# Project 014 Analysis to Support the Development of an Aircraft CO2 Standard

**Georgia Institute of Technology**
**Massachusetts Institute of Technology**
**Booz Allen Hamilton**

## Project Lead Investigator

Co-lead by all participants listed below.

## University Participants/Companies/Organizations

**Georgia Institute of Technology (GT)**

- P.I.(s): Prof. Dimitri Mavris, Dr. Michelle R. Kirby (Co-PI)
- FAA Award Number: 13-C-AJFE-GIT-003, Amendment 003
- Period of Performance: July 1, 2014 to January 31, 2016

**Massachusetts Institute of Technology (MIT)**

- P.I.(s): Prof. R. John Hansman
- FAA Award Number: P.O. DTRT5714P80095
- Period of Performance: Sept. 16, 2014 to Feb. 29, 2016

**Booz Allen Hamilton (BAH)**

- P.I.(s): Dr. Philippe Bonnefoy
- FAA Award Number: DTFAWA-14-D-00013
- Period of Performance: January 1st 2015 to February 2016

## Project Funding Level

Please specify the amount of funding from the FAA. Also include matching funding and source of match.

GT
Funded amount is $500,000 for the period of performance of July 1, 2014 to January 31, 2016. The Georgia Institute of Technology has agreed to a total of $500,000 in matching funds. This total includes salaries for the project director, research engineers, graduate research assistants and computing, financial and administrative support. The institute has also agreed to provide equipment funds as well as tuition remission for the students paid for by state funds.

BAH
FAA Award Number: DTFAWA-14-D-00013and DTRT57-10-D-30015
Period of Performance: September 2014 to February 2016
Project Funding Level: $363,900 FAA funding.

MIT
DOT Volpe TSC Award Number: P.O. DTRT5714P80095
Period of Performance: Sept. 16, 2014 to Feb. 29, 2016
Project Funding Level: $147,385.55 FAA funding and no matching funds. No source of match is required for this contract.

## Investigation Team

GT

Prof. Dimitri Mavris, Dr. Michelle Kirby, Dr. Don Lim, Dr. Yongchang Li, Robert Moss (Graduate Student), Fatma Karagoz (Graduate Student)
MIT
Prof R. John Hansman (PI). Dr. Brian Yutko (I), Edward Mugica (Graduate Student), Morrisa Brenner (Graduate Student)
BAH:
Dr. Philippe Bonnefoy, Dominic McConnachie

# Project Overview

The Federal Aviation Administration's Office of Environment and Energy (FAA/AEE) is working with the International Civil Aviation Organization's (ICAO) Committee on Aviation Environmental Protection (CAEP) to establish an international aircraft carbon dioxide (CO2) standard, which is a combination of a regulatory level and a certification requirement. The research team has been instrumental in the progress made to date within CAEP. The research team will utilize prior efforts to conduct a shadow cost benefit and cost effectiveness analysis of the 10 stringency options that have been established by CAEP in order to provide sound scientific information and insight to the FAA decision-making process.

## Objectives

The objective of ASCENT Project 14 is to conduct analyses on the CO2 standard to shadow those being done internationally, in order to provide sound scientific information to the decision-making process. In particular:

- Continue support of CAEP CO2 standard setting process through the expected decision at the CAEP/10 meeting in Feb 2016
- Inform U.S. policy makers with analytical information for the CO2 standard setting process
- Provide a preliminary analysis of the CO2 cost-benefit analysis ahead of the CAEP cost-effectiveness assessment to ensure that U.S. policy makers are well informed of the expected outcomes and potential issues
- Address any emerging issues associated with various stakeholders in the process either in a quantitative or qualitative manner

## Research Approach

- Conduct extensive cost benefit analysis using the full FAA Tool Suite, in order to inform the U.S. position for the development of an aircraft CO2 standard which will result in technology responses with the greatest environmental benefits while being technically feasible and economically viable
- Provide quantitative and methodological support of CO2 Standard Main Analysis modelling process
- Conduct sensitivity analyses in order to inform decision makers of potential outcomes under different scenarios and assumptions using the FAA Tool Suite, quantitative and qualitative research methods
- Actively engaging stakeholders using a data driven collaborative approach

### Recent Accomplishment #1: Cost Benefit Analysis

ASCENT Project 14 team is conducting extensive cost benefit analysis using the full FAA Tool Suite, as depicted below, in order to inform the U.S. position for the development of an aircraft CO2 standard which will result in technology responses with the greatest environmental benefits while being technically feasible and economically viable.

