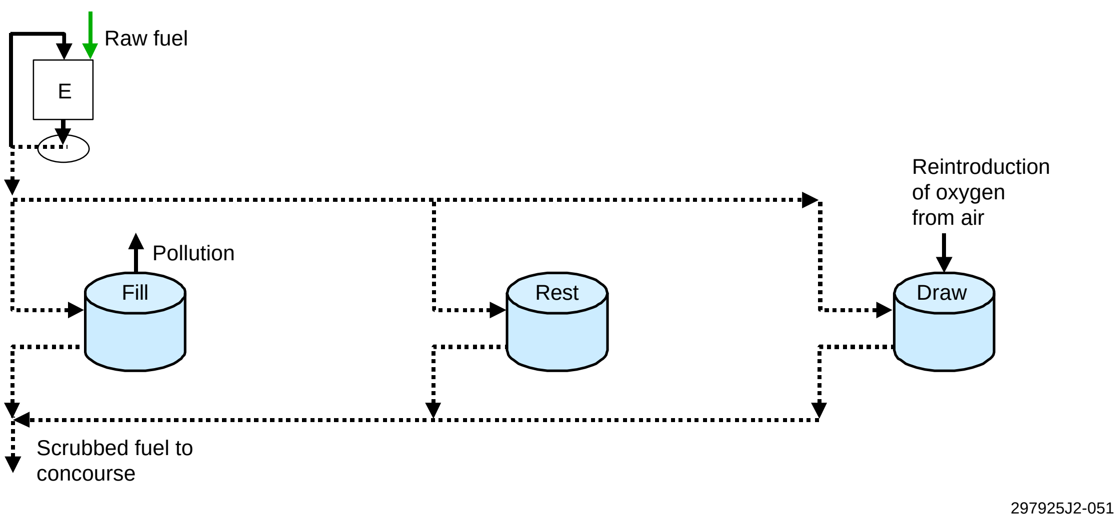


Figure 6-4. Fuel-Farm Piping With Added Fuel Scrubbing Unit

Two issues remain with this level of fuel processing, however. The outgas displaced from the fuel tank being filled and the gas that is vented from the fuel scrubbing unit, both of which contain oxygen and fuel vapors, will pollute the air if not treated. In addition, oxygen in the air aspirated into the fuel tank being drawn down will ruin the fuel treatment previously done by the fuel scrubbing unit. Additional technology needs to be added to that shown in figure 6-4 to avoid these problems and to meet all previously mentioned objectives for fuel scrubbing.

In the complete fuel scrubbing concept shown in figure 6-5, the environmental abatement system and tank blanketing management system have been integrated into the fuel farm to control pollution from VOC emissions and protect against the reoxygenation of the scrubbed fuel in the tanks.

Tank blanketing management systems, mounted one per tank, automate nitrogen blanketing of the tank headspace by measuring and controlling the pressure and oxygen content of the gas above the fuel. In this way, the tanks are continuously maintained at a given pressure and oxygen level.

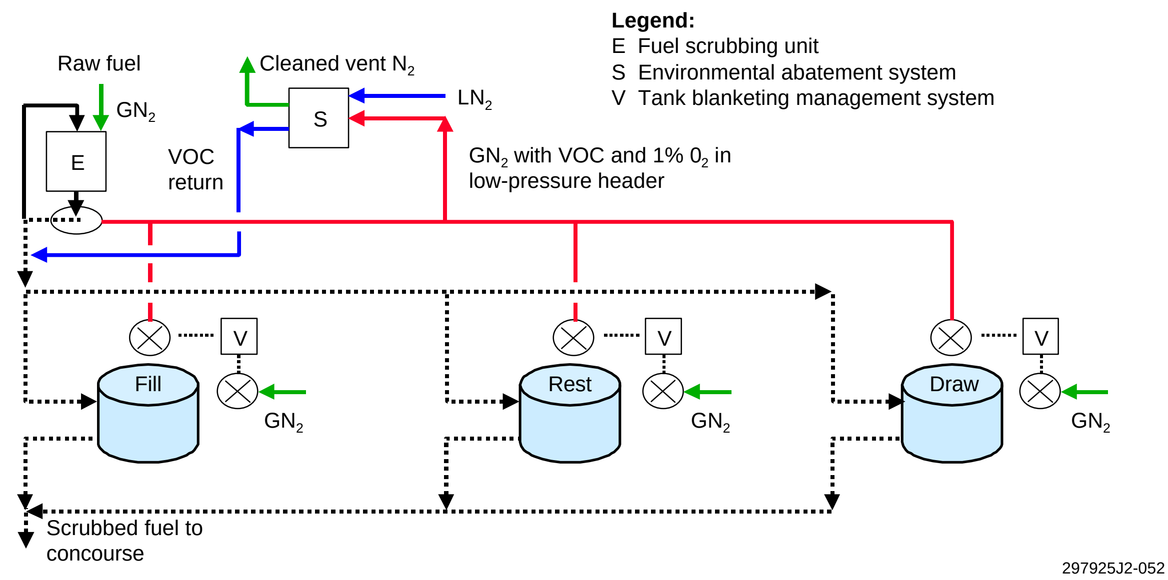


Figure 6-5. Complete Fuel Scrubbing Operation

A low-pressure header connects all vent valves on the fuel tanks and the gas vent from the fuel scrubbing unit to the inlet of the environmental abatement system. The fan on the environmental abatement system will be used to control the backpressure within this low-pressure header.

The process gas flowing through the environmental abatement system contacts stages of increasingly cold heat exchangers to remove nearly 100% of the VOCs by condensation from liquid nitrogen. The liquid fuel is then sent back into the scrubbed fuel line that flows to the storage tank so as not to deplete any compounds out of the normal jet fuel. The nitrogen, which has been stripped of fuel vapors, is then vented to the air or compressed and sent to the concourse for ullage washing if a suitable pipeline is available. The spent nitrogen gas that was vaporized to cool the environmental abatement system is pure and will be sent to the high-purity nitrogen header being fed by the high-purity gas-generator skid.

Distribution of Nitrogen-Scrubbed Jet Fuel by Refueling Tankers

A large number of airports around the world visited by airplanes requiring scrubbed jet fuel might not have the facilities for the bulk distribution of treated jet fuel. These airports may not incorporate a jet fuel hydrant system (underground pipeline distribution network), or the “final rule” from the work of this ARAC study may not apply to a sufficient number of air carriers to warrant bulk fuel scrubbing in the fuel storage facilities. In such cases, limited dedicated treated fuel storage may be preferred for supporting the requirements.

There are many airports that have a jet fuel hydrant system to support the passenger airplane operations, but have cargo and other “feeder” passenger air operations parked in remote (nonhydrant) locations. The mobile refueler tanker method must be modified to enable the supply of the scrubbed fuel to these locations.

This system concept proposes new design criteria and modifications for newly manufactured and in-service refueling vehicles to enable scrubbed fuel to be transported from airport storage to the wing of the airplane.

During airplane refueling, inward venting of the refueler tank is required to prevent collapse of the tank. Airplane refueling would also require NEA to be supplied to the refueler vents to prevent fuel re-oxygenation.

These vents automatically protect the tank from collapse during volumetric contraction during decreases in ambient temperature. Conversely, the vents will also prevent tank rupture resulting from thermal expansion during high ambient temperatures. The current design of typical vapor recovery system equipment does not provide for integration of the existing vent configuration. All vents will need to be interconnected within a system fed by a nitrogen supply. To accomplish this, modification to the refueler will be required.

Relocation of the in-breathing vents may require welding modifications to the tank vessel. If so, these modifications would need to be completed at a facility certified to make such repairs. After modification, the refuelers will mirror the typical vapor recovery system of vehicles transporting flammable liquids on public highways. These vehicles are required by 40 CFR Part 60 to be tested at the time of initial manufacture and periodically thereafter to ensure vapor tightness. It is anticipated that this testing and recertification will be mandated to ensure that only scrubbed fuel is delivered to the airplane and maximum control of VOC emissions is maintained. Relevant portions of 40 CFR Part 60 are found in appendix E.

Modifications include relocation of in-breathing vents to a point where vapor recovery vent hoods and associated piping can connect all vents to a common nitrogen supply. A 1-psig nitrogen pressure stream will be necessary for the vapor recovery system to operate properly at all times.

6.1.3 Fuel Cooling

The Airport Facility Task Team reviewed an airplane fuel tank inerting system design concept developed under a patented process. Because fuel cooling does not directly address the issue of empty CWTs, a supplemental means of inerting these tanks would be required. Time did not allow for a complete review of the technical data. A more detailed description of this process is found in appendix E.

The fuel-cooling concept consists of both refrigerating the fuel and washing the airplane fuel tank ullage with inert gas. The two processes may be used separately or combined. The cooling systems supply fuel to the airplane at less than 40°F. Cooling facilities located away from congestion cool the entire airport fuel supply (hydrant and/or refueler) to less than 40°F. Inerting gas for ullage washing is stored away from congestion and transported to the airplane by gas service vehicles in a cryogenic phase and converted to a gaseous phase for ullage washing. Refinements include combining the two processes into a single system.

6.1.4 Carbon Dioxide Fuel Saturation

The FTIHWG Airport Facility Task Team studied an airplane fuel tank inerting system design concept developed under a patent-pending ERA-7™ process. As with fuel cooling, this system does not directly address the issue of empty CWTs. A supplemental means of inerting these tanks would be required. Because the concept was not sufficiently developed to allow for a complete review of the technical data or a detailed analysis of the system's infrastructure requirements, the developer's claims are presented in abbreviated form. A more detailed description of this process is found in appendix E.

The system consists of a carbon dioxide (commercially available gas)/jet fuel mixing apparatus, which preloads the jet fuel with carbon dioxide. In one variation of the airport facility system, the carbon dioxide is derived from a liquefied carbon dioxide storage tank, converted to carbon dioxide gas, and mixed with the Jet A in a gas absorber tower at an optimum gas-to-fuel ratio. Thereafter the carbon dioxide–enriched fuel is stored in a fuel shipping tank with a floating pan, where the combination tank and pan maintain the desired gas-to-fuel ratio of the treated fuel. The carbon dioxide–enriched fuel is then transferred from the shipping tank to airplane refueling sites using the existing fuel pipeline and hydrant systems (for hub airports) or the existing truck delivery system (at nonhub airports).

6.2 AIRPORT FACILITIES

To expand on the data contained in the FAA report, "Cost of Implementing Ground Based Inerting in the Commercial Fleet," the Airport Facility Task Team conducted additional airport surveys at three U.S. and two international airports. This section describes the methods used by the team to develop the design concepts and costs.

6.2.1 Methodology

The Airport Facility Task Team comprises representatives from airlines, oil companies, industrial gas suppliers, airplane manufacturers, civil engineering firms, mobile equipment suppliers, and other airline equipment and service suppliers. The team looked at three different inerting gases, a fuel cooling concept, methods of supply, airport infrastructure modifications, mobile equipment requirements, fuel scrubbing, and the environmental impact of fuel scrubbing. On-site surveys of airport fueling operations were conducted at five airports; design concepts were developed for large, medium, and small airports. Preliminary laboratory testing was performed on the effects of fuel scrubbing on fuel properties and the environment. Cost estimates were determined from the design concepts developed by the team and typical airport construction practices.

The team used the following assumptions during the study:

Ullage Washing

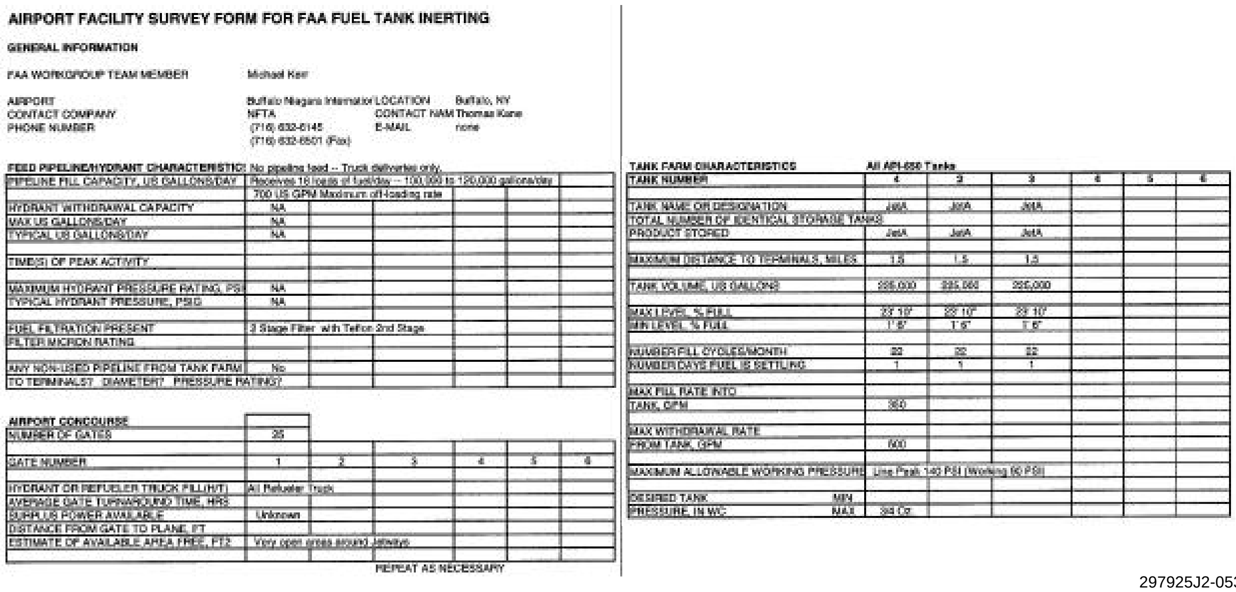
- The process was not to affect airplane turn time.
- Only the CWT would be inerted.
- The process would start when the airplane arrived at the gate (i.e., empty tanks).
- 800 SCF was used as the average gas requirement (i.e., the volume of the small generic airplane model used in the study).
- 1.7 times the ullage volume would be required to perform the task.
- System was sized for a use of 0 to 2.4 times the average to handle peak operations.
- A maximum of 15 min to inert a small airplane would be provided.
- Large and medium airports would use fixed equipment as the primary means for gas supply; and small airports would use mobile equipment.

Fuel Scrubbing

- 50 p/m oxygen content in fuel would be reduced to 5 p/m.
- Fuel scrubbing would be done at the storage facility because of evironmental issues and the ease of siting and constructing fairly complicated processing equipment.

6.2.2 Airport Evaluations

The team conducted on-site airport surveys at Chicago O'Hare, Los Angeles International, Buffalo International Airport, Charles DeGaulle Airport, and London Heathrow to assess the available infrastructure, fueling methods, fuel supply system, and fuel storage system to use in the development of the design concepts and costs of construction. In addition, the data for Atlanta and Atlantic City airports from "Costs of Implementing Ground-Based Inerting in the Commercial Fleet" was used. Figure 6-6 shows a typical survey. One item of note obtained by the survey was the fact that each airport is unique and will require a tailor-made system. There does not appear to be a turnkey solution because of the great differences in airport infrastructures.



AIRPORT FACILITY SURVEY FORM FOR FAA FUEL TANK INERTING

GENERAL INFORMATION

FAA WORKGROUP TEAM MEMBER	Michael Kerr		
AIRPORT	Buffalo Niagara Internatior	LOCATION	Buffalo, NY
CONTACT COMPANY	NFTA	CONTACT NAM	Thomas Kane
PHONE NUMBER	(716) 632-6145 (716) 632-6501 (Fax)	E-MAIL	none

FEED PIPELINE/HYDRANT CHARACTERISTIC: No pipeline feed -- Truck deliveries only.

PIPELINE FILL CAPACITY, US GALLONS/DAY	Receives 18 loads of fuel/day -- 100,000 to 120,000 gallons/day					
	700 US GPM Maximum off-loading rate					
HYDRANT WITHDRAWAL CAPACITY	NA					
MAX US GALLONS/DAY	NA					
TYPICAL US GALLONS/DAY	NA					
TIME(S) OF PEAK ACTIVITY						
MAXIMUM HYDRANT PRESSURE RATING, PSI	NA					
TYPICAL HYDRANT PRESSURE, PSIG	NA					
FUEL FILTRATION PRESENT	2 Stage Filter with Teflon 2nd Stage					
FILTER MICRON RATING						
ANY NON-USED PIPELINE FROM TANK FARM TO TERMINALS? DIAMETER? PRESSURE RATING?	No					

AIRPORT CONCOURSE

NUMBER OF GATES	25					
GATE NUMBER	1	2	3	4	5	6
HYDRANT OR REFUELER TRUCK FILL(H/T)	All Refueler Truck					
AVERAGE GATE TURNAROUND TIME, HRS						
SURPLUS POWER AVAILABLE	Unknown					
DISTANCE FROM GATE TO PLANE, FT						
ESTIMATE OF AVAILABLE AREA FREE, FT2	Very open areas around Jetways					

REPEAT AS NECESSARY

TANK FARM CHARACTERISTICS All API-650 Tanks

TANK NUMBER	1	2	3	4	5	6
TANK NAME OR DESIGNATION	JetA	JetA	JetA			
TOTAL NUMBER OF IDENTICAL STORAGE TANKS						
PRODUCT STORED	JetA	JetA	JetA			
MAXIMUM DISTANCE TO TERMINALS, MILES	1.5	1.5	1.5			
TANK VOLUME, US GALLONS	225,000	225,000	225,000			
MAX LEVEL, % FULL	23' 10"	23' 10"	23' 10"			
MIN LEVEL, % FULL	1' 8"	1' 8"	1' 8"			
NUMBER FILL CYCLES/MONTH	22	22	22			
NUMBER DAYS FUEL IS SETTLING	1	1	1			
MAX FILL RATE INTO TANK, GPM	350					
MAX WITHDRAWAL RATE FROM TANK, GPM	600					
MAXIMUM ALLOWABLE WORKING PRESSURE	Line Peak 140 PSI (Working 60 PSI)					
DESIRED TANK PRESSURE, IN WC MIN						
DESIRED TANK PRESSURE, IN WC MAX	3/4 Oz					

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Figure 6-6. Airport Facility Survey Form for FAA Fuel Tank Inerting

6.3 IMPACT ON AIRPORTS

The potential impact on current airports identified by the team include

- Labor: Because the inerting process closely parallels the fueling process, it is conceivable that the labor needs would be similar.
- Ramp congestion: The space required for the fixed systems and additional vehicles for the mobile systems could create problems at many large airports where the ramp area is already limited.
- Diversion airports: There could be an impact on smaller airports presently used as diversion airports for larger hubs. The lack of inerting capabilities to handle the occasional influx of a large number of airplanes may limit their usefulness. If GBI does not become a global standard, this could create even greater problems at non-U.S. diversion airports and those used for technical stops.
- Economics: The economic impact could affect commercial airline service at smaller airports.

6.4 ENVIRONMENTAL EVALUATION

General environmental issues are addressed to identify basic direct and indirect environmental impact of ullage washing and fuel scrubbing. The impacts fall into the following categories:

- VOC emissions.
- Airport environment.
- Other environmental issues.

Values and quantities of undesirable materials and impacts are not given in this section. Instead, the impacts are identified as they generally relate to existing airport and airline environmental initiatives. Other than the VOC emissions, which could be mitigated by a costly vapor recovery system, environmental impact from implementing ullage washing and fuel scrubbing is assumed to be relatively minor.

Environmental protection infrastructure must be added to each airport fuel storage facility to mitigate release of VOCs during fuel scrubbing. The systems and equipment include pumps and other electric-motor-driven equipment, above-ground liquid nitrogen storage tanks, gas tanks, and piping.

VOC emission data from a simple experiment from two different sources indicates that substantial amounts of light hydrocarbon molecules would be stripped from the fuel during scrubbing. A vapor recovery system would be an essential component of this system to mitigate the adverse impact on the environment.

All refueler trucks that serve airplanes parked in cargo and other remote areas at an airport with no hydrant system have to be modified. A nitrogen-generating unit added to the rear of the vehicle will maintain an inert atmosphere in the tank headspace and a slight positive pressure in the tank by replenishing with NEA while the truck's fuel tank level is being drawn down during airplane refueling. During the refilling cycle of the refueler, a means of capturing vented emissions would have to be developed. If not properly addressed, these modifications could result in an increase in VOC emissions from this intermediate mobile fuel storage.

During airplane fuel tank ullage washing, it is expected that there would be an incremental increase in VOC emissions. This would result primarily from the application of NEA to airplane tanks that normally would not be disturbed during the routine turn-around activities.

Truck traffic to deliver liquid nitrogen to the tank farm area would result in additional use of fossil fuels if the dependence on liquid nitrogen becomes significant.

The increase in the number of ground service equipment vehicles mandated by these new systems will add to emissions from their internal combustion engines. Alternatively, these emissions could be mitigated if alternative fuel technology were incorporated into new vehicle design.

New construction to support fuel scrubbing at the airport tank farm site will require extensive environmental assessment, existing environmental remediation methods be altered, or remediation be undertaken before the construction of any supporting infrastructure.

Indirect impacts to the environment include negatively affecting airport, city, and regional air quality through the release of excessive amounts of VOCs.

No improvements to the environment were identified for any of the concepts in this report, no data is available on the soil condition of any given site, and no quantified air-emission data is available to establish an emission baseline. A baseline would be useful in measuring incremental impacts to the environment.

6.5 COST-BENEFIT ANALYSIS

Figures 6-7 through 6-10 are economic evaluations of the inerting systems considered by FTIHWG for each type of airport. The estimates used a standard form common to each estimate. The economic evaluation was broken into two parts, capital (nonrecurring) and operation (recurring) costs.

The evaluations include only the cost of construction and maintenance; operator labor costs are not included.

Capital				
Description	**Cost per concourse, K**	**Airport size**		
		Large	**Medium**	**Small**
Number of concourses		9	2	NA
• System	0	0	0	—
• Site preparation	35	315	70	—
• Piping, hoses, reels, other	408	3,672	816	—
• Electrical power upgrades	500	4,500	1,000	—
• Engineering and soft costs (19%)	179	1,613	358	—
• Contingency (25%)	281	2,525	562	—
Total	1,403	12,624	2,806	NA

Notes:
- Concourse is 20 gates.
- All figures are in thousands of U.S. dollars.

Operational costs per month				
Description	**Cost per concourse, K**	**Airport size**		
		Large	**Medium**	**Small**
Number of concourses		9	2	NA
• Rent at $20/ft	2	18	4	—
• Lease system if applicable	0	0	0	—
• System maintenance	1	9	2	—
• Maintenance and operation	Per airport	25	13	—
Total		52	19	NA

Note: All figures are in thousands of U.S. dollars.

Figure 6-7. ARAC Facility Estimate—Fixed Ullage System

Capital				
Description	**Cost per mobile unit, K**	**Airport size**		
		Large	**Medium**	**Small**
Number of mobile units		12	7	2
• System and truck	330	3,960	2,310	660
• Parking and site preparation	1	12	7	2
• Piping, hoses, reels, other	0	0	0	0
• Electrical power upgrades	0	0	0	0
• Engineering and soft costs (19%)	1	12	7	2
• Contingency (25%)	83	996	581	166
Total	415	4,980	2,905	830

Operational costs per month				
Description	**Cost per mobile unit, K**	**Airport size**		
		Large	**Medium**	**Small**
Number of mobile units		12	7	2
• Rent at $1.0/ft	4	48	28	8
• Lease system if applicable	0	0	0	0
• System maintenance	1	12	7	2
• Power cost	2	24	14	4
• Maintenance and operation	.5	6	3.5	1
Total	7.5	90	52.5	15

Note: All figures are in thousands of U.S. dollars.

Figure 6-8. ARAC Facility Estimate—Mobile Ullage System

Description	Cost per tank, K	Airport size		
		Large	Medium	Small
Per tank at one fuel facility		20	4	2
• System	0	0	0	0
• Site preparation	20	400	80	40
• Piping, hoses, reels, other	101	2,014	403	201
• Electrical power upgrades	30	600	120	60
• Engineering and soft costs (19%)	29	573	115	57
• Contingency (25%)	45	897	179	90
Total	224	4,483	897	448

Operational costs per month				
Description	Cost per gal/ min delivered, K	Airport size		
		Large	Medium	Small
Thousands of gallons per minute		4.5	1.0	0.4
• Rent at $1.0/ft	2	7	2	1
• Lease system if applicable	1	2	1	0
• System maintenance	1	5	1	0
• Inert gas cost	26	117	26	10
• Power cost (if not already included)	0	0	0	0
• Maintenance and operation	2	9	2	1
Total	31	140	31	12

Note: All figures are in thousands of U.S. dollars.

Figure 6-9. ARAC Facility Estimate—Fixed Scrubber System

Capital				
Description	Cost per truck, K	Airport size		
		Large	Medium	Small
Number of existing refuelers		14	9	4
• System and truck	8	112	72	32
• Parking and site preparation	0	0	0	0
• Piping, hoses, reels, other	0	0	0	0
• Electrical power upgrades	0	0	0	0
• Engineering and soft costs (19%)	0	0	0	0
• Contingency (25%)	2	28	18	8
Total	10	140	90	40

Operational costs per month				
Description	Cost per truck, K	Airport size		
		Large	Medium	Small
Number of refuelers		14	9	4
• Rent at $1.0/ft	0	0	0	0
• Lease system if applicable	0	0	0	0
• System maintenance	1	7	5	2
• Inert gas cost	0	0	0	0
• Power cost (if not already included)	1	7	5	2
• Maintenance and operation	1	7	5	2
Total	2	21	14	6

Note: All figures are in thousands of U.S. dollars.

Figure 6-10. ARAC Facility Estimate—Mobile Scrubber System

Capital

Capital costs are those outlays made to design, install, and commission a system concept. Included in the capital estimates are (1) system and vehicle costs, (2) parking and site preparation costs, (3) piping, hoses, and reels for fixed systems, (4) electrical power upgrades, (5) engineering and soft costs, and (6) contingencies.

Operation

Monthly operational costs are those outlays necessary to operate the system concept and are exclusive of capital costs. Depreciation has been omitted. Included in the operations estimates are (1) rent, (2) inerting system lease, (3) system maintenance, (4) inert gas costs for delivered (not generated) gas, and (5) power costs (if not already included in other line items).

Each outlay is defined for reference here.

System and Truck Costs

- Generators
- Storage tanks for liquid nitrogen
- Controls
- Power, lights, and distribution from supply
- System enclosure (if any)
- Rolling equipment (if applicable)

Parking Site Preparation Costs

- Fence
- Rooms, walls, and so on
- Site lighting
- Ramp striping
- Barricades

Piping, Hoses, and Reels for Fixed Systems

- Piping
- Hoses
- Gas distribution hardware to airplane

Electrical Power Upgrades

- New electrical service
- New supply switchboard
- Space costs and new electrical room

Engineering and Soft Costs

- Design—6% of capital cost for the design concept
- Construction administration—3% of capital cost for the design concept
- Program management—6% of capital cost for the design concept
- Construction management—3% of capital cost for the design concept
- Permit and related costs—1% of capital cost for the design concept
- Infrastructure survey—$25,000 per concourse
- Subtotal—19% plus $25,000

Contingencies in Capital Budget

- Unforeseen conditions
- Conceptual unknowns

Rent

- Lease for concourse space at $20 per year
- Lease for site space at $1 per month, per foot

System Lease Cost

- Inert gas generating system lease cost (if applicable)

System Maintenance

- Inert gas generating system maintenance costs by manufacturer (if applicable)

Inert Gas Costs

- Delivery costs
- Capitalized system cost
- Gas cost
- Backup gas costs
- Power and energy for system

Power Costs

- Monthly power costs to run the system (if not built into other line items)

Airport Maintenance and Operation

- Labor to maintain metering, piping, connections, and so on
- Labor to operate (at $25 per hour)
- Spare parts
- Accounting
- Testing and airport certification

6.6 TECHNICAL LIMITATIONS

Given sufficient implementation time and resources, no major obstacles are foreseen, although it will be necessary to prototype a full-scale system to validate the methods and technology. New worldwide airplane interface and safety standards also would be necessary.

The major cost drivers for ground-based systems are developing the infrastructure and the operating labor for the inerting process. Therefore, these limitations do not offer areas of significant cost reduction.

6.7 POTENTIAL IMPACT ON FUEL PERFORMANCE

The Tasking Statement requested that ARAC provide, among other tasks, an evaluation of the feasibility to saturate jet fuel with nitrogen in ground storage facilities, for example, in trucks or central storage tanks. The design concepts for saturating the fuel with nitrogen, also referred to as fuel scrubbing, provoked concerns over maintaining jet fuel integrity during the processing.

A concept and design methodology for a system that proposes to accomplish this task has been developed. During the conceptual deliberations as to how an effective system might be designed, manufactured, installed, and made operational, concern arose with respect to the effects that ullage washing and fuel scrubbing may have on the performance characteristics of aviation turbine fuel. In addition, there were concerns expressed about the environmental impact of the inerting process, especially as a consequence of fuel scrubbing, which involves vigorously mixing nitrogen gas with a high-flow fuel stream.

This section will summarize the concerns, the findings of preliminary laboratory analyses performed by two oil company task team members, and the recommendations for further study into airplane fuel tank ullage washing and fuel scrubbing.

Concerns were raised that ullage washing and fuel scrubbing would degrade certain performance properties of jet fuel by driving off the lightweight molecular ends of the fuel. The light ends influence several specification properties of jet fuel, including distillation, flash point, and freezing point. Another concern expressed was the uncertainty of how these processes might affect the relight-at-altitude characteristics of the fuel. Questions were also raised regarding the performance of additive packages (e.g., antioxidants and antistatic additives) to enhance or modify particular characteristics of the fuel.

To obtain a broader perspective on these questions and other issues, a notice was circulated by means of the ASTM committee charged with aviation turbine fuel specification maintenance (ASTM D-1655) asking all U.S. and non-U.S. refineries and engine, airframe, and component manufacturers to provide feedback and information they may have on the performance characteristics of fuel subjected to ullage washing, scrubbing, or both. Because these inerting concepts were new to many of the responders, more questions were raised than answers received. Additional concerns expressed ranged from the belief that complete engine recertification may be required to the belief that nitrogen inerting would improve at least the fuel stability characteristics and therefore would be a benefit.

The last area of concern that arose during discussions of the fuel inerting concept involved environmental considerations. Flowing nitrogen gas over a partially filled fuel tank and the vigorous mixing of nitrogen gas with fuel during the scrubbing process would, according to general opinion, result in significant VOC release to the atmosphere at airport fuel storage depots. These VOCs would aggravate the already thorny issue of air pollution at and around today's airports. Feedback and factual data were requested from stakeholders, including the EPA. Again, more questions than answers came from this inquiry.

AirBP and Texaco performed elementary experiments on ullage washing and fuel scrubbing using nitrogen and carbon dioxide gases; final reports are in appendix E.

Preliminary results of these experiments indicate that ullage washing and fuel scrubbing with nitrogen gas have little effect on the conventional properties of jet fuel. However, a measurable change in vapor pressure occurred from fuel scrubbing, and the carbon dioxide–scrubbed fuel exhibited an increase in acidity. Significant VOCs were released during both processes, regardless of the inert gas used. VOC release may lead to serious health and safety issues that must be addressed.

Physical Property Changes. One experiment showed that there is an increase in fuel vapor pressure after the scrubbing process. This vapor pressure increase is not totally understood at this time; however, it does suggest that there may be a deleterious effect in controlling the flammability of the airplane fuel tank headspace atmosphere. The increase in vapor pressure may affect the performance of the different fuel pumping devices used on today's airplanes.

There was also a decrease in the fuel's electrical conductivity, which will require further investigation. Changes in this fuel property will require a full understanding of the phenomenon because of fuel handling safety and additive performance issues.

A significant release of VOCs (addressed further in this summary) occurred during ullage washing and fuel scrubbing, which obviously change bulk fuel composition. Removing and recombining the VOC condensate after a vapor recovery process will require additional study to ensure that there is no deleterious effect on engine performance from a reconstituted fuel blend. Although no statistical difference was measured in the fuel's distillation characteristics, flash point, or freezing point, a more thorough analysis of these properties should be performed to verify the preliminary findings. Additionally, because the loss of these light ends may affect altitude relight, a thorough analysis of this characteristic should also be carried out. Unfortunately, this analysis could not be done in the time allotted to this project.

The experiments using carbon dioxide as the scrubbing gas (carbon dioxide–oxygen injection was one of the inerting processes considered during the team's discussions, but time did not allow for a complete conceptualization of this technique) showed a much greater effect on vapor pressure than nitrogen and also increased the acidity of the bulk fuel. This finding was not totally unexpected; prior experience has shown that with water-laden (including dissolved water) mixtures and subsequent carbon dioxide saturation, carbonic acid may form as a byproduct of this chemistry. The formation of any compound that may enhance or accelerate corrosion of the airplane fuel tanks is not a desirable attribute of a fuel.

Industrial Health and Safety Issues. The experiments indicated that the carcinogen benzene may be concentrated in the vapor phase at concentrations that could exceed the 0.1% weight limit by weight established for regulating a material as toxic. This matter is of the greatest concern with regard to employee health and the environment surrounding airport bulk storage depots and will have to be addressed.

An additional employee and facility safety problem is also introduced when fuel is exposed to the scrubbing process, which creates an extremely flammable vapor atmosphere from light-end VOC emissions. Very careful attention will have to be paid in the design of any mechanical equipment used to recover and dispose of VOCs.

Ullage washing will result in the release of a low-oxygen, high-inert-gas concentration mixture (nitrogen or carbon dioxide) from the CWT vents. People working in and around this area may be exposed to air with an oxygen level below that which is required to sustain normal respiration. The hazard level will increase as the number of airplanes in a localized area undergoing the inerting process increases. This asphyxiation hazard must be studied in more depth before any large-scale inerting is implemented.

Environmental Impact Issues With Fuel Scrubbing. The fuel scrubbing process has been shown to release a significant amount of VOCs. These VOC releases were measured in the more than 1% range by volume during the experiments. To put this volume in perspective, it represents an equivalent volume to more than 21,000 gal of jet fuel from a typical 50,000-barrel storage tank found at many airports. This release is expected to occur each time this amount of fuel is received into storage and subsequently processed through the scrubbing cycle. The environmental as well as economic impact of releases of this magnitude will require careful design and operation of costly vapor recovery systems near bulk storage facilities. As more regulatory pressure is exerted on today's management and operators to clean up the air on and around airports, the release of additional pollutants caused by any new process becomes unacceptable, regardless of the perceived benefits.

The EPA representative queried during the feedback process succinctly put future work on this issue into perspective by recommending *(1) a literature search for theoretical and experimental analysis of the effects of fuel tank inerting or similar fuel treatments on engine exhaust emissions, (2) explicit discussion, involving appropriate experts of this concern in FAA rulemaking activities relating to fuel tank inerting; and (3) experimental research to validate expectations regarding impacts of inerting methods on engine exhaust emissions.*

As this discussion indicates, a number of issues need to be addressed and better understood, and solutions need to be found before ullage washing, fuel scrubbing, or both are implemented on a large scale. The following is only a short list of the issues that come to mind.

- The performance characteristics of scrubbed fuel in today's turbine engines need further investigation.
- The impact of ullage washing and fuel scrubbing on employee health and safety will have to be better understood so appropriate action can be taken.
- The impact of ullage washing and fuel scrubbing on the environment will have to undergo an extensive review. There was not enough time or readily available information during this ARAC project to become fully knowledgeable on the subject or propose concept designs to address the impediments identified.

7.0
OBGI

7.0 ONBOARD GROUND INERTING

The OBGIS is a self-contained method of providing inert gas to the airplane's fuel tanks without relying on an airport to supply the inert gas.

The Onboard Inerting Designs Task Team reviewed the 1998 ARAC FTHWG report for inerting and determined that most of the nitrogen inerting technologies discussed in that report remained unchanged. The team chose to focus on air separator technology because of improvements in technology and manufacturing and a probable benefit of reduced cost.

7.1 SYSTEM REQUIREMENTS

The Tasking Statement requires that the OBGIS inert fuel tanks be located near significant heat sources or fuel tanks that do not cool as quickly as unheated wing tanks. The affected fuel tanks will be inerted on the ground between flights. We will provide the benefits and risks of limiting inerting to fuel tanks near significant heat sources. This report will consider methods to minimize system cost, such as reliable designs with little or no redundancy, and recommendations for dispatching in the event of a system failure or malfunction that prevents inerting one or more of the affected fuel tanks.

We will describe secondary effects of the system, along with an analysis of extracted engine power, engine bleed air supply, maintenance effects, airplane operational performance detriments, dispatch reliability, and so on.

The Tasking Statement also required that information and guidance be provided for the analysis and testing that should be conducted to certify the system.

If the Working Group cannot recommend a system, the group is to identify all technical limitations and provide an estimate of the type of concept improvement that would be required to make it practical in the future.

7.2 CONCEPT DESCRIPTION

Figure 7-1 shows the OBGIS. In its simplest terms, an air separator module (ASM) separates pressurized air into nitrogen and other gases. The ASM supplies nitrogen to the fuel tanks and exhausts the other gases overboard.

The ASM gets pressurized air from either the engine as bleed air or from an electric compressor. This air is cooled if necessary, water is removed to avoid icing, and the dry air is then filtered to avoid ASM contamination.

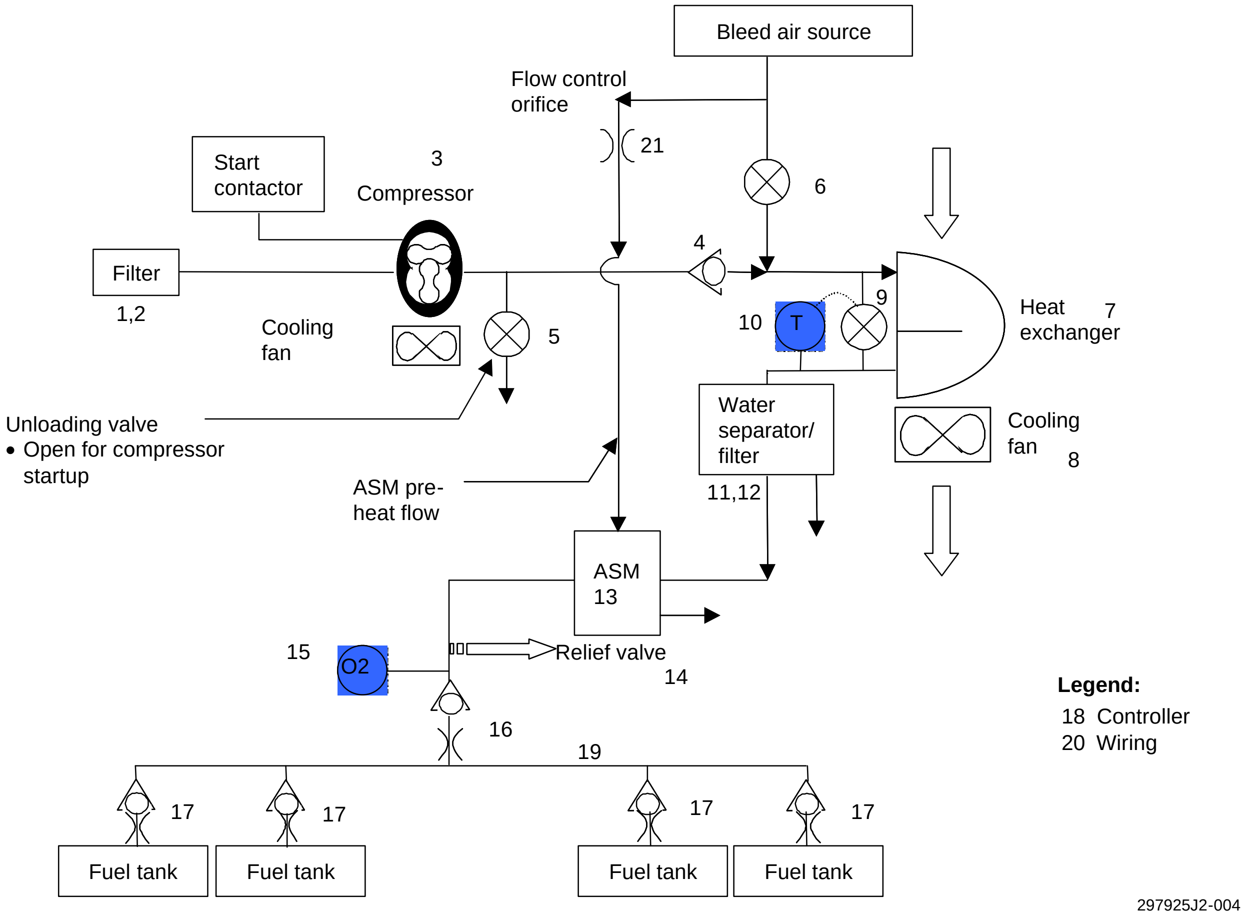


Figure 7-1. OBGIS Schematic

7.2.1 Air Source

The concept uses multiple air sources. Pressurized air can be provided by engine and APU bleed air or by the electric compressor. The air pressure supplied to the ASM is nominally 45 psia.

7.2.2 Pressure Ratio: Match APU Pressure

The electric compressor was sized for a 3:1 pressure ratio in an attempt to supplement bleed air with compressor air to minimize the compressor size and cost. However, check valves would need to be installed to prevent bleed air from creating backflow in the compressor or compressor air from backflowing into the engine. Neither pressure source could supplement the other because the source of higher pressure would close the check valve on the other source. A more complex flow-sharing concept was not pursued.

7.2.3 Air Separator

We studied three concepts for air separation. Hollow-fiber membranes separate nitrogen through molecule-sized passages when air passes through the length of the fiber. Pressure-swing adsorption (PSA) adsorbs oxygen as air passes over the module, leaving nitrogen in the flowstream. Cryogenic distillation relies on separation of a partially liquefied airstream using a distillation column. The product is a high-purity nitrogen gas, which can be sent to the fuel tanks, or a high-purity nitrogen liquid, which can be stored for later use.

7.2.4 Time for Inerting

Like the Ground-Based Inerting Designs Task Team, the Onboard Ground Inerting Designs Task Team assumed that airline operation should not be affected by the addition of the inerting system, if possible, to minimize the cost to the airlines. The primary operation where an impact should be avoided is “gate time,” that is, the time between flights when the airplane arrives at the gate, passengers deplane, the airplane is refueled, and new passengers board for the next flight. One of the design ground rules then was to inert the fuel tanks within the average minimum turnaround time at the gate.

Gate time depends on the airplane size and its use by the airline. Large airplanes have longer gate times because they have long flights and need more time to refuel and board passengers. Small airplanes have short gate times because they have shorter flights.

System size depends on the ullage volume and the gate time. A large ullage volume will require a lot of inert gas to fill it and, if the gate time is short, the inert gas will have to be generated quickly. This requires that the compressor, ASM, heat exchanger, and all interfacing components be large. The weight increases and the electrical power demand of the compressor increases.

“Initialization time,” or the time to inert a fuel tank after it has been opened and vented for maintenance, was estimated after the system size was determined. This was not considered an operational constraint because operators can plan their effort to allow time to inert the fuel tanks after maintenance.

This was a reasonable assumption at the beginning of this ARAC effort because fuel tank maintenance was normally performed only when a failure was noted. This may change and incur potential cost increases because of SFAR no. 88, the result of which may require more frequent tank entries. However, no effort has been made to determine the potential added cost impact of SFAR no. 88.

7.2.5 Flammability Exposure

The flammability exposure is defined as the percentage of the airplane mission when the fuel ullage is flammable and not inert. The 1998 ARAC FTHWG found that CWTs had a flammability exposure of approximately 30% and wing tanks had a flammability exposure of approximately 7%. The FAA has since been refining a model for flammability exposure, which was provided to this ARAC to compare system benefits. The OBGIS reduces the flammability exposure of a heated CWT to at or below the exposure of an unheated wing tank.

7.3 APPLICABILITY OF CONCEPT TO STUDY-CATEGORY AIRPLANES

The design concept applies to all the airplanes in the study category. However, the high electrical demand may exceed the capacity of the existing airplane electrical systems and, at airports that discourage APU operation, the airport’s ability to provide the electricity.

An inerting system can be designed into future airplanes, provided the inerting system size is calculated before engine, APU, and electrical generator selection. This will ensure that bleed air or electrical power is available to supply the inerting system.

7.4 AIRPORT RESOURCES REQUIRED

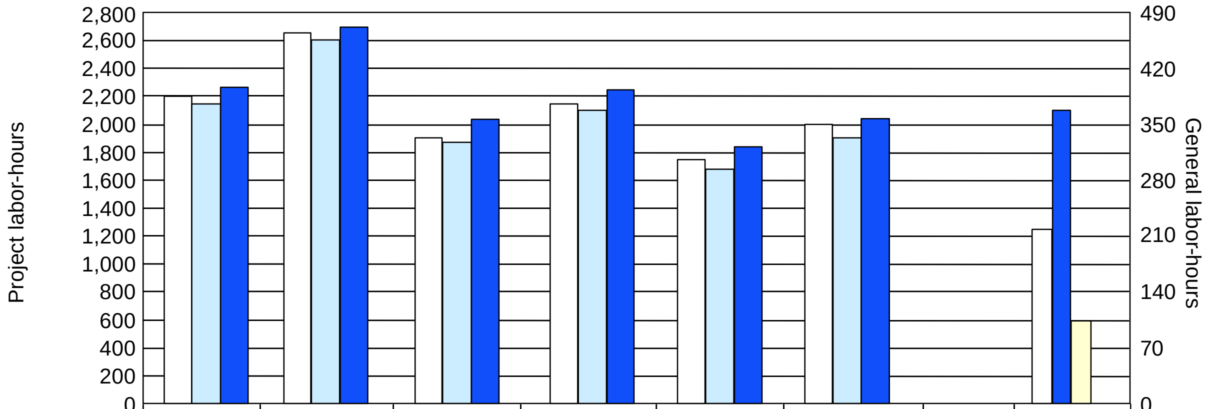
Electrical power from the airplane APU is needed to power the OBGIS. Some airports are sensitive to noise and do not permit APU operation, requiring a ground power source to supply the system.

7.5 AIRLINE OPERATIONS AND MAINTENANCE IMPACT

This section discusses the modification of in-service airplanes to install an OBGIS and the overall effect of OBGIS on airplane operations and maintenance requirements.

7.5.1 Modification

Figure 7-2 shows the modification estimates for the OBGIS. Because there is insufficient space for the OBGIS in the unpressurized areas of regional turbofan, regional turboprop, and business jet category airplanes, we have excluded these airplanes from this estimate. Estimates are made for both a regular heavy maintenance visit and a special visit.



Legend:	Large (heavy check)	Large (special visit)	Medium (heavy check)	Medium (special visit)	Small (heavy check)	Small (special visit)		General
Membrane	2,200	2,650	1,925	2,150	1,750	2,000		
PSA	2,150	2,600	1,875	2,100	1,700	1,950		
Cryogenic	2,250	2,700	2,025	2,225	1,850	2,050		
Engineering								220
Tech pubs								365
Material control								104
Training								
Flight ops eng								

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Figure 7-2. Modification Estimates for the OBGIS

The modification estimates for the OBGIS are based on the estimates of the OBIGGS; however, because the OBGIS is designed only for the CWT and auxiliary tanks, we have reduced the labor estimates to account for installation differences. The following reductions are used:

- For the large-airplane category: 300 labor-hours.
- For the medium-airplane category: 250 labor-hours.
- For the small-airplane category: 200 labor-hours.

The left side of figure 7-2 shows the estimated modification labor-hours per airplane for the different airplane categories. The right side shows the general support labor-hours. The support labor-hours are incurred on a per-operator basis as opposed to per-airplane and are approximately the same for all airplane categories. Task-level detail data used for the estimate is presented in addenda F.A.1 and F.A.2 of appendix F, Airline Operations Task Team Final Report.

7.5.2 Scheduled Maintenance

Scheduled Maintenance Tasks

A list of scheduled maintenance tasks was developed using the OBGIS schematic provided by the design team. The team evaluated each component illustrated in the schematic individually and wrote the tasks accordingly. These tasks included inspections, replacements, and operational and functional checks of the various system components.

The OBGIS consists of several more components than the GBIS, requiring additional tasks and substantially increasing the added labor-hours required in the 2C- and heavy checks. The team assigned these tasks to the various checks (A, C, 2C, and heavy) and also estimated the labor-hours for each task. Appendix F contains a complete list of these tasks. The team assumed that tasks completed at an A-check would also be completed at a C-check. Similar assumptions were made for the C-check and 2C-check tasks (i.e., they would be accomplished at the 2C-check and heavy check, respectively).

Because the size and complexity of the OBGI concept made the system infeasible for existing turbofan, turboprop, and business jet category airplanes, we did not complete an analysis for these airplanes.

