Turbulence
Joint Safety Implementation Team

Research Detailed Implementation Plan
For
Active In-Flight Turbulence Mitigation

DRAFT

Statement of Work: Provide active turbulence mitigation through movement of the aircraft control surfaces for generating forces to counteract acceleration forces experienced in aircraft cabins subject to atmospheric turbulence. Accomplish this mitigation through coupling of a short-range forward-looking gust sensor into the aircraft control system. Use feed-forward concepts to minimize the occurrence of negative acceleration forces that are highly correlated with in-flight turbulence injuries.

Lead Organization for Overall Project Coordination (LOOPC): NASA-Aviation Safety Program

SAFETY ENHANCEMENT 77 (Research): Active Turbulence Mitigation – Next Generation Control Systems – New Production

Score (Injury Reduction): 2007: 0 2020: 0.10 Full: 0.20 '07 Imp: 0%

Total Resource Requirements:

	Government		Manufacturers		Operators		Total
	FTE	$M	FTE	$M	FTE	$M	FTE/$M
2007		1.5					0/$1.5M
2020		14.5		2.0			0/$16.5M
Totals		16.0		2.0			0/$18M

Note: Current level of expenditure at NASA is about $200K annually.

Completion Date: 9 years after CAST approval of Safety Enhancement.

Output 1: Develop a short-range forward-looking gust sensor for measuring the vector gust magnitude of oncoming turbulence. Design the sensor with sufficient accuracy and high data rates and reliability appropriate for integration into a control system meeting the high standards of typical commercial aircraft flight control systems.

Resources: NASA–Aviation Safety Program–Weather Accident Prevention Element (LOOC), Sensor Manufacturers

Timeline: Complete 7 years after CAST approval of Safety Enhancement.

Actions:

- **Sensor Manufacturers** -- Evaluate alternative sensor architecture concepts for accomplishing the gust measurement. Construct demonstration and prototype models for evaluating and demonstrating sensor performance.
- **NASA** -- Facilitate sensor concept demonstrations and flight evaluation of sensor performance.

Output 2: Develop, validate, and implement prototype commercial aircraft flight control systems for mitigating turbulence-initiated cabin accelerations using the short-range gust sensor measurements.

Resources: NASA–Aviation Safety Program–Weather Accident Prevention Element (LOOC), Aircraft Manufacturers

Timeline: Completed 9 years after CAST approval of Safety Enhancement.

Actions:

- **NASA/Manufacturers** -- Develop aircraft response algorithms to control negative aircraft cabin accelerations based on inputs from the forward-looking sensor.
- **NASA Aviation Safety Program WxAP** -- Verify and validate flight control algorithms performance through simulator and flight-testing.
- **NASA AvSP Turbulence Team** -- Develop performance criteria for the mitigation flight control system.
- **NASA** -- Present report to CAST on feasibility and implementation cost for deployment decision.

Performance Goals & Indicators for Safety Enhancement/Outputs

- **Goal:** Turbulence Mitigation flight control system
  - **Indicator: Short Term:** First Generation technology is ready for implementation into the fleet by 2010
  - **Indicator: Long Term:** Deployment decision by CAST.

Relationship to Current Aviation Community Initiatives

Output 1:

The current aviation community initiatives for a short-range forward-looking gust flow sensor consist of the following:

- **MOADS:** Molecular Air Data Sensor is a joint Navy/Air force initiative to develop a flow direction sensor for high performance military aircraft.

- **AVOSS:** A NASA sponsored ground-based system for measuring hazardous near-ground wake vortices to determine decay rates and behavior under varying wind conditions.

- **TALANT:** An airborne system based on Carbon Dioxide lasers for acquiring airspeed and flow direction angles used by Airbus for calibration purposes.

Output 2:

The following aviation community initiatives are on going for turbulence mitigation flight control systems:

- **Turbulence Prediction and Warning System (TPAWS):** Currently NASA is leading a multi-disciplined government/industry team for the development of enhanced turbulence systems. This activity focuses on next generation systems and includes NASA, Aircraft Manufacturers, and Sensor Manufacturers.

    - **NASA and Aircraft Manufacturers** are developing aircraft control algorithms for suppressing turbulence accelerations in the cabin.
    - **NASA** is flight-testing a prototype LIDAR sensor for detection of clear air turbulence.

Programmatic approach

Organizational strategy

At the present time, Government/industry initiatives are in progress that directly address the turbulence issues contained in these safety enhancements. These initiatives consist of industry partners developing systems and concept demonstrations with NASA providing scientific support. NASA currently provides critical support by funding the concept development, evaluation and scientific basis, when the technology reaches sufficient maturity, the industry partners will fund the development of products for commercial service.