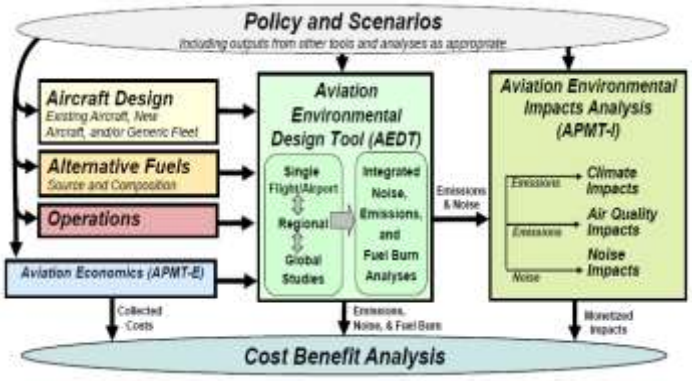


*Figure 1: Depiction of FAA Tool Suite*

## Recent Accomplishment #2: CO2 Main Analysis Support

Research team has provided quantitative and methodological support of CO2 Standard Main Analysis modelling process, which is depicted below.

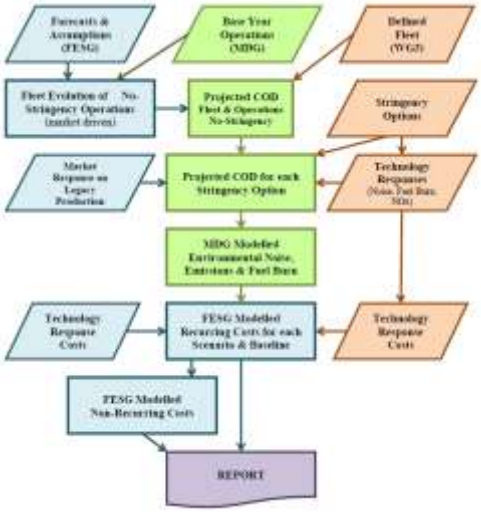


*Figure 2: Illustration of the CO2 Standard Main Analysis*

## Recent Accomplishment #3: Sensitivity Analyses

The ASCENT Project 14 team is conducting sensitivity analyses in order to inform decision makers of potential outcomes under different scenarios and assumptions using the FAA Tool Suite, quantitative and qualitative research methods. A notional example of the sensitivity analysis is depicted below.

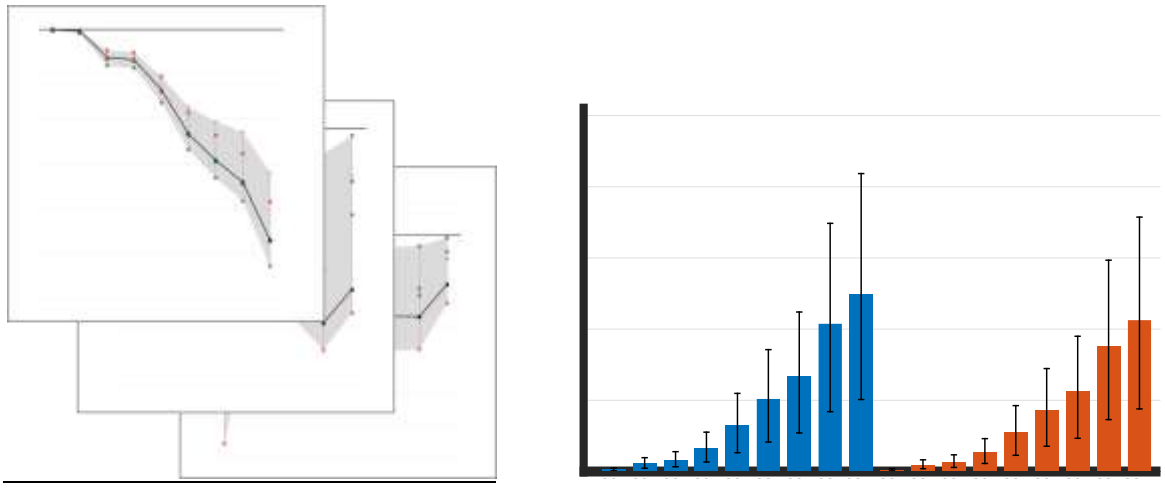

*Figure 3: Illustration of sensitivity analyses*

## Recent Accomplishment #4: Stakeholder Analysis

ASCENT Project 14 team is actively engaging stakeholders using a data driven collaborative approach by quantifying the potential impact of the various CO2 Standard options on forecast fleet evolution, airline and manufacturer economic metrics, and interdependencies using the FAA Tool Suite