Additional Maintenance Labor-Hours

Figure 7-3 shows the estimate of additional scheduled maintenance labor-hours that would be required at each check to maintain an OBGIS.

Airplane category	Additional A-check hours	Additional C-check hours	Additional 2C-check hours	Additional heavy check hours	Average additional labor-hours per year
Small	3	4	18	51	50.55
Medium	3	4	18	55	48.31
Large	3	4	18	59	46.51

Figure 7-3. OBGI Additional Scheduled Maintenance Hours

7.5.3 Unscheduled Maintenance

The OBGIS consists of approximately 26 major components and is significantly more complex than the GBIS. Like the full OBIGGS, the airplane system is self-sufficient, which is the reason for the increased complexity.

System Annual Use Rate

Although the OBGIS equipment is similar to that of the full OBIGGS, the operating philosophy is significantly different. Unlike OBIGGS, the classic OGBIS—although an onboard system—operates only while the airplane is at the gate. Therefore, the operating time of the OBGIS is significantly less than for full OBIGGS over the same period of time, reducing the wear and tear on system components. To account for the reduced operating time, the system annual use rate (fig. 7-4) for OBGI is then a function of the typical gate time and number of daily operations for each airplane category.

Airplane category	Airplane use rate, flight-hours/year	OBGI system operational time, hours/year
Large transport	4,081	1,095
Medium transport	2,792	1,278
Small transport	2,869	1,916
Regional turbofan	2,957	1,080
Regional turboprop	2,117	1,034
Business jet	500	365

Figure 7-4. OBGIS Annual Use Rate

System Reliability

As with the unscheduled maintenance analysis on the other system concepts, we based the reliability of OBGIS components primarily on a comparison with similar components currently in use on commercial airplanes. The significant decrease in the reliability level of the OBGIS, compared with that of the GBIS, is a result of increased system complexity. The increase in the number of parts and the introduction of lower reliability, higher maintenance components such as compressors and ASMs decrease the system reliability by a factor of 10 times. The OBGIS MTBUR was calculated to be 945 hr for the PSA system and 960 hr for the membrane system. The difference between the systems was the slightly higher reliability of the membrane ASM.

Because similar component reliability data for a range of component sizes was not available, the analysis assumes that the OBGIS reliability is the same for all airplane sizes. In reality, system reliability may vary with the system size but, for the purposes of this study, the variation is assumed to be well within the margin of error for the reliability estimate.

System Annual Failure Rate

The annual failure rate for the inerting system is a function of its reliability and the system annual use rate. Using the OBGIS annual use rate, the frequency of inerting system failures on each airplane was predicted to be approximately two failures per year for an OBGIS.

The system annual failure rate, shown in figure 7-5, is significant because it indicates how maintenance intensive the inerting system is and what level of impact the system will have on flight operations. In the case of the OBGIS, an operator with a fleet of 300 airplanes could expect to have to address 600 additional maintenance problems per year because of the inerting system.

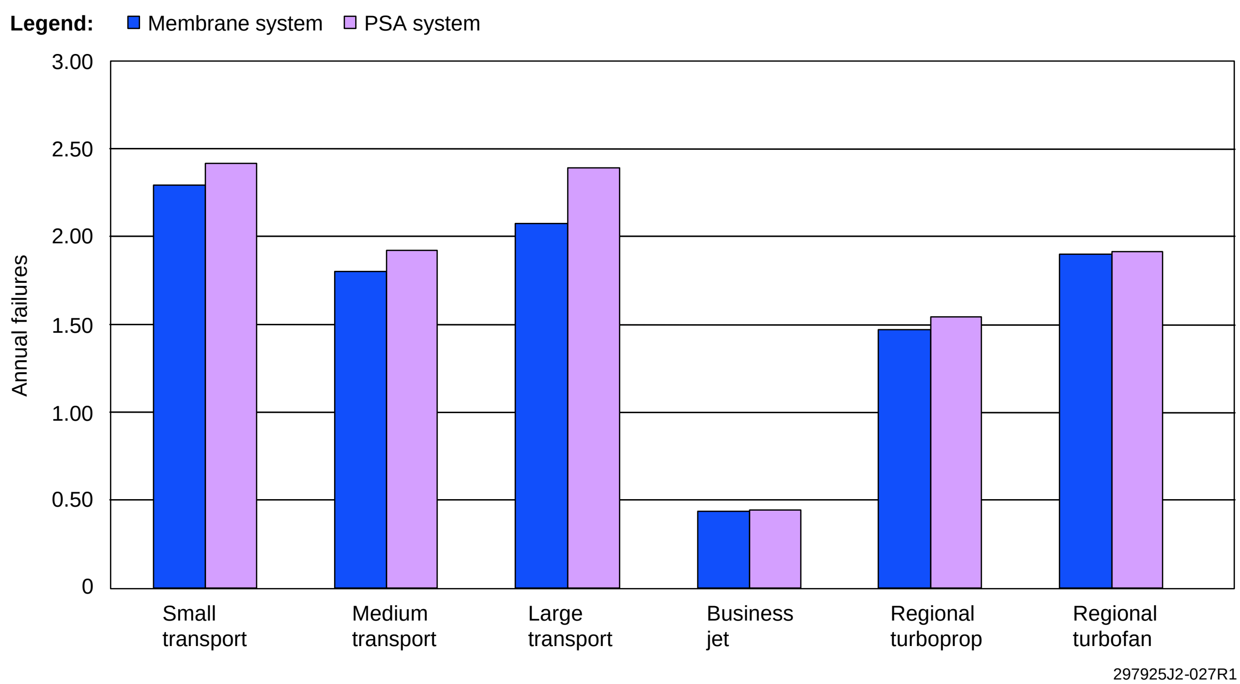


Figure 7-5. Predicted OBGIS Annual Failure Rate

Unscheduled Maintenance Labor Estimate

As with other system concepts, we surveyed potential component locations for each airplane category. Based on this survey, we developed estimates for troubleshooting, removal, and installation of each component. The tables in addendum F.C.2 of appendix F detail the troubleshooting, removal, and installation labor-hour assumptions. We also considered probable component locations, size, and weight in developing this estimate. We used the labor estimate and the component's predicted failure rate to estimate annual unscheduled maintenance labor rate for the OBGIS on each airplane category, summarized in figure 7-6.

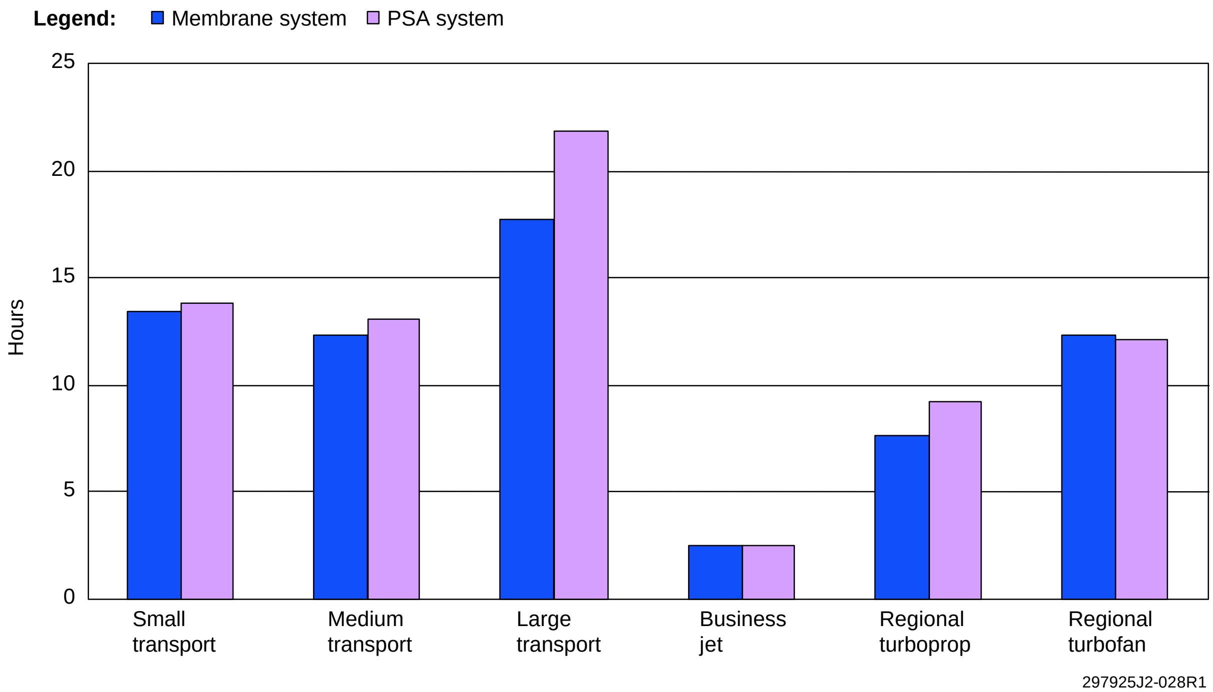


Figure 7-6. Annual Unscheduled Maintenance Labor Estimate per Airplane

Inerting System Availability

The OBGIS availability (fig. 7-7) is a function of the system reliability and the repair interval assumed for MEL dispatch relief. For example, if the system has an annual system failure rate of two failures per year and the MEL dispatch relief allows a 3-day repair interval, the inerting system may be assumed to be inoperative 6 days per year. Another way to look at system availability is as a percentage of departures. If the airplane typically has seven departures per day (as the small transport does), then the airplane would depart on 42 flights per year out of 2,555 with the inerting system inoperative. Assuming that an inerting system would remain inoperative for the maximum allowable number of days is a worst case scenario. In reality, the systems would likely spend 50% to 75% of the allowable time on MEL but, for the purposes of this study, we assumed that the full repair interval is used all the time. When considering the effect of the number of days a system is allowed to remain on MEL, decreasing the number of days improves system availability but comes at a price of increased flight delays, cancellations, and operating costs.

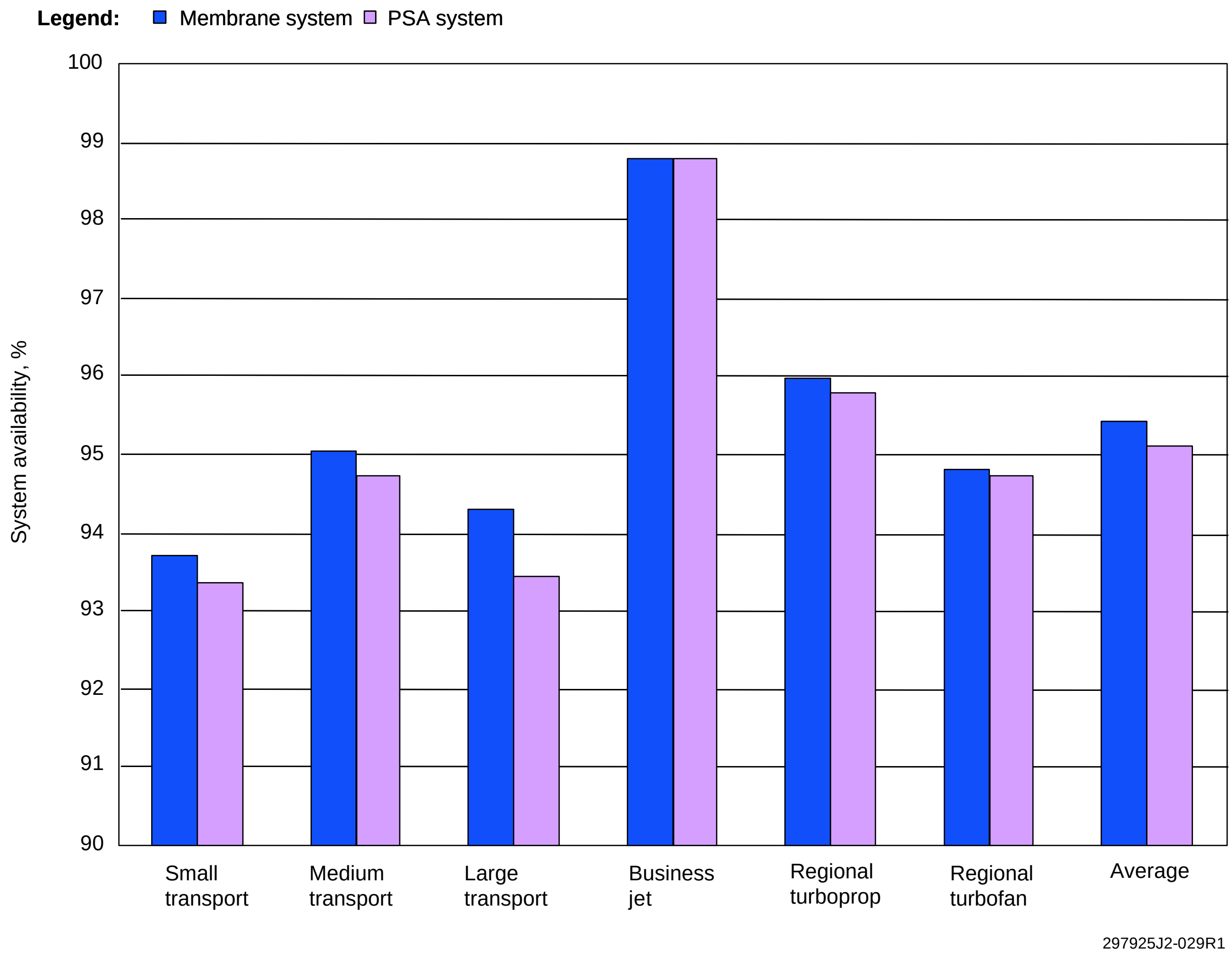


Figure 7-7. OBGIS Availability

MEL Dispatch Relief Effect

Section 10.0 discusses the effect of the MEL dispatch relief assumption in detail. The availability of MEL dispatch relief for noncritical airplane systems and the length of time allowed before the system must be repaired have a large impact on the airplane's dispatch reliability and cost of operation. As an illustration, we calculated the number of delays and cancellations an operator might experience for a typical small transport airplane equipped with an OBGIS. This estimate is based on the projected OBGIS annual failure rate and some assumptions on the frequency of delays and cancellations based on a system failure.

If no MEL dispatch relief, shown in figure 7-8, is available, there is a high probability that system failure would result in multiple flight cancellations. If dispatch is available, the likelihood of flight delays and cancellations decreases as more time is allowed to route the airplane to a location where maintenance is available. The system can then be repaired during an overnight maintenance visit. The specific assumptions used here are based on typical operator experience and are presented in appendix F.

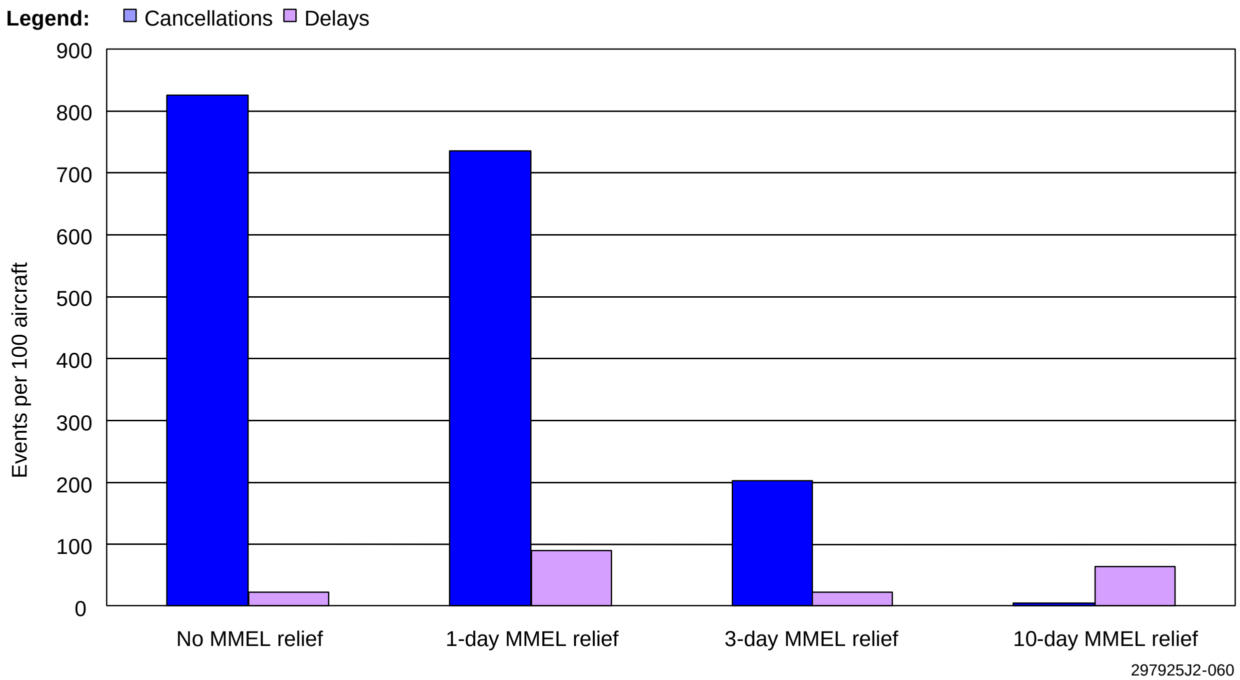


Figure 7-8. MEL Dispatch Relief Effect

<u>*Delay Hours per Year*</u>

The team estimated the effect of inerting system failures on flight departure schedules based on the OBGIS annual failure rate. Section 10.0 discusses the delay assumptions used for this estimate (fig. 7-9). Although not every system failure causes a delay, it is equally true that a single maintenance delay frequently causes multiple downline delays as a result of a cascade effect in the daily flight schedule. The number of delays and delay hours per year affect customer service. The airlines, through experience, have determined the impact of the reduction in customer satisfaction as a result of delays on operational revenue. Flight delays also affect operating costs through schedule changes, downline flight cancellations, and loss of passengers.

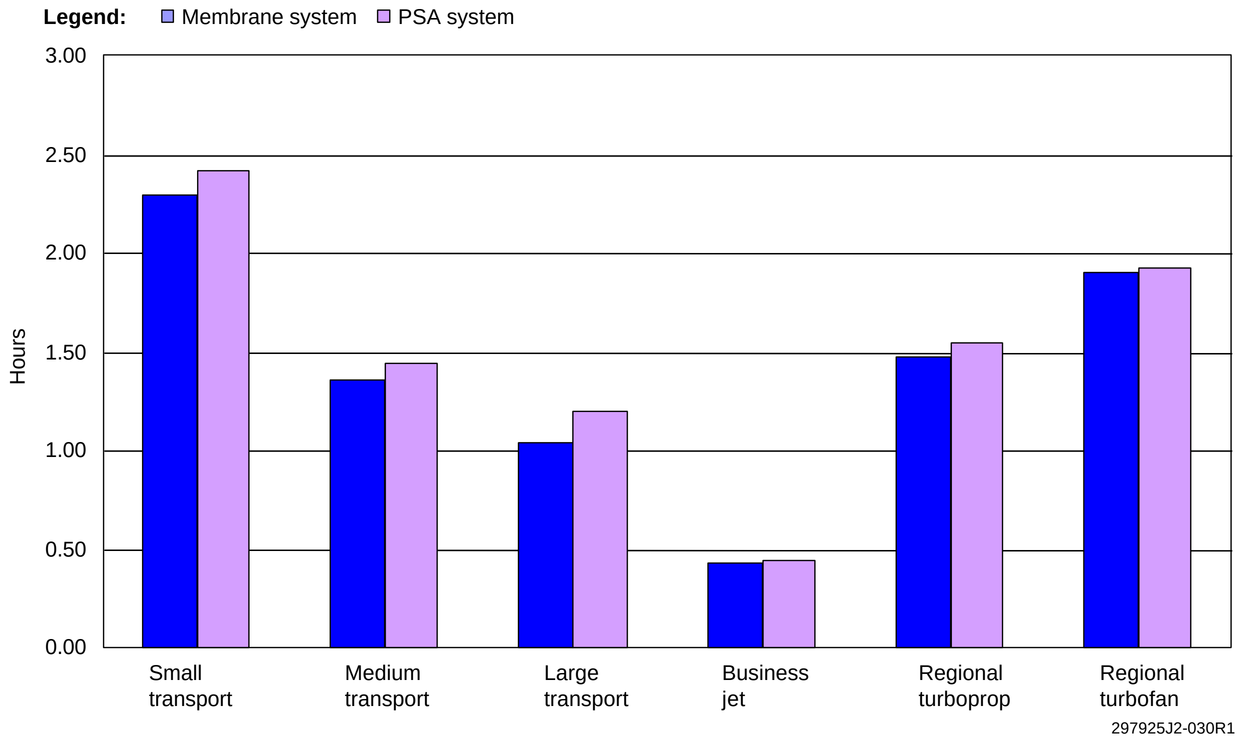


Figure 7-9. Annual OBGIS Flight Delay Hours

7.5.4 Flight Operations

The OBGIS allows for the availability of NEA for ground inerting techniques to be used at any airport that the airplane is deployed to if an adequate electrical power source is available. The system is designed to have adequate output to preclude delays beyond what are considered average minimum turn times for that airplane. The system is designed to require minimal activation and supervision by the flight crew with minimal cockpit indication and a simple on/off switch being redundant to automatic activation. Training for flight crews would serve to familiarize them with the system’s benefits, functions, and characteristics. Additional training for crew and dispatchers would have to address MEL and dispatch provisions and requirements. The system should be designed to be fail-safe so that no hazard is presented by its operation to passenger or ground personnel.

A moderate weight penalty is incurred in carrying this system on board, which is manifested in additional fuel burn. However, there are no power drain requirements during flight.

7.5.5 Ground Operations

Both GBIS and OBGIS are operating only on the ground. The major difference between GBI and OBGI is that inerting with the OBGIS is accomplished without the requirement for additional airport facilities, except for additional ground-power requirements. The OBGIS is a self-contained system.

Maintenance training requirements should be incorporated within the initial training programs similar to those discussed earlier, but tailored to this specific design. One concern that differs from the GBIS is that the OBGIS would require constant monitoring, particularly while fuel tanks are being inerted before the first flight of the day. The system design is such that the systems will have to be turned on 2 hr before the first flight of the day. Once power is put on the airplane and the inerting system is turned on, a normal safety procedure requires that a maintenance technician must monitor the airplane for problems. This does not necessarily mean that a maintenance technician must sit in the cockpit, but someone must be close enough to respond to alarms or other problems. Activation and monitoring the airplane an hour earlier than is currently required adds significant work to line maintenance during an already busy time of day.

Other added responsibilities include making sure that the cabin is ventilated properly to ensure there is no possibility for nitrogen buildup in the cabin. These tasks would typically be the responsibility of the remain-overnight technician. In the event a flight crew member is not available, then a qualified technician should also monitor the inerting process during all through-flights. All other maintenance concerns typically go hand in hand with the concerns mentioned earlier for GBI.

7.6 SAFETY ASSESSMENT

Figures 7-10 and 7-11 show the impact that OBGIS could have on reducing future accidents in the United States and worldwide, respectively. If selected, the forecast assumes the system will be fully implemented by the year 2015 (see sec. 11.0 for implementation assumptions). At that time, the forecast indicates the time between accidents in the United States would be 16 years with SFAR alone, 31 years with SFAR and inerting in heated CWTs, and 33 years for SFAR and inerting in fuselage tanks. The corresponding time between accidents for the worldwide fleet would be approximately half that estimated for the U.S. fleet.

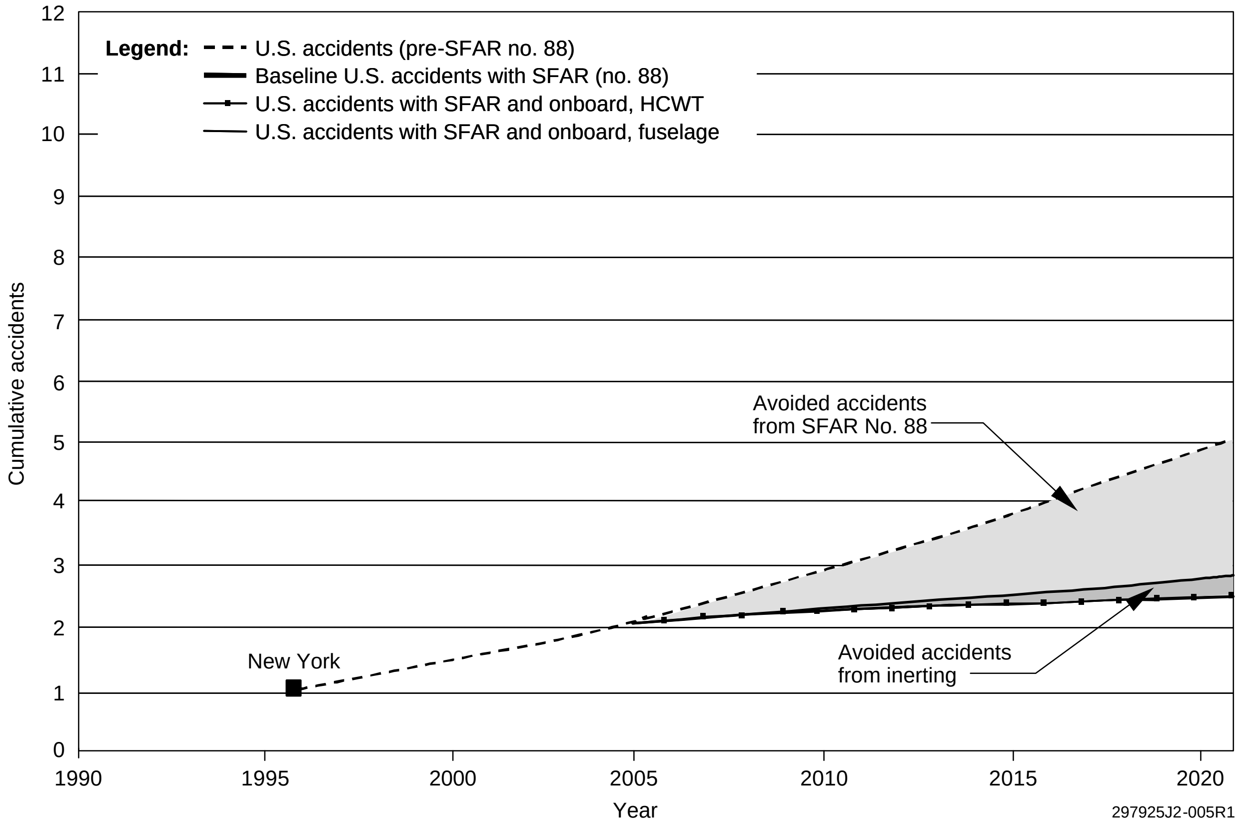


Figure 7-10. U.S. Cumulative Accidents With Onboard Ground Inerting

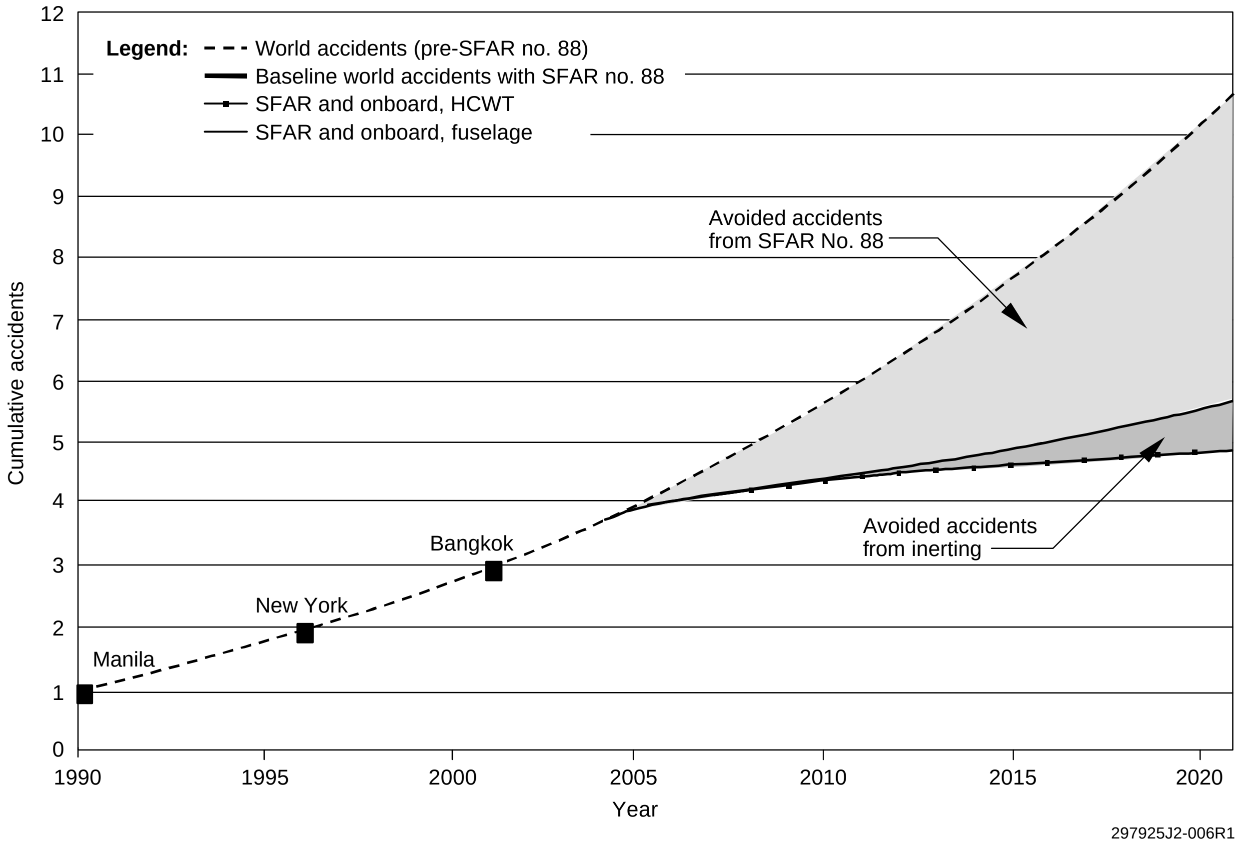


Figure 7-11. Worldwide Cumulative Accidents With Onboard Ground Inerting

7.7 COST-BENEFIT ANALYSIS

Figures 7-12 though 7-19 graphically represent the cost-benefit analyses of the scenario combination examined for onboard ground inerting.

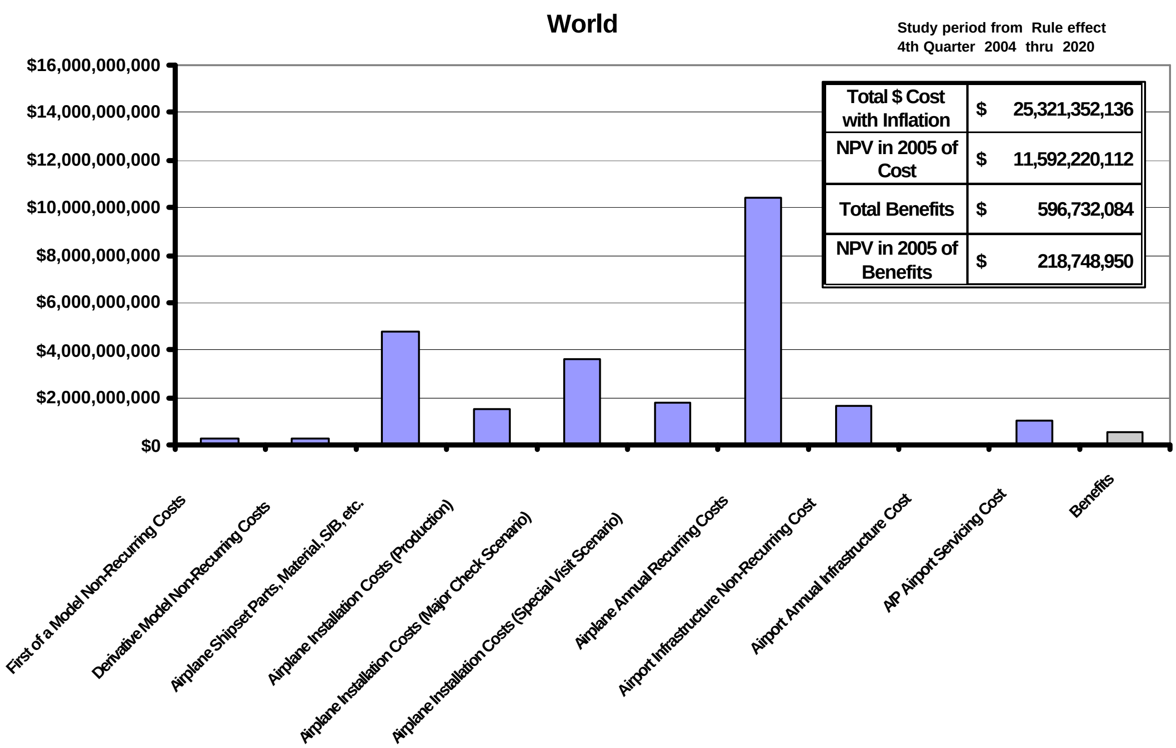


Figure 7-12. Scenario 1—Onboard Ground Inerting, HCWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (World)

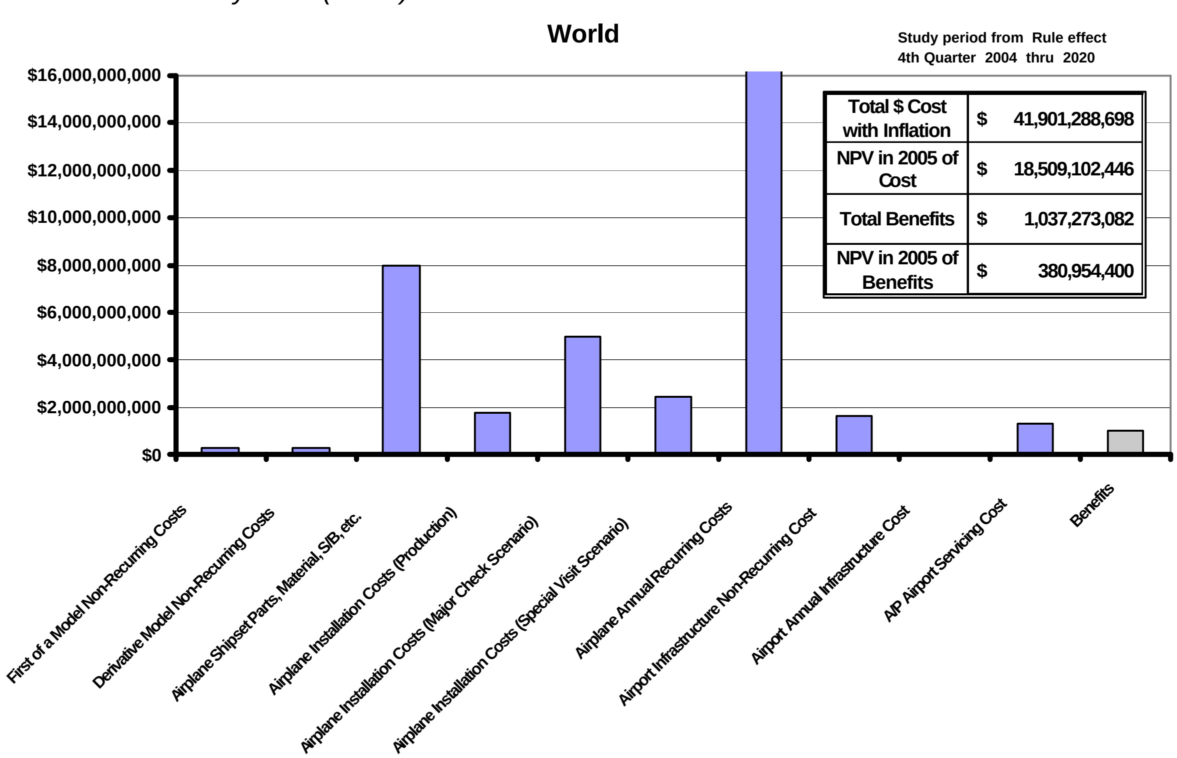


Figure 7-13. Scenario 2—Onboard Ground Inerting, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (World)

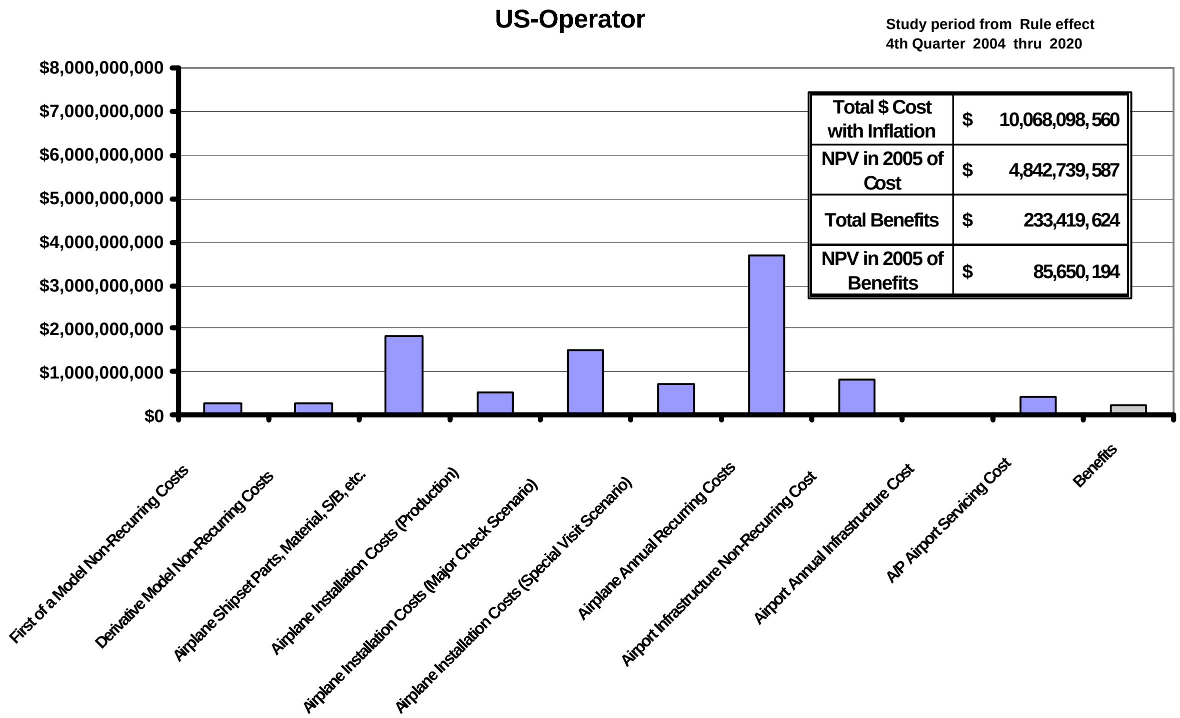


Figure 7-14. Scenario 1—Onboard Ground Inerting, HCWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (U.S.)

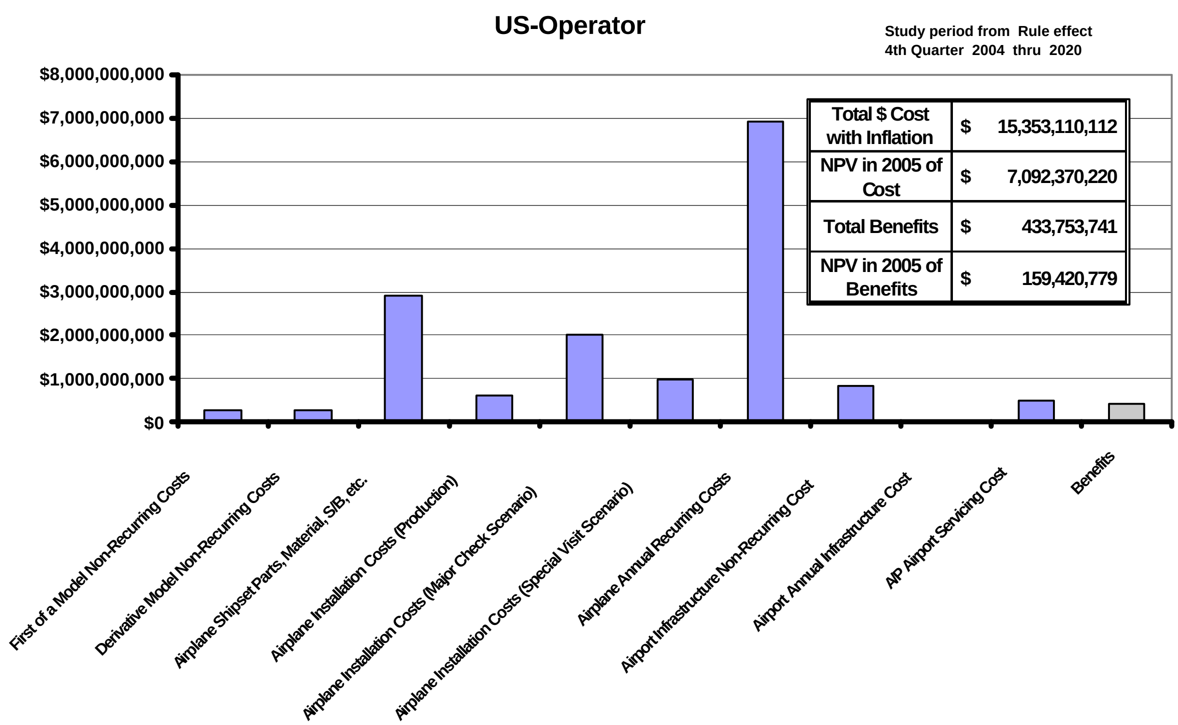


Figure 7-15. Scenario 2—Onboard Ground Inerting, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (U.S.)

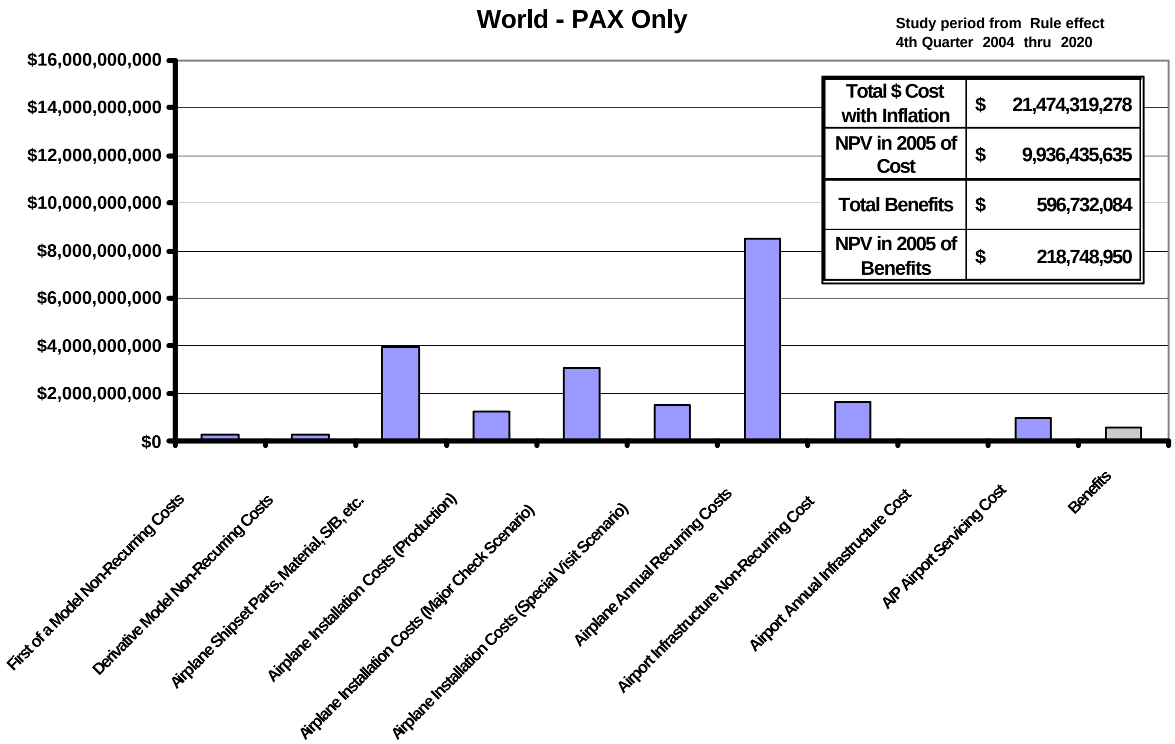


Figure 7-16. Scenario 1—Onboard Ground Inerting, HCWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (World, Passenger Only)

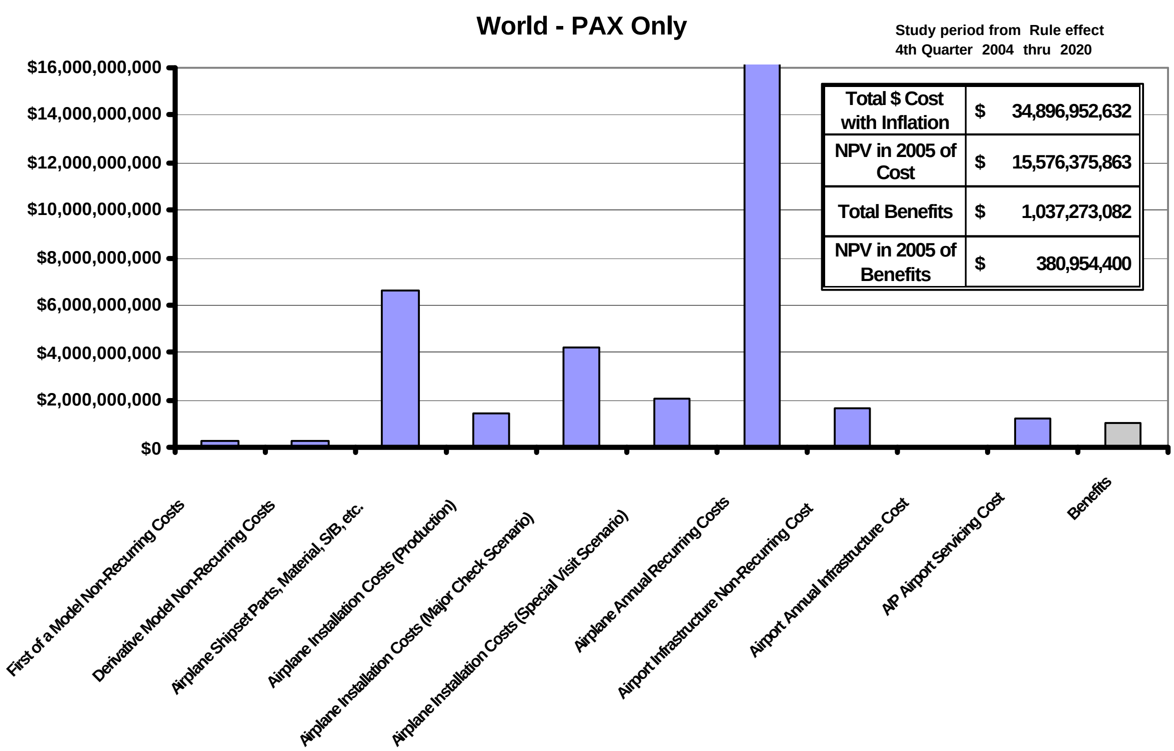


Figure 7-17. Scenario 2—Onboard Ground Inerting, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (World, Passenger Only)

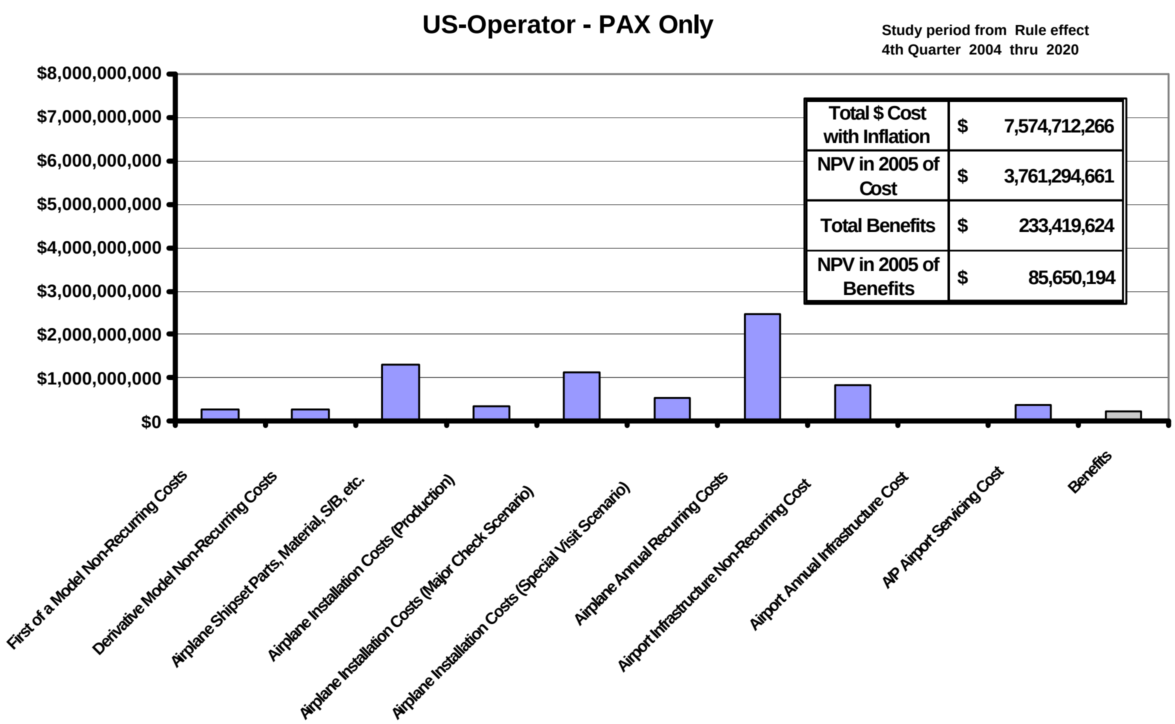


Figure 7-18. Scenario 1—Onboard Ground Inerting, HCWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

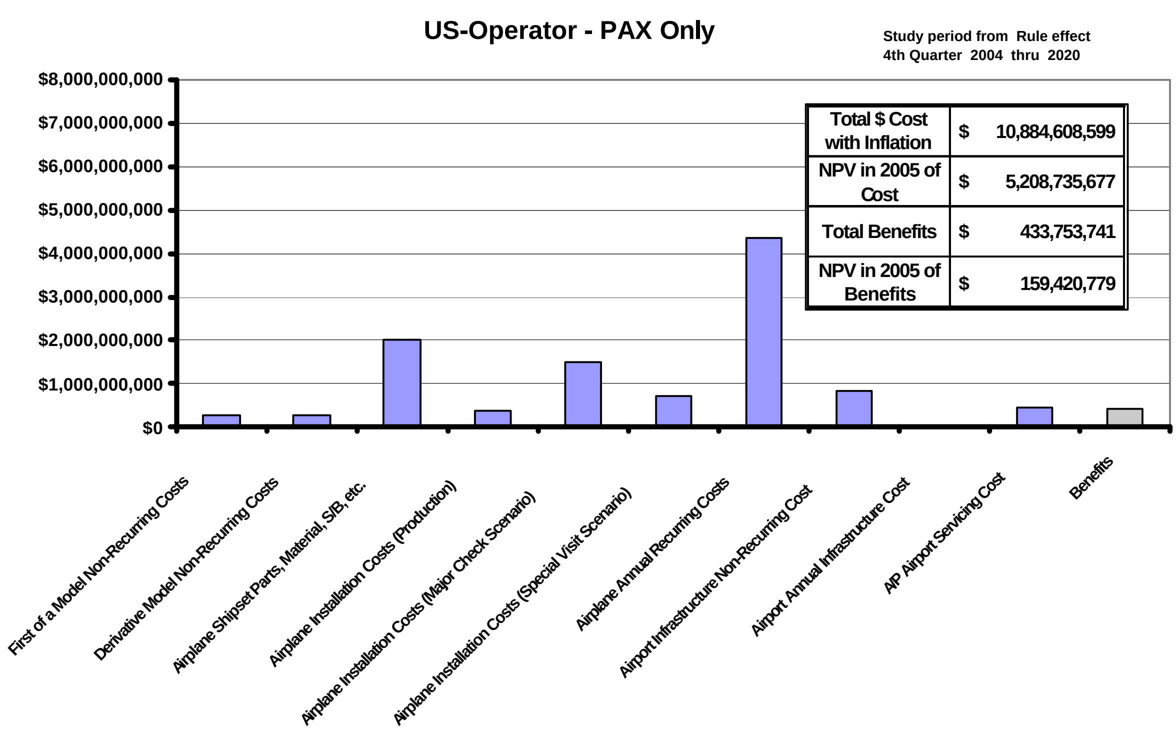


Figure 7-19. Scenario 2—Onboard Ground Inerting, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

7.8 PROS AND CONS

Pros

- The OBGIS reduces total flammability exposure comparable with that of GBI.
- Certification is simpler than for an OBIGGS because it runs only on the ground, so interference with other airplane systems is minimized.
- The OBGIS potentially reduces corrosion and condensation in the fuel tanks, depending on where and how the operator uses the system.