NASA is the critical enabling body that allows industry partners to continue technology growth. CAST support of these projects also provides priority and emphasis within the FAA to support development of performance and certification criteria for these initiatives.

Our organizational strategy is to make sure NASA continues to be funded at present or greater levels to provide enabling scientific research and development in support of industry initiatives that will advance turbulence safety issues. This research will include the scientific background for turbulence detection and aircraft response characterization. Demonstrations will be required that include data standard evaluation, flight-testing and full evaluation of turbulence mitigation systems. Principle stakeholders (regulators, airframes, airlines, and manufacturers) must be involved in developing the requirements,

performance and certification criteria. The program priorities must be consistent with the dates laid out in this plan, and performed in a timely manner to support and meet aviation safety goals.

Implementation Activities

The flow of this program is to develop the science behind turbulence, demonstrate prototype system(s), complete system requirements, and report feasibility and cost to CAST for a deployment decision. Actions to complete these activities are found in the **Key Products and Milestones** section.

Key Products and Milestones

Safety Enhancement 77: Active Turbulence Mitigation – Next Generation Control Systems – New Production.		
Output 1: Develop a short-range forward-looking gust sensor for measuring the vector gust magnitude of oncoming turbulence. Design the sensor with sufficient accuracy and high data rates and reliability appropriate for integration into a control system meeting the high standards of typical commercial aircraft flight control systems.		
Action	**Responsible Party**	**Completion Date**
Evaluate alternative sensor architecture concepts for accomplishing the gust measurement. Construct demonstration and prototype models for evaluating and demonstrating sensor performance.	**Sensor Manufacturers**	**7 years after CAST approval**
Facilitate sensor concept demonstrations and flight evaluation of sensor performance.	**NASA**	**7 years after CAST approval**
Output 2: Develop, validate, and implement, prototype commercial aircraft flight control systems for mitigating turbulence-initiated cabin accelerations using the short-range gust sensor measurements.		
Action	**Responsible Party**	**Completion Date**
Develop aircraft response algorithms to control negative aircraft cabin accelerations based on inputs from the forward-looking sensor.	**NASA/ Manufacturers**	**12 months after CAST approval**
Verify and validate flight control algorithms performance through simulator and flight testing	**NASA Aviation Safety Program WxAP**	**60 months after CAST approval**
Develop performance criteria for the mitigation flight control system.	**NASA AvSP Turbulence Team**	**36 months after CAST approval**
Present report to CAST on feasibility and implementation costs for deployment decision.	**NASA**	**9 years after CAST approval**

Risk Description and Risk Mitigation Plan:

RISK DESCRIPTION	RISK MITIGATION PLAN
R6 - Government does not maintain monetary support of turbulence effort within NASA AvSP.	M6 – CAST and industry assist the responsible Government agency by advocating funding and prioritization for continued turbulence funding. Industry provides guidance for needs and priorities to support aviation safety.
R7 - Responsible Government organization priority shifts away from turbulence.	M7 - CAST and Industry assist the responsible Government organization by advocating funding and prioritization for continued turbulence funding. Industry provides guidance for needs and priorities to support aviation safety.
R8 - Responsible Government organization schedule not compatible with industry need.	M8 - Industry assists the responsible Government organization in aligning goals with industry needs through AvSP Turbulence Team meetings.
R9 – Inability to complete significant fleet installations in time to impact 2007 safety goals	M9 – Align the responsible Government organization/industry goals to optimize completion of required outs, involve airlines in planning and development, ensure compatibility with airline needs.
R11 – Lack of manufacturer/OEM incentives/commitment	M11.1 Manufacturers/OEMs develop business cased based on airline needs to show economic feasibility of system product development M11.2 Competition between suppliers will drive development.
R12 – Human Factors (CHI) display product relevance – flight deck real estate.	M12.1 – Conduct Human Factors evaluations early in system development, involving OEMs, airlines and regulators to ensure best practices and effective use of flight deck resources. M12.2 – Evaluation of alternative methods of presentation.
R13 – Performance of sensors falls short of minimum performance expectations for safety improvement.	R13.1 – Continue research for improved sensor performance. M13.4 – Restructure turbulence mitigation algorithm to utilize available sensor performance.

Impact on Non-Part 121 or International Applications

Part 129 – International. Since this enhancement is for new production aircraft, once approved, international implementation will likely match domestic implementation.

Part 135. Would benefit Part 135 operations to the degree that those aircraft are capable.

General Aviation. Size and cost of sensor suite expected to diminish with increasing technology maturity so that sensors could fit in limited space available. High-end GA aircraft control systems may be amenable to incorporating turbulence mitigation algorithms.