Cons

- The OBGIS is the heaviest system studied, takes up the same or slightly more volume than full-time OBIGGS, and requires as much or more electrical power.
- The cost of components (only a part of the total system cost) far exceeds the potential benefit.
- Additional cost is incurred as a result of the weight of the system—which causes a fuel penalty—and airplane drag is increased because of inlet and exhaust ports for the system.
- The airplane's center of gravity may be adversely affected because of the system's location in some airplane models, which would also incur a fuel penalty.
- Compressor and fan noise may have to be damped, depending on local noise standards.

Indeterminate

Pollution:

- Normally, some fuel vapor exits the tanks during refueling, and some vapor will be pushed out when adding nitrogen to the tank.
- Fuel vent systems will need to be isolated to prevent crosswinds from diluting the nitrogen, which would be an improvement over present-day conditions.

No attempt was made to quantify this because of the complexity of the problem for each airplane model at each airport.

7.9 MAJOR ISSUES AND RESOLUTIONS

The technical limitations for retrofit of the OBGIS are its size, contamination issues with the ASMs, and a potential hazard with static electricity. The system size cannot be resolved without relaxing the requirements. A description of the improvements needed for the other limitations follows.

7.9.1 System Size

Some OBGI issues relate to the large system size. For the large-transport CWT only, the system weighs between 500 and 1,000 lb (depending on the separator technology) and consumes almost all the power available from the APU generator. Little power remains for running the airplane's normal electrical equipment, such as lights, galleys, avionics, and their cooling fans, while on the ground (see fig. 7-20).

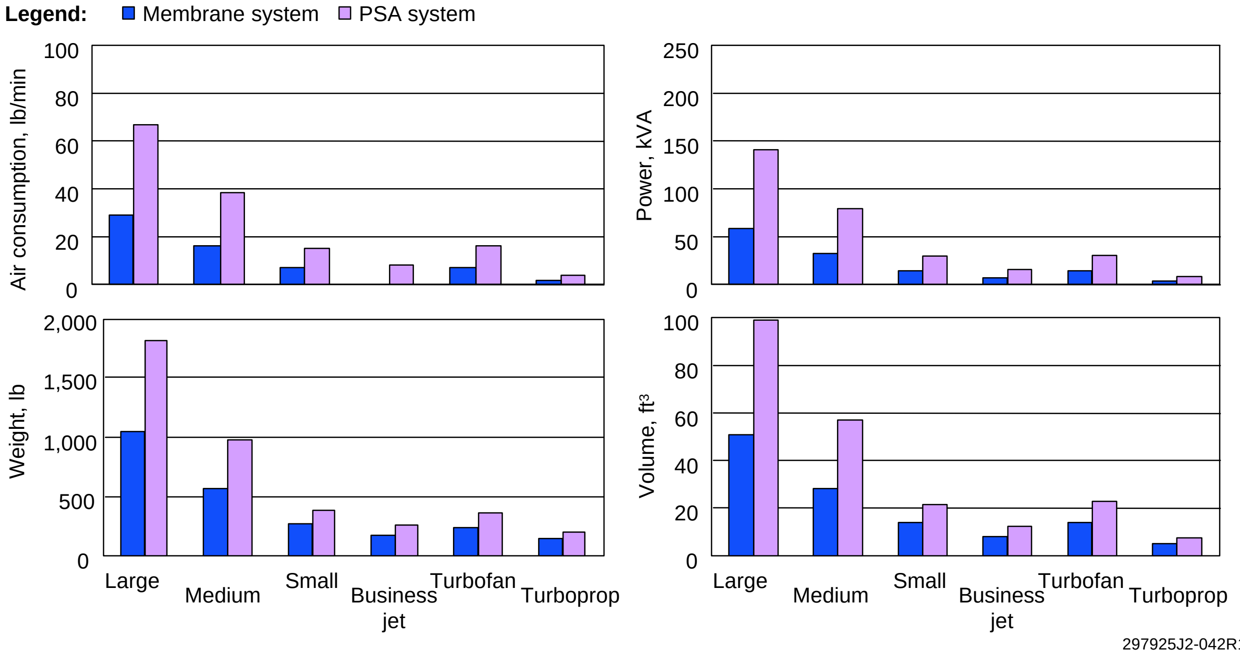


Figure 7-20. OBGI Required Resources for All Tanks

No matter what size the airplane, the system requires significant electrical power to run, may not fit in all airplanes because of its size, and is heavy. The only reasonable resolution is to increase the gate time, which will incur cost penalties for the operators.

Another issue is the compressor weight, which for the large and medium transports is too heavy for an average mechanic to lift. This can be resolved by changing the design to incorporate multiple compressors in parallel, making each compressor smaller and lighter but increasing overall volume.

7.9.2 Air Separator Modules

ASMs are susceptible to water contamination, which reduces performance. A water separator has been included in the design concept to avoid this problem.

Permeable membrane modules also are susceptible to hydrocarbon contamination from the fuel and oil vapor in engine bleed air. A coalescing filter has been included in the design concept to capture the vapor before it reaches the membrane.

In addition, permeable membranes have no service history onboard airplanes to prove their durability. They have been used in ground applications, however, where they have demonstrated a very long life.

7.9.3 Static Electricity

The rapid flow of dry gas in a distribution manifold inside the fuel tank can generate static electricity and cause sparks. This can be mitigated by using large-diameter manifolds to keep the gas velocity low and by bonding the manifold to structure (electrical ground).

7.10 CONCLUSIONS

The OBGIS reduces flammability exposure. But the concept suffers from the limited gate time available between flights and the large ullage volumes (small fuel load) required for short missions. The protection offered is approximately that of the ground-based concept but at a much higher price. Therefore, we do not recommend this concept.

8.0
OBIGGS

8.0 ONBOARD INERT GAS GENERATING

The OBIGGS is a self-contained method of providing inert gas to the fuel tanks without relying on an airport to supply the inert gas.

The Onboard Inerting Designs Task Team reviewed the 1998 ARAC FTHWG report for inerting and determined that most of the nitrogen inerting technologies discussed in that report remained unchanged. The team chose to focus on air separator technology because of improvements in technology and manufacturing and the probable benefit of reduced cost.

The 1998 ARAC FTHWG found OBIGGS to be a heavy and expensive system. The FAA Tasking Statement for this ARAC has provided the means to reduce weight and cost, with specific recommendations to design without redundancy and to allow airplane operation when OBIGGS is inoperative. This has provided some improvements over the 1998 study.

Cryogenic distillation was investigated as a means to reduce the demands on the airplane. This technology produces nitrogen gas and stores liquid nitrogen by partially liquefying incoming air and separating the nitrogen. The nitrogen gas is used for on-demand inerting through all phases of flight. The liquid nitrogen is used to initialize and inert the fuel tanks at the start of the day. The cryogenic distillation system is not yet an available technology but is near term; that is, with current funding it could be available within 5 years.

8.1 SYSTEM REQUIREMENTS

The Tasking Statement requires that OBIGGS inert all fuel tanks during normal ground and typical flight operations. Nonnormal operations, such as an emergency descent, are not to be considered typical flight operations. This report will consider methods to minimize system cost, such as reliable designs with little or no redundancy, and recommendations made for dispatching in the event of a system failure or malfunction that prevents inerting one or more of the affected fuel tanks.

Secondary effects of the system must be described. The Tasking Statement requires that the FTIHWG analyze and report on extracted engine power, engine bleed air supply, maintenance impacts, airplane operational performance detriments, dispatch reliability, and so on. FTIHWG also is required to provide information and guidance for the analysis and testing that should be conducted to certify the system.

If the Working Group cannot recommend a system, the group is to identify all technical limitations and provide an estimate of the type of concept improvement required to make it practical in the future.

8.2 SYSTEM CONCEPT DESCRIPTION

Figure 8-1 shows the OBIGGS. In its simplest terms, the ASM pressurizes cabin air and separates it into nitrogen and other gases. This nitrogen is supplied to the fuel tanks while the other gases are exhausted overboard.

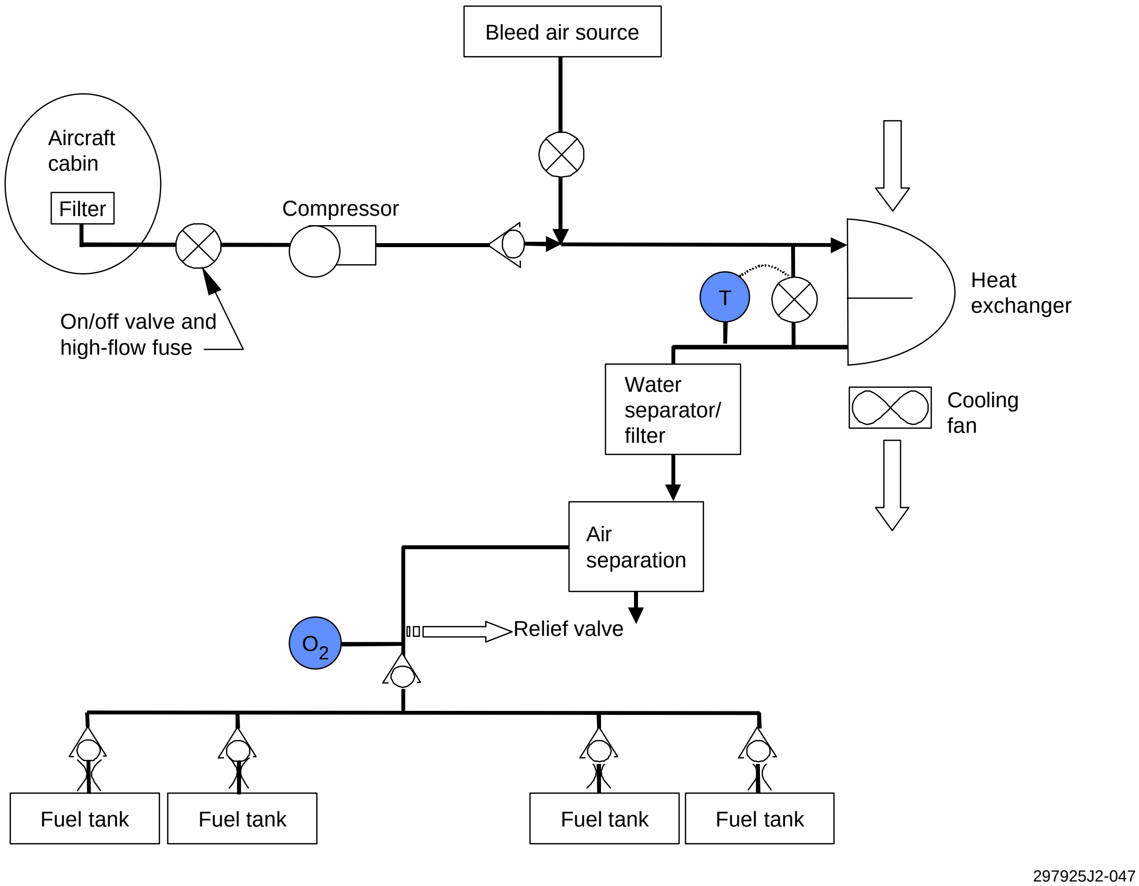


Figure 8-1. OBIGGS Schematic

The team reviewed and substantiated the 1998 ARAC FTHWG finding that engine bleed air is insufficient at critical times to supply OBIGGS. An electric compressor was deemed a viable primary source of air, when supplemented by engine bleed air as available.

The source air is cooled if necessary, water is removed to avoid icing, air is filtered to avoid ASM contamination, and the ASM separates nitrogen and supplies it to the fuel tanks.

The team hoped that using cabin air would reduce costs because it lowers the compressor's pressure ratio. ASMs require approximately 45 psia for their best performance. Ambient air at altitude is roughly 3 psia, requiring a compressor with a 15:1 pressure ratio. This is a daunting task. However, the cabin air is already pressurized to roughly 8 to 12 psia and is normally exhausted overboard, so this seemed a reasonable supply for the inerting system and only required a pressure ratio of between 4:1 and 6:1 from the compressor.

For passenger protection, a high-flow fuse closes to keep air inside the cabin in the event of a duct rupture in the inerting system. Similar valves are incorporated in airplane environmental systems today.

8.2.1 Air Source

The concept uses multiple air sources. Pressurized air can be provided by engine and APU bleed air or by the electric compressor. The air pressure supplied to the ASM is nominally 45 psia.

8.2.2 Pressure Ratio

The electric compressor was sized for a pressure ratio between 4:1 and 6:1. This provides 48 to 60 psia to the ASMs on the ground (depending on airport altitude) and about 44 psia in flight (depending on airplane altitude).

8.2.3 Air Separator

We studied three concepts for air separation. Hollow-fiber membranes separate nitrogen through molecule-sized passages when air passes through the length of the fiber. PSA adsorbs oxygen as air passes over the module, leaving nitrogen in the flowstream. Cryogenic distillation relies on separation of a partially liquefied airstream using a distillation column. The product is a high-purity nitrogen gas, which can be sent to the fuel tanks, or a high-purity nitrogen liquid, which can be stored for later use.

8.2.4 Descent Rate

Descent is the dominant airplane operation that determines the size of OBIGGS, and the faster the airplane descends, the larger the system required. OBIGGS prevents outside air from entering the fuel tank and increasing the oxygen concentration, so it must generate more gas during descent than at any other time in flight.

Military airplanes use climb-dive vent valves to keep outside air out of the fuel tanks, but these valves are quite complex because their failure could severely damage the fuel tanks. The FAA sought to avoid this complexity for the hybrid, and the Onboard Inerting Designs Task Team also wanted to avoid it for full-time OBIGGS. This goal requires that OBIGGS provide a high flow of nitrogen or high-purity nitrogen to dilute outside air as it enters the fuel tank (military systems with climb-dive vent valves can afford to provide slightly less flow). The team believes a somewhat larger OBIGGS was a lighter, cheaper choice than one using the complex vent valves.

8.2.5 Flammability Exposure

The flammability exposure is defined as the percentage of the airplane mission when the fuel ullage is flammable and not inert. The 1998 ARAC FTHWG found that CWTs had a flammability exposure of approximately 30%, and wing tanks had a flammability exposure of approximately 7%. The FAA has since been refining a model for flammability exposure, which was provided to this ARAC to compare system benefits. OBIGGS reduces the flammability exposure of all tanks to nearly zero.

8.3 APPLICABILITY OF CONCEPT TO STUDY-CATEGORY AIRPLANES

The design concept applies to all the airplanes in the study category. However, the high electrical demand may exceed the capacity of the existing airplane electrical systems and, at airports that discourage APU operation, the airport’s ability to provide the electricity.

An inerting system can be designed into future airplanes, provided the inerting system size is calculated before engine, APU, and electrical generator selection. This will ensure that bleed air or electrical power is available to supply the inerting system.

8.4 AIRPORT RESOURCES REQUIRED

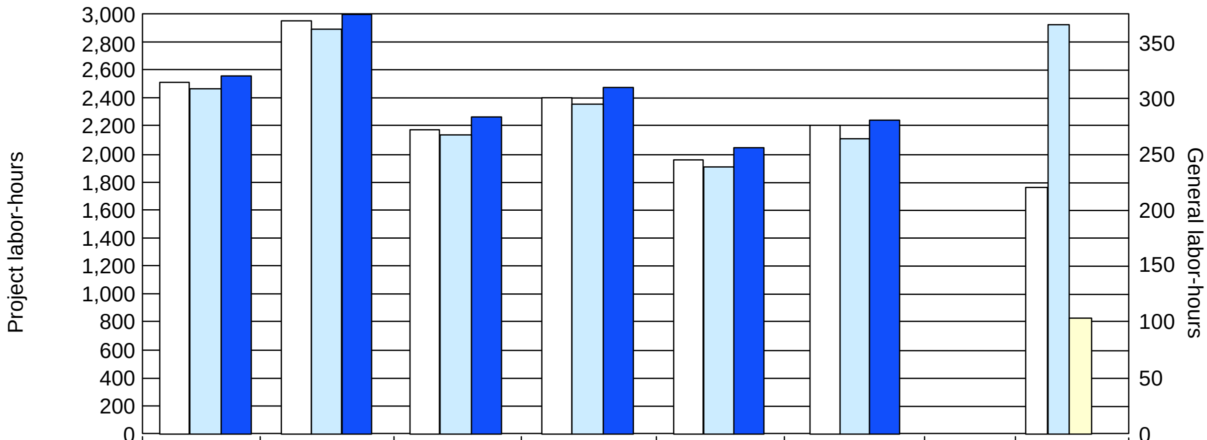
OBIGGS is a self-contained system that does not normally require any airport resources. However, ground electrical power may be preferred by some operators for systems without storage capabilities to power the system after tank maintenance and to inert the fuel tanks before the next flight.

8.5 AIRLINE OPERATIONS AND MAINTENANCE IMPACT

This section discusses the modification of in-service airplanes to install an OBIGGS and describes the overall effect of OBIGGS on airplane operations and maintenance requirements.

8.5.1 Modification

Figure 8-2 shows the modification estimates for the OBIGGS. Because there is insufficient space for the OBIGGS in the unpressurized areas of regional turbofan, regional turboprop, and business jet category airplanes, we have excluded these airplanes from this estimate. For the other airplane categories, estimates are made for both a regular heavy maintenance visit and a special visit. Appendix F, Airline Operations Task Team Final Report, addenda F.A.1 and F.A.2, contains a detailed table with costs and labor-hours.



Legend:	Large (heavy check)	Large (special visit)	Medium (heavy check)	Medium (special visit)	Small (heavy check)	Small (special visit)		General
☐ Membrane	2,500	2,950	2,175	2,400	1,950	2,200		
☐ PSA	2,450	2,900	2,125	2,350	1,900	2,150		
■ Cryogenic	2,550	3,000	2,275	2,475	2,050	2,250		
☐ Engineering								220
☐ Tech pubs								365
☐ Material control								104
■ Training								
☐ Flight ops eng								

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Figure 8-2. Modification Estimations for OBIGGS

After OBIGGS installation, an operational test flight may be required. The estimates do not account for costs of test flight.

8.5.2 Scheduled Maintenance

Scheduled Maintenance Tasks

The Scheduled Maintenance Subteam developed concepts for two types of OBIGGS and considered them separately. The subteam developed a list of scheduled maintenance tasks for a cryogenic OBIGGS and for a membrane OBIGGS using the system schematics provided by the Onboard Inerting Designs Task Team. The subteam evaluated each component illustrated in the schematic individually and wrote the tasks accordingly. These tasks included inspections, replacements, and operational and functional checks of the various system components. The subteam assigned these tasks to the various checks (A-, C-, 2C-, and heavy) and estimated labor-hours for each. Appendix F lists these tasks for each airplane category.

We assumed that tasks completed at a C-check would also be completed at a 2C-check. We made similar assumptions for the 2C-check tasks (i.e., they would be accomplished at the heavy check [or 4C-check equivalent]).

Both OBIGGS concepts consist of unique components that require additional tasks when compared with the GBI and OBGI systems. Thus, additional tasks are required, substantially increasing the extra labor-hours required in the C-, 2C-, and heavy checks.

Because of the size and complexity of the OBIGGS concept, we did not complete an analysis for turbofan, turboprop, and business jets category airplanes.

Pressure Check

Extra labor-hours have been added to each C- and heavy checks to perform a fuselage pressure decay check and rectification. The system uses cabin air as a supply for the inerting system, which increases the demand on the airplane air-conditioning packs. Consequently, the maximum allowable cabin leakage rate will have to be maintained at a lower level to ensure that the airplane air-conditioning packs will be able to maintain the required cabin pressurization.

Additional Maintenance Labor-Hours

Figure 8-3 shows the estimate for additional scheduled maintenance labor-hours required at each check to maintain a cryogenic OBIGGS. Figure 8-4 shows the estimate of additional scheduled maintenance labor-hours required at each check to maintain a membrane OBIGGS.

Airplane category	Additional A-check hours	Additional C-check hours	Additional 2C-check hours	Additional heavy check hours	Average additional labor-hours per year
Small	3	55	74	87	124.03
Medium	3	55	74	91	126.03
Large	3	55	74	95	115.52

Figure 8-3. OBIGGS Additional Scheduled Maintenance Times—Cryogenic System

Airplane category	Additional A-check hours	Additional C-check hours	Additional 2C-check hours	Additional heavy check hours	Average additional labor-hours per year
Small	3	50	65	76	113.96
Medium	3	50	65	80	114.56
Large	3	50	65	84	105.77

Figure 8-4. OBIGGS Additional Scheduled Maintenance Times—Membrane System

8.5.3 Unscheduled Maintenance

The full OBIGGS inerting system is the most complex system of all the design concepts studied. The characteristics that make OBIGGS different for other systems studied from a reliability and maintainability standpoint are its size and its operating time.

Because OBIGGS operates during all phases of flight it has an additional effect on other airplane systems. The demand the inerting system puts on the airplane electrical power generation, cabin pressurization, and engine bleed air systems will reduce the reliability and increase the maintenance requirements for these systems.

The larger size and weight of OBIGGS components will make performing maintenance more difficult and in some cases may create an additional safety risk when lifting the components during removal and installation.

System Annual Utilization Rate

The system annual utilization rate for OBBIGS, shown in figure 8-5, reflects the amount of time that any of the systems would operate in 1 year. We calculated this figure from the airplane daily utilization rate plus the minimum turn times, multiplied by the number of daily cycles. The large transport airplane with a high daily rate had the highest system annual utilization rate; the small transport came in a close second because of its high daily cycles.

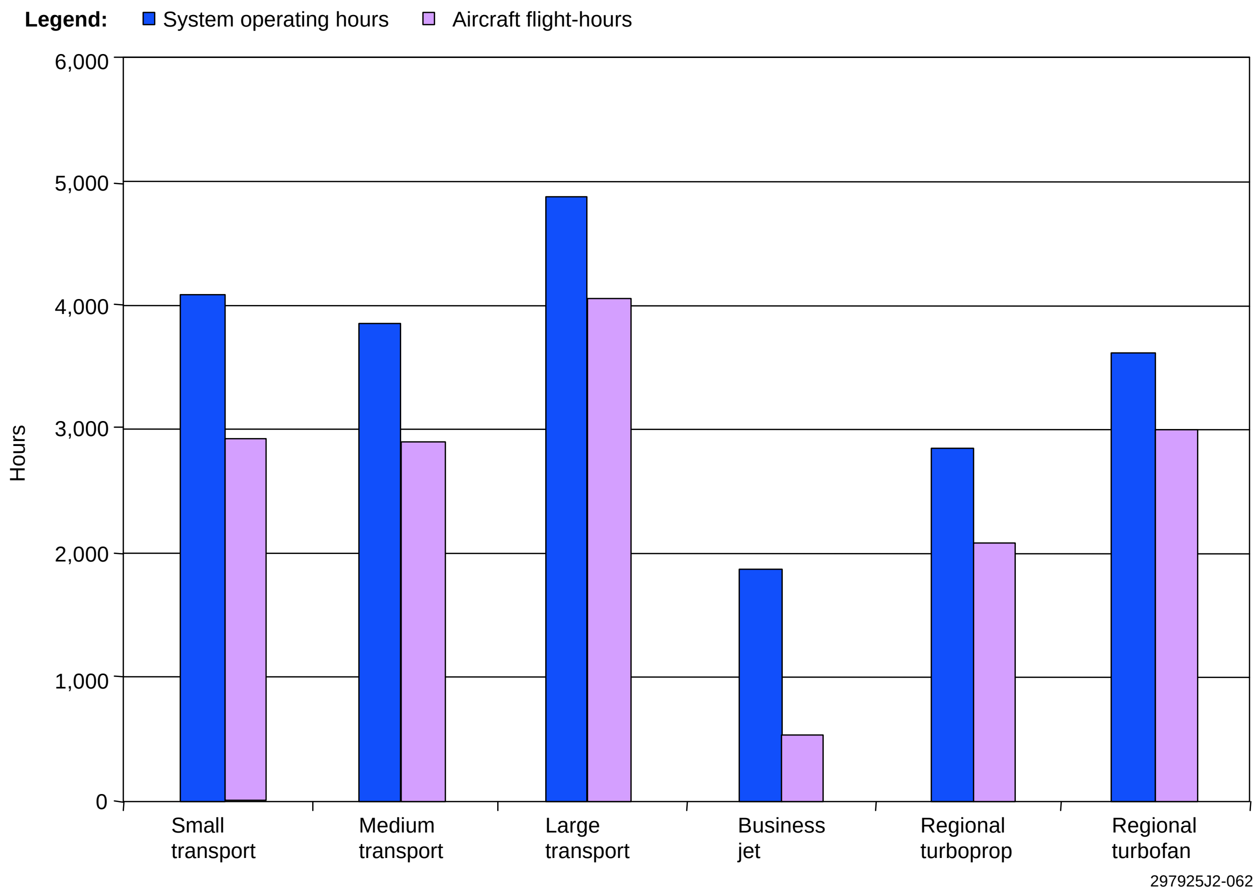

Figure 8-5. System Annual Utilization Rate

Component Reliability

To estimate the impact and related costs associated with the operation and maintenance of an OBIGGS we had to first establish a likely system reliability figure. From the system design we could compile a list of components for each system. In most cases it was possible to use historical data from similar components to suggest an OBIGGS component MTBUR. Where possible, more than one similar component was used.

One example of component reliability calculation was the OBIGGS shutoff valve. This valve would typically be a motorized butterfly-type valve that is found in many positions on different airplanes. Several similar valves were identified and, using the historical component MTBUR data from more than one operator, we calculated an average MTBUR figure. The OBIGGS design team suggested an MTBF of 50,000 hr; the average MTBUR figure was in fact calculated at 38,315 hr. This differential was expected and indeed confirmed that this method of MTBUR calculation was valid.

Where insufficient historical data was available, we used an MTBF figure, set by the system design team, or a most likely figure, based on team members' experience.

Establishing the component reliability in the form of an MTBUR figure was crucial in determining system reliability and in enabling the team to determine not only the component and system annual failure rate but overall impact on airplane maintenance and operations that result from system failures. This includes

- System weight.
- Cost to carry per airplane per year ($).
- System availability (driven by number of days of MMEL relief).
- Delays per year (hours).
- Delay costs per airplane per year ($).
- MMEL relief ranging from 0 to 120 days.

System Reliability

The MTBUR for the system was then determined from the individual component estimates.

We made an effort to determine the difference in MTBUR among airplane categories (fig. 8-6). Where sufficient component data was available, we found that there was little difference in MTBURs among the different airplane sizes. We felt that it did not prove to be a significant factor in further calculations. Therefore, with the resources available, we did not develop these figures further.

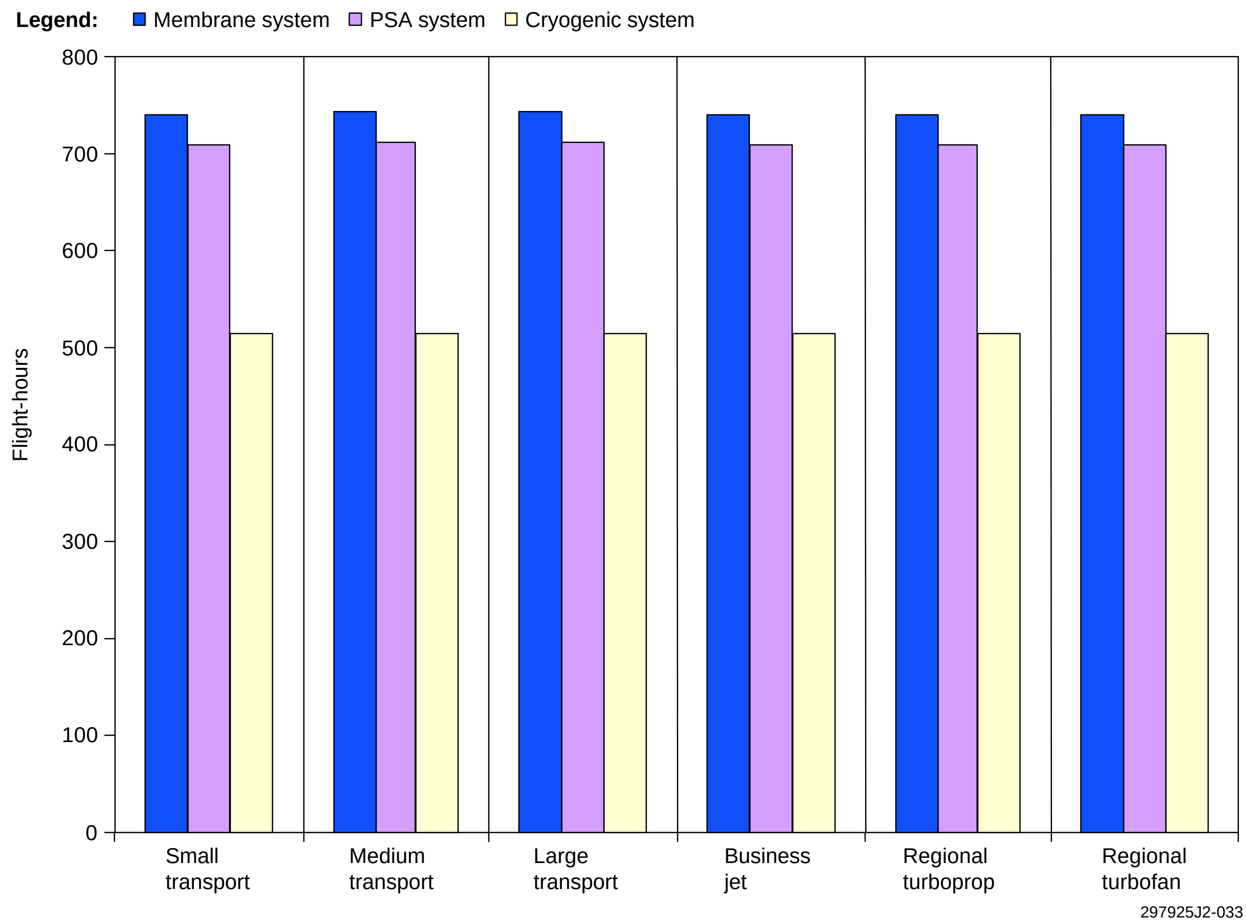

Figure 8-6. System MTBUR

System Annual Failure Rate

Using the component MTBURs and the airplane yearly utilization rate, we calculated the annual failure rate for each component. The system annual failure rate was the sum of these component annual failure rates.

As expected from the increased system complexity and the maturity of the cryogenic and PSA system technology, OBIGGS has a much higher predicted failure rate, shown in figure 8-7. This calculation was crucial for many further calculations such as system availability and the effects of different MMEL repair periods.

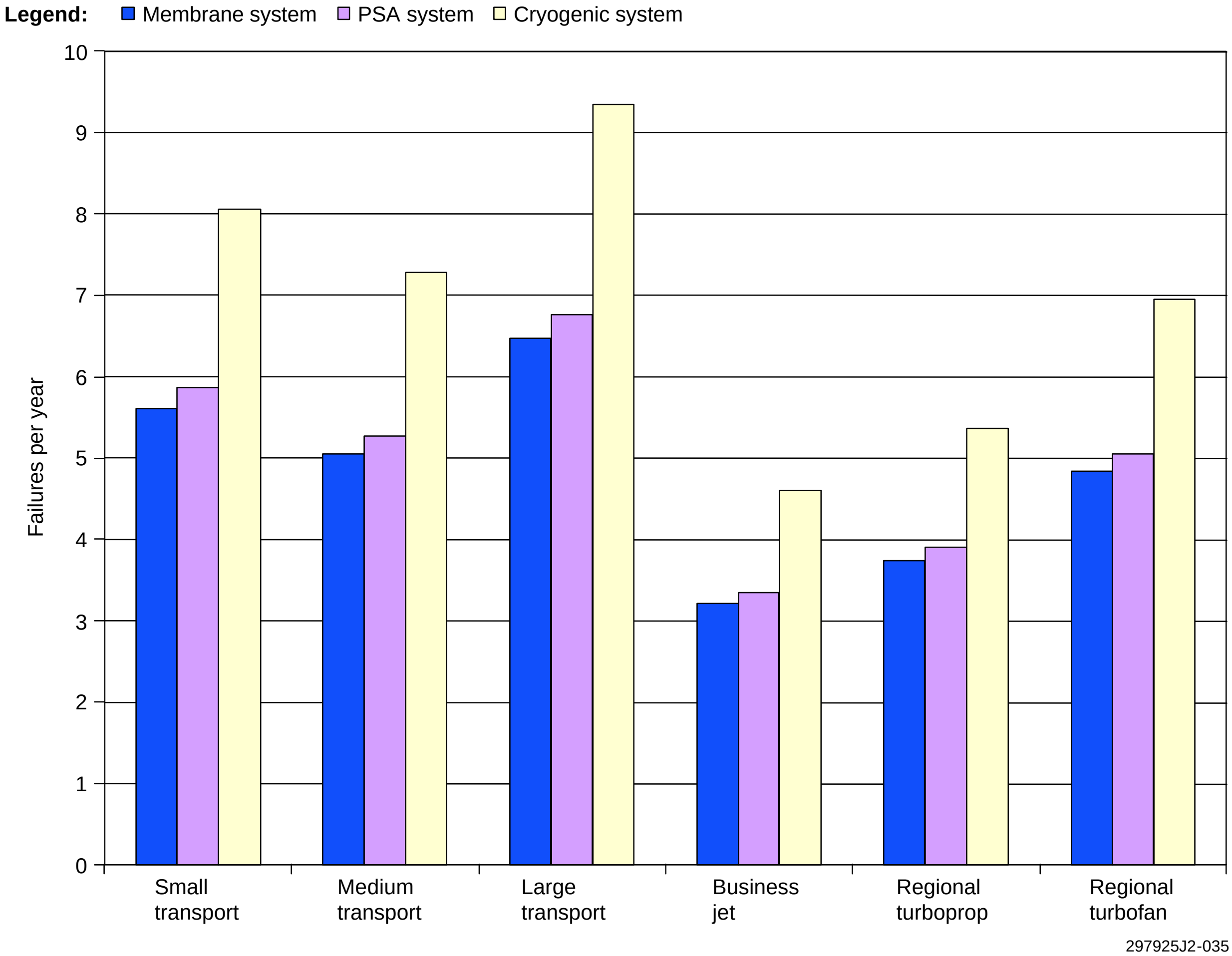

Figure 8-7. System Annual Failure Rate

Unscheduled Maintenance Labor Estimate

The amount of additional workload an OBIGGS would add to an airplane's maintenance requirements is a function of the annual failure rate and the component maintenance time, which in turn is a combination of the following:

- Component removal and replacement time.
- Component access time.
- Troubleshooting time.

To calculate the labor-hours per year we must make some assumptions as to the locations of the components. For example, the heaviest components would be located in areas that would allow access with lifting equipment (e.g., air-conditioning bay or wing-to-body fairing areas). We assessed each component individually and estimated the time to troubleshoot, access, and remove and replace based on similar tasks on existing airplanes.

The figures calculated refer only to the hours taken to rectify OBIGGS failures. It does not take into consideration the additional hours to maintain other airplane systems that are required to support OBIGGS (i.e., electrical or pneumatic systems) or systems affected by OBIGGS (i.e., cabin pressurization).

These figures may appear to be minimal but, where an operator has many airplanes arriving and departing within a short period of time, existing staffing levels may not be able to perform the rectification tasks, and additional staff will need to be recruited. This additional labor requirement is very difficult to quantify and has not been included. Therefore, the labor-hour estimate shown in figure 8-8 is presented as an indicator of the requirement for an increased number of maintenance technicians.

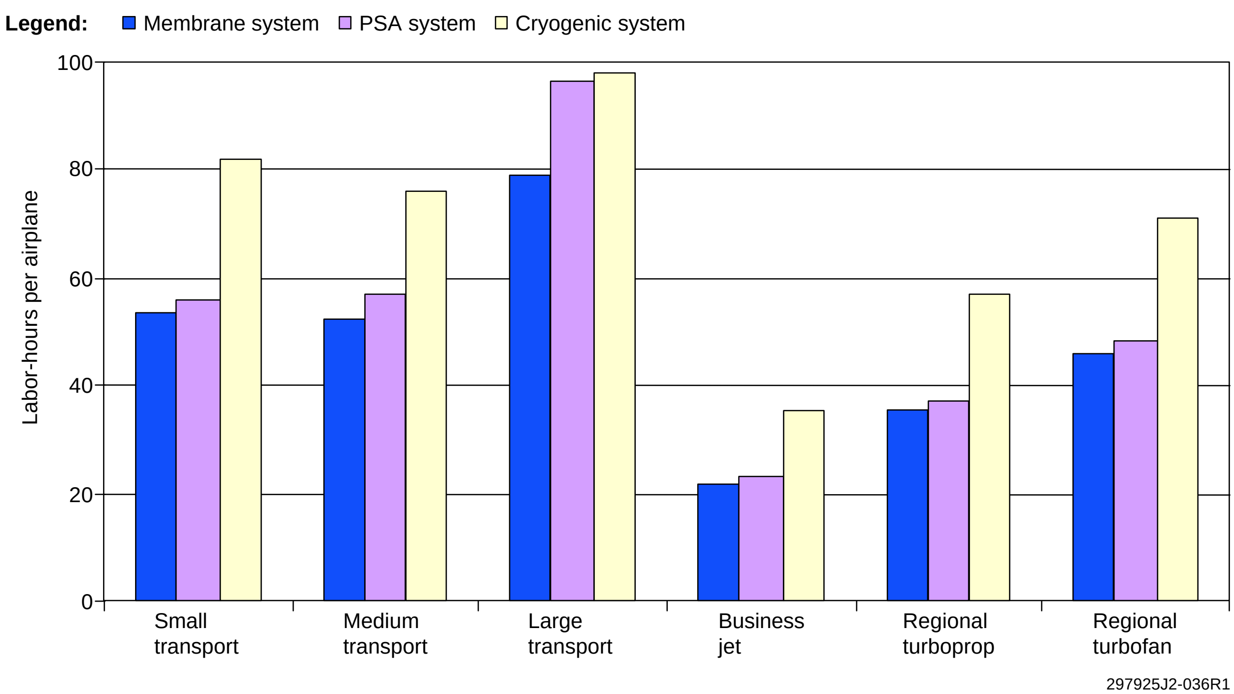

Figure 8-8. Additional Annual Labor-Hours

<u>*Annual Labor Costs*</u>

This is a product of the additional unscheduled labor-hours per year and the FAA’s standard burdened labor rate for airplane maintenance technicians of $75/hr.

The costs shown in figure 8-9 are for the additional labor-hours only. Operators may have to hire additional staff to fulfil these requirements, resulting in an increased financial burden for recruitment, administration, and training of the required staff.

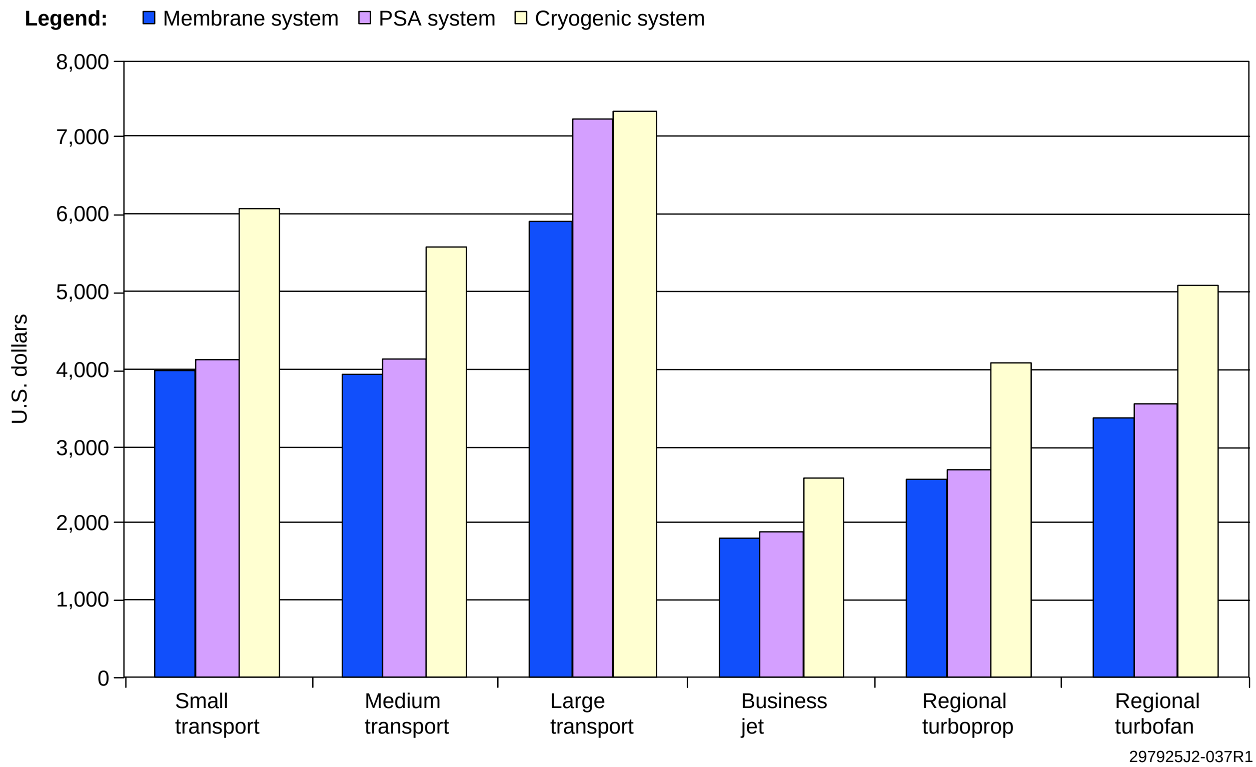

Figure 8-9. Additional Annual Labor Costs

System Weight

System weight has been calculated from the sum of the component weights specified by the design teams. The additional weight of the system installed on an airplane will not be limited only to the additional components. This estimate does not include the added weight of structural modifications to support heavy components.

Many operators are trying hard to reduce the weight of their airplane in an effort to achieve best economy.

This system weight has been used to calculate the cost to carry per airplane per year ($).

System Availability

System availability is a product of system annual failure rate and the variable input, MMEL repair interval. For example, if the system has a failure rate of five times per year and has 10 days' MMEL relief, the worst case scenario could mean that it is inoperative for 50 days per year, or 14% of the time. This would result in a system availability rate of 86%.

As mentioned earlier in this report, we evaluated the potential impact of 3-day and 10-day MEL repair intervals. Because system repairs are frequently accomplished in less time than the allowed per the MEL repair interval limits, we made assumptions on the average amount of time an inerting system would be inoperative under MEL relief. Under the 2-day MEL relief repair interval we assumed that the average system would be inoperative for 2 days. For the 10-day MEL relief repair interval the average system would be inoperative for 7 days.

The complexity of OBIGGS and the immaturity of both the PSA and cryogenic inerting technology result in a relatively high system annual failure rate, which drives the system availability rate down. Information from the Safety Analysis Task Team suggested that a system availability of 97.5% is desired to ensure the concept's predicted benefits. On most OBIGGSs, to achieve higher than 97% availability a 1-day MMEL repair interval is required but will seriously affect airline operations.

Figure 8-10 shows a comparison of the system availability of the membrane system with 1, 3, and 10 days' relief.

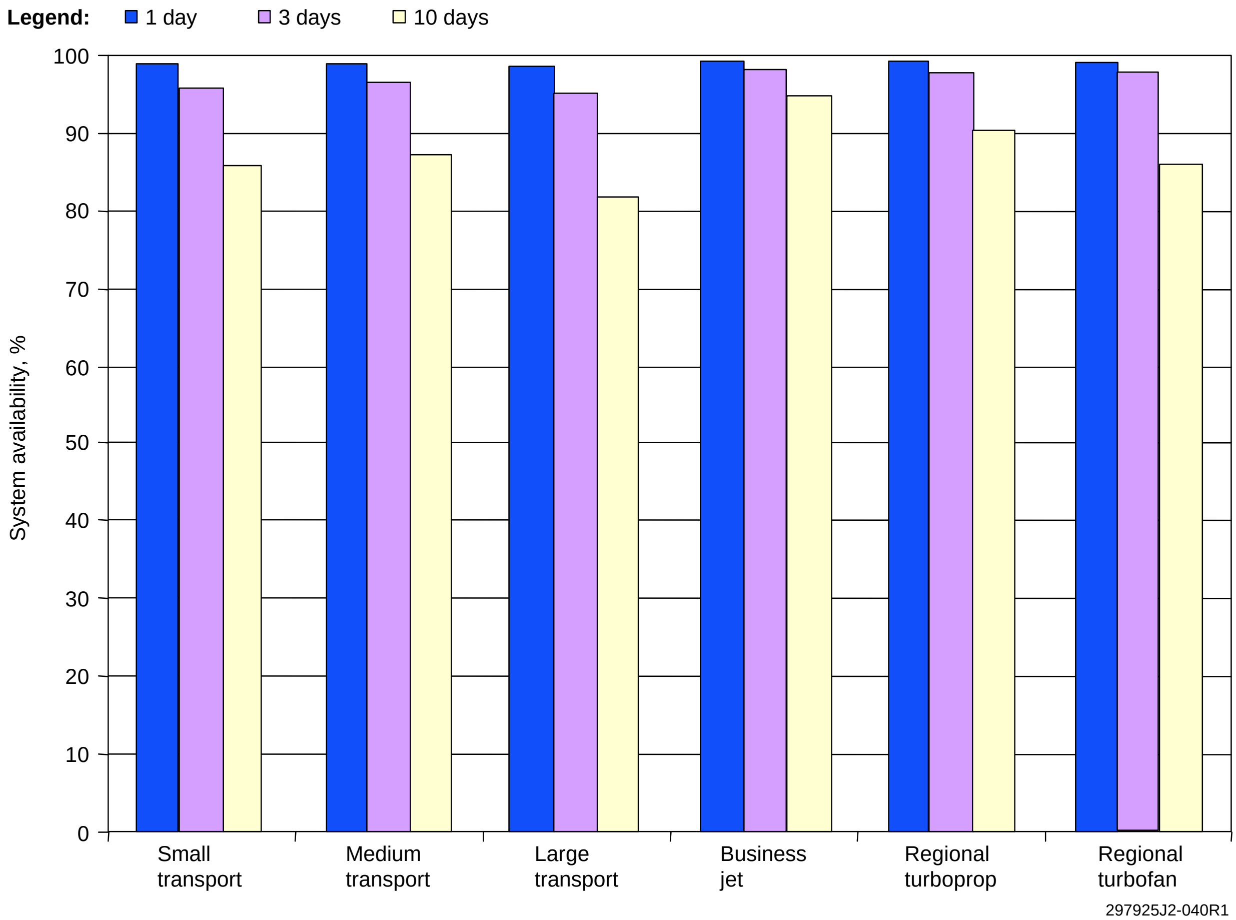

Figure 8-10. System Availability (10 Days' MMEL Relief)

<u>*Delays per Year (Hours)*</u>

We calculated the number of hours in annual delays, shown in figure 8-11, by making a delay assumption that if an airplane has a fault in the system it will take a period of time for the mechanics to assess the situation, perform any maintenance action in accordance with the MMEL, and complete any paperwork. Each airplane category has a delay assumption value that, when multiplied by the component annual failure rate, results in a total time delay for each component. The sum of the component delays results in the total annual system delay time (hours).

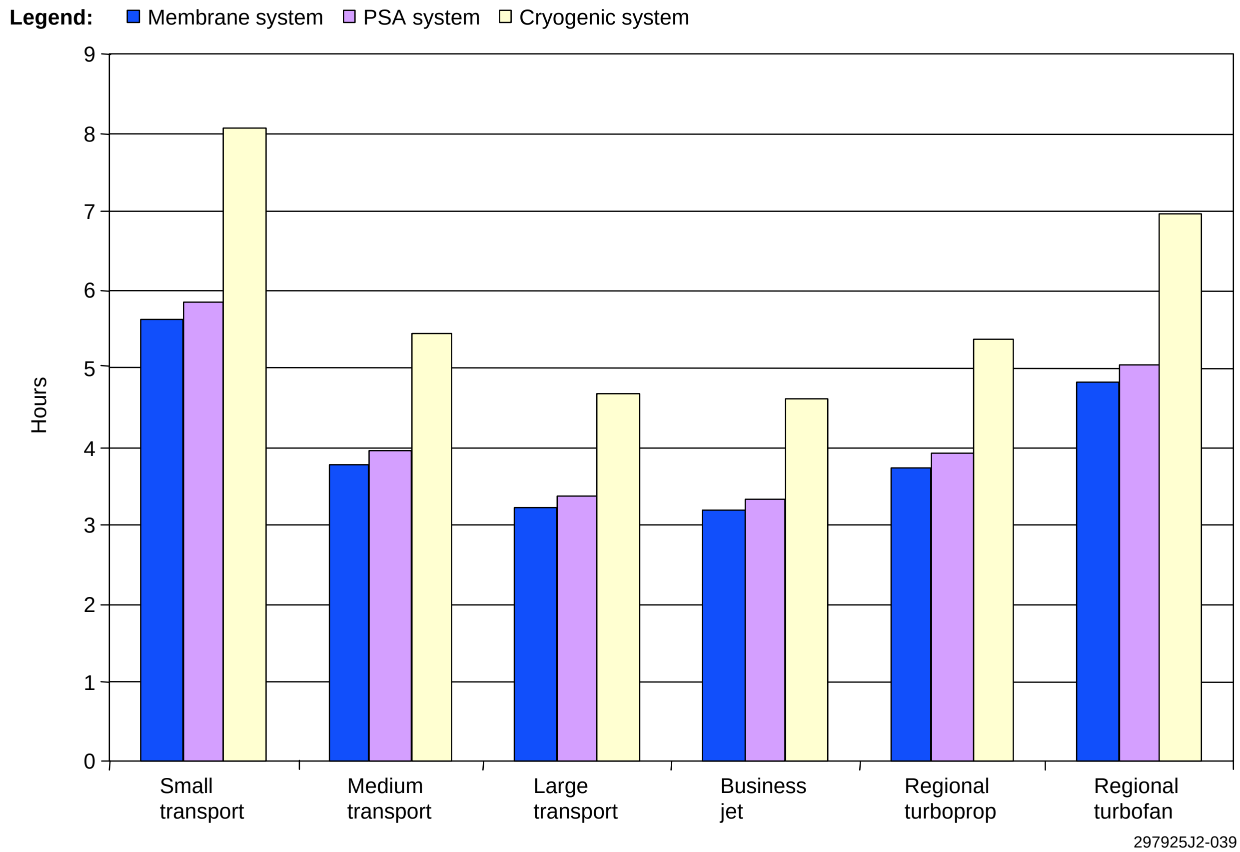

Figure 8-11. Delays per Year (Hours)

World reliability figures are measured against delays and cancellations. Customers are often driven by such figures, and operators make every effort to ensure on-time departures. Such delays and cancellations not only directly affect operators with costs of customer accommodation and remuneration but also loss of repeat customers and reputation.

The causes of such delays and cancellations are actively pursued by operators with a view to reducing them to the minimum, adding another system to the airplane that could affect such figures and is of great importance to operators.

Personnel Safety

It is a major concern for the operators and ground service agencies that installing an inerting system might threaten the safety of personnel. The danger to personnel from entering confined spaces that could be contaminated with NEA is a real possibility. In most developed countries health and safety legislation is adhered to much of the time, but in designing a system that reduces oxygen in some of the airplane's confined spaces, we could be building a trap for people to fall into.

Another major concern is the size and weight of some of the components in the various systems. These range from lightweight valves and other components to heavy compressors, heat exchangers, cryocoolers, and ASMs. These range in weight from 100 lb to more than 225 lb. There is a recognized need for specialized lifting equipment, but the risk of damage and injury from falling heavy components would exist where it previously did not.

OBIGGS Effects on Other Airplane Systems

The installation of an OBIGGS on an airplane will affect the reliability and cost of operation for other airplane systems. The OBIGGS concepts studied by this Working Group would add a very large additional electrical load on the airplane electrical system. The OBIGGS also relies on the airplane pneumatic system as a supplemental air supply, increasing the demand on this system. Last, in an attempt to reduce the size and power requirements of the OBIGGS air compressors, the design team chose to take the system's supply air from the passenger cabin. This will put an additional demand on the cabin air-conditioning and pressurization systems.

Electrical Power Generation

The OBIGGS power requirements may exceed the current available power.

For example, as shown in figure 8-12, the large transport airplane will require between 115 and 145 kVA. A typical Boeing 747 Classic will produce a maximum continuous rate of 216 kVA, of which 175 kVA is required in cruise, leaving a maximum of 41 kVA. A further consideration is that this remaining power would be distributed among four power-supply buses that cannot be permanently linked.

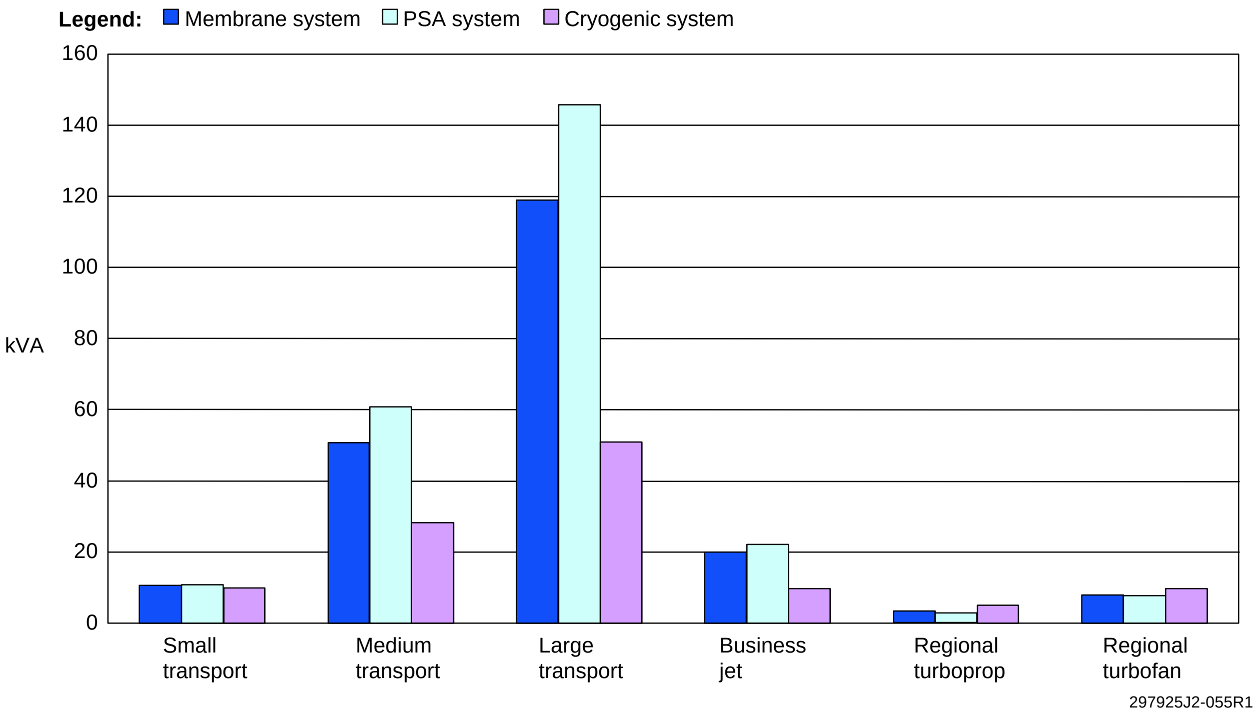

Figure 8-12. OBIGGS Power Requirements (kVA)

A Boeing 747-400 can produce more power because of greater capacity generators, but greater loads are required and the remaining power is again spread among power-supply buses that cannot be permanently linked.

Depending on the airplane, the increased power demands may require an increase to the capacity of the power-generating system. The cost of increasing the electrical system capacity and the cost of maintaining a larger system were not calculated. Increasing system capacity would require larger generators, heavier wiring, and modifications to the electrical buses to handle the loads. This may not even be an option on some airplanes because of engine limitations. Needless to say these changes would be expensive and time consuming.

Increased capacity power-generating systems will increase unscheduled maintenance requirements. This additional unscheduled maintenance figure has not been quantified, either.

Airplane Pressurization System

As previously discussed in the Scheduled Maintenance section, extra labor-hours have been added to the scheduled maintenance checks to perform a fuselage pressure decay check and accomplish repairs. Most operators' experience has shown that airplanes currently in service periodically require this pressure decay check to maintain leakage limits prescribed in airplane maintenance manuals.

Because OBIGGS takes air from the cabin, operators will have to reduce the allowable cabin air leakage rate to compensate for the demand and maintain a safety margin.

Should a leak occur during operation it may not allow continued operation of OBIGGS, which uses some cabin air pressure. Instead of allowing the airplane to continue in service until the next scheduled pressure decay check, immediate rectification will be required.

We have not quantified these extra unscheduled maintenance costs.

Bleed Air System

Bleed air also is used by OBIGGS. Where this system interfaces with OBIGGS, use and associated scheduled and unscheduled maintenance will be increased. Again, we have not quantified this increase in unscheduled maintenance.

Spare Parts Holding

The amount of spare components required to be held by an operator to ensure a reliable system varies according to system reliability, number of airplanes operated, and the type of operation, such as ETOPS. It was not possible to make a detailed study of the costs for all systems and airplane categories, but from the figures already calculated it was possible to see that a pool of spares of more than $900,000 would be required to operate one airplane with a membrane system. This figure is a conservative estimate and does not take into account the storage, transportation, administration, or capital investment costs or any lease fees.

8.5.4 Flight Operations

OBIGGS provides full-time inerting protection in normal operations including descent, landing, and postlanding incidents that might present a tank ignition hazard. The system should be designed to be fully automatic and to be automatically shed in case of engine power, electrical, bleed source, or cabin pressure failures. It is assumed that it will be monitored by the flight management systems and annunciation of failure modes will be provided to the flight crew for recording in the maintenance log. Little if any cockpit instrumentation should be provided because inerting is considered a safety enhancement with MEL provisions and the crew is not expected to troubleshoot it to reactivate the system or discontinue routing operations. Some basic descriptions of the inerting concept and the OBIGGS equipment, location, power sources, heat exchangers, and so forth need to be provided as additional training but should be limited to need to know. "If the crew cannot affect it, don't train for it." Both flight crew and dispatch personnel will be trained as far as MEL operating rules, and the airplane may need to be rerouted to a suitable repair facility. OBIGGS will draw power, bleed air, and incur drag from intercooler openings, and the increased fuel burn costs will result in reduced range and endurance. This could affect some long-haul and international routes.

8.5.5 Ground Operations

OBIGGS ideally would solve many of these ground-base concerns and issues after installation. The FTIHWG believes that a continual monitoring system should be installed on the flight deck to ensure that proper inerting takes place during the more critical phases of the airplane's route structure, such as taxi and takeoff. Any anomalies should immediately be put on a master caution light to alert the flight crew. The flight crew would then have the ability to shut the system down, if needed. Like the APU fire warning system on many commercial airplanes, an aural warning system should be considered while the airplane is on the ground in the event this system malfunctions without a flight crew member on board.

A valid concern was raised with the possibility of nitrogen entering the cabin during continuous inerting with this system. Considerations should be given to redundancy with the material used to enhance safety for passengers and crew. Examples include using double-walled pipe for plumbing purposes and installing nitrogen sensors in the cabin.

Maintenance training procedures fall within the above-mentioned training recommendations, and would merely be tailored again to the system desired for installation.

8.6 SAFETY ASSESSMENT

Figures 8-13 and 8-14 show the impact that OBIGGS could have on reducing future accidents in the United States and worldwide, respectively. If selected, the forecast assumes that the system would be fully implemented by the year 2015 (see sec. 11.0 for implementation assumptions). At that time, the forecast indicates the time between accidents in the United States would be 16 years with SFAR alone, 41 years with SFAR and inerting in heated CWTs, and more than 51 years for SFAR and inerting in all tanks. The corresponding time between accidents for the worldwide fleet would be approximately half that estimated for the U.S. fleet.

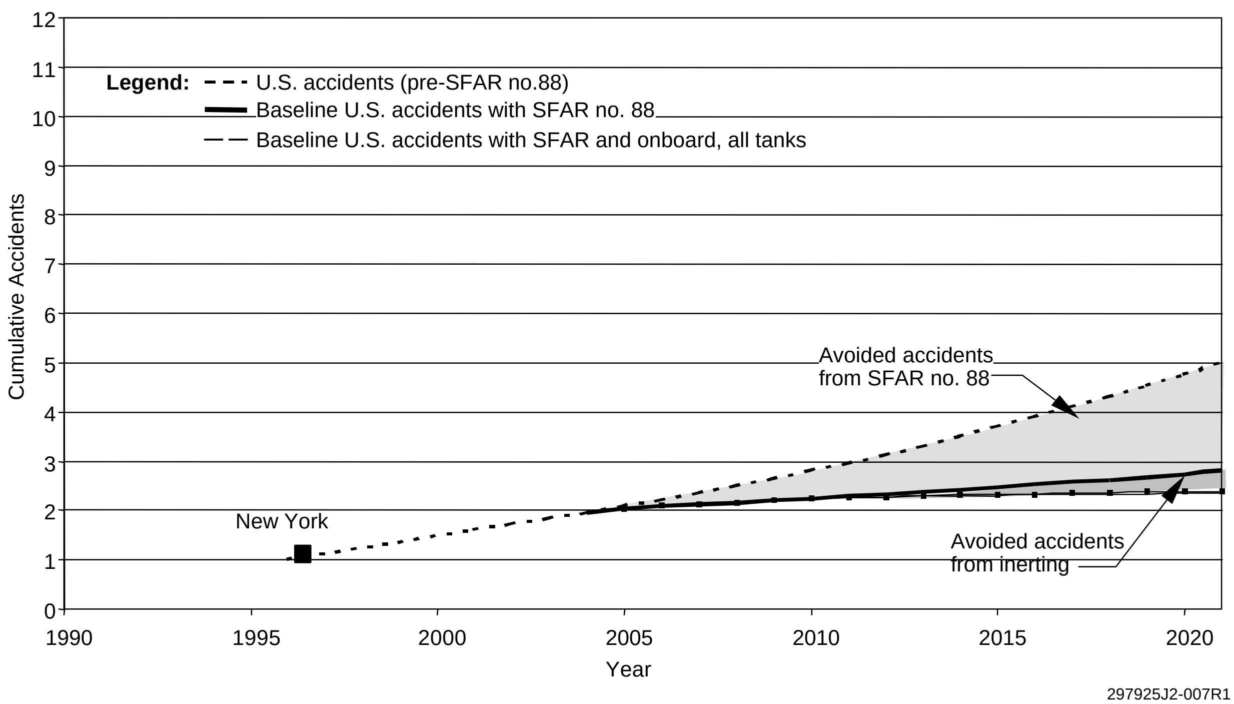

Figure 8-13. U.S. Cumulative Accidents With OBIGGS

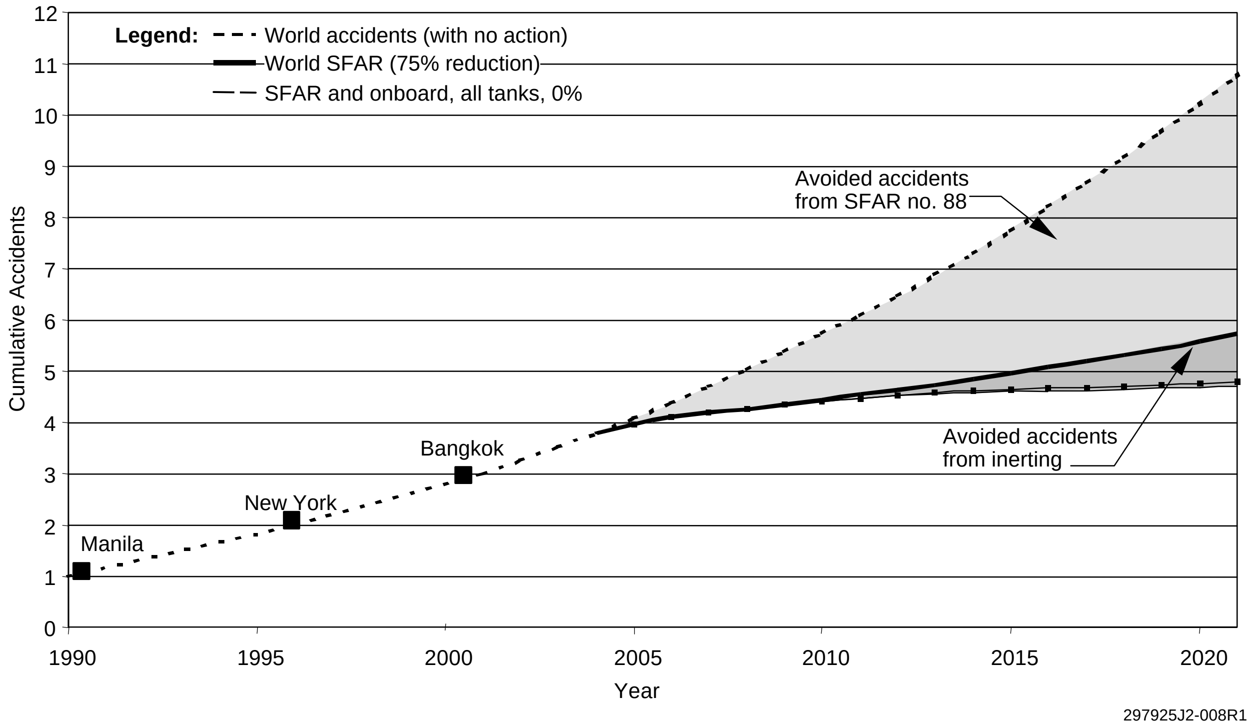

Figure 8-14. Worldwide Cumulative Accidents With OBIGGS

8.7 COST-BENEFIT ANALYSIS

Figures 8-15 though 8-21 graphically represent the cost-benefit analyses of the scenario combination examined for the OBIGGS concept.

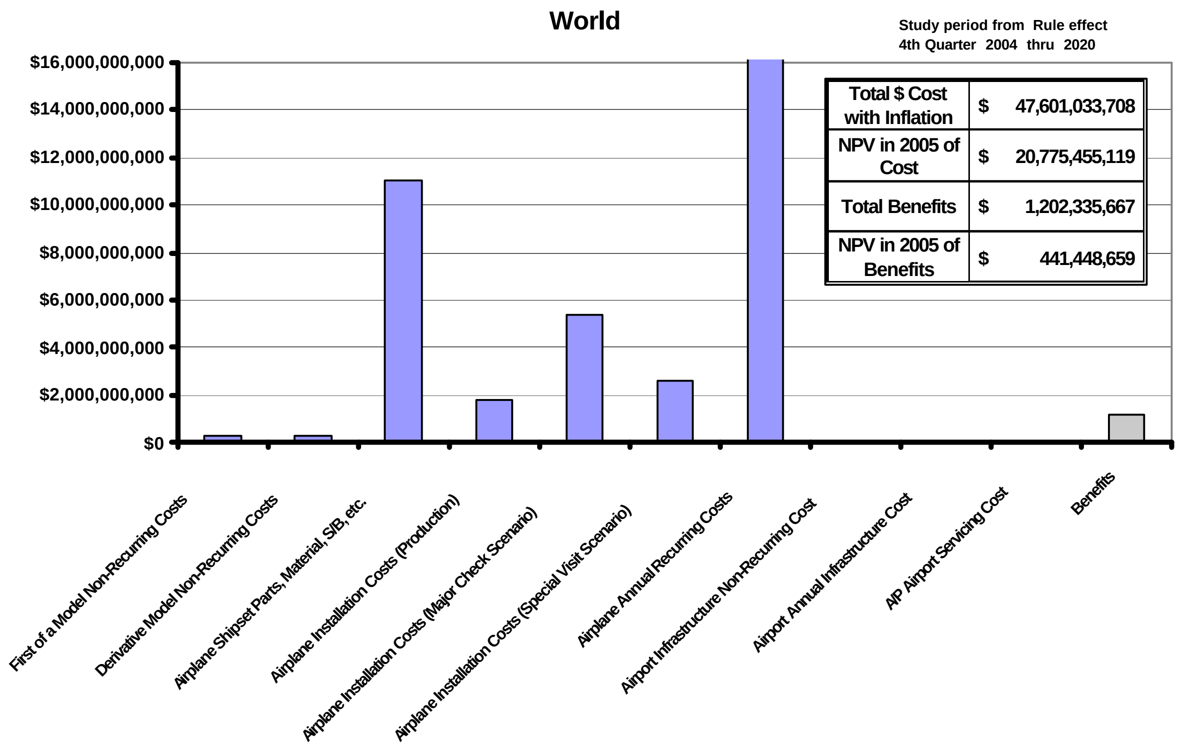

Figure 8-15. Scenario 5—OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (World)

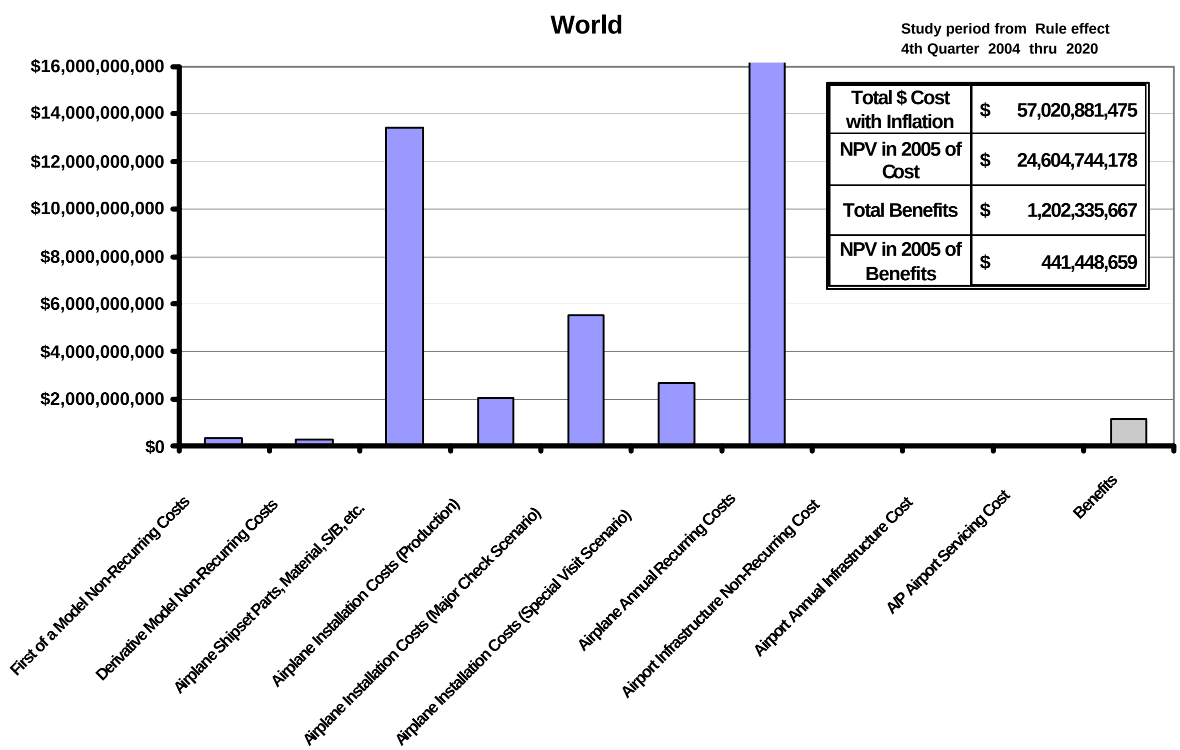

Figure 8-16. Scenario 13—OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (World)

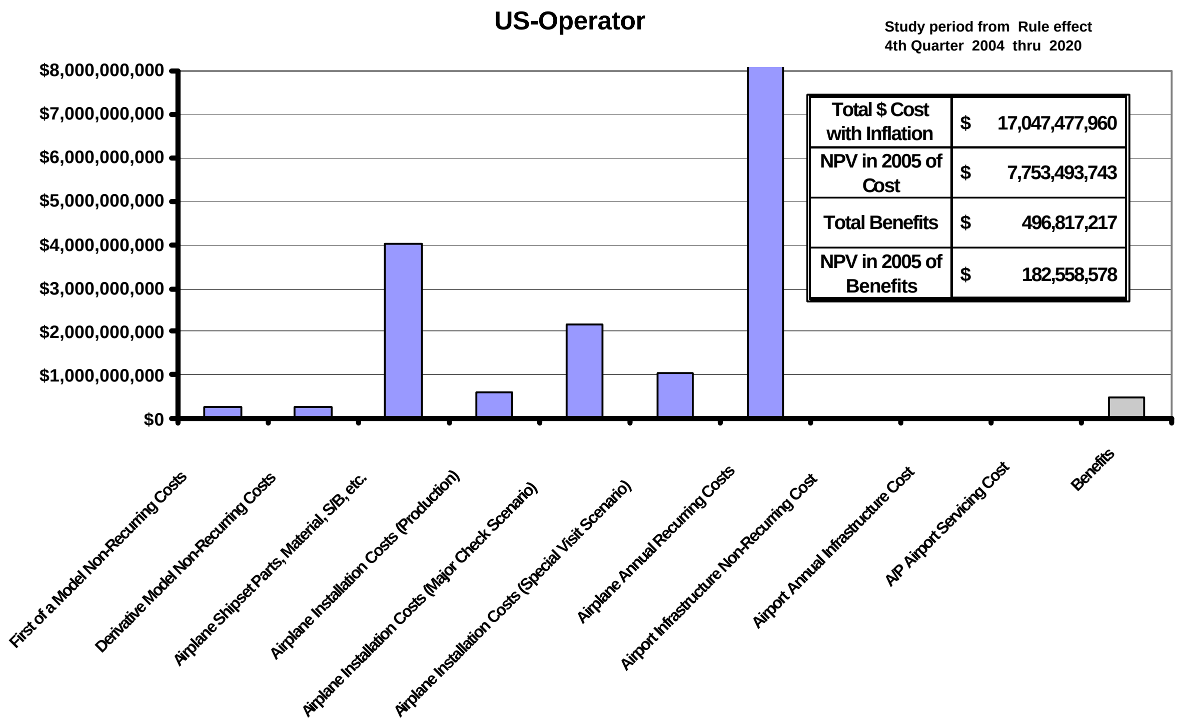

Figure 8-17. Scenario 5—OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (U.S.)

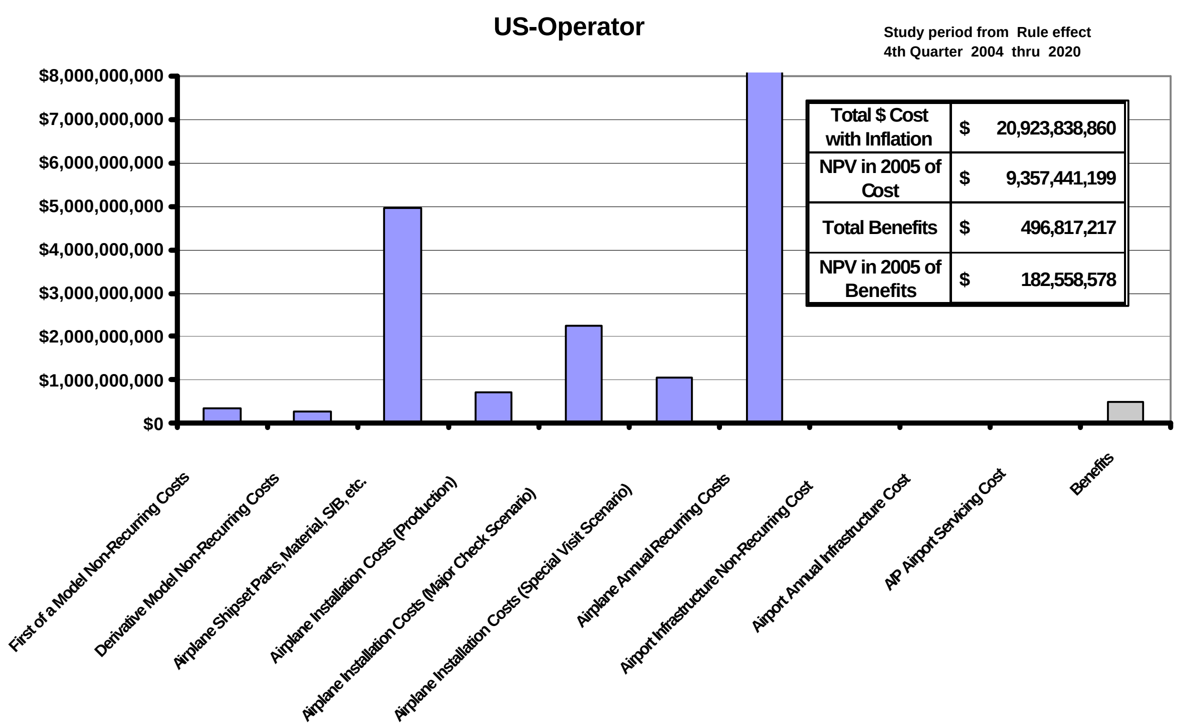

Figure 8-18. Scenario 13—OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (U.S.)

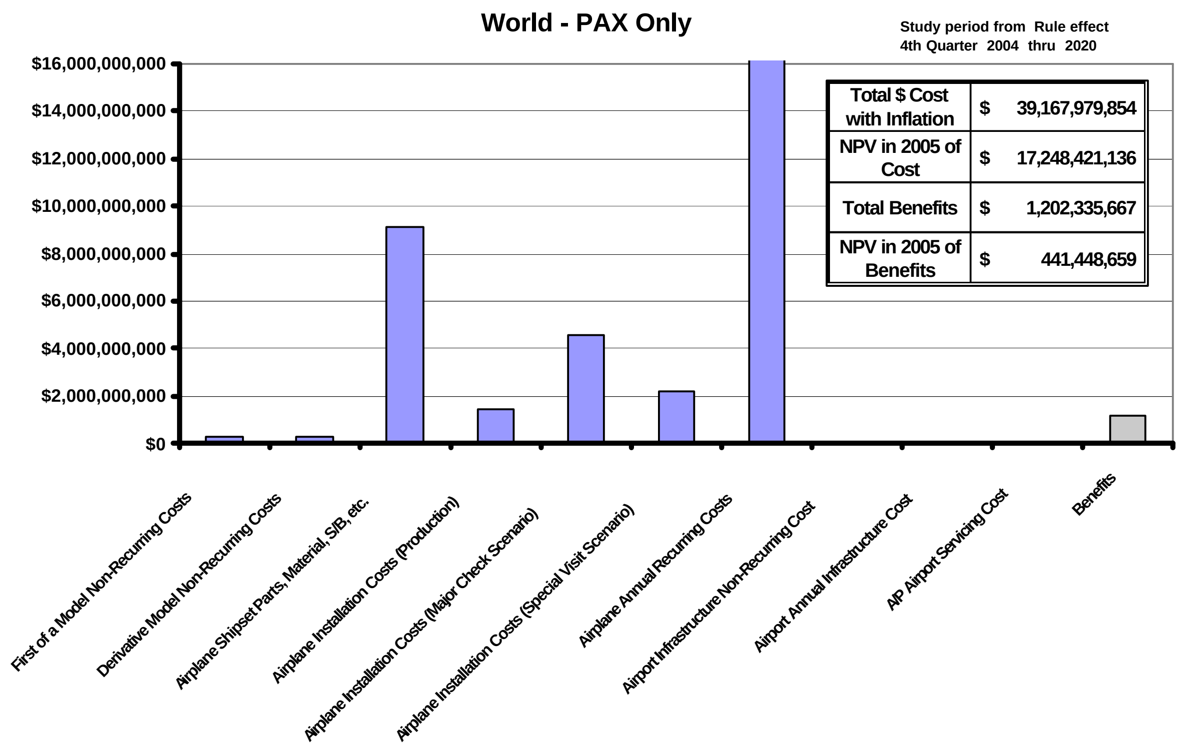

Figure 8-19. Scenario 5—OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

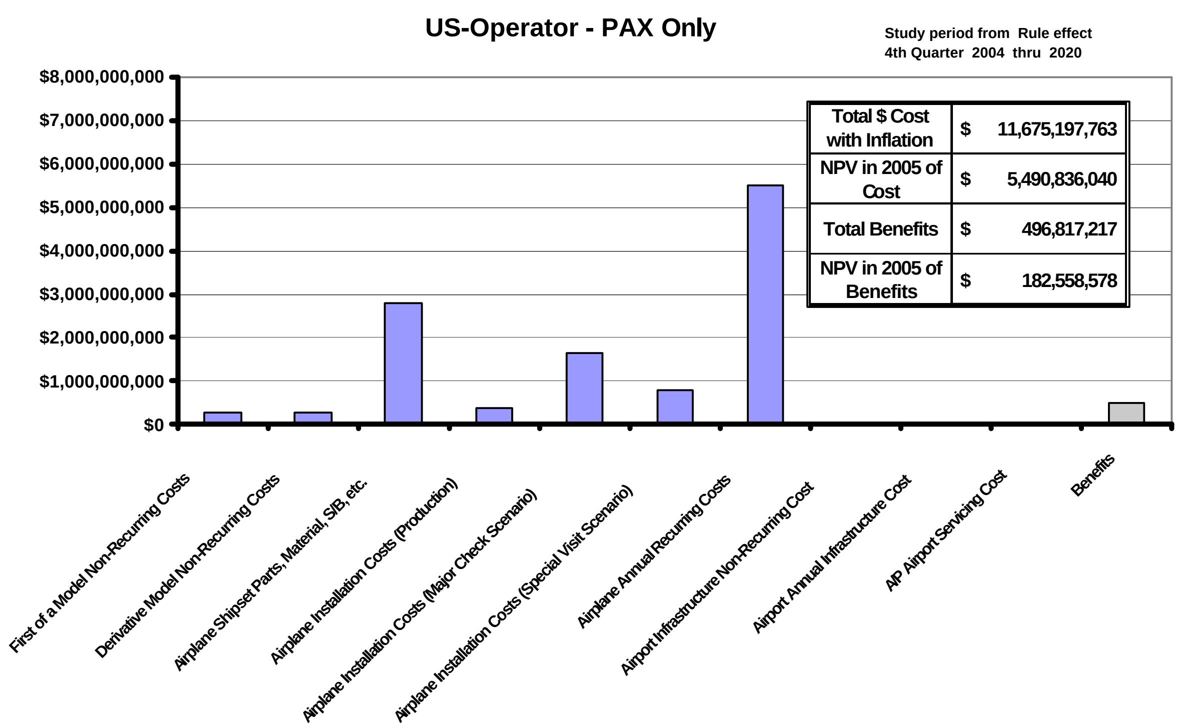

Figure 8-20. Scenario 5—OBIGGS, All Tanks, Large and Medium Transorts, Membrane Systems, and Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

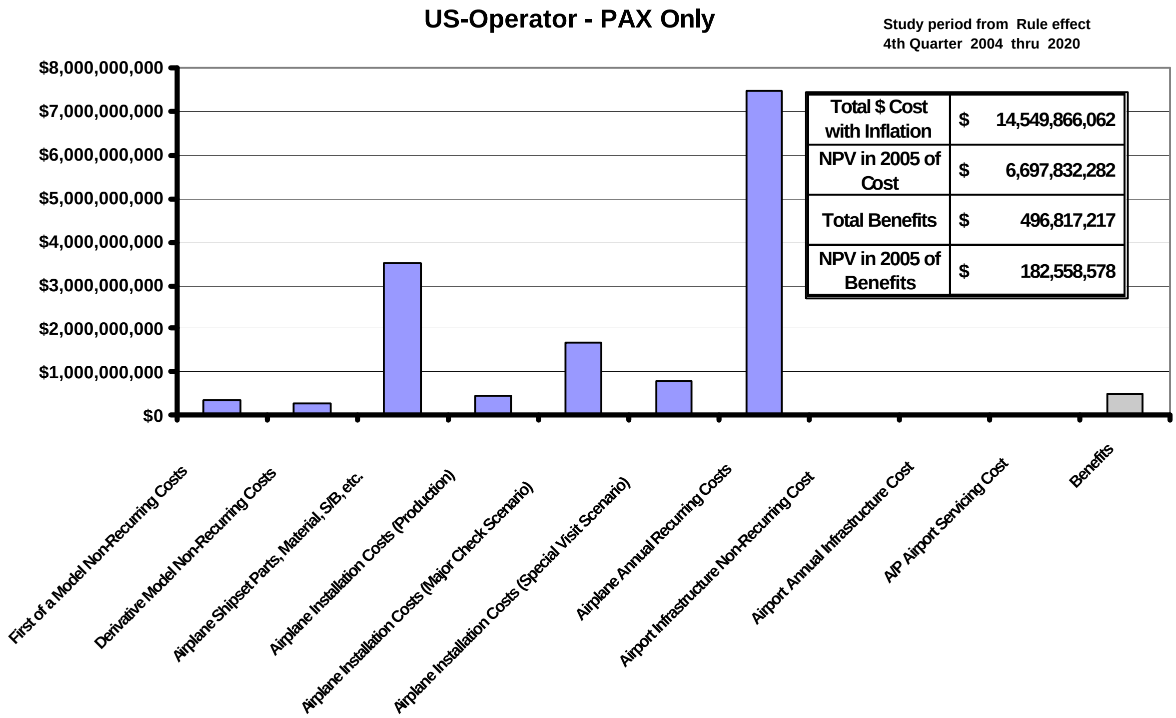

Figure 8-21. Scenario 13—OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

8.8 PROS AND CONS

Pros

a. OBIGGS reduces total flammability exposure almost to zero, except for those times when the airplane is not powered or the maneuvers exceed typical maneuvering.
b. OBIGGS potentially reduces corrosion and condensation in the fuel tanks, depending on how the operator uses the system.

Cons

a. OBIGGS is the most costly option of those examined and weighs approximately the same as the OBGIS.
b. The cost of components (only a part of the total system cost) far exceeds the potential benefit.
c. Additional cost is incurred because of the weight of the system—which causes a fuel penalty—and airplane drag is increased, because of inlet and exhaust ports for the system.
d. The airplane's center of gravity may be adversely affected because of the system's location in some airplane models, which would also incur a fuel penalty.
e. Compressor and fan noise may have to be damped, depending on local noise standards.

Indeterminate

Pollution:

a. Normally, some fuel vapor exits the tanks during refueling and some vapor will be pushed out when adding nitrogen to the tank.

b. Fuel vent systems will need to be isolated to prevent crosswinds from diluting the nitrogen, which would be an improvement over present-day conditions.
c. No attempt was made to quantify this, because of the complexity of the problem for each airplane model at each airport.

8.9 MAJOR ISSUES AND RESOLUTIONS

The technical limitations for retrofit of the OBIGGS are its size, contamination issues with the ASMs, and a potential hazard with static electricity. A description of the improvements needed for the other limitations follows.

8.9.1 System Size

Some OBIGGS issues relate to the large system size, as shown in figure 8-22. For the large transport, the system weighs between 1,120 and 1,600 lb (depending on the separator technology) and consumes between 55 and 160 kVA of electrical power during descent. These power levels are a significant fraction of the large transport electrical capacity (240 kVA). The team was unable to obtain estimates of the electrical power available by flight phase to determine whether these power requirements could be met.

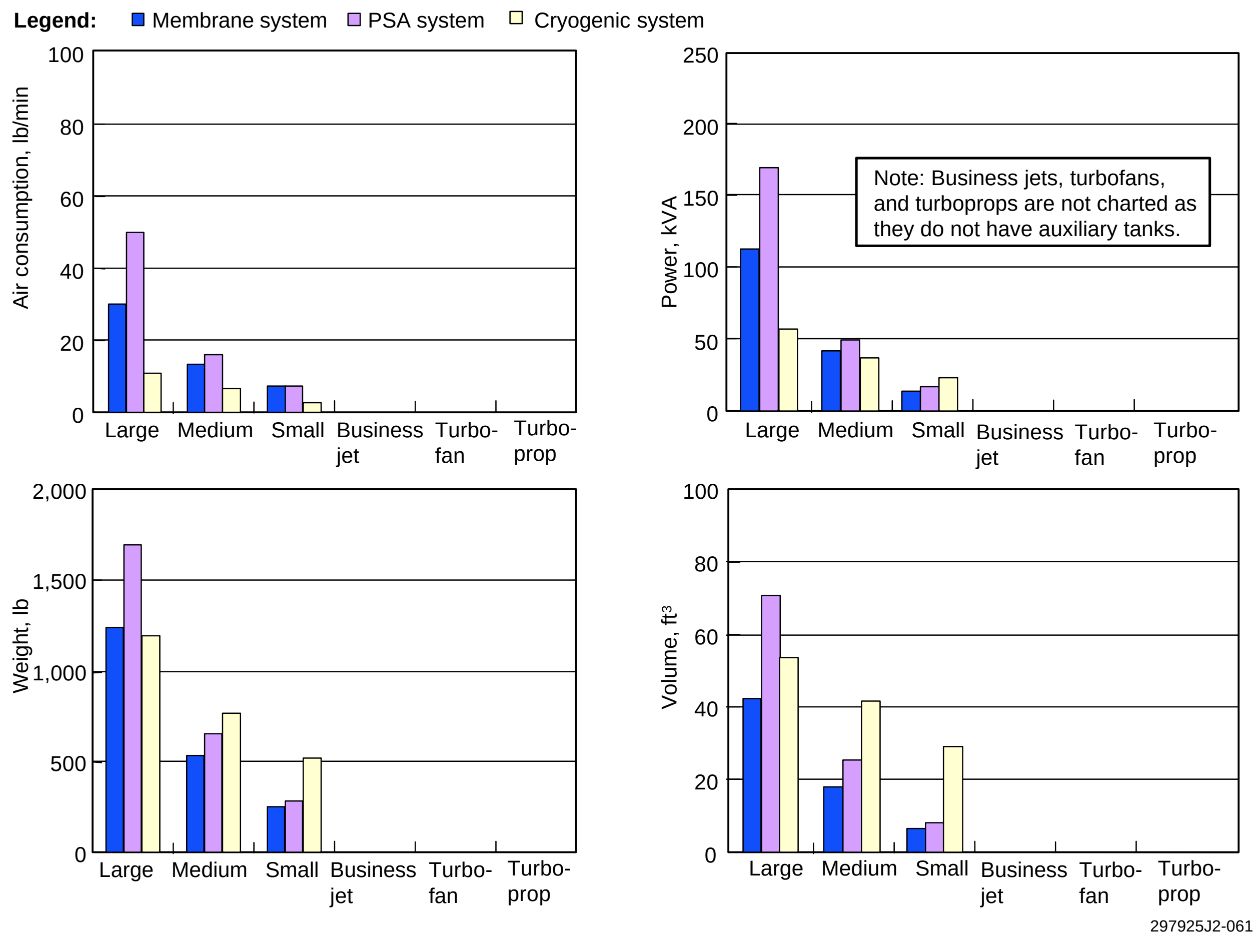

Figure 8-22. OBIGGS System Size Issues

No matter what size the airplane, the system requires significant electrical power to run, may not fit in all airplanes because of its size, and is heavy.

Another issue is the compressor weight, which for the large and medium transports is too much for an average mechanic to lift. This can be resolved by changing the design to incorporate multiple compressors in parallel, making each compressor smaller but increasing overall volume.

8.9.2 Air Separator Modules

ASMs are susceptible to water contamination, which reduces performance. A water separator has been included in the design concept to avoid this problem.

Some permeable membrane modules also are susceptible to hydrocarbon contamination from the fuel and oil vapor in engine bleed air. A hydrocarbon element may be required to be added to the coalescing filter included in the design concept.

In addition, permeable membranes have no service history onboard airplanes to prove their durability. They have been used in ground applications, however, where they have demonstrated a very long life.

Like permeable membranes, the cryogenic distillation system has no flight history. However, cryogenic distillation technology has been used for years on naval ships with high reliability.

8.9.3 Static Electricity

The rapid flow of dry gas in a distribution manifold inside the fuel tank can generate static electricity and cause sparks. This can be mitigated by using large-diameter manifolds to keep the gas velocity low and by bonding the manifold to structure (electrical ground).

8.10 CONCLUSIONS

OBIGGS reduces flammability exposure to nearly zero. But the concept suffers from keeping all fuel tanks inert during descent and from large ullage volumes required for short missions. The protection offered is the best a nonredundant system can offer, but at the highest price. Therefore, the FTIHWG does not recommend this concept.

9.0
Hybrid System

9.0 HYBRID INERT GAS GENERATING SYSTEM

The team has developed two hybrid concepts, each concentrating on reducing the major constraint to the size of the OBGIS and the OBIGGS. The hybrid OBGIS assumes that the baseline OBGIS would operate during taxi-in to the gate and while at the gate. The hybrid OBIGGS assumes the baseline OBIGGS is sized for all operations except descent. Both these systems offer reductions in flammability exposure similar or superior to that of the GBIS.

The average taxi-in time was determined to be 5 min. This adds 25% more time to inert for the small transport (which has the shortest gate time at 20 min) and 8% more time to the large transport (gate time of 60 min). However, this additional gate time does not reduce the weight, volume, power required, or cost of the OBGIS hybrid significantly from that of the baseline OBGIS.

The hybrid OBIGGS managed a more substantial improvement, reducing the weight, volume, power required, and cost by 25% to 70% compared with that of full OBIGGS. Ultimately, the overall cost of the system is still many times that of any potential benefit.

9.1 SYSTEM REQUIREMENTS

The Tasking Statement requires that the hybrid system be operated during some phases of flight as an option to installing equipment that might otherwise be necessary to keep the fuel tank inert during those phases of flight (e.g., vent system valves), and as a cost tradeoff that could result in reduced equipment size.

The Tasking Statement also requires that the team describe secondary effects of the system and analyze and report extracted engine power, engine bleed air supply, maintenance impacts, airplane operational performance detriments, and dispatch reliability.

The team must also provide information and guidance for the analysis and testing that will be conducted to certify the system.

If the FTIHWG cannot recommend a system, then all technical limitations must be identified and an estimate of the type of concept improvement that would be required to make it practical in the future must be provided.

9.2 CONCEPT DESCRIPTION

The hybrid OBGIS is schematically identical to the full OBGIS. It would be slightly smaller than the full OBGIS and would have to be certified not to interfere with other airplane equipment because it would be running during taxi-in.

The hybrid OBIGGS is simpler than full OBIGGS because it provides a constant flow of NEA to the fuel tanks, whereas full OBIGGS has a variable flow scheme.

9.3 APPLICABILITY OF CONCEPT TO STUDY-CATEGORY AIRPLANES

The OBGIS hybrid is applicable to the same in-service and production airplanes as the full OBGIS.

The hybrid OBIGGS is applicable to all the airplanes in the study category. There is insufficient information to determine whether the airplanes can meet the electrical demand of the system. Preliminary estimates by the Airplane Operation and Maintenance Task Team indicate that this system may exceed available electrical power.

An inerting system can be designed into future airplanes, provided the system size is calculated before engine, APU, and electrical generator selection. This will ensure that bleed air or electrical power is available.

9.4 AIRPORT RESOURCES REQUIRED

Powering the hybrid OBGIS requires electrical power from the airplane APU. Some airports are sensitive to noise and do not permit APU operation, requiring a ground power source to supply the system.

Hybrid OBIGGS is a self-contained system that does not normally require any airport resources. Some operators, however, may prefer using ground electrical power to operate the system after tank maintenance and inert the fuel tanks before the next flight.

9.5 AIRLINE OPERATIONS AND MAINTENANCE IMPACT

From an airplane operations and maintenance perspective, there is very little difference between the full OBGIS and OBIGGS and their hybrid systems. The Airplane Operation and Maintenance Task Team looked at the hybrid systems, but when it was determined that these systems were nearly identical from an operational and maintenance perspective, further work was discontinued. The reader may assume that the maintenance, operations, and modifications impact described in the OBGI and OBIGGS sections also apply to the hybrid systems.

9.6 SAFETY ASSESSMENT

Figures 9-1 and 9-2 show the impact that the hybrid OBIGGS could have on reducing future accidents in the United States and worldwide, respectively. If selected, the forecast assumes the system will be fully implemented by the year 2015. At that time, the forecast indicates the time between accidents in the United States would be 16 years with SFAR alone, 40 years with SFAR and inerting heated CWTs, and 48 years for SFAR and inerting all tanks. The corresponding time between accidents for the worldwide fleet would be approximately half that estimated for the U.S. fleet.

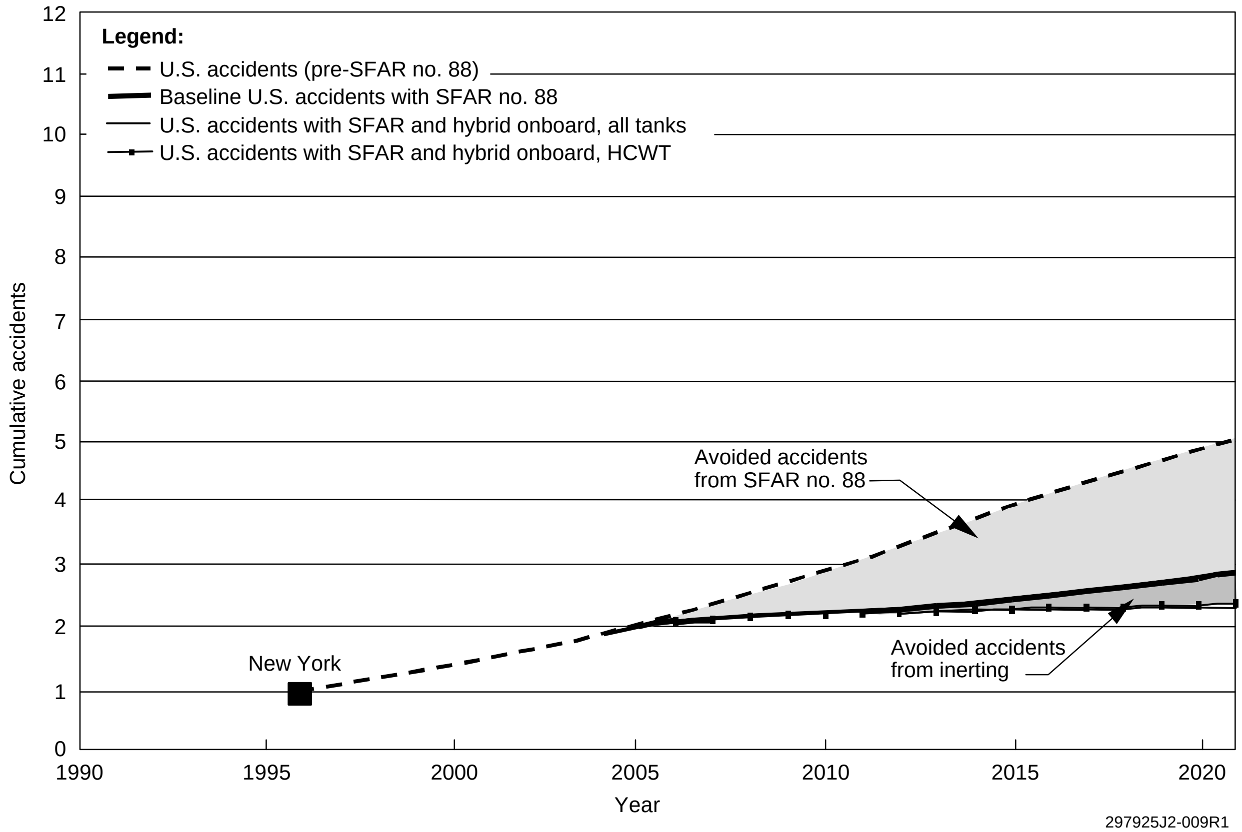

Figure 9-1. U.S. Cumulative Accidents With Hybrid OBIGGS

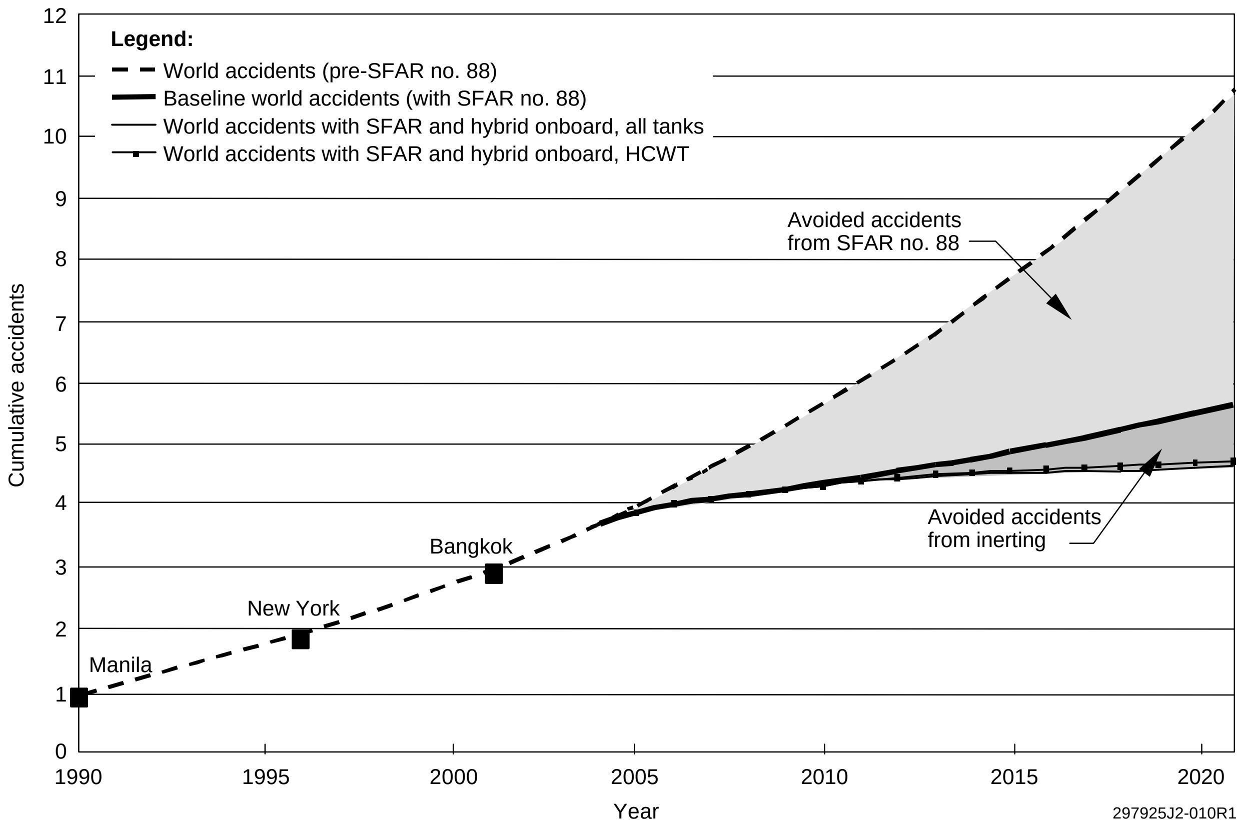

Figure 9-2. Worldwide Cumulative Accidents With Hybrid OBIGGS

Figures 9-3 and 9-4 show the impact that the hybrid OBGIS could have on reducing future accidents in the United States and worldwide, respectively. If the hybrid OBGIS were selected, the forecast assumes this system will be fully implemented by 2015. At that time, the forecast anticipates a time between accidents in the United States of 16 years with the SFAR alone, 31 years with the SFAR and hybrid OBGI inerting of heated CWTs, and 32 years with the SFAR and hybrid OBGI inerting of all fuselage tanks.

Corresponding times between accidents for the worldwide fleet would be approximately half those forecast above for the U.S. fleet, or about 8, 15, and 16 years, respectively.

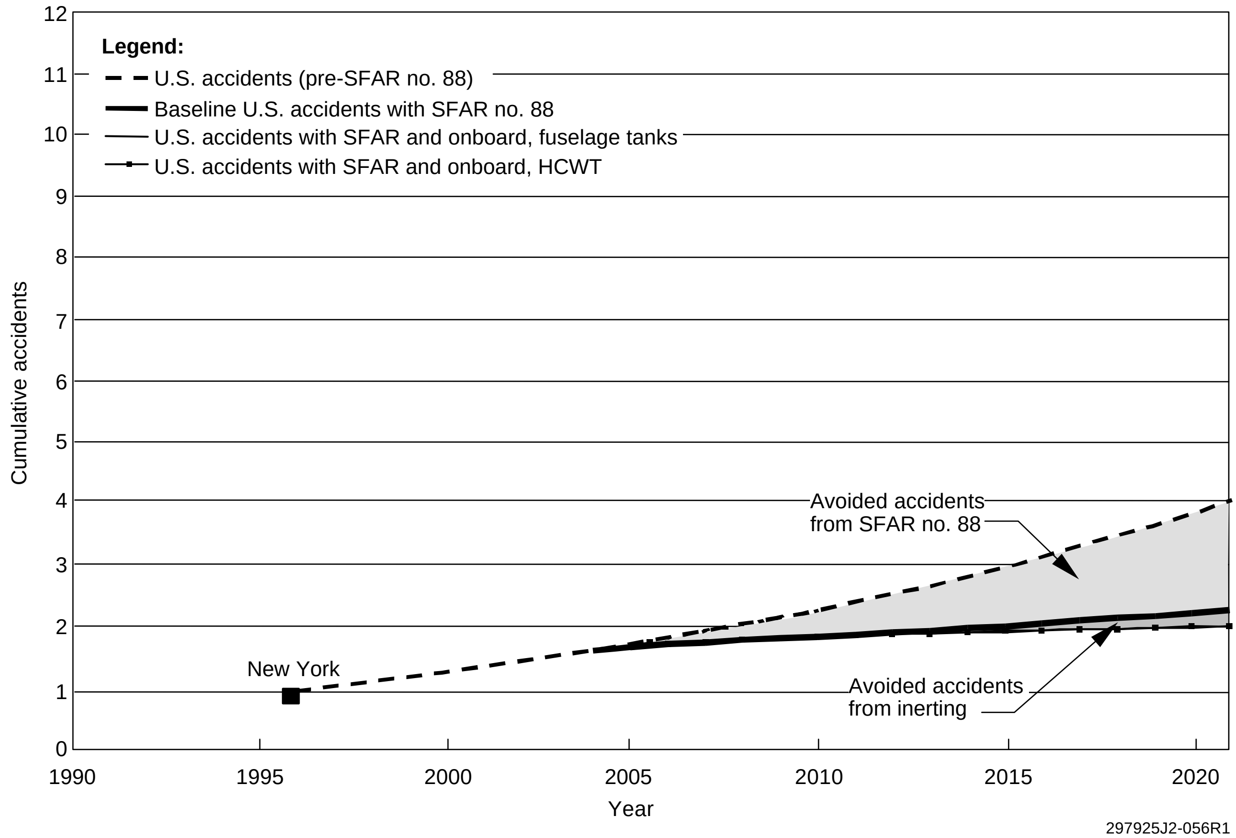

Figure 9-3. U.S. Forecast Cumulative Accidents With Hybrid OBGIS

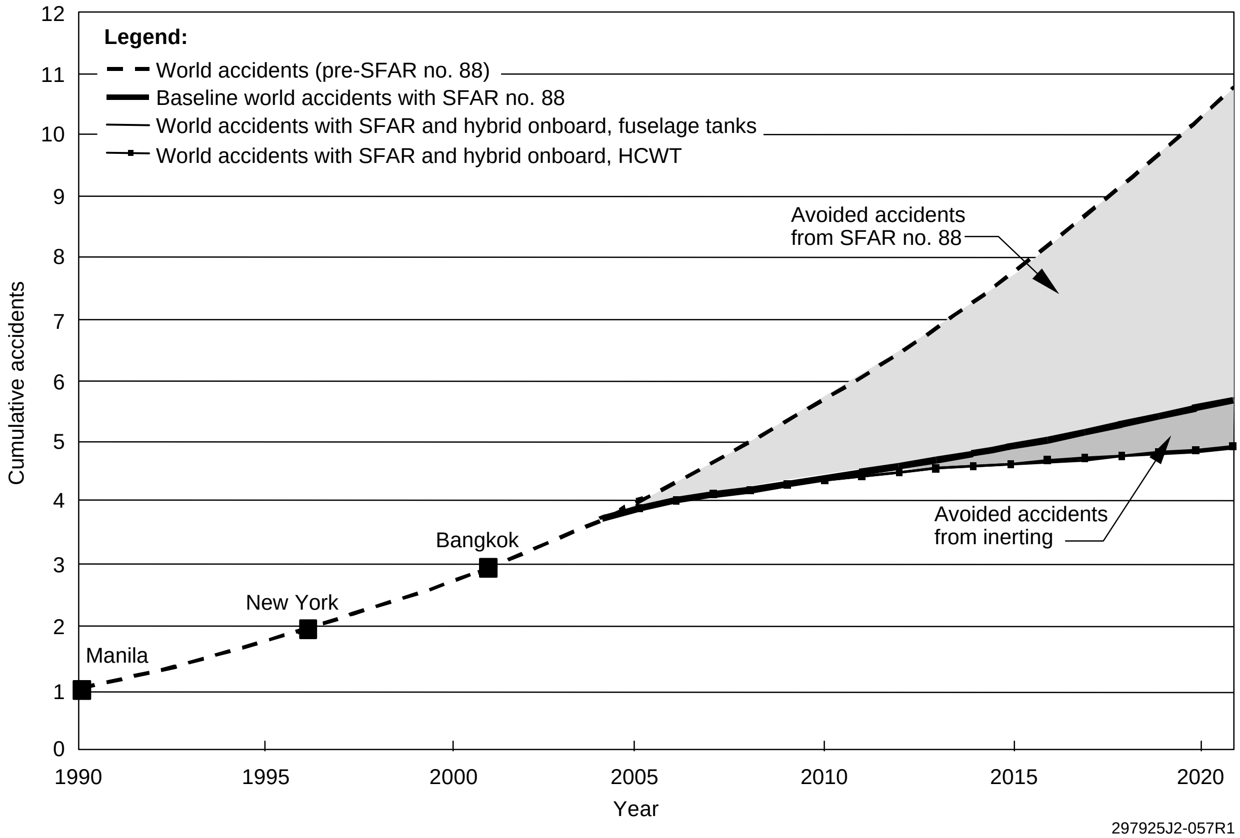

Figure 9-4. World Forecast Cumulative Accidents With Hybrid OBGIS

9.7 COST-BENEFIT ANALYSIS

Figures 9-5 through 9-29 graphically represent the cost-benefit analyses of the scenario combination examined for the hybrid inert gas generating system concept.

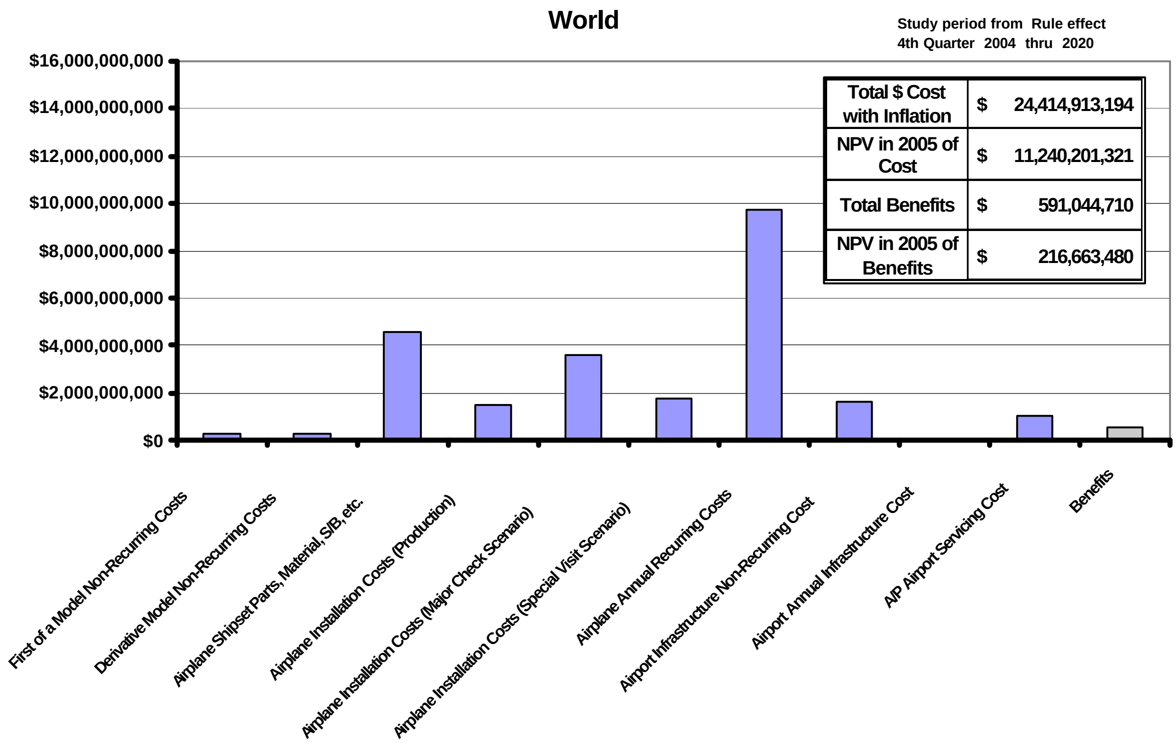

Figure 9-5. Scenario 3—Hybrid OBGI, Heated CWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (World)

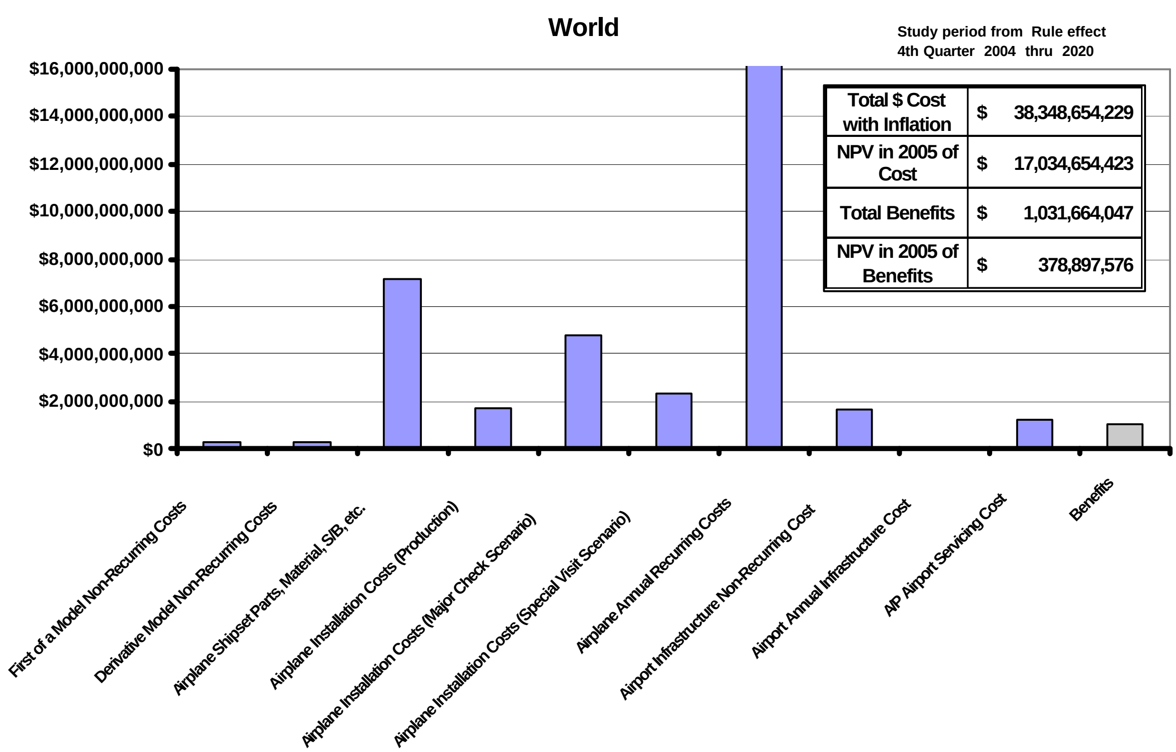

Figure 9-6. Scenario 4—Hybrid OBGI, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (World)

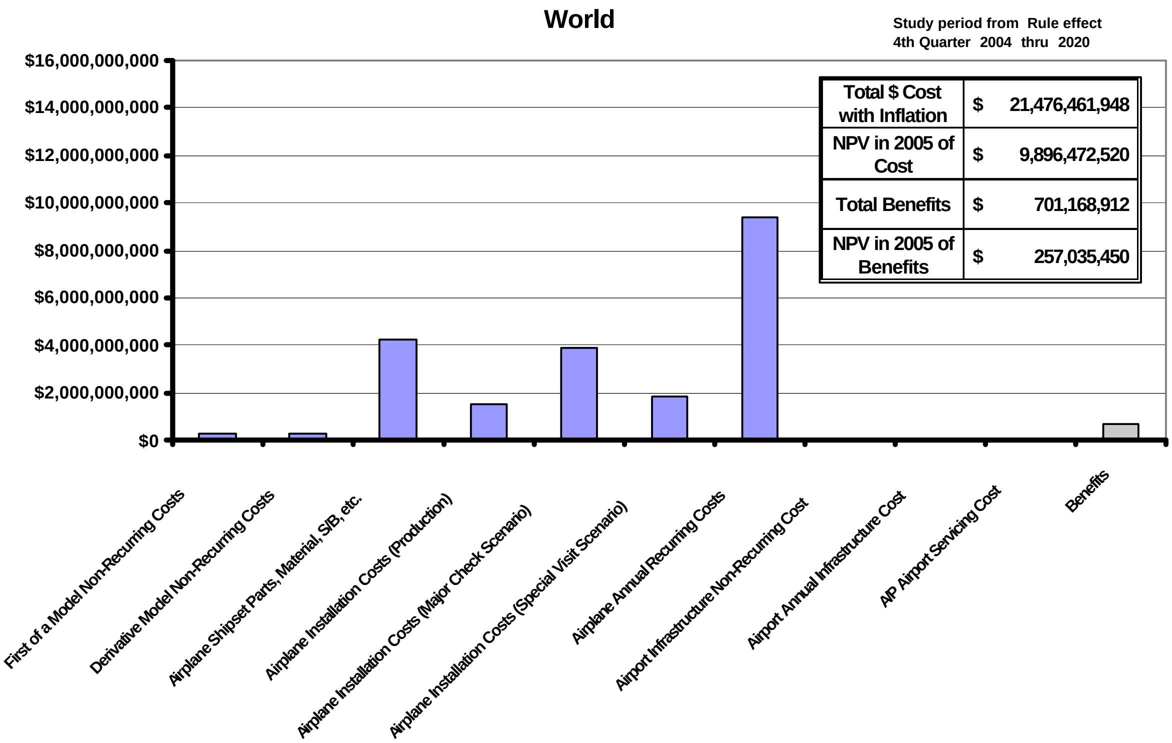

Figure 9-7. Scenario 7—Hybrid OBIGGS, Heated CWT Only, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (World)

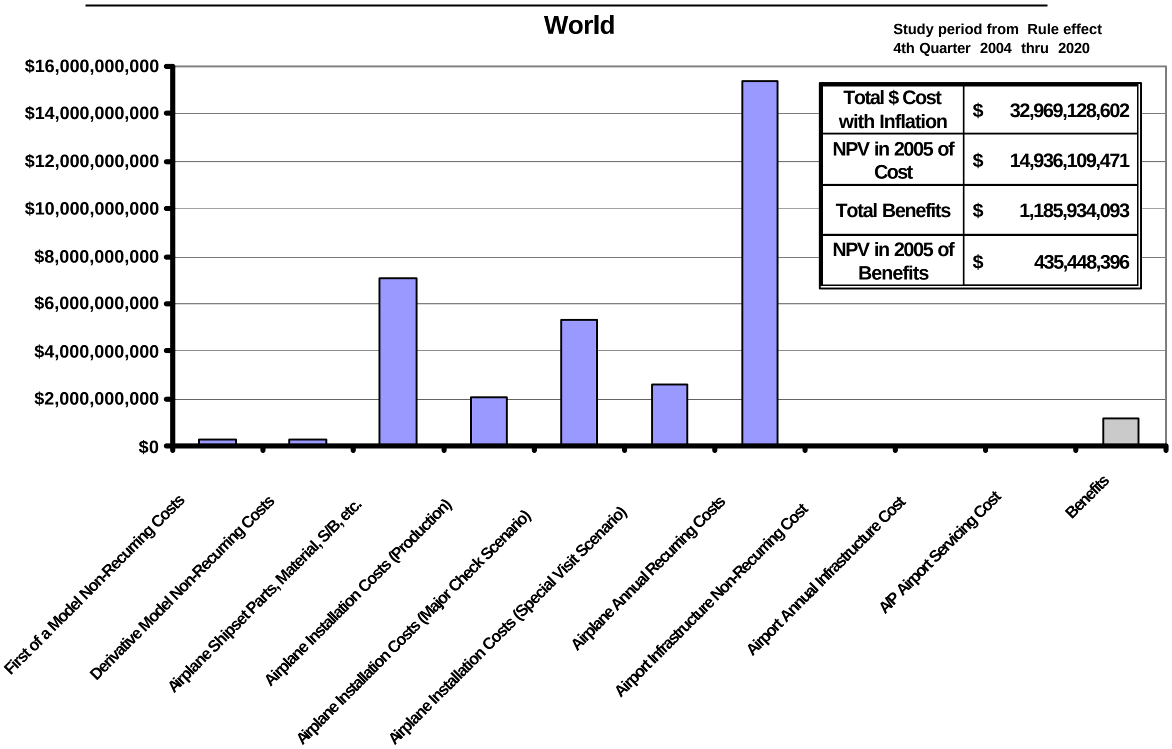

Figure 9-8. Scenario 9—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (World)

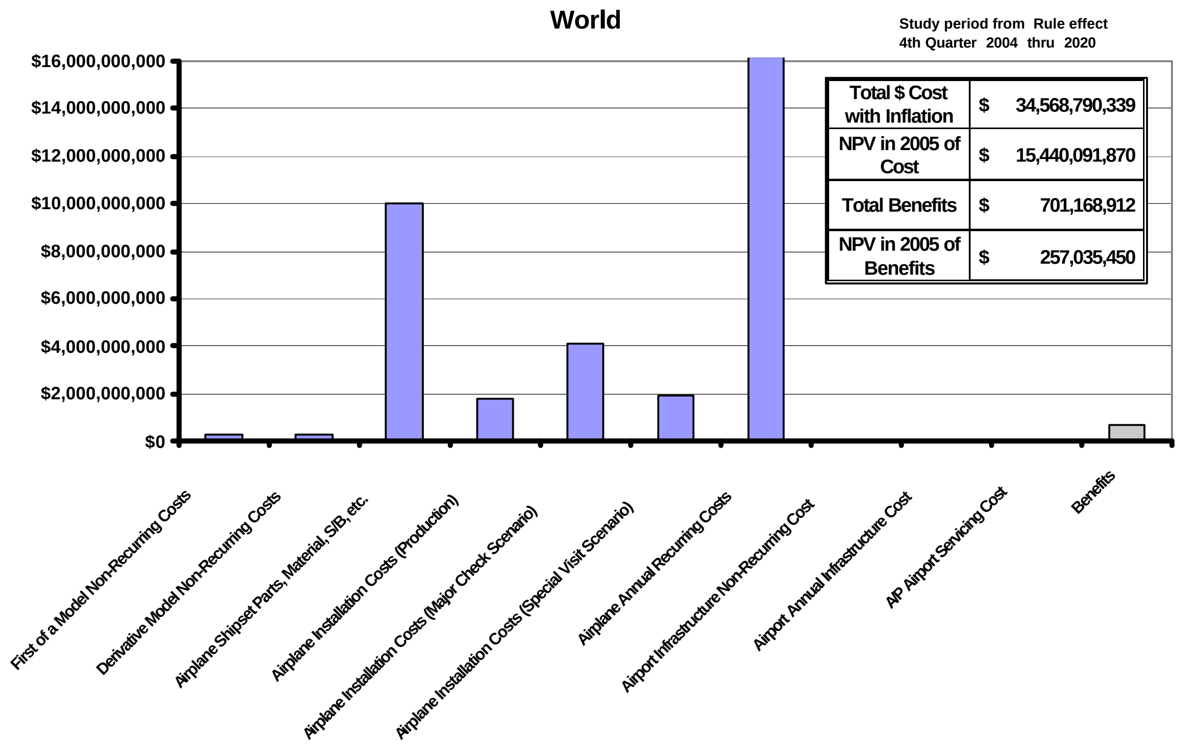

Figure 9-9. Scenario 14—Hybrid OBIGGS, Heated CWT Only, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (World)

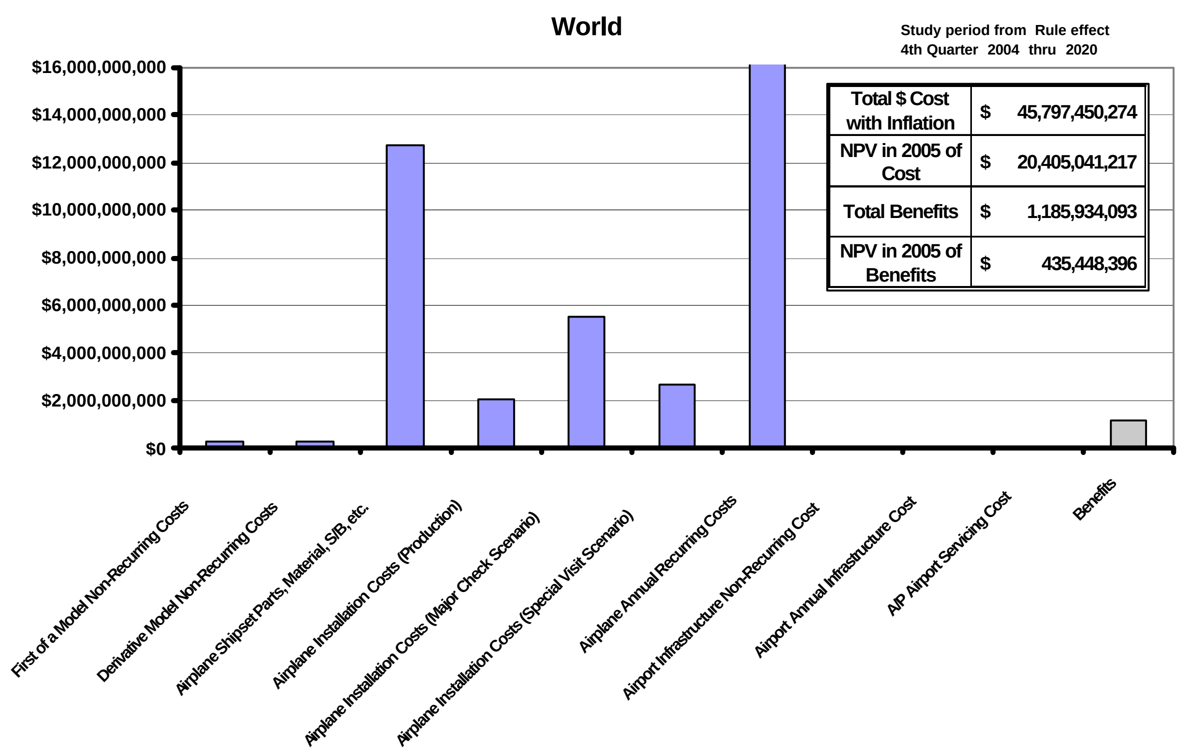

Figure 9-10. Scenario 15—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (World)

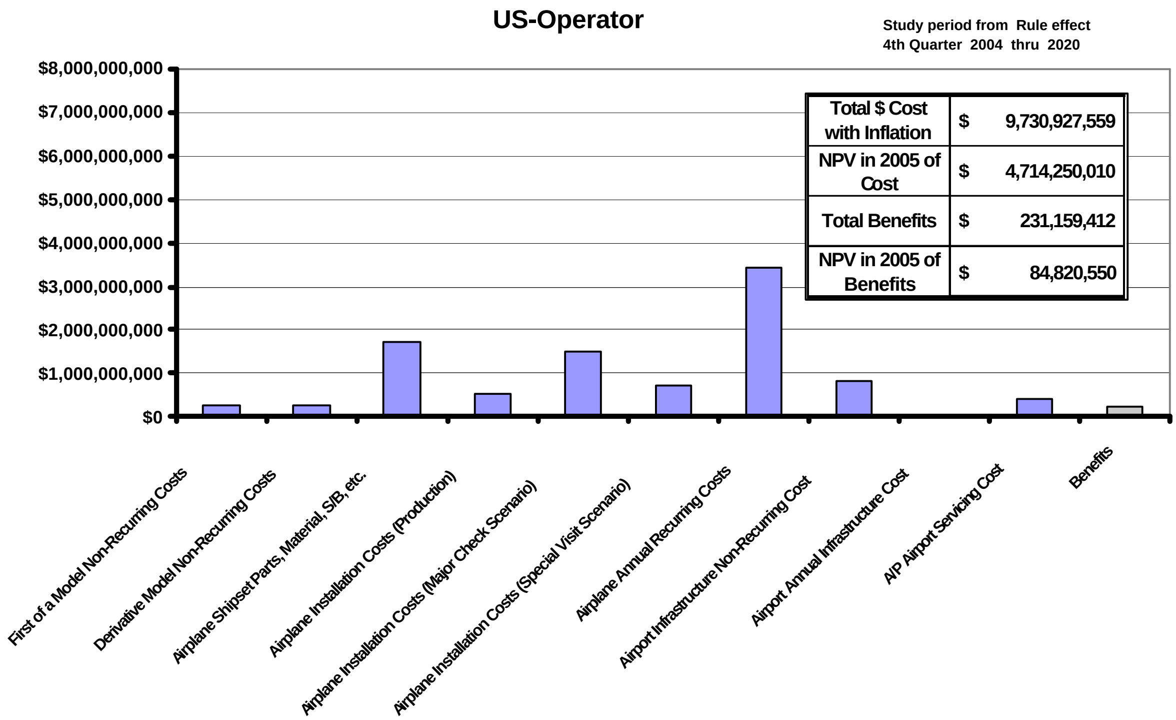

Figure 9-11. Scenario 3—Hybrid OBGI, Heated CWT Only, Large, Medium, and Small Transports, PSA/Membrane Systems (U.S.)

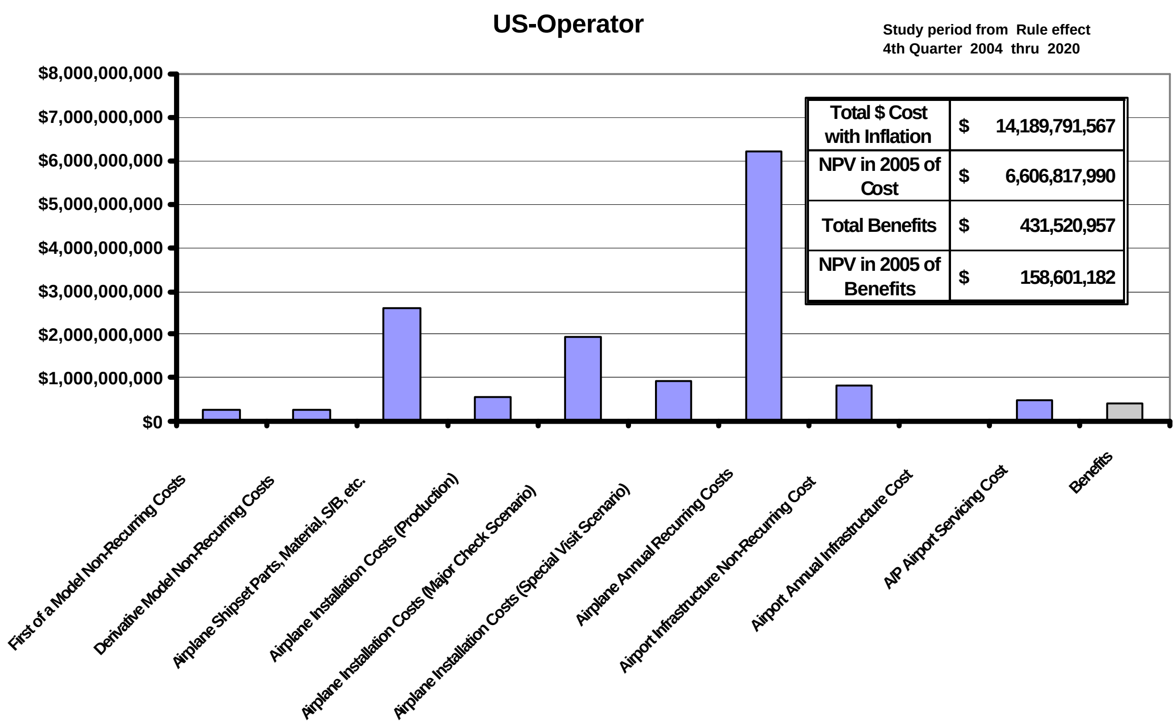

Figure 9-12. Scenario 4—Hybrid OBGI, All Fuselage Tanks, Large, Medium, and Small Transports, PSA/Membrane Systems (U.S.)

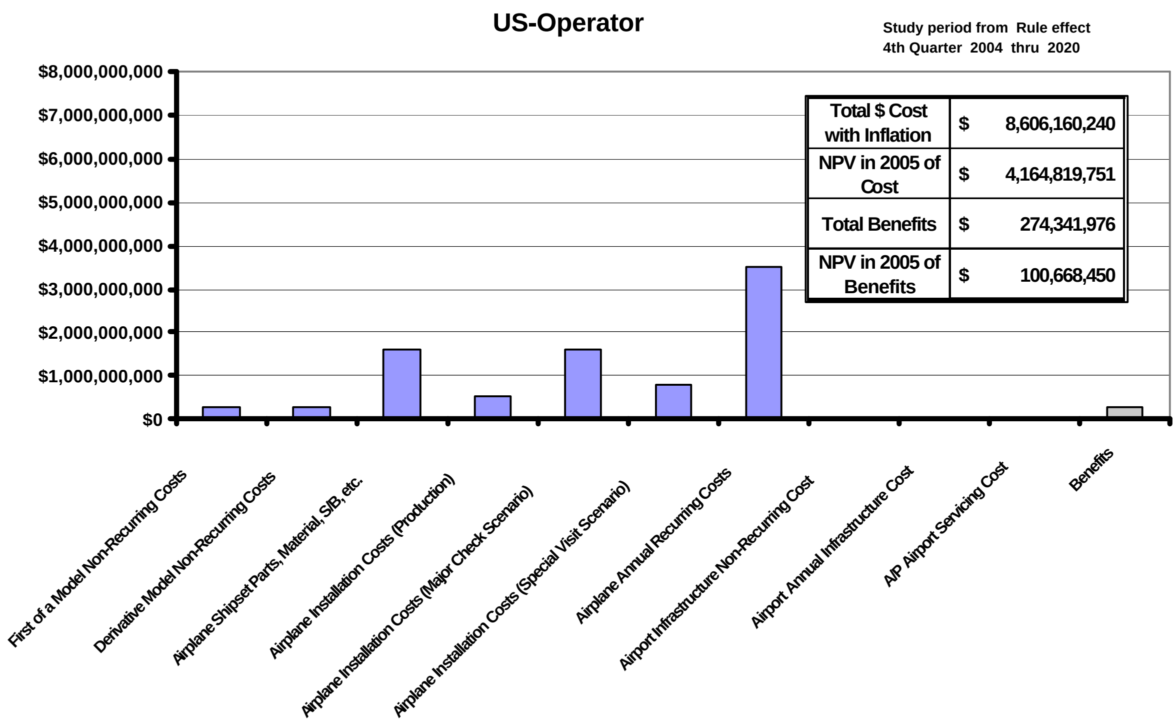

Figure 9-13. Scenario 7—Hybrid OBIGGS, Heated CWT Only, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (U.S.)

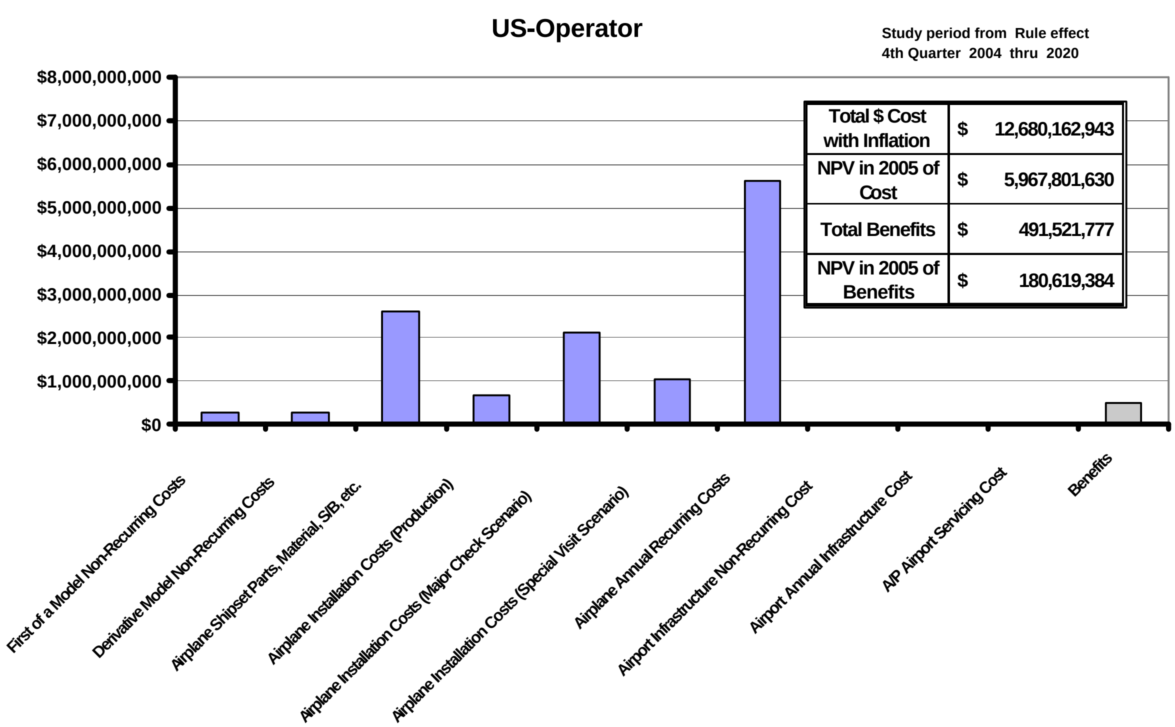

Figure 9-14. Scenario 9—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (U.S.)

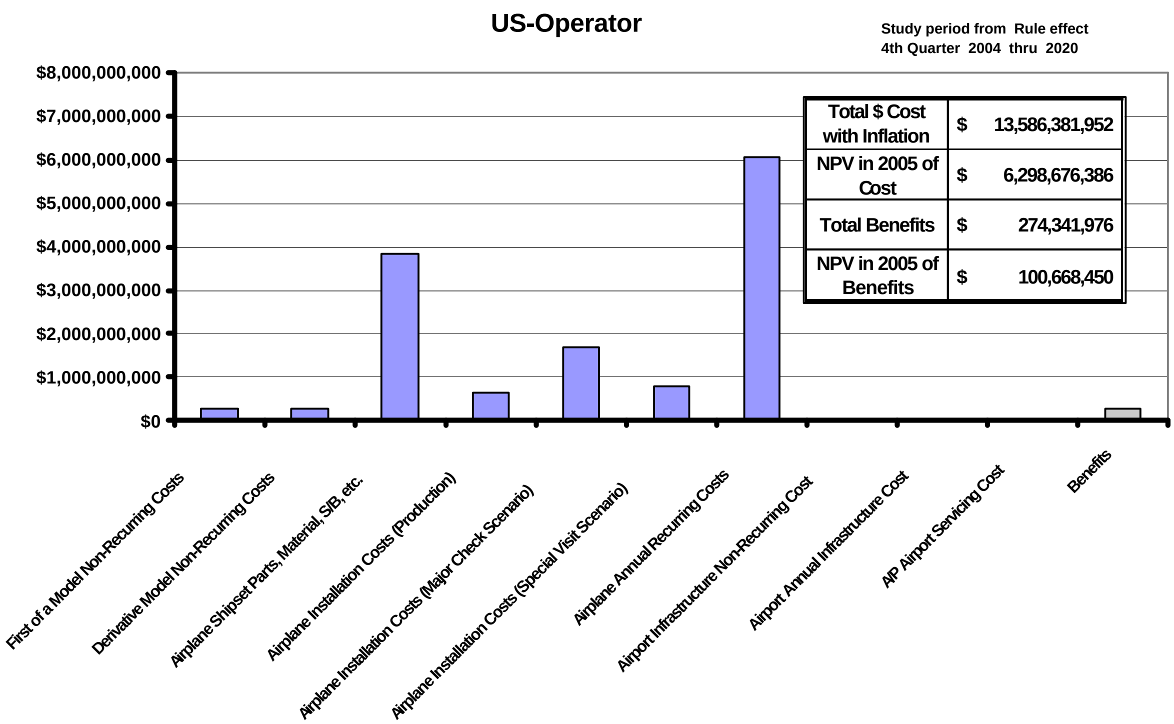

Figure 9-15. Scenario 14—Hybrid OBIGGS, Heated CWT Only, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (U.S.)

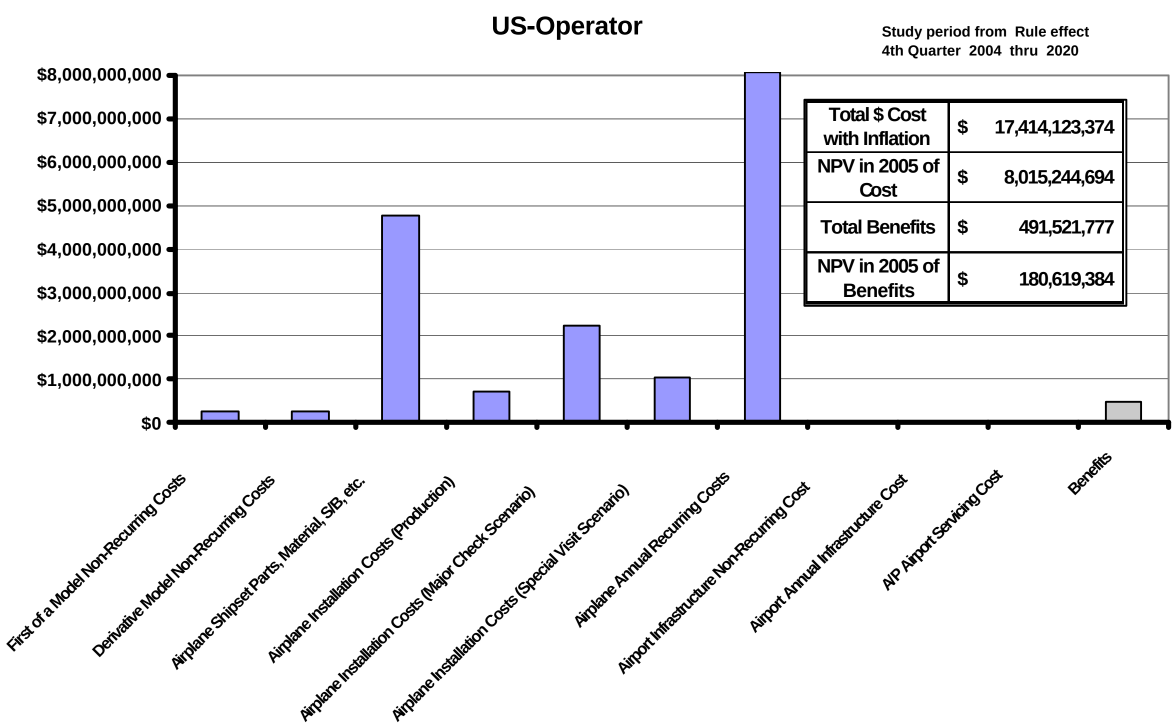

Figure 9-16. Scenario 15—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (U.S.)

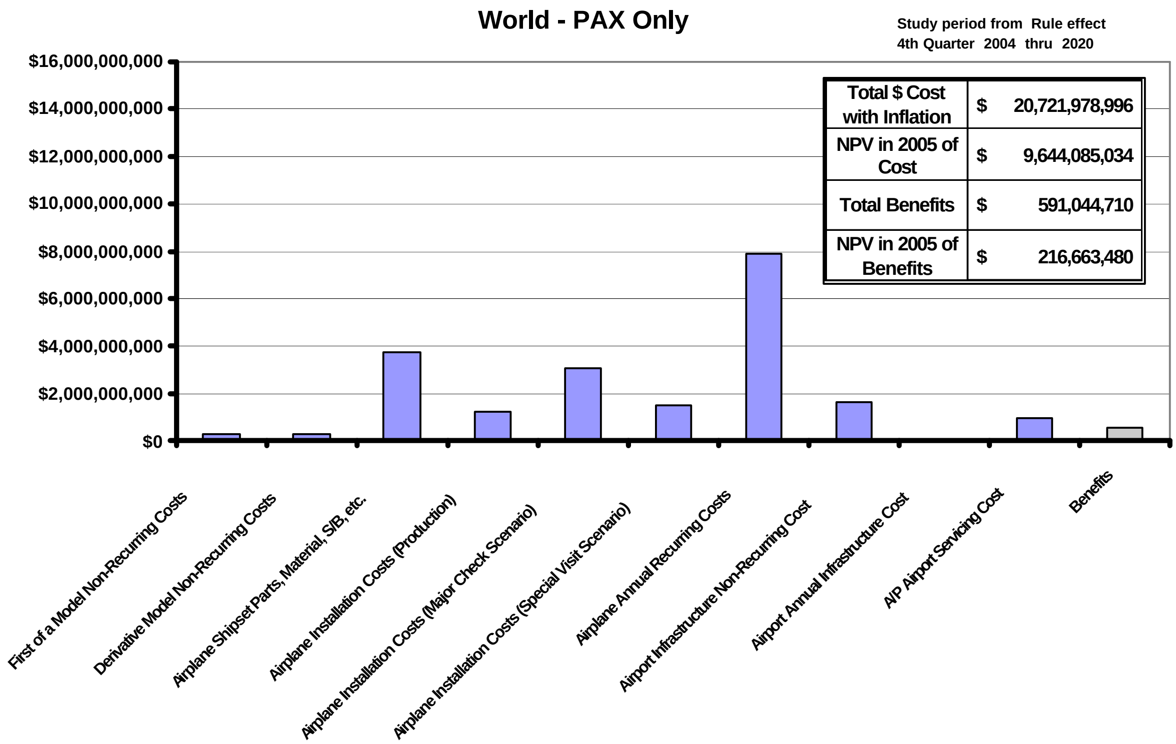

Figure 9-17. Scenario 3—Hybrid OBGI, Heated CWT Only, Large, Medium, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

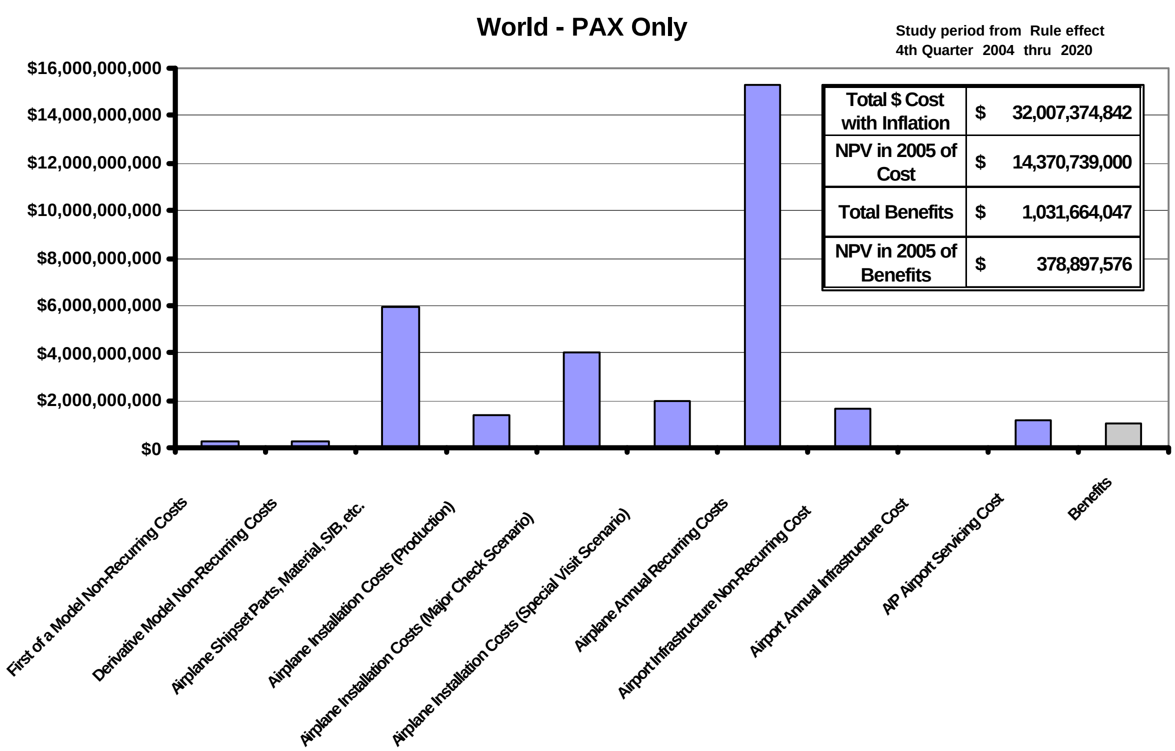

Figure 9-18. Scenario 4—Hybrid OBGI, All Fuselage Tanks, Large, Medium, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

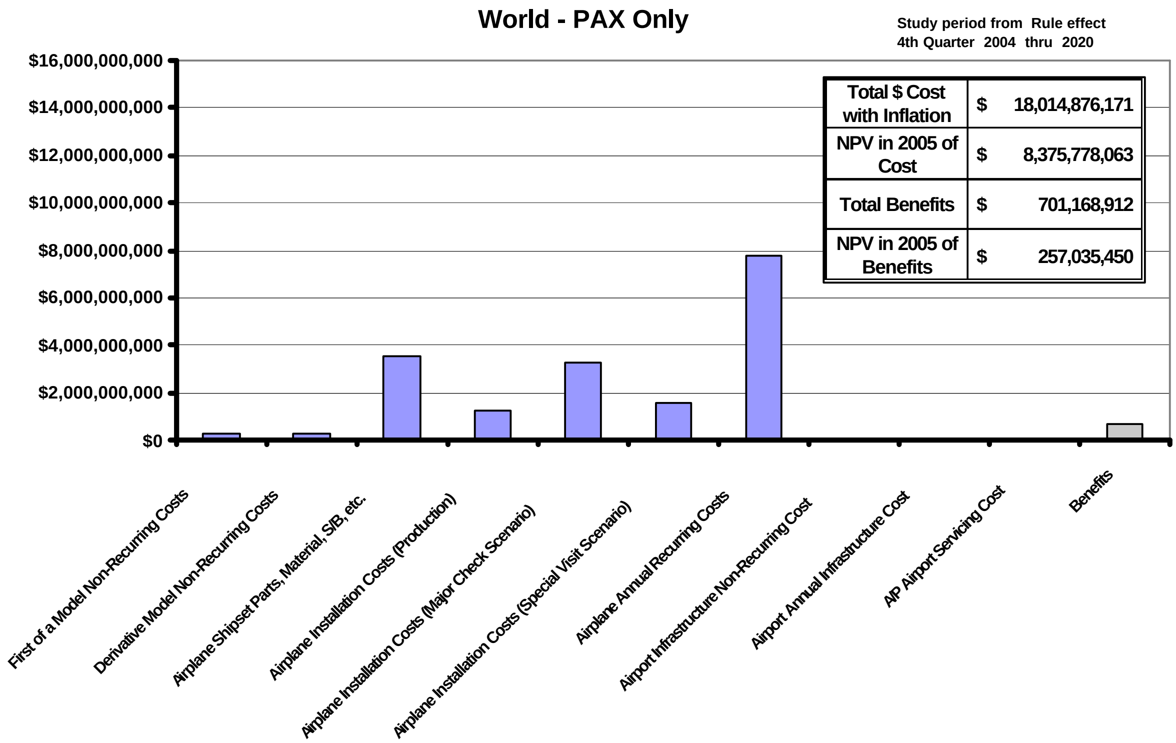

Figure 9-19. Scenario 7—Hybrid OBIGGS, Heated CWT Only, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

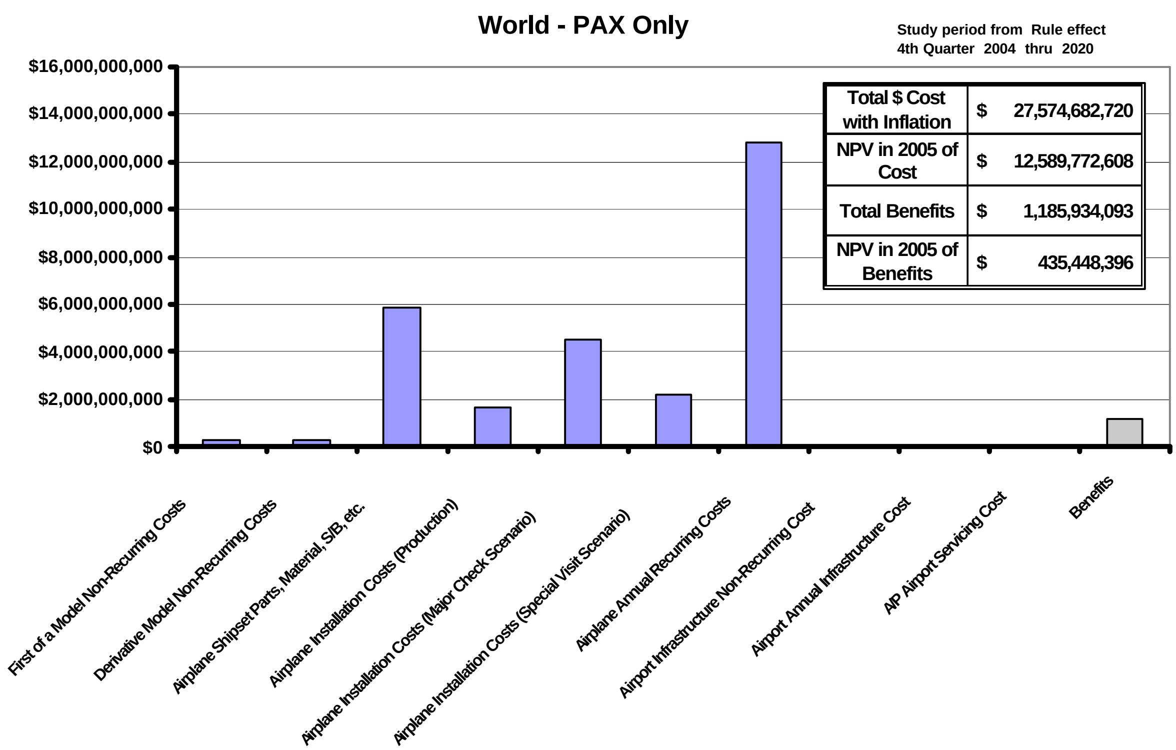

Figure 9-20. Scenario 9—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

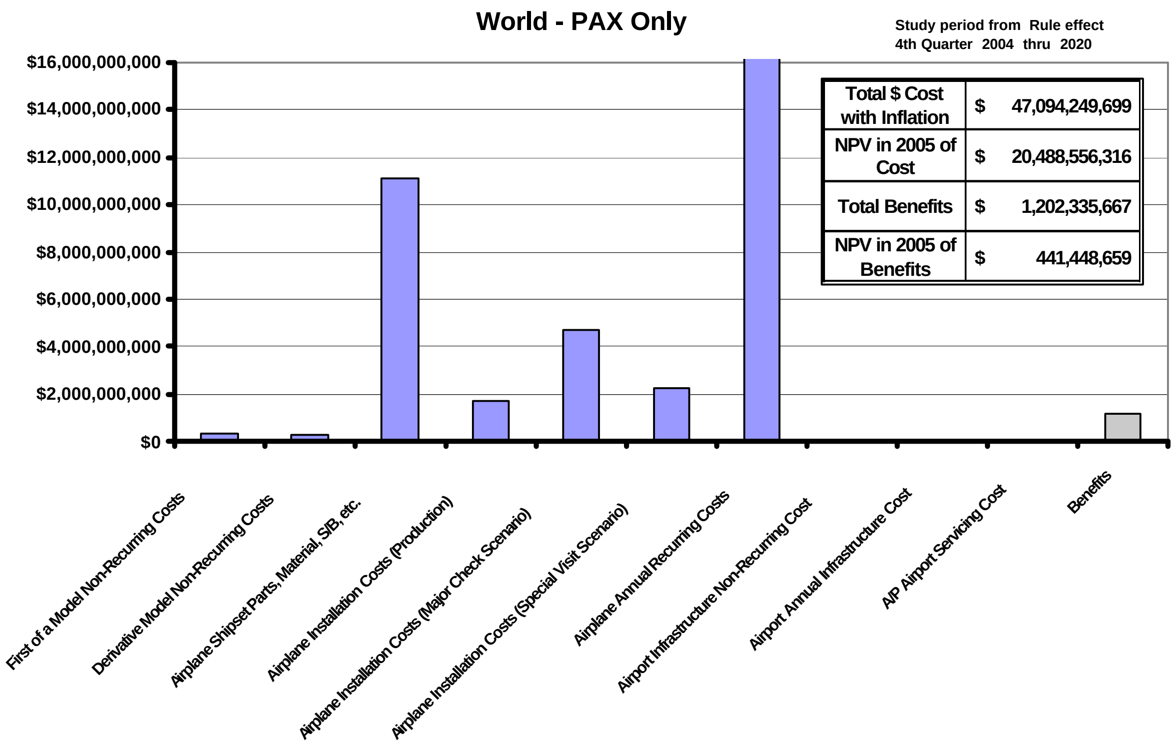

Figure 9-21. Scenario 13—OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

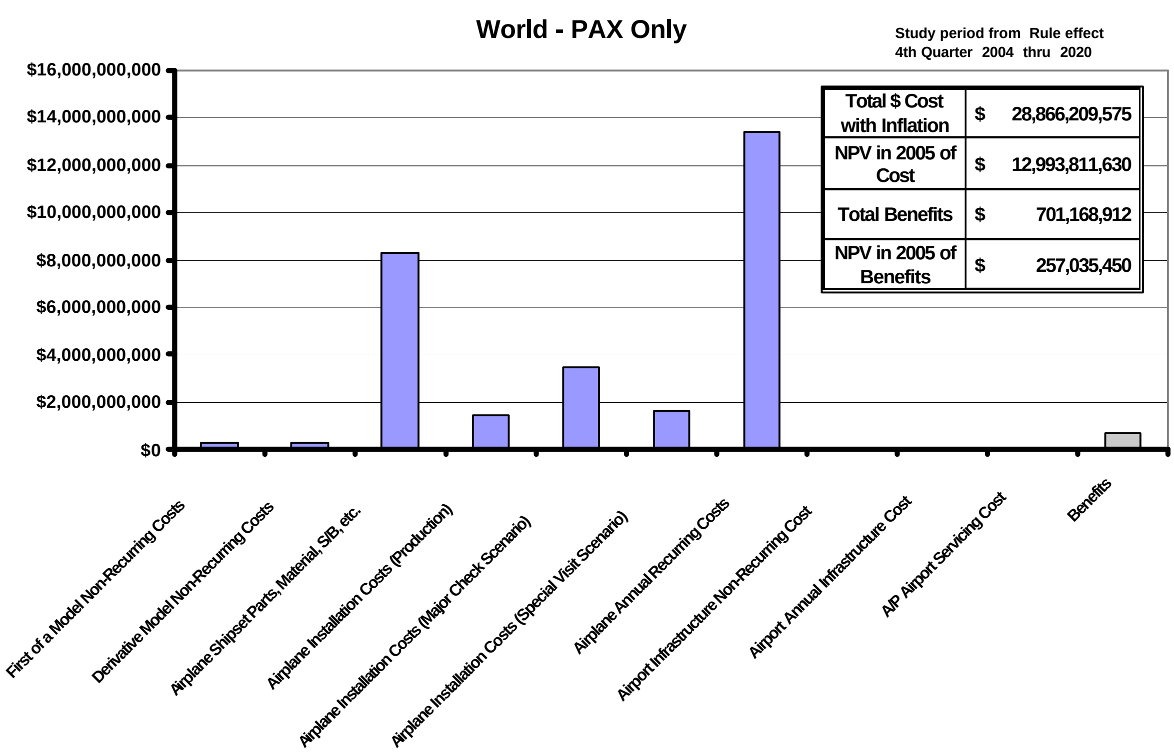

Figure 9-22. Scenario 14—Hybrid OBIGGS, Heated CWT Only, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

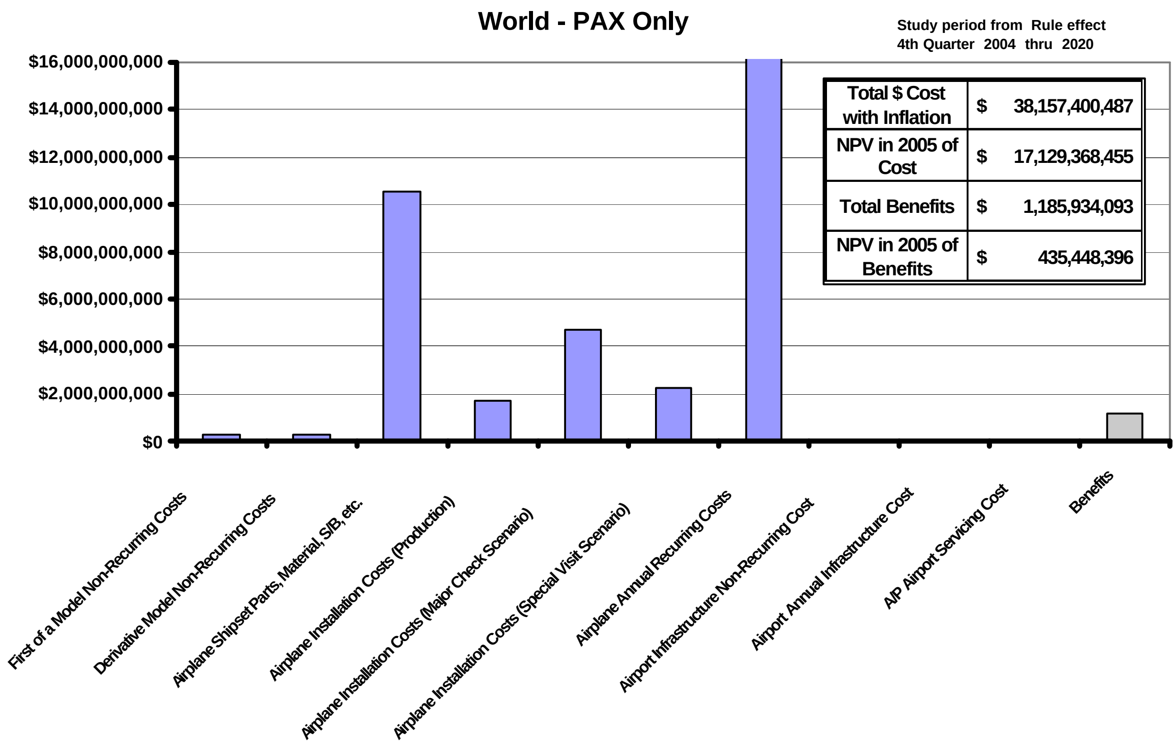

Figure 9-23. Scenario 15—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (World, Passenger Only)

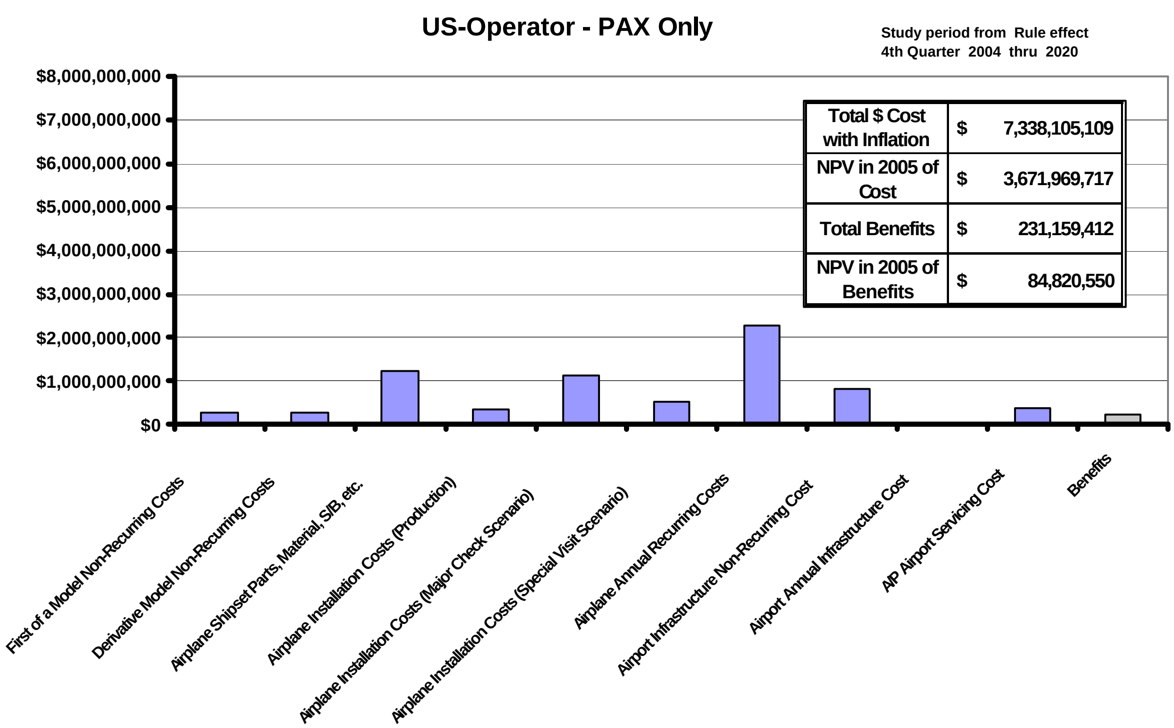

Figure 9-24. Scenario 3—Hybrid OBGI, Heated CWT Only, Large, Medium, Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

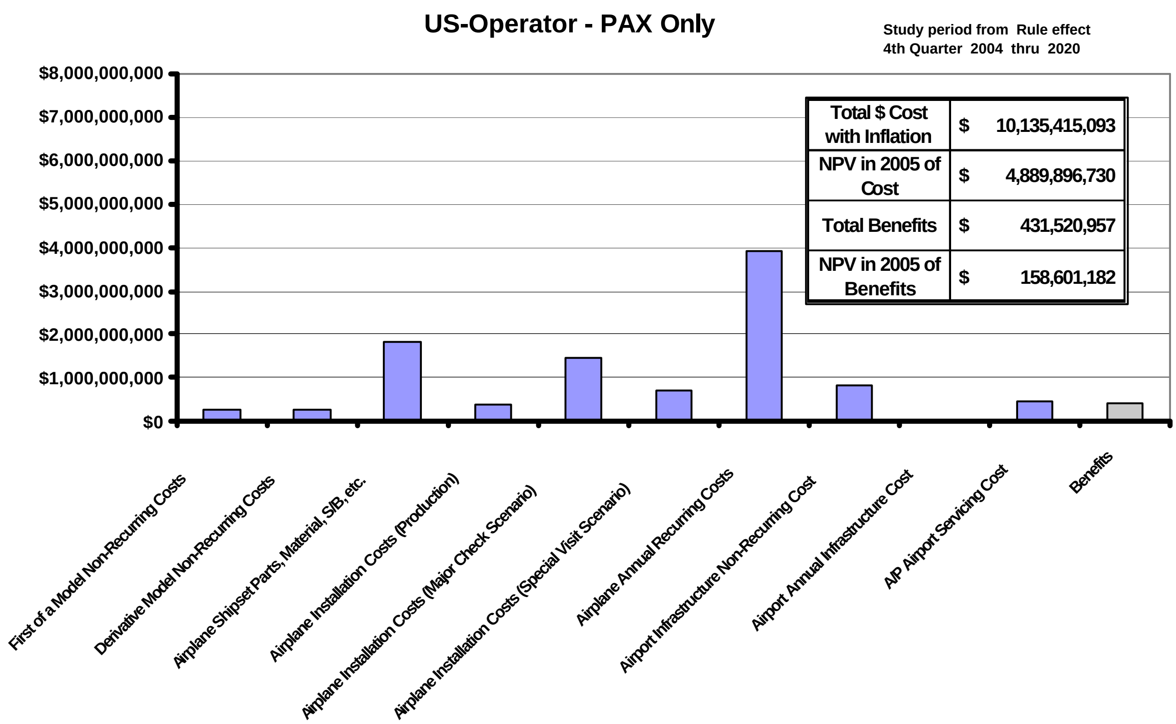

Figure 9-25. Scenario 4—Hybrid OBGI, All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

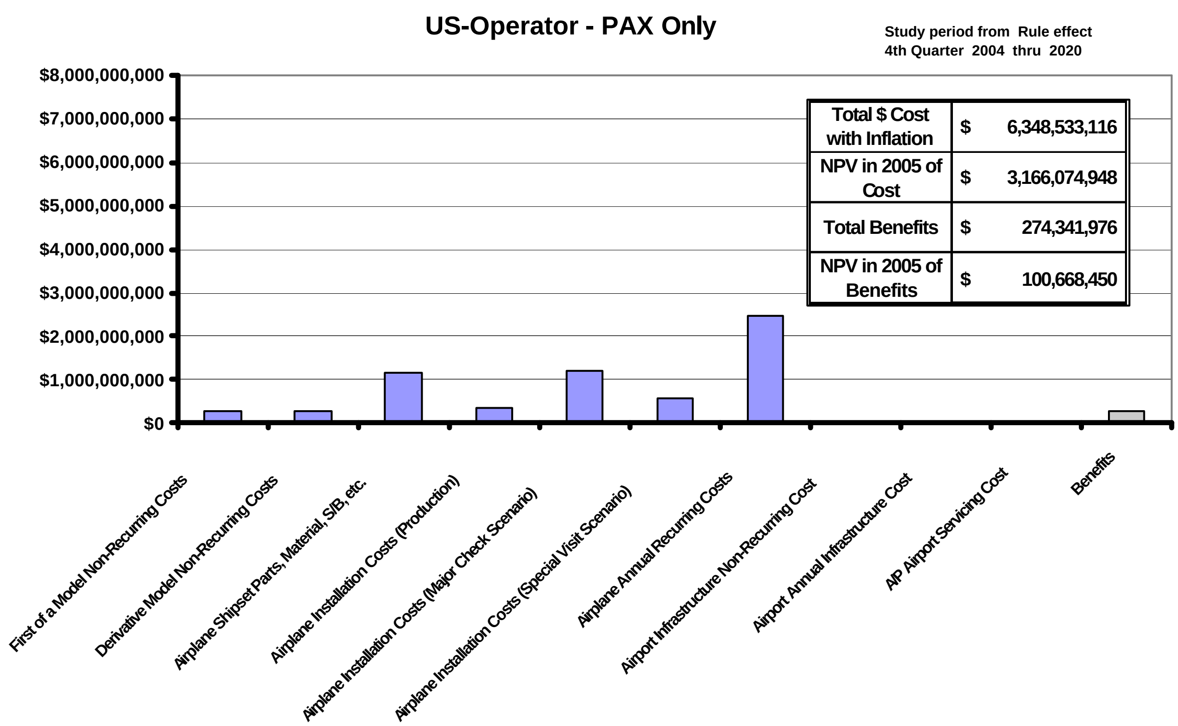

Figure 9-26. Scenario 7—Hybrid OBIGGS, Heated CWT Only, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

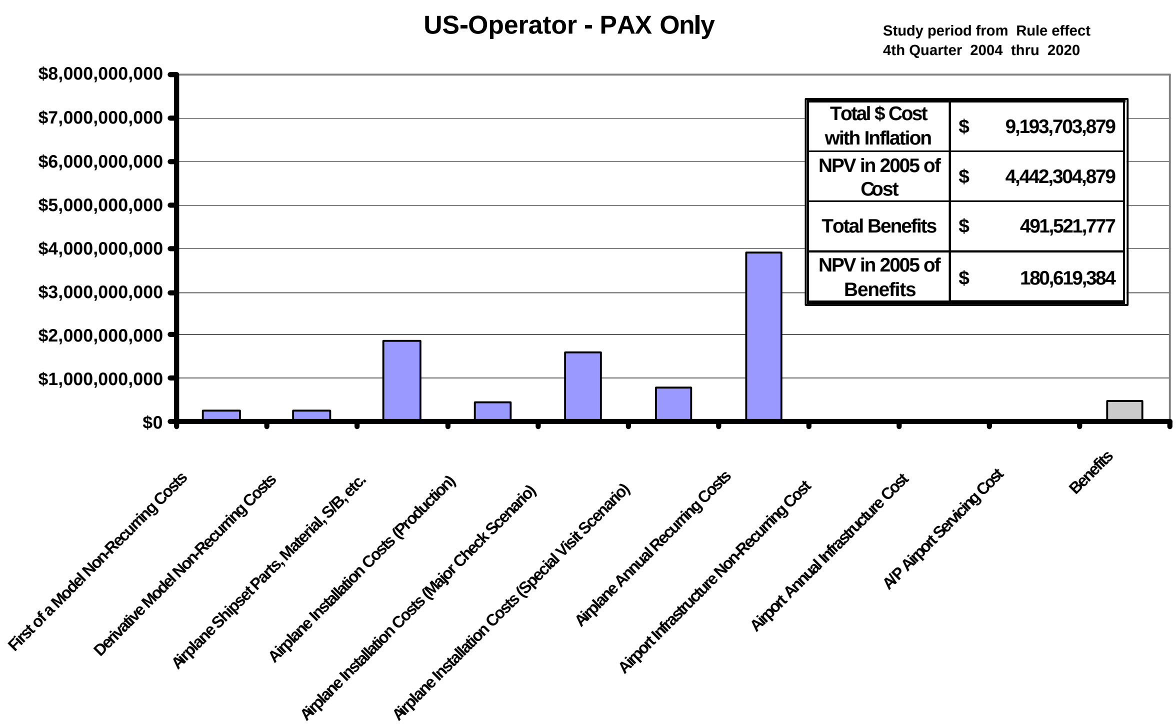

Figure 9-27. Scenario 9—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems, and Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

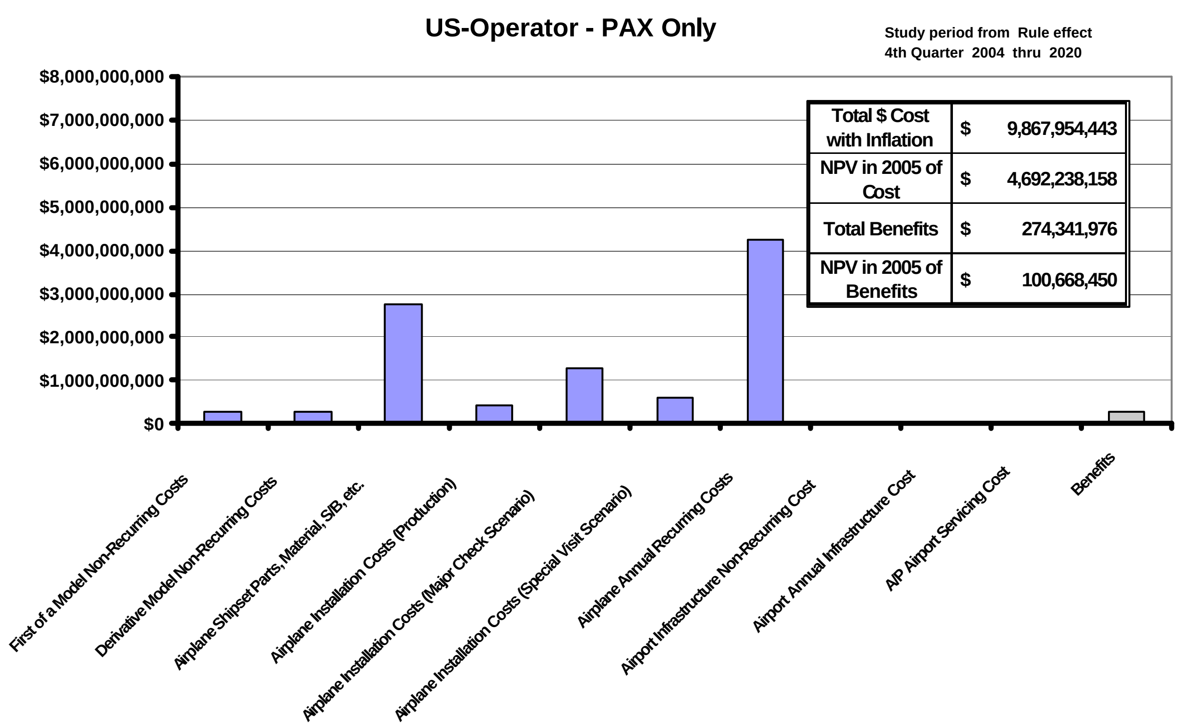

Figure 9-28. Scenario 14—Hybrid OBIGGS, Heated CWT Only, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

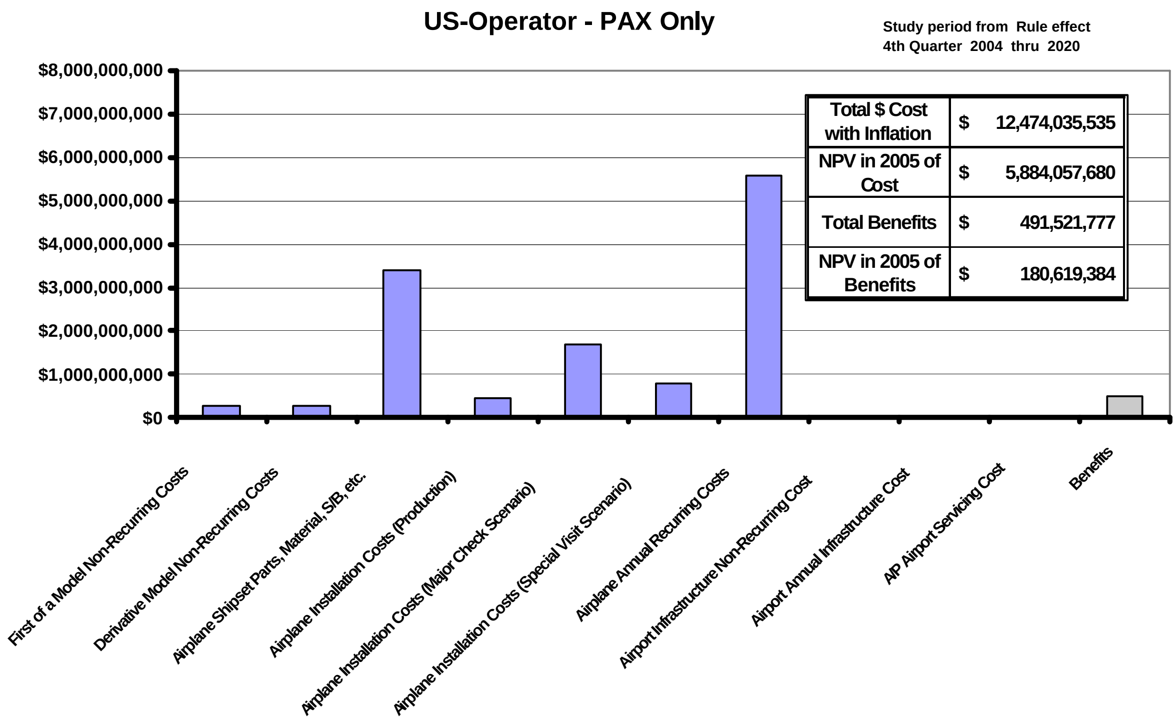

Figure 9-29. Scenario 15—Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, and Small Transports, PSA/Membrane Systems (U.S., Passenger Only)

9.8 PROS AND CONS OF SYSTEM DESIGN CONCEPT

Pros of the Hybrid OBGIS

a. The hybrid OBGIS provides a reduction in total flammability exposure comparable to that of GBI.
b. The hybrid OBGIS potentially reduces corrosion and condensation in the fuel tanks, depending on where and how the operator uses the system.

Cons of the Hybrid OBGIS

a. The hybrid OBGIS is almost as large as the full OBGIS.
b. The cost of components (only a part of the total system cost) far exceeds the potential benefit.
c. Additional cost is incurred because extra fuel is burned as a result of the weight of the system plus the added aerodynamic drag caused by its inlet and exhaust ports.
d. The airplane's center of gravity may be adversely affected by the system's location in some airplane models, which will also cause a fuel penalty.
e. Compressor and fan noise may have to be damped, depending on local noise regulations.

Pros of the Hybrid OBIGGS

a. The hybrid OBIGGS provides a reduction in total flammability exposure comparable to that of GBI.
b. It is the smallest and least expensive of all the onboard design concepts.
c. The hybrid OBIGGS potentially reduces corrosion and condensation in the fuel tanks, depending on how the operator uses the system.

Cons of the Hybrid OBIGGS

a. The cost of components (which is just one component of the total system cost) far exceeds the potential benefit.
b. Additional cost is incurred because extra fuel is burned as a result of the weight of the system plus the added aerodynamic drag caused by its inlet and exhaust ports.
c. The airplane's center of gravity may be adversely affected by the system's location in some airplane models, which will also cause a fuel penalty.
d. Compressor and fan noise may have to be damped, depending on local noise standards.

9.9 MAJOR ISSUES AND RESOLUTIONS ASSOCIATED WITH CONCEPT

The issues and resolutions for these hybrids are similar to those of their full-sized counterparts, except that each is smaller than the full-sized version. See figure 9-30 for the hybrid OBGIS and figure 9-31 for the hybrid OBIGGS.

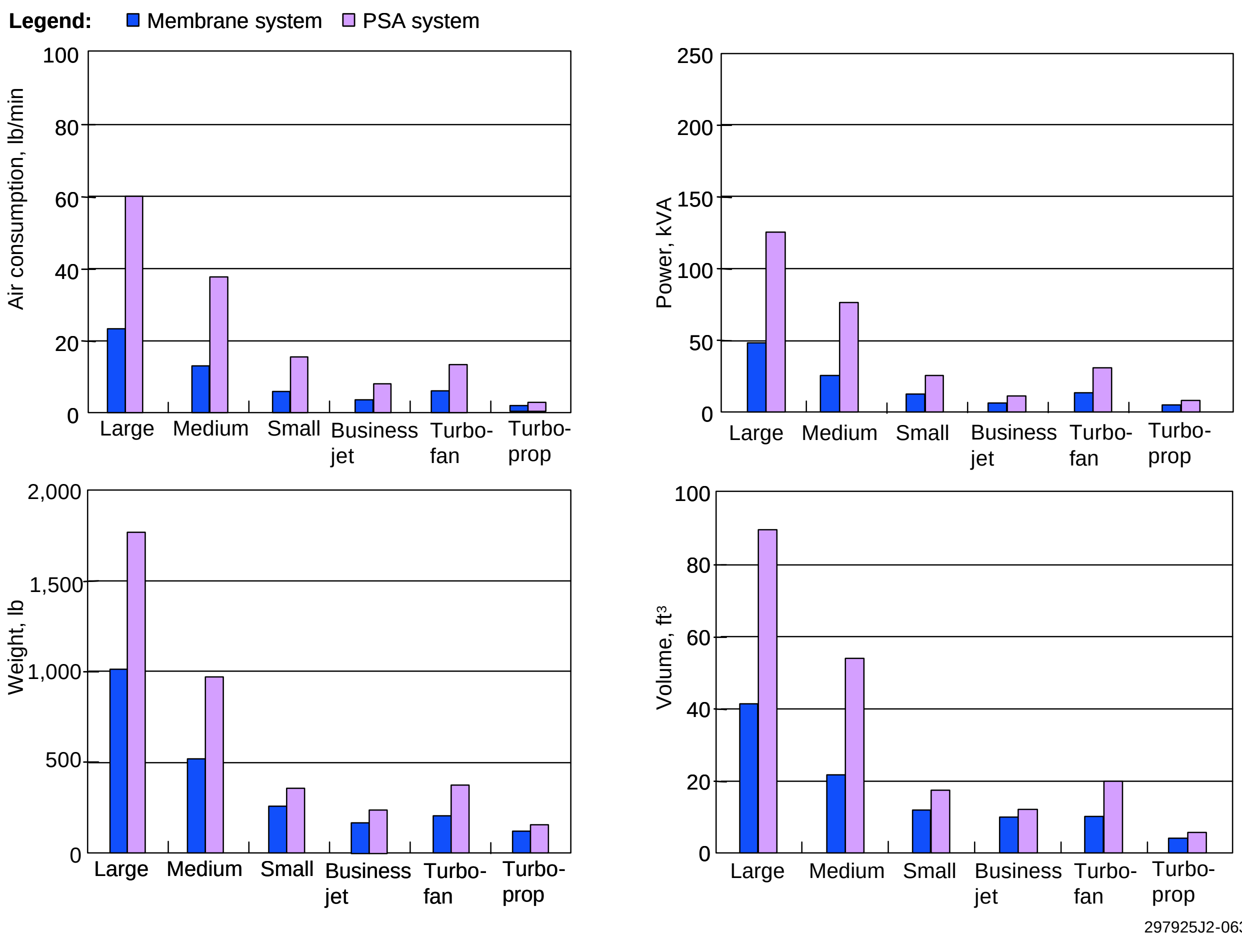

Figure 9-30. Hybrid OBGIS Installation Issues

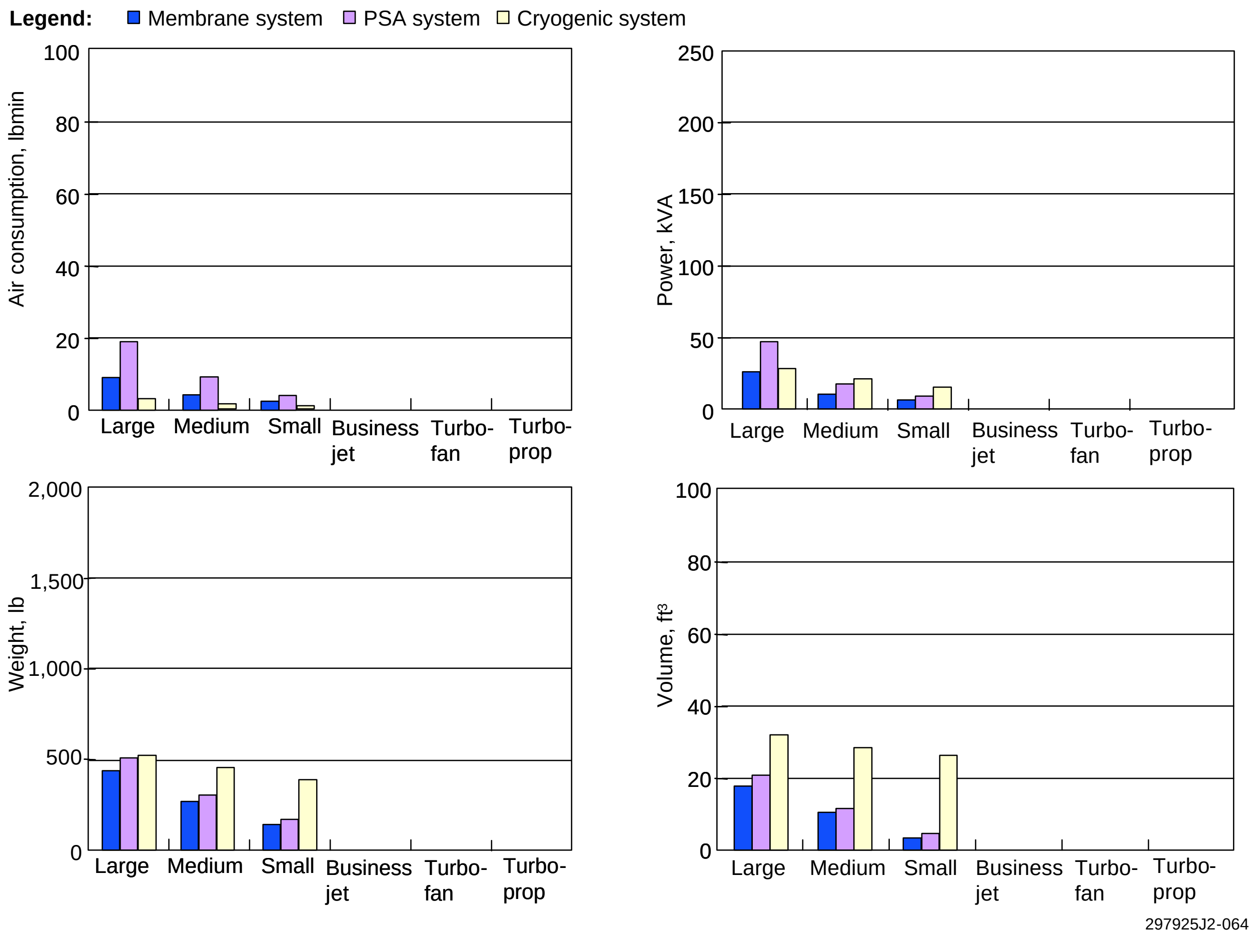

Figure 9-31. Hybrid OBIGGS Installation Issues

9.10 CONCLUSIONS

The hybrid OBGIS does not offer significant benefit for the extra certification effort required to operate it during taxi-in. Therefore, the FTIHWG does not recommend this concept.

The hybrid OBIGGS offers the flammability exposure of a GBIS, with a small and relatively inexpensive onboard system. However, its cost still far exceeds the potential benefit. Therefore, the FTIHWG does not recommend this concept.

10.0
Airline O&M

10.0 AIRPLANE OPERATIONS AND MAINTENANCE

The Airplane Operation and Maintenance Task Team was assembled by the Working Group to support the fuel tank inerting study. The primary functions of this team were to

- Review operational and maintenance data on existing fuel tank inerting systems.
- Evaluate the effect of the proposed inerting system design concepts on airplane operations, maintenance, and fleet planning.
- Evaluate the cost impact of the proposed inerting system concepts on flight operations, ground operations, and maintenance.
- Provide technical expertise in the area of airline and airplane operations and maintenance to the other Working Group teams.
- Document the results of the team's findings.

The team comprised individuals with extensive experience in airline flight operations, maintenance, ground operations, engineering, and aviation regulations.

10.1 METHODOLOGY

Data Review

The team's first task was to search for and review all available documentation relating to the operation, maintainability, and reliability of airplane fuel tank inerting systems. The team searched libraries and databases belonging to U.S. and European regulatory agencies, the Airline Pilots Association (ALPA), the petroleum industry, airplane manufacturers, and U.S. military services. The team also searched the Internet for information.

Little publicly available data on airplane fuel tank inerting systems exists. The team did identify some reports, primarily FAA studies, including one on the modification of a DC-9 to incorporate a fuel tank inerting system 30 years ago. With the exception of the data produced as a result of the 1998 ARAC FTHWG report and a 2000 FAA Technical Center report on GBI, none of these reports included any operational or maintenance data relevant to the current study.

The team identified several military fuel tank inerting system applications similar to those being considered for this study. However, the team obtained very little operational, maintenance, or reliability data on those systems because that data is classified.

Inerting System Concept Review

As information became available from the Ground-Based Inerting Designs and the Onboard Inerting Designs teams, the Airplane Operation and Maintenance Task Team began reviewing the systems to identify operational and maintainability considerations for each concept. We initially evaluated each concept to identify how it might affect airplane flight operations, ground operations, dispatch reliability, maintainability, and training requirements. We also considered the potential effect on passenger, crew, and maintenance personnel safety.

After this initial evaluation, the team split up into subteams to begin detailed analyses. The four subteams addressed flight and ground operations, airplane modification and retrofit, scheduled maintenance, and unscheduled maintenance and reliability.

Flight and Ground Operation Subteam. This subteam identified and quantified the operational issues, impact, and costs associated with flight operations and gate or ramp operations needed to support airplanes equipped with inerting systems for each of the inerting systems concepts. They also analyzed and developed data relating to training requirements, airplane servicing, flight dispatch requirements and resources, cost-to-carry estimates, flight operating manual procedures, and manual revisions for each of the airplane-system combinations.

Modification and Retrofit Subteam. This subteam identified and quantified the costs and impact associated with modification of each existing airplane types to install the various inerting systems. The sub-team assumed that the modification would be done according to an airplane manufacturer service bulletin that provided modification data, and that the manufacturer would make available modification kits. The subteam considered two different modification scenarios: First, the airplane is modified during a regularly scheduled heavy maintenance check. Second, the airplane is modified during a dedicated maintenance visit. The advantage of the first scenario is that access to most maintenance areas is already open for the regular maintenance check, which would reduce the total labor requirement, cost of modification, and airplane time out of service.

They developed data and estimations for each of the airplane-system combinations. These estimates were to include but not be limited to material and kit costs, modification labor-hours, engineering support requirements, technical publication revisions, airplane time out of revenue service, spares and training requirements, and any other issues related to the retrofit of inerting systems on existing airplanes.

Scheduled Maintenance Subteam. This subteam identified and quantified the costs and impact associated with the routine maintenance of the inerting system as well as any effects the inerting systems might have on the maintenance requirements of other airplane systems or equipment.

The subteam developed data for each of the airplane-system combinations. This data would include but would not be limited to airplane and component maintenance tasks, task intervals, task labor-hours, estimate of annual scheduled maintenance labor-hours, annual material costs, and the impact on check schedules, tooling requirements, and all other aspects of scheduled maintenance.

Unscheduled Maintenance Subteam. This subteam identified and quantified the costs and impacts associated with the nonroutine maintenance of the inerting system. They also would work with the Design, Rulemaking, and Safety teams to define MMEL requirements and limitations.

They also developed data for the cost and impact of unscheduled maintenance on each of the airplane-system combinations, including but not limited to

- Line maintenance tasks.
- Line maintenance labor-hours for troubleshooting and repair based on reliability data.
- Delay and cancellation rates.
- Airplane-on-ground time.
- Line maintenance training requirements and costs
- Component overhaul interval, labor, and material costs.
- All other impacts related to unscheduled maintenance and system reliability as measured in MTBF or MTBUR.

10.1.1 Modification

General

The inerting systems would be installed by way of modification or retrofit. OEMs would retrofit airplanes in production. OEMs would also need to provide modification to operators through a service bulletin. Operators, maintenance facilities, or OEMs will modify in-service airplanes.

An FAA-approved OEM service bulletin for retrofitting an inerting system should be available before any final rule compliance date is set for retrofit of in-service airplanes. Failure to do this has caused problems for operators in the past. For example, in 1998 the FAA issued an AD for 747-100/-200/-300/-SP/-SR–series airplanes on changing wire separation requirements for fuel quantity indicating system wiring. Although an approved retrofit solution was not available, a 3-year AD compliance time for airplane modification was set. The FAA expected the OEM to complete design changes, gain approval, and make service bulletins available within 1 year of the effective date of the AD. This would have allowed the operators 2 years to modify their affected fleet. However, the FAA-approved retrofit solutions did not become available until almost 24 months into the compliance period, thereby significantly affecting the operator’s ability to complete the modifications within the remaining compliance time. Because of the potential for delays in the design approval, it is critical that before the establishment of any compliance date requiring installation of an inerting system, an approved service bulletin must be available. This will ensure that operators have sufficient time to complete the modifications within the compliance period of a rule. Because of the scope of the modification, it must be accomplished during a heavy maintenance check or a special visit. Estimates have been developed for both scenarios.

The modification estimations are split into two major parts. The first is the nonrecurring costs that comprise engineering time, technical publication changes, and material control. The labor-hour estimates for these nonrecurring costs are the same for all airplane categories and are per airplane type per operator. The second part of the modification estimate includes recurring costs and comprises actual airplane modification time. This part of the estimate is per airplane.

Appendix F, Airplane Operation and Maintenance Task Team Final Report, addendum F.A.1, shows the total modification estimate. The following sections present a short description of each topic.

Engineering

Before a modification can be accomplished, the operator’s engineering department must review the OEM service bulletin to determine applicability and check for variations in airplane configurations. Then Engineering must write modification orders, including creation of the necessary drawings and job cards, and coordinate with the maintenance and material planning groups. After the modification order has been completed and is ready for production, Engineering has to create the necessary tracking numbers and maintain the records for all components and their trends. The maintenance program must be updated before release of the first modified airplanes. The engineer assigned to this modification becomes the project manager. In addition to the responsibilities described here, he or she will be assisting and monitoring the progress of this modification.

Technical Publications

The introduction of the inerting system affects the following technical publications:

- Aircraft Maintenance Manual.
- Illustrated Part List.
- Component Maintenance Manual.
- Aircraft Flight Manual.

- Flight Operations Manual.
- Structural Repair Manual.
- Fueling Manual.
- Ramp Maintenance Manual.
- General Maintenance Manual (including company procedures).
- Wiring Diagram Manual.
- Weight and Balance Manual.

In the modification estimation analyses, the team assumes that the normal revision procedures of the airplane manufacturer are used. The estimated time is the time required to revise the manuals.

Material Control and Kits

The inerting system introduces new serialized parts and consumable parts. Those new parts have to be added to the company's databases. Because insufficient data exists on the inerting system, we did not account for the material cost of consumables.

Before the establishment of any compliance date requiring installation of an inerting system, modification kits must be available and the airframe manufacturers should coordinate the flow of kits to the operators. In this way, large operators will not adversely affect the availability of kits for smaller operators.

Kit costs—the price of the kit, its storage costs, and the labor-hours needed to check it—are not taken into account because of the large variation among airplanes, which prevents the use of detailed generic data and pricing.

Project Estimation

For the modification estimation, the following airplanes were used as examples of each of the six category airplanes:

- Large-airplane category: Boeing 747 series.
- Medium-airplane category: Boeing 767 and MD-11.
- Small-airplane category: Boeing 737.
- Regional turbofan–airplane category: Fokker 28 and 70.
- Regional turboprop–airplane category: No airplane[1] .
- Business jet–airplane category: Gulfstream IV.

Appendix F, addendum F.A.2, shows the task with the labor-hours to perform the project. For this estimation, we assumed that the airplane has integrated tanks. Rubber cells are used by the Fokker 28/70/100–series airplane and as auxiliary tanks on some other transport airplanes. Introduction of the inerting system requires modification or redesign of the rubber cells. For the regional turbofan airplanes estimates were developed to show the differences in labor-hours of integral and bagged fuel tanks. Neither is the time required for moving or replacing existing installations to accommodate the piping of the inerting system.

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[1] We made no estimate for the regional turboprop airplane category because we could not find a company that does the maintenance for propeller airplanes with a CWT. Fokker Services, which made the estimate for the regional turbofan airplanes, told us that the Fokker 27, 50, and 60 airplanes (turboprop airplanes) do not have a CWT.

The engineering support requirements (e.g., engineering, technical publications, and material management) for retrofit of an operator fleet are based on a nominal fleet size.

Airplane Out-of-Service Time Estimate

We made the following assumptions to estimate the downtime for the airplane:

- Modification is accomplished based on a 5-day workweek.
- There are three shifts each with 10 people (5 mechanics, 3 avionics, and 2 sheet metal workers).

Maintenance Training

The basic training requirement for this fuel tank inerting modification consists of classroom lectures, use of the jet airplane maintenance fundamentals, CBT courseware, basic training workshops, and practical training on in-service airplanes at a maintenance organization. Substantial time is needed to educate and train the professional maintenance technicians who will be responsible for safely handling and maintaining airplanes equipped with inerting systems.

Operator maintenance and ground training departments and vendor and manufacturer training departments will need substantial time to create and present all necessary training materials for the different kinds of inerting systems. The diversity of airplane fleets and available inerting systems will compound this challenge.

Existing training manuals will need to be revised to reflect airplane modifications and operational requirements created by fuel tank inerting.

There are significant differences in training regulations among various countries. An accurate estimate would require knowing the exact number of licensed mechanics and the average number of licensed mechanics per airplane per operator. An additional factor is the fact that some operators contract with training centers to educate their maintenance personnel. Because of these and other factors the team was not able to make a labor-hours estimate for training costs. However, the team described the impact on maintenance training from the introduction of inerting systems.

10.1.2 MEL Relief

FARs require that all equipment installed on an airplane be in compliance with the airworthiness standards and that operating rules be operative. However, the FARs also permit the publication of an MEL where compliance with certain equipment requirements is not necessary in the interests of safety under all operating conditions. Experience has shown that with the various levels of redundancy designed into an airplane, operation of every system or installed component may not be necessary when the remaining operative equipment can provide an acceptable level of safety. Under the MEL, dispatch relief is granted for listed components and systems for specific periods of time before the system or component must be repaired or made operational. If repair is not made before the specified time period expires, the airplane may not be flown again until the repairs are made. The FAA uses several standard repair intervals that range from one flight to 120 days.

Primary Assumptions

As defined in the Tasking Statement, the FTIHWG's *Evaluations of all systems should include consideration of methods to minimize the cost of the system. For example, reliable designs with little or no redundancy should be considered, together with recommendations for dispatch relief authorization using the master minimum equipment list (MMEL) in the event of a system failure or malfunction that prevents inerting one or more affected fuel tanks.* The FTIHWG in general and the Airplane Operation and Maintenance Task Team specifically felt that these instructions were contradictory to the normal application of the MMEL.

These assumptions vastly affect the maintenance and operational costs for an airplane equipped with a fuel tank inerting system. Requiring system redundancy would greatly increase the cost and complexity of the inerting system and also would greatly increase maintenance and operating costs.

Likewise, if dispatch relief were not available on a system without redundancy, the maintenance requirements would be greatly increased. In addition, the rate of flight delays and cancellations would increase significantly because the system would have to be repaired before flight.

After lengthy discussions at the team and Working Group levels, we decided to proceed with the evaluation using the guidelines in the Tasking Statement. It must be understood, however, that airplane operations and maintenance costs would significantly increase with a change to either assumption. Because all FTIHWG analyses are based on these two assumptions, changing them would invalidate most of the results.

For purposes of the study, the Airplane Operation and Maintenance Task Team made an attempt to evaluate the impact of a category B or 3-day repair interval and a category C or 10-day repair interval. The impact was evaluated based on the reliability of the system, the typical amount of ground time between flights, and the typical maintenance capture rate or the frequency that an airplane overnights at a maintenance base. An effort also was made to predict the impact of having no dispatch relief, which essentially meant that one or more flights would be canceled while repairs were being accomplished. While these estimates are not comprehensive, they suggest the potential impact of the various options.

Frequency of Dispatch on MEL

To determine how frequently an airplane might be dispatched with the inerting system inoperative, the average annual flight-hours for the specific airplane category were divided by the inerting system reliability factor of MTBUR to determine the typical frequency of inerting system failures. Available time to troubleshoot and repair the system between flights is typically very short. Therefore, the assumption was made that, given the availability of dispatch relief per the MEL, maintenance would probably place the system on MEL and dispatch the airplane with the system inoperative rather than creating a lengthy flight delay.

Flight Delays

To dispatch an airplane with a system or component on MEL, some minimal amount of troubleshooting by a mechanic is required to identify the problem and verify that the system is safe for continued flight in its existing condition. The mechanic also must check the MEL to determine if there are maintenance procedures to deactivate or reconfigure the system before dispatch. The mechanic then must fill out the proper paperwork to place the system on MEL and release the airplane. The shorter the turn time, the more likely that a significant flight delay would occur. The availability of maintenance also is a factor because the number of available mechanics is very limited at many airports. Typical flight delays can range from a few minutes to several hours, depending on conditions, such as the maintenance workload at the time and weather. To reflect the potential impact on flight schedules for each dispatch on MEL, we assumed flight delay times (fig. 10-1) based on the typical turn time for that category airplane.

Airplane category	Flight delay per MEL dispatch, min
Large transport	30
Medium transport	45
Small transport	60
Regional turbofan	60
Regional turboprop	60
Business jet	60

Figure 10-1. Flight Delay Assumptions

The annual number of delays and delay time is then a function of the number of times the system fails and must be put on MEL times the estimated delay time in accordance with MEL dispatch.

10.1.3 Scheduled Maintenance

The Scheduled Maintenance Subteam was tasked with identifying and quantifying the costs and impact associated with the routine maintenance of an inerting system. Each proposed inerting system was addressed for each of the six airplane categories. (Airplanes were grouped according to standard seating configuration, and the airplane models were then placed into the six categories under consideration.) Because of the size and complexity of the onboard inerting concepts, however, we did not complete the analysis for turbofan, turboprop, or business jet categories.

Scheduled maintenance requirements should be minimal, based on the following assumptions:

- Most components will be maintained on condition.
- The system will be designed so that the risk of an undetected accumulation of nitrogen in spaces occupied by people or animals in flight or on the ground will be minimized.
- Failure of the inerting system will not provide any immediate risk to the airplane or its occupants.

A Boeing 757 (small airplane category) was chosen to establish a baseline of maintenance tasks and intervals. From there, we determined that maintenance intervals and data could be established for other airplane categories by scaling the Boeing 757 data as applicable.

To facilitate the calculation of scheduled maintenance labor-hours for each of the selected inerting systems, average use rates and maintenance intervals were obtained from Boeing and Airbus for all their jetliner models. From this information, we calculated the average maintenance intervals presented in figure 10-2. This information was used to determine the frequency, or portion, of each maintenance check per year. From that, we could establish the average additional labor-hours per year required for scheduled maintenance of an inerting system.

Airplane category	Check intervals, hr		
	A	C	Heavy
Large transport	650	5,000*	4C
Medium transport	500	4,350**	4C
Small transport	500	6,000**	4C
Regional turbofan	400	4,000	4C
Regional turboprop	500	3,200	9,600
Business jet	400	4,000	16,000

*Or 24 mo
**Or 18 mo

Figure 10-2. Average Fleetwide Maintenance Intervals

Maintenance Labor-Hours

We estimated maintenance labor-hours for the Boeing 757. These labor-hours were to be scaled to determine the additional scheduled maintenance labor-hours for other airplane categories, but no significant differences among categories were discovered. From the information available, components among airplane categories do not vary significantly. Although the size of components may differ, the scheduled maintenance labor-hours needed to inspect or remove and replace these components do not. When compared with a small-airplane category, medium- and large-airplane categories will require additional labor-hours during a heavy check to inspect the wiring and ducting of the additional wiring and tubing.

Scheduled maintenance tasks and inspection intervals for components within each concept were obtained using tasks and intervals for similar components on existing airplanes, or components performing similar functions on the V-22 Osprey. It is important to note that the V-22 Osprey currently operates with a fuel tank nitrogen inerting system.

To obtain the estimated labor-hours, the team identified maintenance tasks for similar components (e.g., components in ATA[2] 21, 28, and 36) used on in-service airplane models and then queried maintenance personnel as to whether the labor-hours per task were reasonable. The estimate was based partly on the expertise of the maintenance personnel because the actual locations of components will not be known until an inerting system is actually designed.

Cycles Versus Operating Time

It is important to note that GBIS and OBGIS maintenance intervals are based on cycles and an average system operating time per cycle. OBIGGS maintenance intervals are based on flight-hours plus ground operating time.

The team excluded scheduled maintenance for the GBIS at the heavy check for small, medium, and large airplanes. Because the amount of equipment internal to the airplane or the fuel tanks is limited, we assumed that C-check inspections would suffice.

Scheduled maintenance for the GBIS on turboprop and turbofan airplanes is required at heavy check because of the time between heavy checks.

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[2] Airplane manuals are divided in chapters according to ATA standards. Each chapter describes a specific airplane system. The ATA chapters referred to here are “Air-Conditioning” (ATA 21), “Fuel System” (ATA 28), and “Pneumatic System” (ATA 36), respectively.

Scheduled maintenance for the GBIS on business jets would be required annually.

Additional Maintenance Tasks

Numerous maintenance checks will be required but cannot be evaluated until final designs are determined. These would include, but are not necessarily limited to, preflight checks (i.e., BITE checks, fault checks, extended-range checks) and pretank entry checks (which will depend on the actual operator, the equivalent of OSHA, or both). In addition, we do not include unusual scheduled tasks based on the system chosen (e.g., daily warmup period for membrane OBIGGS).

We cannot include other scheduled maintenance items because of the peculiarities of each system, which will not be known until the system has been designed. Without knowing the design life of many of the components to be used in the proposed inerting systems, the team could not estimate labor-hours required for scheduled removals. These include specific consumables, other than filters, that are only required by the design itself (e.g., liquid nitrogen for the cryogenic inerting system).

The team recognized that a true picture of the maintenance program could be achieved only by performing an MSG-3 analysis. However, lack of design data prevented that from being accomplished for this report. (MSG-3 is a document produced by the ATA that outlines a decision and selection process for determining the scheduled maintenance requirements initially projected for an airplane system or powerplant.)

10.1.4 Unscheduled Maintenance

Component Reliability

As mentioned in previous sections, little or no documentation exists relating to the operation, maintainability, and reliability of airplane fuel tank inerting systems. The challenge for the team has been to develop a reasonably accurate method to estimate the reliability of the fuel tank inerting system design concepts.

After a review of each of the design concepts, the similarity between the proposed inerting systems and other existing airplane systems became evident. For many components, strong similarities exist with fuel, pneumatic, and air-conditioning system components that are currently used on commercial airplanes. In fact, there is a possibility that some existing valves, sensors, or fans currently used in other systems could be used in an inerting system. Therefore, for each inerting system component, the team identified as many similar airplane components as possible. The team gathered information on similar components and averaged available reliability data for those components. For components that are unique to the inerting systems, such as ASMs, the team used the manufacturers' estimates of the component reliability.

MTBF Versus MTBUR

We determined that the MTBUR would be a better indicator of the impact on the airplane maintenance requirements and operational performance than the system MTBF. Using MTBUR factors in some of the typical maintenance inefficiencies in system troubleshooting and repair, and therefore more accurately reflects the real-world problems encountered in airplane maintenance.

Airplane Use Rate

To ensure that uniform and consistent analysis methods were used to evaluate the effect on maintenance and operations, we determined airplane use rates for each of the study-category airplanes based on industry data (fig. 10-3). These use rates included daily and annual airplane flight-hours and the number of

	Daily flight-hours (hr)	Annual flight-hours (hr)	Flights per day (avg. no.)	Minimum turn time (min)
Large transport	11.18	4,081	2	60
Medium transport	7.65	2,792	3.5	45
Small transport	7.86	2,869	7	20
Regional turbofan	5.8	2,117	7.1	15
Regional turboprop	8.1	2,957	6.8	15
Business jet	1.37	500	1.5	60

Figure 10-3. Airplane Use by Category

System Reliability

The team calculated the system reliability as an inverse sum of the MTBUR inverses. We used the same method to determine the system reliability for each of the inerting system concepts.

System Annual Use Rates

Because of differences in the operating requirements and characteristics of each inerting system design concept, the amount of operating time a specific system experiences varies. System operating time is important because it directly affects system reliability and, therefore, operating costs. To account for these differences, the team developed the system annual use rates based on the operating requirements for each inerting system concept and each category of airplane.

System Annual Failure Rate

The team determined the inerting system failure rate by multiplying the system MTBUR by the system annual use rate for the category airplane. This rate was then used as an estimate of the frequency that the airplane would be dispatched with the system inoperative (MEL). We used it with the MEL repair interval requirements to estimate the percentage of time the system would be operational.

System Maintenance Workload

To determine the amount of additional workload an inerting system would add to an airplane's maintenance requirements, the team made some assumptions about the location of the inerting system components. We worked with the design teams to identify the likely locations of components. Identifying potential locations on some airplane categories was relatively easy. On the 747, for example, the teams determined that an area beneath the CWT adjacent to the air-conditioning packs was large enough for an onboard system; it met most of the design and safety requirements. This location also would provide good access for maintenance. On other airplanes, space was limited. Many of these spaces were inside the fuselage pressure vessel, raising safety concerns, and they had poor access for maintenance. On some airplanes, space inside wheelwells and wing-to-body fairings was available. In many others, the only potential locations tended to be in the aft fuselage area just forward or behind the aft pressure bulkhead. The team also considered differences in access time as a result of the time necessary to purge the fuel tanks because of the differences in fuel tank volumes.

Based on this survey of potential locations, we developed estimates for troubleshooting, removal, and installation of each component. We used this estimate and the components' predicted failure rate to develop a maintenance labor estimate for the system onboard each airplane category.

10.1.5 Flight Operations

To evaluate this process and come to the conclusions and recommendations stated further in this document, the team used several implications and assumptions. First and foremost was the assumption that, in the event the inerting system was inoperative or ground inerting equipment was not available, a means to dispatch the airplane without the fuel tanks inerted must be defined. Much discussion went into this decision, ranging from requiring inerting on every flight regardless of circumstances to treating the system as supplementary only. In the event that MEL or dispatch relief was not available, operators would incur major limitations. The scope of such limitations could be great enough to change entire route structures. Airports that could not provide nitrogen or maintenance procedures would not be available as alternatives, refueling stops, or diversions because their use would have the potential to ground airplanes and passengers short of their destinations. If inerting systems were required for safety of flight, then additional air turnbacks, flight cancellations, and delays would also have to be considered. This and the guidelines set forth in the Tasking Statement led us to our final premise. Consequently, our evaluation and methodology regarded the system as being a safety enhancement system similar to the present traffic collision and avoidance systems required on airplanes today.

The cost-to-carry estimates are a function of the weight of the system and the cost of the fuel to carry the additional load. The loss of revenue from the decrease in useful load on flights routinely operating at maximum gross weight is also considered. Because determination of the cost associated with the production of power and the resulting drag incurred by onboard systems requires detailed design data, we have not quantified these costs.

We derived flight crew procedures and associated training expenses from past typical training events similar to the requirements of the proposed system. We also assumed that an AC will be published by the FAA as a training aid from a high-level or general standpoint.

Based on the assumption that fuel tank inerting systems would not be considered a requirement for safety of flight, the Airplane Operation and Maintenance Task Team concluded that in-flight indication requirements for an onboard system would be minimal. The flight crew must be able to shut down the system in case of a catastrophic failure and would need some indication of inerting system status. This could include positive indication that the system had powered down in the event of manual system shutdown. Failure of an onboard inerting system would also be annunciated to maintenance personnel after landing. These assumptions reduce the potential for flight delays, diversions, air turnbacks, and their associated costs. Any change in the assumptions would greatly increase flight interruptions and operating costs.

10.1.6 Ground Operations

The effect an inerting system has on ground operations depends on the system concept being considered. Training, ground handling, and line maintenance requirements were considered along with the associated costs. To accomplish this, we developed conceptual models of operations with ground-based and onboard inerting systems based on inerting system concepts and airline operational experience.

The team also assumes that the FAA will provide an AC that addresses training for operators and technicians. Recent modifications to 737 CWTs and installation of smoke detection and fire suppression systems in class-D cargo compartments allow the team to draw some parallels in the processes under review. Based on the modification and training requirements involving these systems, a generic description of the model follows:

Training programs for line maintenance technicians should cover system operation, MMEL processes, and special procedures, including troubleshooting procedures. While operator training requirements and internal policies and procedures vary widely, task-specific training for technicians accomplishing the initial airplane modification should be implemented. A separate or additional program dealing with nitrogen safety and usage should be developed for those individuals working around the airplane during inerting. This team estimates that 8 hr of initial, and 4 hr of annually recurring training would be required for each technician.

10.2 MAINTENANCE IMPACTS

The retrofit and operation of any of the proposed inerting systems will significantly affect airplane maintenance programs and schedules, dispatch reliability, maintenance workload in the line environment, and safety of the maintenance personnel.

10.2.1 Modification and Retrofit

This team concludes that because of the scope of the modifications, most operators would not be able to schedule the modifications to incorporate the inerting system during an airplane's regular heavy maintenance visit (app. F, add. F.A.1). The additional labor-hours would extend the scheduled maintenance visit so much that it would interfere with the airline's maintenance schedules. Operators must complete the maintenance requirements on schedule or risk grounding airplanes. Most operators would likely start dedicated modification lines or contract the modifications out to other maintenance facilities. The disadvantage of this approach is that the existing access available during heavy maintenance visits would be lost. This would increase the total labor-hours required for the modification. Another disadvantage of this approach is that it may cause a worldwide problem with hangar availability. The team estimated that approximately 100 dedicated hangars would be necessary for modification of the existing fleet during the proposed compliance period. If the operators need to perform the modifications in a special modification line extra slots are necessary; this may result in insufficient hangar space.

Because of the number of airplanes affected, the Airplane Operation and Maintenance Task Team has serious concerns about the availability of trained maintenance technicians required to modify the airplanes within the proposed compliance period. Completing the modification of all the affected airplanes in a 7-year period would require 3,000 to 4,000 trained maintenance technicians working full time.

10.2.2 MEL Relief

The assumption of dispatch relief for the fuel tank inerting system is fundamental to estimating its potential impact on airplane operations and maintenance. If the assumption changes, the approach to evaluating the scheduled maintenance requirements would also need to change, resulting in a significant increase in estimated time and costs.

If a typical airline could not dispatch an airplane with its inerting system inoperative, the airplane would have to be taken out of service to repair the failed inerting system. The result would be a heightened burden on the airline's line maintenance functions to get the airplane back into service. Therefore, airlines would most likely focus on the inerting system's scheduled maintenance program, driving many components off the airplane for overhaul earlier in an attempt to reduce system failures in service. This would significantly increase the scheduled maintenance, overhaul, and operating costs for the inerting system.

10.2.3 Scheduled Maintenance

As shown in the specific inerting design concept sections, scheduled maintenance impact reflects access, inspection of component, and closure, but does not reflect any nonroutine correction of discrepancies. Neither does it include the cost of any special equipment or tooling required to accomplish the inspections or any of the costs related to the airplane's modification. It begins after the inerting system has been incorporated.

The heavy check inspections shown for the different inerting design concepts do not reflect any additional workforce required to comply with safety requirements for fuel tank entry into confined spaces with NEA present.

Airplane fuselage seal deterioration occurs because of increasing airplane age, and pressure decay checks allow discovery of seals that require replacement or rework. The use of cabin air to supply the inerting system increases the demand on the airplane air-conditioning packs. Consequently, the maximum allowable cabin leakage rate will have to be maintained at a lower level to ensure that the air-conditioning packs will continue to maintain the required cabin pressurization.

We have added extra labor-hours to each C- and heavy check to allow for a fuselage pressure decay check and rectification if cabin air is used to supply the inerting system. Operator experience has shown that in-service airplanes periodically require a pressure decay check in order to maintain limits prescribed in airplane maintenance manuals.

The extra labor-hours are averages obtained from those operators whose maintenance programs currently require fuselage pressure decay checks.

10.2.4 Unscheduled Maintenance

Each of the design concepts included in this study, from the least complex (GBI) to the most complex (OBIGGS), will affect line maintenance, as will the introduction of any new system onto an airplane. From a general perspective, the introduction of a new system, and hence the introduction of new components or line-replaceable units, will affect line maintenance by affecting airplane dispatch reliability.

In simple terms, the more components there are, the less reliable the system, resulting in a lower overall airplane dispatch reliability rate. The reliability of each component or line-replaceable unit and its MTBUR directly relates to unscheduled line maintenance activity. This in turn means increases in labor-hours (i.e., troubleshooting, component access, and component removal and replacement times), material, and labor costs, and most likely in airplane delays and cancellations. The introduction of a new system and its components can also affect other systems by limiting access to their components, thus affecting unrelated component replacement times.

The specific effect on line maintenance as a result of the introduction of inerting is best evaluated by looking at component MTBUR data for similar or related systems. The effect on other systems resulting from operating the various inerting systems must also be considered. For example, the proposed OBIGGS design concept extracts cabin air as an air source during certain flight phases. Although a scheduled maintenance task to accomplish a periodic fuselage pressure decay check will need to be implemented, cabin air extraction will undoubtedly affect airplane pressurization, especially on older airplanes. This leads to unscheduled maintenance activities and associated costs to isolate and rectify air losses. The effect on line or unscheduled maintenance varies depending on the inerting system used. We discussed these differences in more detail in each of the system design concept sections.

We did not include unscheduled maintenance costs associated with component overhaul, including labor and material costs, and costs associated with special equipment and tooling in the analysis because of insufficient data.

Special precautions must be taken when performing line maintenance on some inerting system components such as confined space entry procedures, depending on their location. Additional hazards associated with gaseous and liquid nitrogen must also be considered. These special precautions and additional hazards result in increased line maintenance costs through increased training (both initial and recurring), equipment, and procedure and policy implementation. The specific issue related to maintenance personnel safety associated with nitrogen inerting systems is discussed in more detail in the Maintenance Safety section.

Because of the unique safety precautions associated with performing line maintenance tasks on inerting system components, specially trained line maintenance personnel would be required, similar to wet cell entry-skilled personnel. Some airlines may use contracted personnel to perform such tasks.

10.2.5 Maintenance Training

To provide a safe working environment, operators are required to provide maintenance training before introducing an inerting system. Training instructors may need to modify their schedules, additional instructors may need to be hired, and training personnel may need to attend vendor and manufacturer classes. Afterward, these instructors will need to spend time adapting vendor training materials to their operators' standards. Only after the new training material is finished and approved by the local regulatory authorities can regularly scheduled classes begin for maintenance and ground support personnel. The variety of airplane fleets and available inerting systems will require mechanics and ground support personnel to be trained for all systems applicable to all airplane categories in the operator's fleet. This fuel tank inerting training requirement will consist of classroom lectures, jet airplane maintenance fundamentals, CBT courseware, and basic training workshops, as well as practical training on in-service airplanes after the new system is introduced.

10.3 OPERATIONAL IMPACT

The installation and operation of a fuel tank inerting system on an airplane significantly affects the daily operations of that airplane, its flight crew, and its ground support personnel. System reliability affects flight schedules and airplane dispatch rate. Flight crews will have to monitor the system to maintain operational safety. Ground support personnel will have to service ground-based systems, and everyone working on or around the airplane will have to be aware of the potential hazards associated with working around large quantities of nitrogen.

10.3.1 Flight Operations

Schedule, MEL and dispatch relief, lost revenue, operational safety, and training will likely have the greatest impact on flight operations. The following is a brief discussion of the severity of the impact in relation to the degree of restriction in a final rule. The impact ranges from inerting having a relatively minor impact on flight operations to its being rendered impractical in service.

10.3.1.1 Schedule Impact

Potential impacts to flight schedules will vary greatly depending on the type of inerting system used, the type of operation, and the availability of MEL and dispatch relief. Schedule delays from inadequate turn times are likely to be significant in those operations that routinely turn their airplanes around in less time than the systems were designed to accommodate. These types of delays are most likely to occur while using GBI. To minimize the potential impact on flight operations, we collected average minimum turn time data (fig. 10-4) from operators to determine the design goals for the inerting system concepts. This data was used by the Ground-Based Inerting Design and the Onboard Inerting Design teams to minimize the impact of inerting on airplane turn times. Under normal situations, the concept design goals preclude the requirement for extended gate time, however, some operators with very quick airplane turns could still be affected.

	Average minimum turn time (min)	Average airplane cycles per day	Airplane annual use rate
Small transport	20	7	2,869
Medium transport	45	3.5	2,792
Large transport	60	2	4,081
Business jet	60	1	500
Regional turboprop	15	6.8	2,117
Regional turbofan	15	7.1	2,957

Figure 10-4. Average Minimum Turn Times

The costs associated with such delays may be quantified by taking the percentage of flights that normally operate below the minimum scheduled time and multiplying it by the industry standard delay costs for each minute incurred.

MEL and dispatch relief, or lack thereof, have the greatest potential to escalate costs exponentially. The following section addresses this issue more fully. The installation implementation time for this proposal may also have a great effect if the modification cannot be accomplished during normally scheduled maintenance visits.

Airplane Out-of-Service Time

Most operators would not be able to schedule the inerting modification project during a regular heavy maintenance visit because of the scope of the project (app. F). The large number of required labor-hours would significantly extend the maintenance visit, which in turn would disturb the airline's operational schedule.

10.3.1.2 MEL Relief

The potential impact of MEL and dispatch relief, or lack thereof, cannot be emphasized enough, especially for onboard inerting systems. Without dispatch relief, every system malfunction would likely result in one or more flight cancellations. With estimated system failure rates ranging from two to six per year for each airplane, the average operator could experience 1,000 to 2,000 additional flight delays and cancellations per year.

10.3.1.3 Lost Revenue

The factor of lost revenue is an issue only on the percentage of flights operating at or near maximum takeoff weight for the specific flight. We took no other flights into consideration because the additional weight of the inerting system would not be expected to affect the planned revenue load. See appendix F for costs associated with this function. Cost to carry, however, must be applied to all systems on every flight. This is basically a function of design weight multiplied by the average industry cost per pound to demonstrate the increased fuel burn required to support the system. See appendix F for industry average costs to carry specific weights. These costs will vary greatly according to fluctuations in fuel prices. The costs associated with producing the power to run systems, such as electrical load, bleed load, or drag, will also need to be considered.

10.3.1.4 Flight Operations Safety

The major safety issues relating to flight operations are in regard to NEA leaking into the cockpit or passenger cabin and the accumulation of highly concentrated oxygen at or near a fuel source. Because of these concerns, it is recommended that nitrogen- and oxygen-level sensors be installed to provide a warning in case of a leak in critical areas. Flight crews and cabin crews will also need to be trained on how to react in the event of such an alarm. Under normal in-flight conditions, the air-conditioning system on an airplane will supply sufficient fresh air to prevent leaks from reducing the oxygen level in the cabin. However, under abnormal conditions and on the ground this may not be the case. We believe strongly that this warning system will be required to prevent subsequent loss of life in case of an unknown failure.

10.3.1.5 Flight Operations Training

Flight operations training for the purpose of this report will include training requirements for both pilots and dispatchers. A general course should be administered to both groups describing the benefits and hazards associated with nitrogen inerting systems. Also, a review of the basic fire triangle and flammability characteristics of jet fuel should be conducted to familiarize both groups with the dangers associated with warm ullage temperatures. This will allow them to evaluate operational practices, such as ground air-cart usage on warm days, to control these circumstances. Dispatchers will also need to be trained to understand any dispatch deviation requirements necessary for dispatch with an inoperative inerting system. Pilot training requirements vary greatly depending on equipment type, inerting design, and operational environment. For example, a corporate pilot operating in or out of a remote airport may have responsibilities that a pilot in airline operations may not. A typical in-house training program would basically consist of a training bulletin followed up by a regularly scheduled module during recurrent training. Outside or contracted training would typically consist of a training program established by a commercial training facility and administered during special training events. Both would greatly benefit from an AC provided by the FAA to assist operators with developing training materials.

10.3.2 Ground Operations

Installation and operation of any inerting system will affect ground operation regardless of which inerting concept is considered. Introduction of any system will add new considerations regarding safety, new tasks, or dealing with new support equipment. Obviously, GBI has the largest impact on ground operations because of the servicing requirement before each flight.

10.3.2.1 Ground Operations Safety

The safety training course for ground operations should include the hazards of nitrogen and other inert gases. Some gases such as nitrogen are particularly insidious because of their poor warning properties. Oxygen-depleted environments from the inerting process have been reported to cause fatalities to workers in confined spaces. NIOSH has provided data from a 10-year study (National Traumatic Occupational Fatalities Data) pertaining to the number of victims in single and multiple fatalities for all types of confined-space incidents.

A startling 585 separate fatal incidents in confined spaces claiming 670 lives occurred within the 10-year study period. This data strongly underscores the need for increased ground operational safety requirements by all operators before introducing any inerting systems. Because of the nature of this type of gas, confined areas such as cargo bins and equipment bays are particularly susceptible to this hazard.

The minimum ARAC recommendation is that all ground operation personnel be aware of these dangers and know what to do in the event that something goes wrong while using nitrogen to accomplish inerting. Airport fire, rescue, and safety personnel would also require additional training on the uses of nitrogen and confined-space rescue in airplane fuel tanks.

The possibility of overpressurizing the airplane fuel tanks is also a serious safety concern when using nitrogen to inert the ullage. This concern can be alleviated by having trained technicians safely and efficiently perform inerting.

10.3.2.2 Ground Operations Training

Mandatory awareness training on the dangers of using nitrogen in the quantities required to inert airplane fuel tanks is recommended. An 8-hr initial program should be provided for all technicians involved with installation and servicing.

We recommend up to a 4-hr annual recurrent program to maintain the heightened awareness on the hazards of working with nitrogen in these volumes. As an example, 1 hr could include a video on servicing while another hour encompasses troubleshooting and servicing. The remainder of the time can be used for applicable system training and open discussions. Other groups working on and around the airplane should also be aware of the dangers associated with nitrogen. These groups should receive recurrent safety training annually. These different groups should include but are not limited to cleaners, fuelers, baggage handlers, caterers, ticket and customer service agents, flight attendants, and pilots. The video, for example, may adequately educate these individuals on the dangers and cautions involved with nitrogen inerting.

For maintenance training purposes, a $75 per hr rate provided by the FAA (app. G) establishes a value for estimating an operator's cost to properly train a technician to install and service inerting systems. All other group rates will vary respectively.

10.3.2.3 Ground Servicing

With the above-mentioned dangers of using nitrogen to inert airplane fuel tanks, the servicing of airplanes with GBI systems should not be performed by ground service employees unless they are specifically trained maintenance technicians for the required inerting task. With the continual industry concerns with on-time performance, having the technician in place will help facilitate that process. Numerous discussions took place on this topic and this group concluded that, after the system has been in operation for several years, reconsideration could be given to who should perform the inerting task.

Trained technicians with a thorough understanding of the system and the consequences of improper operation would be better prepared to monitor and interrupt the inerting process at all times for diagnosis and troubleshooting of system anomalies. To enhance on-time performance, having a technician in place will provide the operator with immediate troubleshooting capability for a system discrepancy during the inerting process, thus minimizing any ground delay from maintenance problems associated with the inerting system. This process would require technicians in all airplane stations, and considerations should be given to contract maintenance personnel requirements at locations not staffed by operator-employed technicians.

11.0
Estimating & Forecasting

11.0 ESTIMATING AND FORECASTING

11.1 METHODOLOGY

Cost-benefit analysis considers a range of costs and benefits in monetary terms. The benefits in this study include the prevention of potential airplane accidents and possible resulting injuries and fatalities from postcrash fires. This analysis accounts for the annual costs and benefits over a 16-year period from the first quarter of 2005 to the fourth quarter of 2020 (rule released first quarter 2005, designs completed first quarter 2008, fully implemented first quarter 2015, and end of study fourth quarter 2020). The analysis applies an inflation factor to the monetary values of both cost and benefit cash flows and discounts these cash flows to the year 2005. This allows the continuous stream of costs and benefits to be compared directly.

This analysis evaluated 13 different combinations of inerting, airplanes, and fuel tanks, as well as both a worldwide and a U.S.-only implementation (see fig. 11-1). The analysis was also divided into in-service, and new and future production airplanes. Freighter and passenger airplanes were evaluated separately.

Number	Inerting scenario	Fuel tanks	Airplanes	Systems
1	Onboard ground inerting	HCWT only	Large, medium, and small transports	PSA/membrane systems
2	Onboard ground inerting	All fuselage tanks	Large, medium, and small transports	PSA/membrane systems
3	Hybrid onboard ground inerting	HCWT only	Large, medium, and small transports	PSA/membrane systems
4	Hybrid onboard ground inerting	All fuselage tanks	Large, medium, and small transports	PSA/membrane systems
5	OBIGGS	All tanks	Large and medium transports	Membrane systems
			Small transports	PSA/membrane systems
6	Hybrid OBIGGS	HCWT only	Large and medium transports	Membrane systems
			Small transports	PSA/membrane systems
7	Hybrid OBIGGS	All tanks	Large and medium transports	Membrane systems
			Small transports	PSA/membrane systems
8	Ground-based inerting	HCWT only	All transports	—
9	Ground-based inerting	All fuselage tanks	All transports	—
10	OBIGGS	All tanks	Large and medium transports	Cryogenics systems
			Small transports	PSA/membrane systems
11	Hybrid OBIGGS	HCWT only	Large and medium transports	Cryogenics systems
			Small transports	PSA/membrane systems
12	Hybrid OBIGGS	All tanks	Large and medium transports	Cryogenics systems
			Small transports	PSA/membrane systems
13	Onboard liquid nitrogen inerting	—	—	—

Figure 11-1. Inerting Combinations Evaluated

<u>*Methodology Used to Quantify the Benefits*</u>

The following assumptions define the methodology used to estimate the benefits of an inerting system:

- The worldwide fuel tank explosion rate, as modified by the implementation of SFAR, provides an accurate model for future fuel tank explosion rates.
- Based on the DOT's latest estimate, the amount that society would pay to prevent a potential fatality is $2.7 million.
- The average value of a destroyed airplane would be approximately $20 million (Note: this is an average value that includes both new and older airplanes of different sizes that are susceptible to fuel tank explosions).

- Based on the Lockerbie, Scotland, investigation updated to 1997 dollars, the FAA estimates that investigation of an in-flight airplane explosion would cost the U.S. Government $30 million. Although the cost of the TWA Flight 800 accident investigation will be considerably greater than $30 million, that accident investigation cost was compounded by its location in the Atlantic Ocean. The number of fatalities for an in-flight accident is determined by the weighted average number of seats within each category multiplied by the weighted average load factor.
- The monetary value of the accidents is distributed annually and treated the same as the costs (i.e., escalated with inflation and discounted to year 2005).
- The estimated accident rate is based on the worldwide rate. The estimated number of accidents in the United States is based on the worldwide rate divided by U.S. operating hours.
- Each system's flammability exposure is used to calculate the expected benefits.
- Benefits for the U.S. fleet assume that N-registered airplanes are modified by the end of the implementation period (first quarter 2015). Benefits for the worldwide fleet assume that all airplanes have been modified by the end of the implementation period.

11.2 ECONOMIC MODEL FACTORS

Data Sources

This analysis used data constructed from several different sources, because no single database contained all the necessary data. Nevertheless, we believe that this data provides a sufficiently accurate base from which to complete a valid analysis. To the extent possible, this analysis used data from the 1998 ARAC fuel tank study.

The analysis based costs on 2000 US$ and calculated costs for in-service, production, and future airplane designs separately. This study does not include costs for supplemental type certificate fuel tanks, regulatory flexibility analysis, or international trade impact assessments.

Airplane costs are divided into recurring and nonrecurring, and then into the first of a model and each of its follow-on derivative models. The derivative model costs are generally lower than those for the first of a model. Nonrecurring costs include

- OEM engineering hours, including modifications and additions to fuel system components, interfaces, instruments and displays, relocation of other equipment, wiring, tubing and ducting, and avionics software and modules.
- Documents, including specifications and internal control documents.
- Manuals, including Airplane Flight Manual, Operations Manual, and Maintenance Manual.
- Production change records.
- Lab, ground, and flight tests.
- FAA or JAA certification.

Airplane costs for parts and installation include

- Major supplier parts.
- Major assemblies.
- Tubing, wiring, and ducting.
- SB and kitting costs for retrofitting.
- Special tooling.
- Labor for planning, installation, and inspection of production airplanes.
- Airline engineering.
- Airline technical publications.

- Material control.
- Initial maintenance training.
- Flight operations engineering.
- Installation labor.
- Airplane downtime.
- Consumables.

Annual airplane recurring costs include

- Maintenance checks and inspections.
- Unscheduled maintenance.
- Delay.
- Weight.
- Maintenance, ground service, and flight crew training.

Airport costs for ullage washing—both hydrant and cart systems—were divided into large, medium, and small airport costs. The nonrecurring costs include

- Engineering design.
- System installation labor, including relocation of other equipment.
- System parts and materials.
- Other equipment, including ground service equipment, electrical, and tooling.
- Emissions controls.

Recurring annual costs for the hydrant and cart systems include

- Nitrogen for washing.
- Washing labor.
- Washing power costs.
- Washing system maintenance, inspection, and training.

This study assumes that there is no systemic increase in airplane gate turn time. Appendix G lists added costs of a systemic delay caused by an inerting system. Turnaround times for the six airplane models are

- Large: 60 min
- Medium: 45 min
- Small: 20 min
- Regional turbofan: 15 min
- Regional turboprop: 15 min
- Business jet: 60 min

The cost analysis assumes that there are no cancellations, ATBs, or diversions for any of the systems.

This study assumes

- Fuel costs of $1 per gallon (see *Air Transport World*, January 2001).
- Cost for professionals of $110 per labor-hour (FAA estimate).
- Cost for technicians and mechanics of $75 per labor-hour (FAA estimate).
- Cost for ground service personnel of $25 per labor-hour (FAA estimate).

The cost-benefit analysis assumed the ramp-up time for introducing a fuel tank inerting system into existing and current in-production fleets to be 7 years from design certification. The analysis assumed no constraints on engineering, manufacturing, parts, or facilities.

The analysis used the Campbell-Hill forecast of unconstrained growth to estimate annual changes in airplane model types, after adjusting the Campbell-Hill data for ARAC airplane categories. This weighted average growth rate is estimated at 3.6%.

For cost estimates of applying an onboard system to new airplane designs, this study assumed the designs could be optimized in the initial design phase to minimize initial and recurring costs.

Number of airports: worldwide total, 1,200 (85 large, 101 medium, 1,014 small)

Number of U.S. airports modified for U.S.-operated airplanes:

- B category: 31
- C category: 37
- D category: 354

Number of foreign airports modified for U.S.-operated airplanes:

- All categories: 158

The Airport Facility Task Team provided recurring and nonrecurring airport costs (except for inerting labor). Inerting labor estimates were based on 20 min for small airplanes, 25 min for medium airplanes, and 30 min for large airplanes at $25 per hour for burdened ground service labor.

Airplane out-of-service costs are equivalent to the average lease rates for each airplane category.

Nonrecurring development and certification costs were based on the number of major and derivative airplane models within each category (large: 6 major, 16 derivative; medium: 3 major, 9 derivative; and small: 11 major, 42 derivative).

Airline per-fleet costs were based on an average of major and minor fleet costs.

The cost penalty per pound of added weight for each airplane category is based on 1998 ARAC cost estimates.

The worldwide and U.S. average nitrogen cost in US$ is $0.13 per 100 ft^3.

11.3 STUDY PERIOD

The costs and benefits are accounted for annually over a 16-year period from the first quarter of 2005 to the fourth quarter of 2020 (rule released first quarter 2005, designs completed first quarter 2008, fully implemented first quarter 2015, and end of study fourth quarter 2020).

11.4 IMPLEMENTATION

We assumed that any proposed new rules would affect, at a minimum, both type certificate and supplemental type certificate design approval holders under FAR Parts 21 and 25, or equivalent.

We also assumed that any proposed new operational rules would affect all turbine-powered transport airplanes with a type certificate issued to large, medium, and small transport category airplanes operated under FAR Parts 91, 121, 125, or 129, or equivalent.

11.5 COST SUMMARIES

Figures 11-2 through 11-5 are cost summaries of all the inerting scenarios considered for the worldwide fleet, U.S. fleet, world passenger-only fleet, and U.S. passenger-only fleet.

Summary of Inerting Scenario Results **World**

Values in Millions	Scenario 1 - On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA/Membrane Systems	Scenario 2 - On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems	Scenario 3 - Hybrid On-Board Ground Inerting HCWT only, Large, Medium, Small Transports PSA/Membrane Systems	Scenario 4 - Hybrid On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems	Scenario 5 - OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems & Small Transports, PSA/Membrane Systems	Scenario 7 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PSA/Membrane Systems	Scenario 9 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems & Small Transports, PSA/Membrane Systems	Scenario 11 - Ground Based Inerting HCWT only, All Transports	Scenario 12 - Ground Based Inerting All Fuselage Tanks, All Transports	Scenario 13 - OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, & Small Transports, PSA/Membrane Systems	Scenario 14 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Cryogenic Systems, & Small Transports, PSA/Membrane Systems	Scenario 15 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, & Small Transports, PSA/Membrane Systems	Scenario 16 - On-Board Liquid Nitrogen Inerting
Total $ Cost with Inflation	26,321	41,901	24,416	38,349	47,601	21,476	32,969	22,973	26,203	57,021	34,569	46,797	77,735
NPV in 2005 of Cost	11,592	18,509	11,240	17,035	20,775	9,896	14,936	10,374	11,885	24,605	15,440	20,405	31,527
Total Benefits	597	1,037	591	1,032	1,202	701	1,186	668	1,109	1,202	701	1,186	1,202
NPV in 2005 of Benefits	219	381	217	379	441	257	435	245	407	441	257	435	441

Figure 11-2. Cost Summary—Worldwide Fleet, All Transports

Summary of Inerting Scenario Results **US-Operator**

Values in Millions	Scenario 1 - On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA/Membrane Systems	Scenario 2 - On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems	Scenario 3 - Hybrid On-Board Ground Inerting HCWT only, Large, Medium, Small Transports PSA/Membrane Systems	Scenario 4 - Hybrid On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems	Scenario 5 - OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems & Small Transports, PSA/Membrane Systems	Scenario 7 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PSA/Membrane Systems	Scenario 9 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems & Small Transports, PSA/Membrane Systems	Scenario 11 - Ground Based Inerting HCWT only, All Transports	Scenario 12 - Ground Based Inerting All Fuselage Tanks, All Transports	Scenario 13 - OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, & Small Transports, PSA/Membrane Systems	Scenario 14 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Cryogenic Systems, & Small Transports, PSA/Membrane Systems	Scenario 15 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, & Small Transports, PSA/Membrane Systems	Scenario 16 - On-Board Liquid Nitrogen Inerting
Total $ Cost with Inflation	10,082	15,367	9,744	14,203	17,047	8,606	12,680	10,429	11,588	20,924	13,586	17,414	27,692
NPV in 2005 of Cost	4,849	7,099	4,721	6,613	7,753	4,165	5,968	4,758	5,314	9,357	6,299	8,015	11,656
Total Benefits	233	434	231	432	497	274	492	258	459	497	274	492	497
NPV in 2005 of Benefits	86	159	85	159	183	101	181	95	169	183	101	181	183

Figure 11-3. Cost Summary—U.S. Fleet, All Transports

Summary of Inerting Scenario Results **World - PAX Only**

Values in Millions	Scenario 1 - On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA/Membrane Systems	Scenario 2 - On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems	Scenario 3 - Hybrid On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA/Membrane Systems	Scenario 4 - Hybrid On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems	Scenario 5 - OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems & Small Transports, PSA/Membrane Systems	Scenario 7 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PSA/Membrane Systems	Scenario 9 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems & Small Transports, PSA/Membrane Systems	Scenario 11 - Ground Based Inerting HCWT only, All Transports	Scenario 12 - Ground Based Inerting All Fuselage Tanks, All Transports	Scenario 13 - OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, & Small Transports, PSA/Membrane Systems	Scenario 14 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Cryogenic Systems, & Small Transports, PSA/Membrane Systems	Scenario 15 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, & Small Transports, PSA/Membrane Systems	Scenario 16 - On-Board Liquid Nitrogen Inerting			
Total $ Cost with Inflation	21,474	34,897	20,722	32,007	39,168	18,015	27,575	21,286	24,085	47,094	28,866	38,157	65,236	-	-	-
NPV in 2005 of Cost	9,936	15,576	9,644	14,371	17,248	8,376	12,590	9,600	10,907	20,489	12,994	17,129	26,698	-	-	-
Total Benefits	597	1,037	591	1,032	1,202	701	1,186	668	1,109	1,202	701	1,186	1,202	-	-	-
NPV in 2005 of Benefits	219	381	217	379	441	257	435	245	407	441	257	435	441	-	-	-

Figure 11-4. Cost Summary—Worldwide Fleet, Passenger Planes Only

Summary of Inerting Scenario Results **US-Operator - PAX Only**

Values in Millions	Scenario 1 - On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA/Membrane Systems	Scenario 2 - On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems	Scenario 3 - Hybrid On-Board Ground Inerting HCWT only, Large, Medium, Small Transports, PSA/Membrane Systems	Scenario 4 - Hybrid On-Board Ground Inerting All Fuselage Tanks, Large, Medium, Small Transports, PSA/Membrane Systems	Scenario 5 - OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems & Small Transports, PSA/Membrane Systems	Scenario 7 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Membrane Systems & Small Transports, PSA/Membrane Systems	Scenario 9 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Membrane Systems & Small Transports, PSA/Membrane Systems	Scenario 11 - Ground Based Inerting HCWT only, All Transports	Scenario 12 - Ground Based Inerting All Fuselage Tanks, All Transports	Scenario 13 - OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, & Small Transports, PSA/Membrane Systems	Scenario 14 - Hybrid OBIGGS, HCWT only, Large and Medium Transports, Cryogenic Systems, & Small Transports, PSA/Membrane Systems	Scenario 15 - Hybrid OBIGGS, All Tanks, Large and Medium Transports, Cryogenic Systems, & Small Transports, PSA/Membrane Systems	Scenario 16 - On-Board Liquid Nitrogen Inerting			
Total $ Cost with Inflation	7,588	10,898	7,352	10,149	11,675	6,349	9,194	9,321	10,207	14,550	9,868	12,474	19,817	-	-	-
NPV in 2005 of Cost	3,768	5,215	3,678	4,896	5,491	3,166	4,442	4,246	4,672	6,698	4,692	5,884	8,598	-	-	-
Total Benefits	233	434	231	432	497	274	492	258	459	497	274	492	497	-	-	-
NPV in 2005 of Benefits	86	159	85	159	183	101	181	96	169	183	101	181	183	-	-	-

Figure 11-5. Cost Summary—U.S. Fleet, Passenger Planes Only

12.0
Regulatory Impact

12.0 REGULATORY IMPACT

Fuel tank inerting systems affect regulations embracing type certification, airplane operations, maintenance operations, and (possibly) airport facilities. This section addresses the impact on the regulations of these areas.

12.1 TYPE CERTIFICATION

<u>*14 CFR Part 25*</u>

The certification of a fuel tank inerting system would involve two aviation regulations:

- *Flammability Rule*—sets flammability exposure standards for which an inerting system may be designed to reach compliance.
- *Inerting System Rule*—governs the design of inerting systems.

<u>*Flammability Rule*</u>

The purpose of the Flammability Rule is to regulate the allowable flammability level of the fuel tank ullage.

Because the FTIHWG has determined that all fuel tank inerting systems are impracticable in accordance with the FAA regulatory evaluation requirements, new regulatory content cannot be recommended for a Flammability Rule. Therefore, no change is recommended to the text of the current Flammability Rule (14 CFR §25.981(c), introduced by FAR Amendment 25-102, effective June 6, 2001) to establish a new acceptable minimum flammability level that is equivalent to that which could be achieved by an inerting system design concept.

This decision is based on the overall work of the FTIHWG, which used the following ground rules established by the FAA Tasking Statement:

- "Flammability" is defined as the susceptibility of the fuel/air vapor (ullage) present in a fuel tank to readily ignite or to explode.
- For the proposed regulatory text, fuel tank inerting could be an acceptable method of compliance.
- Flammability is to be treated independently from fuel tank ignition prevention.
- A performance-based definition provides the applicant with a set of design requirements, not a prescriptive design requirement.
- Flammability reduction only through fuel tank inerting was to be considered by the FTIHWG, which was asked not to address or consider other methods for controlling the flammability of fuel tank ullage.

The pros and cons of five different regulatory text proposals were evaluated against the 13 fuel-tank-inerting design proposals. No improvements to the current regulatory text could be found because the current text clearly states that *in the context of this rule, 'minimize' means to incorporate practicable design methods to reduce the likelihood of flammable vapors*. This wording allowed current applicants to comply with the Flammability Rule without being required to incorporate an inerting system, which the FTIHWG determined not to be practicable.

The team decided to discard the other options (discussed in app. I) because they were

- Not practical to impose a numerical limitation because of the lack of an industry-agreed pass/fail criteria (option A).

- Too shortsighted to limit the rule to a flight phase considering that the "risk" may occur in a flight phase other than ground (option B).
- Too restrictive for inerting and the Tasking Statement because the primary means of compliance would be through heat control (option C).
- Linked to ignition source control and, therefore, outside the scope of the Tasking Statement. Not practical to impose a numerical limitation because of the lack of an industry-agreed pass/fail criteria (option D).

Flammability Assessment—Guidance Material

Because of the adverse results of the cost-benefit evaluation performed by the FTIHWG, we recommend not to set a flammability design objective that is achievable only with an inerting system.

We therefore recommend that, if possible, the FAA formulate with industry experts a flammability evaluation method and follow-on flammability standard that meet the FAA regulatory evaluation requirements.

Inerting System Rule

Although the FTIHWG determined that fuel tank inerting systems were not practicable, the existing Flammability Rule, 14 CFR §25.981(c), does not preclude an applicant from voluntarily fitting an inerting system on its airplane.

If an inerting system is fitted, the Rulemaking Task Team determined that certain design features should be regulated within the inerting system design. This control can be done either by means of a special condition or by a change to 14 CFR Part 25.

This determination was made following a certification-compliance evaluation of the proposed ground-based and onboard inerting designs. The evaluation considered the inerting system's safety, design (including installation requirements), and operational performance requirements.

This review process identified a total of

- Three insufficiencies in 14 CFR 1-1-00 Edition (current regulation could be slightly modified to address the specifics of the inerting design).
- Thirty-six applicable paragraphs in 14 CFR 1-1-00 Edition, but not requiring regulatory text modifications.
- Three new concerns unique to inerting systems.

Because of the number of considerations that must be regulated within a fuel system inerting design, the team recommends that a dedicated 14 CFR Part 25 paragraph titled "Fuel Tank Inerting System" be adopted if inerting systems are to be installed on transport category airplanes. This paragraph should be worded in such a way that it can apply to both ground-based and onboard inerting systems. A proposed wording is provided later in this section.

Inerting System—Guidance Material

If inerting systems are to be considered as aviation equipment, guidance material needs to be prepared and published. This guidance material should be consistent with the inerting technology under certification.

14 CFR Part 21

14 CFR Part 21 provides airplane certification procedure for products and parts. It was reviewed to determine if any current certification procedures would need to be changed if inerting systems were implemented on transport category airplanes.

The FTIHWG concluded that there is no impact on the current regulations versus type certification or modification activities.

The team also concluded that 14 CFR Part 21 is affected if the FAA were to initiate a retroactive rule action. The retroactive rule action would require a change to 14 CFR Part 21, which is the SFAR section. The SFAR regulatory action would need to state the airplane applicability and the required compliance, including the task accomplishment statement and FAR 25 rule references, the time frame for compliance, and the reference to any maintenance or inspection activities.

12.2 MAINTENANCE AND AIRPLANE OPERATIONS

The Rulemaking Task Team identified and assessed the following 14 CFR sections that relate to airplane maintenance and operations, considering that either a ground-based or onboard inerting system was installed in the airplane:

- Part 43, Maintenance, Preventative Maintenance, Rebuilding, and Alteration.
- Part 91, General Operating and Flight Rules.
- Part 121, Operating Requirements: domestic, flag, and supplemental operations.
- Part 125, Certification and Operations: airplanes having a seating capacity of 20 or more passengers or a maximum payload capacity of 6,000 or more.
- Part 129, Operations: foreign air carriers and foreign operators of U.S.–registered airplanes engaged in common carriage.

The Part 43 assessment was carried out independently.

The other parts were assessed using Part 121. That is, the team assumed that any change applicable to Part 121 could be read over to Parts 91, 125, and 129. This assumption was made based on the FAA’s ignition source prevention activity (NPRM 99-18/SFAR no. 88, effective June 6, 2001).

The team did not consider Part 135 operating requirements, which cover commuter and on-demand operations. The Rulemaking Task Team decided that the FAA could adapt the recommendations made for 14 CFR Parts 91, 121, 125, and 129 to other similar 14 CFR sections.

The Rulemaking Task Team also assessed the impact on retroactive rulemaking.

Maintenance and Airplane Operational Regulations

14 CFR Part 43. The Rulemaking Task Team determined that, if a fuel tank inerting system were installed on an airplane, the 14 CFR Part 43 standards did not need to be modified. Today’s standards can adequately accommodate an inerting system.

14 CFR Parts 91, 121, 125, and 129. The Rulemaking Task Team determined that the type of inerting design and the final decisions by the designers, airlines, and operators would greatly influence the types of changes needed for 14 CFR operational sections.

The following conclusions are provided:

General Conclusions. The Rulemaking Task Team recognized that the regulatory impact of the operational sections of 14 CFR sections may go well beyond the conclusions made within this report.

The group acknowledged that, if inerting systems were incorporated, considerations on how to grant MMEL relief in accordance with prescribed FAA procedures need to be further studied. The number of potential installations, the complexity of these installations, and the method by which they are introduced all influence allowed MMEL.

Regulatory Impact on All Fuel Tank Inerting Systems. Three specific concerns that affect the regulations and apply to all inerting systems were identified:

- The requirement to have an approved operational and maintenance program.
- Assurance that NEA (oxygen-depleted air) cannot physically harm passengers and crew.
- Statement of when and under what conditions an airplane may need a fuel tank inerting system.

Approved Operational and Maintenance Program. The team recommends that the regulatory change be presented in a new 14 CFR 121 (or equivalent) paragraph in a manner similar to §121.629, Operation in Icing Conditions. In this way, all the information can be found in one place and not dispersed between a variety of paragraphs. A proposed wording is offered later in this section.

NEA's Physiological Effects. Because nitrogen-enriched or oxygen-depleted air can physically harm passengers and crew in confined spaces without adequate ventilation, we propose that §121.229(c), Location of Fuel Tanks, be amended to state that nitrogen gas should be isolated from personnel compartments. The isolation should be shown for nitrogen gas present in both the fuel tanks and the inerting system equipment (pipes, valve, and so on).

Conditions Under Which a Fuel Tank Inerting System Is Installed. If the FAA decides to mandate fuel tank inerting systems, then the perceived role of this system should be stated within 14 CFR Part 121 (or equivalent).

The team recommends creating a new §121.300 paragraph to state when and under what conditions airplanes may need a fuel tank inerting system. This may be accomplished by a sentence stating that a fuel tank inerting system may be installed on an airplane as a means of meeting the requirements of §25.xxx of the chapter in effect on a given date.

An alternative recommendation is to modify §121.316, Fuel Tanks, using the same wording.

Ground-Based Inerting Systems. For GBIS, five additional regulatory paragraphs need to be created or modified. We have identified the concept of what these paragraphs should contain. Specific regulatory changes should be reviewed with the operational specialists using a design concept for in-service use.

The Rulemaking Task Team's conclusions on these impacts were based on three facts:

- Ground-based inerting is a specific action that requires a specific, independent procedure.
- Ground-based inerting cannot be accomplished without the complementary airport facilities.
- The operational program will be developed using procedures inherent to the ground-based inerting design concept.

Because ground-based inerting systems are not self-contained aboard the airplane and thus require interface with the airport and ground personnel, the team recommends that the new fuel tank regulatory paragraph make references to other applicable paragraphs within 14 CFR.

The team proposes that five additional 14 CFR 121 paragraphs be modified (or concepts be included within the new fuel tank inerting paragraph):

- §121.97, Airports: Required Data—add nitrogen supply capability under (b)(1), Airports.
- §121.105, Servicing and Maintenance Facilities—include nitrogen supply capability in equipment example.
- §121.117, Airports: Required Data—add nitrogen supply capability under (b)(1), Airports.
- §121.123, Servicing Maintenance Facilities—include nitrogen supply capability in equipment example.
- 121.135(b)(8), Contents, information contained in the manual—add new equipment, (b)(25), concerning inerting facilities or modify (b)(18) to add inerting to the refueling procedures.

Onboard Inerting Systems

OBIGGS. For onboard inerting systems, we anticipate no impact on the operational regulatory sections; no additional paragraphs were identified for creation or modification.

If pressure-vessel air is used for inerting, regulatory changes may need to be implemented somewhere in the 14 CFR code to ensure that cabin air pressure is maintained as the airplane ages or if it is dispatched on MMEL relief with an inoperative pack.

Onboard hybrid systems may require the regulatory modifications as described under ground-based inerting, recognizing that the airport facility requirements would be different (onboard ground electrical source requirement; ground-based inerting nitrogen supply requirement). Specific regulatory changes should be reviewed with the operational specialists using a design concept proposed for in-service use.

The Rulemaking Task Team's conclusion was based on three facts:

- Onboard inerting is a system integral to the airplane; airport facilities are not needed.
- The activation of the onboard system would be done on the airplane (automatically or manually).
- The team determined that the operational program would be developed using procedures inherent to the onboard inerting design concept.

OBGI. If an onboard ground system is developed, both ground-based inerting recommendations should be considered, recognizing that the airport facility requirements would be different (onboard ground electrical source requirement; ground-based inerting nitrogen supply requirement).

Impact on 14 CFR Part 121 (or equivalent) Subparts L, N, and T. Given the amount of knowledge that the Rulemaking Task Team had on the inerting systems and their impact on airplane operations, it concluded that there was no impact on Subparts L, N, and T. The current wording is sufficient to ensure proper training on inerting systems. Modifications or new paragraphs may need to be introduced once an inerting system is actually proposed for in-service use.

Retroactive Rule Action. A retroactive rule would be initiated by FAA decision and by a simultaneous change to 14 CFR Parts 21 and 121 (or equivalent). The retroactive rule needs to be closely coordinated within both the FAA's certification and airworthiness standard branch and the Aircraft Evaluation Group. The FAA needs to consider carefully any retroactive rule action against its impact on the MMEL or MEL.

FAR 121.300 will have to be updated to be in line with the SFAR (FAR 21) rule change. The new 121 rule will have to contain provisions concerning time required to introduce the new rule, airplanes affected, operational requirements, and any grandfather clauses (especially if there is a time factor linked to equipping domestic and foreign airports).

Operational Guidance Material

An operator will need to have an approved inerting maintenance and operational program. This program is very important because there is a risk of death if nitrogen is not handled properly. Guidance material should be issued to that effect before any inerting system is operated.

Considering that no commercial aviation operation has ever operated or maintained a fuel tank inerting system, the guidance material should be updated on a regular basis until the subject becomes mature.

12.3 AIRPORT FACILITIES

The Rulemaking Task Team assessed 14 CFR Part 139 as to whether the standards for certification and operation of airports serving certain carriers would be affected by fuel tank inerting systems.

The team determined that one change to 14 CFR Part 139 standards would be needed if ground-based inerting were implemented.

The regulatory change could be justified in one of two ways: (1) regulate the safety of the public and airport when handling nitrogen and (2) regulate the hazard of the airplane and state that the airport must ensure that this hazard does not exist. The proposed regulatory text composition is found in the regulatory text section 12.5.2.

No changes to 14 CFR Part 139 have been identified if onboard inerting were to be implemented.

12.4 ENVIRONMENTAL

There is currently no regulatory impact identified from the increase in the amount of VOCs vented from the fuel tank as a result of inerting.

It was determined that 14 CFR Part 34, Fuel Venting and Exhaust Emission Requirements for Turbine Engine Powered Airplanes, would not be affected because these regulations concern the intentional discharge of liquid fuel to the atmosphere that is drained from the nozzle manifold after the airplane gas turbine engines are shut down.

12.5 REGULATORY TEXT AND GUIDANCE MATERIAL

The FAA Tasking Statement requested that the FTIHWG do the following:

- Review existing regulations, advisory material, and continued airworthiness instructions concerning the elimination or reduction of the flammable environment in the airplane fuel tank system.
- Prepare regulatory text for new rulemaking by the FAA to eliminate or significantly reduce the flammable environment in airplane fuel tank systems.
- Develop and propose guidance material for all recommended system concepts that describes the necessary analysis, testing, or both that may be required to show compliance with the new regulatory text for certification and continuing airworthiness.

The Tasking Statement further requested that the FTIHWG propose recommendations based on achieving the lowest flammability level that can be provided by an inerting system design that would meet FAA regulatory evaluation requirements.

In this section, we summarize the regulatory assessment method, provide specific regulatory text recommendations, and present an overview of potential guidance material that is associated with the regulatory text proposals.

12.5.1 Methodology

This section describes the method adopted by the Rulemaking Task Team to meet the requirements stated above.

Basic Assumptions

The Rulemaking Task Team assumed that both the ground-based and onboard inerting designs would be certified and used. This broad assumption was made because the absolute and relative practicality of these individual design approaches was not known.

Determination of 14 CFR Sections to Be Evaluated

The team examined the airplanes used to determine which sections of 14 CFR might be affected by the two inerting designs. The team confirmed that, at a minimum, airplane certification, maintenance, operational approval, and airport facilities would be affected. The team concluded that an assessment of the major issues affecting 14 CFR could easily be transferred to a Joint Aviation Requirements assessment if final rulemaking were pursued.

Analyses of the Regulatory Impact on the Existing Codes

The Rulemaking Task Team then used the design concepts developed by the other FTIHWG task teams to analyze the impact on the existing regulations, advisory material, and continued airworthiness instructions. This analysis was performed throughout the FTIHWG process to ensure that all design issues were accounted for in the final 14 CFR change recommendations.

Development of Guidance Material

The team developed guidance material to support the 14 CFR change proposals.

Flammability Regulatory Text Proposals

Finally, regulatory text was proposed within the FTIHWG that could be used by the FAA to regulate an airplane's fuel tank environment to the level of flammability reduction achieved by a practicable inerting system design concept. The Rulemaking Task Team highlighted the pros and cons of each proposal, including its possible certification interpretations and its capability to allow an inerting system as an acceptable means of compliance.

Certification Cost Assessment

The Rulemaking Task Team calculated a certification cost estimate for both ground-based and onboard inerting systems. These costs were inputted into the overall cost-benefit study.

HWG Flammability Regulatory Text Recommendation

The FTIHWG was tasked with determining which proposal, if any, to recommend. This recommendation would be based on the outcome of the regulatory evaluation for new rulemaking as required by the Tasking Statement.

12.5.2 Regulatory Text

Flammability Regulatory Text Proposal

No new regulatory text is proposed because there are no inerting systems that are practicable. Therefore, a minimum allowable flammability level based on an inerting design concept cannot be incorporated into a regulatory text.

Inerting System Regulatory Text Proposal

An applicant who decides to incorporate an inerting system should include a minimum number of design precautions for the system. The regulatory text proposal in this section provides words that address the concerns identified within the certification compliance evaluation. This text can be used either as a special condition or be added as a new paragraph to 14 CFR Part 25.

§25.xxx Fuel Tank Inerting System

If, in order to show compliance with §25.981(c), a fuel tank inerting system is installed,

(a) the fuel tank inerting system must not, under normal and failure conditions:

- *(i) allow any inerting agent leakage into the pressurized or personnel compartments, or confined spaces; and*
- *(ii) allow overpressure of the fuel system.*

(b) The fuel tank inerting system must have:

- *(i) A connecting port such that a cross-connection with any other supply line is not possible (applicable if supplied by an external inerting gas source).*
- *(ii) At each inerting agent filler opening and each airplane opening leading to direct contact with the inert gas, a placard at or near the filler cover or opening with the words "Fuel tank inerting" and the agent denomination.*
- *(iii) A means to prevent the escape of hazardous quantities of fuel from the system in the case of loss of system supply pressure.*
- *(iv) A shutoff or isolation means, whose failure to function is evident, that prevents undesirable system functioning and possible fuel leakage.*
- *(v) A tolerance to variable inerting gas pressures or surges in the gas delivery system.*

(c) Cautions (placards) and warnings (indication system) should be provided to prevent unintentional entry into a confined space filled with a hazardous inert gas.

(d) The characteristics and designation of the inert gas that ensure correct operation of the fuel tank inerting system shall be recorded in the operating limitations section of the Aircraft Flight Manual or equivalent.

Maintenance and Airplane Operational Regulatory Text

If an inerting system is installed on an airplane, then a new 14 CFR 121 (or equivalent) paragraph should be introduced in a manner similar to §121.629, Operation in Icing Conditions. In this way, all the information can be found in one place and not dispersed between a variety of paragraphs.

The fuel tank inerting paragraph should include the following topics and include or refer to specific concerns that are only relevant to ground-based inerting operations or onboard inerting operations.

§121.xxxx (or equivalent) Operation of Fuel Tank Inerting System.

(a) A section providing a statement of the dispatch or release condition of an airplane containing a fuel tank inerting system.

(b) A section providing a requirement for an approved fuel tank inerting program including details of:

- *(i) How the certificate holder determines that he or she needs to inert the airplane fuel tanks.*
- *(ii) Who is responsible for this decision.*
- *(iii) The procedures for implementing this decision.*
- *(iv) The specific duties and responsibilities of each operational position.*
- *(v) Define confined space procedure for the inerting system.*
- *(vi) Initial and annual recurrent ground training and testing for all affected personnel that addresses the:*

  - *Identification of system limitations (e.g., minimum time to inert on landing or before takeoff).*
  - *Creation of communication procedures.*
  - *Identification of flight crew's role at dispatch and at landing.*
  - *Identification of the nitrogen's specifications and characteristics.*
  - *General conditions under which the more specific requirements are alleviated.*

More specific regulatory text wording was not developed because it was undetermined at the time of the evaluation which if any of the inerting systems would be practicable.

Airport Facilities Regulatory Text

If ground-based inerting were to be implemented, then a regulatory text change to 14 CFR Part 139 would be recommended to ensure that the services are available to carry out ground-based inerting.

The regulation should address

- The availability of nitrogen gas.
- Facility, procedures, and personnel training standards.
- Infrastructure to ensure that airplanes are inerted within a minimum time before their next scheduled departures.

More specific wording was not developed because of the immaturity and impracticality of ground-based inerting.

Environmental Regulatory Text

There are no regulatory text proposals associated with addressing environmental concerns because no regulatory impact has been identified.

12.5.3 Intent of Proposed Guidance Material

The Rulemaking Task Team developed guidance material to support the regulatory text recommendations.

The Rulemaking Task Team defined a working methodology, developed the foundation of a guidance material proposal using the work developed within the FTIHWG, and formed recommendations for further improvements.

Methodology Used to Develop the Inerting System Guidance Material

The regulatory text change review identified four core subjects:

- Retroactive rule, SFAR (14 CFR Parts 21 and 121).
- Design and certification (14 CFR Parts 25 and 34).
- Operation and maintenance (14 CFR Parts 43, 91, 121, 125, and 129).
- Airport facilities (14 CFR Part 139).

The Rulemaking Task Team developed guidance material for two of the four subjects:

- Design and certification (14 CFR Parts 25 and 34), further split into two topics:
  - Flammability Rule guidance material.
  - Inerting System Rule guidance material.
- Operation and maintenance (14 CFR Parts 43, 91, 121, 125, and 129) as applicable to the use of an inerting system.

The team determined that the retroactive rule did not need associated guidance material by nature and that issues surrounding airport infrastructure were too immature to develop effectively.

Flammability Rule Guidance Material

The Rulemaking Task Team agreed that the flammability regulatory text (or the existing FAA flammability recommendation, where a flammability regulatory text could not be recommended) should be associated with some guidance material.

The purpose of the guidance material should be to define the “standard” by which the applicant’s product is going to be evaluated and judged acceptable. It should be used to identify the design, the procedures, or both that are needed to ensure the safety of the airplane design. The guidance material should not identify how to design a system. For example, the guidance material associated with this rule should not provide advice to an applicant on how to design and operate a fuel tank inerting system.

The standard should be subdivided into four subtopics:

- The circumstances for conducting an assessment of flammability.
- The decision to pursue regulatory text evaluation.
- The assessment of the flammability—the state under which the product needs to be placed to obtain the parameters needed to make a judgment on performance (i.e., the “playing field” and “rules of the game”).
- The standard itself—the basis on which the compliance decision will be based (determination of compliance).

The team agreed that an acceptable performance-based rule is one in which the regulatory text and the standard are compatible and ensure an equivalent safety level across all product lines.

Development of the Standard as Limited by the Tasking Statement. The Tasking Statement limited the team's ability to develop a flammability standard. The Tasking Statement required the team to determine whether fuel tank inerting could be used as the practicable industry standard to show compliance with a flammability regulatory text. The FAA considered that subtopics a through c were addressed by FAA AC 25.981-2.

Development of a Standard Excluding the Tasking Statement Instructions. Some team members felt that if the FTIHWG were to endorse or create a flammability regulatory text, then all subtopics within the standard's definition should be addressed irrespective of the Tasking Statement.

The team decided to discuss each subtopic and document its general concerns. These concerns could then be expanded as appropriate to the regulatory text development.

Circumstances for Conducting an Assessment of Flammability. AC 25.981-2 provides guidance in this area. However, some team members felt that a flammability rule should not be applied to fuel tank ullage if all the mechanical and electrical potential ignition sources were removed.

This determination could be made by developing a qualitative pass/fail criterion; no credit is given for probability of failure. The design either complies with the condition (i.e., " pass") or it does not (i.e., "fail"). If the applicant passes the checklist, then the flammability regulatory text is not applicable.

Decision to Pursue Regulatory Text Evaluation. The team agreed that the purpose of the flammability regulatory text needed to be clearly stated within the guidance material.

The airplane design goal (airplane safety objective) needs to be stated. Any performance-based words (e.g., "minimize" or "limit") need to be defined. The goal can be defined as specific (e.g., X% flammability exposure) or can be defined by a design assessment associated with a pass/fail criterion.

Some team members felt that the guidance material should give credit for mitigation of ignition sources by either of two means:

- Protection of the fuel tank from structural and systems damage in the event of an ignition of the tank's fuel/vapor air mixture.
- Snubbing of the spark before it comes in contact with the flammable fuel/air vapor mixture so that ignition does not occur.

In the first of the above approaches, an example of an acceptable means is the use of appropriate foam. The fuel tank is filled with a type of foam that ensures the control of the pressure rise following ignition of the fuel/air vapor mixture.

Assessment of the Flammability. AC 25.981-2 provides a method to determine the average flammability exposure of a given tank.

Some team members raised concerns over whether an average flammability exposure calculation really provides the correct type of assessment needed to prevent the "accident risk."

The team estimated that at least seven parameters needed to be assessed to determine whether in fact the accident risk has been mitigated:

- *Influence of outside ambient air temperature.* ISA/ISA +73.4°F variation can be used to determine operational limitations and measure the effectiveness of any design or operational changes based on outside conditions.
- *Effect of fuel loading on the fuel tank heat transfer characteristics*. The results can be used to show the thermodynamic influence of fuel on the overall ullage cooling behavior and resultant flammability exposure.
- *Thermodynamic characteristics of each piece of equipment or each system.* The results can be used to identify the contribution of each piece of equipment or each system to the overall ullage characteristics. This in turn can be used to identify design changes or operational constraints (e.g., MMEL or ground operation procedures).
- *Influence of ground operation time*. The results can be used to understand the influence of ground operation on the fuel tank ullage temperature. The results can be used to substantiate design decisions or operational procedures.
- *Identification of hot spots*. The results can identify whether there is a local change in the flammability characteristics of the ullage.
- *Differences or similarities between the tanks*. The results can identify whether any tank has an unusual thermodynamic characteristic as compared to the others. The reason for this difference can be evaluated and then used to determine whether any design or operational actions need to be taken.
- *Identification of the degree to which a design is influenced by natural physical properties versus by design choices*. The results can be used to establish a comparison basis with ambient conditions. The results from the unheated configuration show the flammability exposure characteristic of the design based only on fuel loading, pressure, and aerodynamic effects. The results from the heated configuration show the influence of the internal fuel system mechanical components and the adjacent systems on the flammability exposure. The comparison of heated and unheated results can be used to show the direct benefit on flammability exposure of any design or operational changes under a certain fuel loading and outside ambient air condition.

Team members agreed that probably both the average risk and specific risk were needed to ensure that all hazards were addressed within the design.

Determination of Compliance. Team members voiced concerns over use of subjective, imprecise words and phrases such as “minimize” or “limit the development.”

Experience has shown that differing opinions between the applicant and regulatory authority as to what constitutes “minimize” or “limit” has led to costly delays in some certification programs.

Industry team members encouraged the FAA and the JAA to work with them as an industry group to develop a process and associated numerical conditions by which the word “applicable” can be judged. An example of a process is a flowchart that provides acceptable design conditions and choices about how to proceed depending on conditions. An example of a numerical condition is an average flammability exposure percentage or a temperature limit.

Inerting System Rule Guidance Material

The guidance material was created using the fuel tank inerting systems design proposals of two FTIHWG design teams and the regulatory evaluation assessment.

The team recommends, however, that this guidance material be refined using real fuel tank inerting design concepts that are proposed for in-service airplanes.

The objective of the guidance material is to provide information and guidance on the design, installation, and certification of an NEA inerting system. It can then be used, if desired, to create an FAA AC pertaining to fuel tank inerting systems.

The team assumed that the applicant chose to install an NEA inerting system on one or all of its airplane's fuel tanks. The design objective of the inerting system is to reduce or eliminate the flammable environment created in the fuel tanks' fuel/air vapor ullage (the means by which to show compliance to FAR/JAR 25.xxx).

The team took for granted that this guidance material would not become mandatory and would not constitute a regulation. Its purpose is to provide the applicant with advice and a method of compliance that has been found acceptable to the FAA and the JAA (certifying authorities).

Maintenance and Airplane Operations Guidance Material

The guidance material was created using the fuel tank inerting systems design proposals of two FTIHWG design teams, the regulatory evaluation assessment, and guidance material written on systems that interface with airport facilities or systems that are implemented because of environmental concerns.

The team recommends that this guidance material be refined using real fuel tank inerting design concepts that are proposed for in-service airplanes.

The objective of the guidance material is to provide

- Information and guidance on the operation and maintenance of an NEA inerting system.
- Guidance in obtaining approval for a fuel tank inerting program.

This material may be used, if desired, to create an AC pertaining to fuel tank inerting systems.

The team assumed that the airplane had a fuel tank inerting system (ground or onboard) installed and that the applicant (AC user) is an operator seeking to gain approval of its fuel tank inerting maintenance and operation program.

The team took for granted that this guidance material would not become mandatory and would not constitute a regulation. Its purpose is to provide the applicant with advice and a method of compliance that has been found acceptable to the FAA and the JAA (certifying authorities).

12.5.4 Guidance Material

Guidance material was developed for

- Fuel tank inerting system—design, installation, and certification.
- Fuel tank inerting system—operation and maintenance.

This section provides a general overview of the contents of each guidance material evaluation.

Fuel Tank Inerting System—Design, Installation, and Certification

The detailed guidance material proposal is found in appendix I, attachment 1. It complements the guidance material already published in AC 25.981-2. That AC describes the general concept of an inerting system, whereas this proposal discusses not only the general concept but specific design considerations as well.

This guidance material provides an overview and background details about its purpose, background, related documents, and definitions and abbreviations.

The guidance material then discusses the general concept of fuel tank inerting and explains the fundamental principles behind the different fuel tank inerting design concepts (based on the FTIHWG's design concept studies). This section further provides an applicant with information concerning the flight phases for which the design is most likely effective, the general impact on the airplane design and operation (system criteria and operational impact, including airport facilities interface), and specific information concerning dedicated inerting system equipment.

Also discussed are specific concerns relating to

- System installation considerations.
- Airplane interfaces.
- Certification plan and compliance demonstration.
- Continued airworthiness and maintenance considerations.
- Nitrogen precautions.
- Environmental impact.
- MMEL assessment.

If inerting systems are installed on airplanes, the team recommends that either AC 25.981-2 be expanded to include fuel tank inerting design considerations, or that a dedicated AC titled "Fuel Tank Inerting Design and Certification" be created.

It is recommended that any AC be again reviewed using an actual certified inerting design because the design considerations recommended in this guidance material are based on hypothetical designs. The lessons learned during an actual design project may assist others in designing and certifying airplanes.

Fuel Tank Inerting System—Operation and Maintenance

The detailed guidance material proposal is found in appendix I, attachment 2. There are no other known recommended guidance material or ACs existing in the public domain.

The guidance material provides an overview and background details about its purpose, background, related documents, and definitions and abbreviations. This material then states that all fuel tank inerting operation and maintenance programs will contain six parts:

- Management plan.
- Dispatch conditions, including any timetables.
- Operations manual—inerting operational procedures.
- Maintenance program—maintenance manual.
- Training.
- Health and safety standards.

Note that local airport emission requirements may have to be evaluated against the possible excess of fuel tank emissions resulting from inerting (these emission effects will be design and airplane dependent).

Next, the guidance material explains the specifics of each of the above six parts.

Management Plan. The management plan is a detailed description of the operational responsibilities and procedures associated with the implementation and conduct of the certificate holder's "fuel tank inerting program." The management plan may differ depending on the type of inerting system.

The purpose of the management plan is to ensure operational control over the execution of a fuel tank inerting program.

Dispatch Conditions, Including Any Timetables. Certain design features of airplanes (e.g., their fuel tank vent system) and fuel tank inerting system may impose certain usage conditions or limitations. These conditions and limitations may be related to time, outside ambient temperatures, flight phase, fuel tank loading, or a set of multiple conditions.

If limitations exist, then the certificate holder's program should define operational responsibilities and develop procedures to instruct the flight crews, airplane dispatchers, flight followers, and maintenance and ground personnel on the condition limitations, evaluation of these limitations, and resultant actions to be taken.

Operations Manual—Inerting Operational Procedures. Operational procedures associated with the fuel tank inerting system installed on the airplane type should be approved as part of an operator's initial operational manual approval or as a revision to that manual, the Airport Handling Manual, or the MEL.

A quality assurance program should be established in accordance with the management plan and applicable 14 CFR regulations.

The MEL should be developed based on the manufacturer's recommendations and the operator's operational policies and national operational requirements.

Maintenance Program—Maintenance Manual. Maintenance procedures for the fuel tank inerting system installed on the airplane type should be approved as part of an operator's initial maintenance manual approval or as a revision to that manual.

For ground-based inerting, the characteristics and specification of the nitrogen that will be used to inert the fuel tanks should be defined and recorded in the appropriate manuals.

For onboard inerting, particular attention should be paid to the efficiency (service life) of the ASM (which provides nitrogen), noting that NEA will not be produced if this component does not perform its intended function.

Training. Initial and recurrent ground training and testing for all affected personnel (e.g., airplane dispatchers, ground crews, contract personnel, and flight crew) need to be conducted.

A quality assurance program should be established in accordance with the management plan and applicable 14 CFR regulations.

Health and Safety Standards. The operator's health and safety standards should be updated to include working with nitrogen.

If inerting systems are installed on airplanes, the team recommends that this guidance material be used to issue an AC titled "Fuel Tank Inerting Operational Program Approval."

It is recommended that any AC be again reviewed using an actual operation and a maintenance program developed for using a certified fuel tank inerting system. The lessons learned during the implementation of the operation and maintenance program may assist others in any future implementation exercise.

Other Potential Regulatory Impact

Fuel tank inerting systems implemented on a large scale may increase VOCs vented from fuel tanks as their fuel/air vapors are displaced by the inerting process. However, environmental regulations are outside the scope of FAA jurisdiction and the scope of this task.

13.0
Conclusions &
Recommendations

13.0 CONCLUSIONS AND RECOMMENDATIONS

13.1 OVERALL CONCLUSIONS

Based on the investigation and evaluation conducted, the FTIHWG has concluded the following:

Service History

- There is a close relationship between the incidence of explosions in wing tanks and the use of "wide-cut aviation fuel."
- Wing tanks operating with less volatile Jet A type fuel have demonstrated an acceptable safety record.
- In comparison, heated CWTs are more vulnerable to explosion in the presence of ignition sources.
- The three most recent events (1990 Manila, 1996 New York, and 2001 Bangkok) form the basis for forecasting future events.
- Inerting fuel tanks may enhance occupant survival in accidents in which a fuel tank explosion is the primary cause.

Safety Assessment

- Because the fuel tank explosion rate has been statistically shown to be fairly consistent, the actual occurrence of incidents will increase in the future as a result of forecasted fleet growth.
- Ignition source reduction activities associated with SFAR no. 88 are expected to provide a reduction in the fuel tank explosion rate.
- Inerting systems will offer little benefit to three categories of airplanes studied: regional turboprops, regional turbofans, and business jets. These categories of airplanes do not have heated CWTs, and the flammability exposure of the wing tanks is already low.
- The flammability exposure levels achieved by inerting systems can result in an improvement in the accident rate.

Ground-Based Inerting (GBI and OBGI)

- Installing the airplane portion of a GBI system does not require any new technology to be developed. However, retrofit GBI systems will be extremely difficult and will require an evaluation of each airplane category model to determine if a retrofit installation is practical.
- The availability of airport supply systems to supply NEA at each terminal gate and remote parking area is a serious problem that needs to be resolved before GBI can be implemented.
- Development of a new NEA-to-airplane interface panel and associated components is necessary and requires agreement on configuration and control for a worldwide standard before a GBI system operation is practical.
- OBGIS was the heaviest system evaluated. System size is determined by the relatively short turnaround time between existing commercial flights at the gate and by the large ullage volumes (small fuel load) required for short missions.
- Because an OBGIS runs only on the ground, interference with other airplane systems would be minimized and the certification process should be simpler.

Airport Facilities

- Before promulgating an airplane GBI requirement, it will be necessary to resolve the current lack of global regulatory authority and industry control over the introduction and construction of new airport inerting supply systems, either fixed or mobile.
- Developing, constructing, and integrating into the current airport infrastructure fixed inerting equipment for large and medium-sized airports will be a major problem.

- Test data from elementary testing, using nitrogen and carbon dioxide, indicated that ullage washing and fuel scrubbing with either gas has little effect on the conventional properties of jet fuel. However, a measurable change in vapor pressure occurred as a result of fuel scrubbing, and the carbon dioxide–scrubbed fuel had an increase in acidity.
- Significant quantities of VOC were released during both processes, regardless of the inert gas used. This increase in VOC emissions should be investigated and resolved to avoid any serious potential health, environmental, and safety issues.
- Because a fuel cooling process does not address the scenario of operating with an empty CWT, this system of reducing flammability exposure was not pursued.
- The lack of NEA availability at smaller airports currently used as diversion airports for larger hubs would affect airline operations. In addition, if GBI is not implemented worldwide, the impact may be significant on non-U.S. diversion airports or those used for technical stops.

Onboard Inert Gas Generating System

- An OBIGGS would reduce the flammability exposure to almost zero, except when the airplane is not powered, operating under the MEL, or is in a nonnormal operational mode.
- When the OBIGGS is installed, noise reduction measures may have to be taken as a result of system compressor and fan noise.
- The electrical power requirements to run an OBIGGS are large and constitute a majority of the total electrical power available on an airplane category.
- The weight of an installed OBIGGS is significant; for example, for a large transport category airplane, the OBIGGS weighs between 1,120 and 1,600 lb.
- Retrofit of OBIGGS will require an evaluation of each airplane category model to determine if a retrofit installation is practical for that airplane model.
- Current technology components of an OBIGGS have demonstrated low reliability.
- Technological advancements that will decrease the complexity, size, weight, and electrical power requirements of an OBIGGS are needed.
- NEA membrane air separation systems that have improved efficiency and performance, and lower nonrecurring costs would be a necessary part of a practical membrane-type OBIGGS.
- For cryogenic systems, basic research into high-efficiency, vacuum-jacketed heat exchangers and lighter, more efficient cryogenic refrigerators is required to achieve a practical cryogenic-type OBIGGS.

Hybrid Systems (OBGI and OBIGGS)

- The issues and resolutions for hybrid systems are similar to their respective full-sized systems stated above.
- The OBGIS provides a reduction in flammability exposure comparable to that of the GBI system.
- The hybrid OBGIS is almost as large as the full-sized OBGIS.
- A hybrid OBIGGS that would provide the flammability exposure of a GBI system is the smallest onboard system of all onboard designs.

Airplane Operations and Maintenance

- The Tasking Statement defined an inerting system with little or no redundancy as a basis for this evaluation. Therefore, no inerting design concept evaluated was considered flight critical and airplanes could be dispatched with an inoperative inerting system (MEL). This assumption is fundamental to the technical and cost conclusions reached by this report.
- If the inerting system is not included in the MEL, then the complexity and cost of the system design concepts and airplane operational impact evaluated in this study would be significantly increased.

- If inerting systems are required to be installed in existing in-service airplanes, the resultant maintenance burden on the airline industry will be substantial and there may not be sufficient modification facilities, depending on the allowed modification incorporation time period and skilled personnel available.
- The current reliability of inerting system technology is unacceptable from a maintenance and operational viewpoint and requires an order of magnitude improvement to make them operationally viable.

Estimating and Forecasting

- The cost-benefit methods used by the FTIHWG to determine a practical inerting system were the same as the economic analysis practices used by the FAA.
- Based on the above economic analysis, none of the inerting design system concepts studied were found to be reasonably balanced by their incurred costs.
- Of the design concepts studied, the one with the lowest cost-benefit ratio was the GBI and the hybrid OBIGGS concept applicable to heated CWTs only.
- There is little difference in system costs between in-service and current production of a particular airplane model except for higher (20% to 30%) installation costs for retrofit of service airplanes and associated airplanes because of downtime during installation. Also, with today’s technology, there is little difference in system cost between current production and new type design airplanes.

Regulatory Impact

- Because this evaluation has not found a practical fuel tank inerting system, a new 14 CFR regulatory text should not be proposed.
- The environmental and regulatory impact of any future practical fuel tank inerting system needs to be addressed by the appropriate regulatory organizations when such a system is developed and proposed.
- Any requirement to incorporate a fuel tank inerting system would significantly affect existing CFR Title 14 parts, for example, Airworthiness Standards: Transport Category Airplanes (Part 25), Flight Operations (Parts 91 and 121), and possibly Airport Facilities.

13.2 RECOMMENDATIONS

The ARAC FTIHWG specifically recommends the following actions to be expeditiously carried out by the FAA, NASA, and the industry:

Inerting Systems

- Continue to evaluate and, where appropriate, investigate means to achieve a practical onboard fuel tank inerting system design concept for future new type design airplanes.
- Pursue technological advancements that would result in onboard fuel tank inerting designs having decreased complexity, size, weight, and electrical power requirements, and increased efficiency, reliability, and maintainability.
- Perform NEA membrane research to improve the efficiency and performance of membranes resulting in lower nonrecurring costs of NEA membrane air separation systems, for example, basic polymer research to increase the operational temperature of membranes to a level above 302°F.
- Conduct basic research into high-efficiency, vacuum-jacketed heat exchangers, and lighter, more efficient cryogenic refrigerators for use in inerting systems.
- If a practical means of achieving a cost-beneficial fuel tank inerting system is found, establish a corresponding minimum flammability level and reevaluate and propose regulatory texts and guidance materials accordingly.

Fuel Tank Flammability

- Evaluate means to reduce fuel tank flammability based on existing (e.g., directed ventilation, insulation) or new technology that might be introduced sooner into the in-service fleet and current airplane production.
- Initiate a project to improve and substantiate current flammability and ignitability analyses to better predict when airplane fuel tank ullage mixtures are flammable. This research is needed to support informed design decisions and rulemaking.
- Initiate a project to thoroughly document and substantiate the flammability model used in this study.