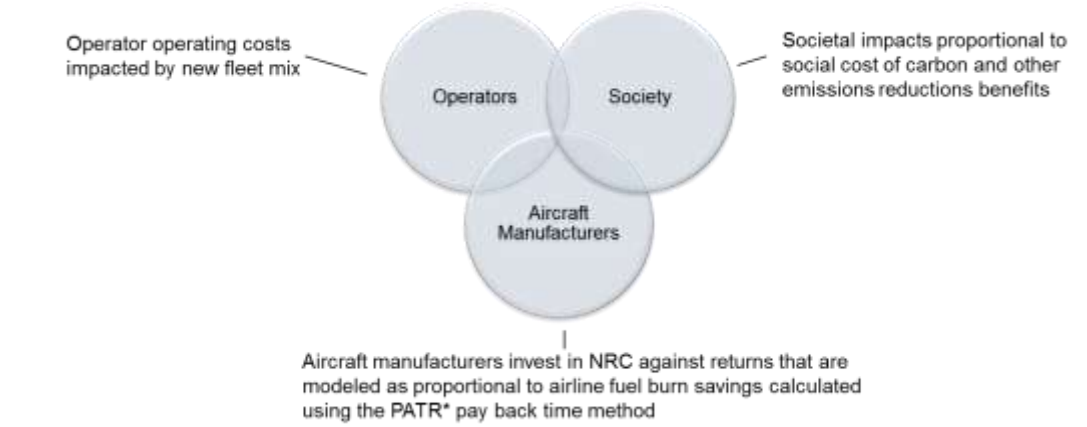


*Figure 4: Illustration of Stakeholder Analysis*

## Recent Accomplishment #5: Green House Gas (GHG) Modeling in FAA's AEDT using Direct Transformation Approach

ASCENT Project 14 has been investigating how to perform GHG modeling in AEDT 2b. As a result, a direct transformation approach has been developed that can directly manipulating the database to create a GHG modeling study in AEDT for any size of schedule data generated from the APMT-E outputs. This approach used an empty AEDT study DB and developed SQL scripts to populate the data tables of the Study DB required to run AEDT analysis. To test this process, the 629 operation schedules given as part of BADA3 vs BADA4 comparison study in October 2014 were used as a test study. The direct transformation approach was successfully conducted on the test study, and the results generated by this approach were compared with the results produced by Volpe. It shows that most of the results have a good agreement with the results produced by Volpe, and for a small portion the flights (from 2 of 9 OD pairs), AEDT does not generate right results. The team is working with AEDT support team to resolve this inconsistency and will give the updates once it is accomplished.

## Recent Accomplishment #6: Connecting CO2 Stringency Options

The ASCENT Project 14 team has developed a tool which can help the CAEP members to connect CO2 stringency options. Some of the CAEP Member States, including the United States, have proposed different SO lines for aeroplane types below and above the 60t MTOM kink point. If different SOs are selected, it would be necessary to agree on a method to join the SO lines. However, there are various methods that can be used to connect SOs, and it is recognized that no method is perfect or better than the other. The research team developed guiding principles that the connecting methods should meet.

The first guiding principal is to minimize market distortions. Considerations should be given to the magnitude of the impacts by the connecting method on the CO2 main analysis results. Depending on the selection of the SOs, some connecting methods may not have any impacts on aeroplane types (e.g. due to gaps or lack of aeroplane types) in the MV-MTOM space. Other connecting methods, however, may impact aeroplane types (e.g., fail, or imply a different technology response) and slightly perturb the CO2ma results from CAEP MDG/FESG.

The second guiding principle is to minimize impacts to aeroplane types above 60t MTOM. The connection of SOs should strive to avoid changing the regulatory level of the aeroplane type above 60t since the majority of the CO2 reduction benefits come from the aeroplane types above 60t. Therefore, perturbation of the SO lines below 60t due to a connecting method is likely to have fewer impacts on the CO2ma results than perturbation of the lines above 60t.

The third guiding principle is to avoid separating aeroplane type families. This principle address the concerns that, to the extent possible, avoid connecting SOs such that existing aeroplane type families are separated by a line between stringency options. Since this could create significant differences in margins to regulatory levels across aeroplane types within the same family (i.e., technology level) and could result in unintended consequences.

A few connecting methods were investigated and a decision support tool was developed to implement these methods, as shown in Figure 5. There are three methods implemented in this decision support tool, including plateau, fanning and plateau shift methods. The tool can allow the user to choose which two SOs to connect below and above 60t MTOM. In addition, the user can adjust the MTOM at left or right hand kink for different method. With these inputs (green cells in Figure 5) defined, the tool can interactively illustrate the blended SO line (red line). And it can also automatically filter out the aeroplane which are impacted by the blended SO, that is the aeroplane whose margin(s) to the SO line change after connecting. By using this tool, the user can effectively make decision on selecting the method which adhere to the guiding principles for connecting different SOs.

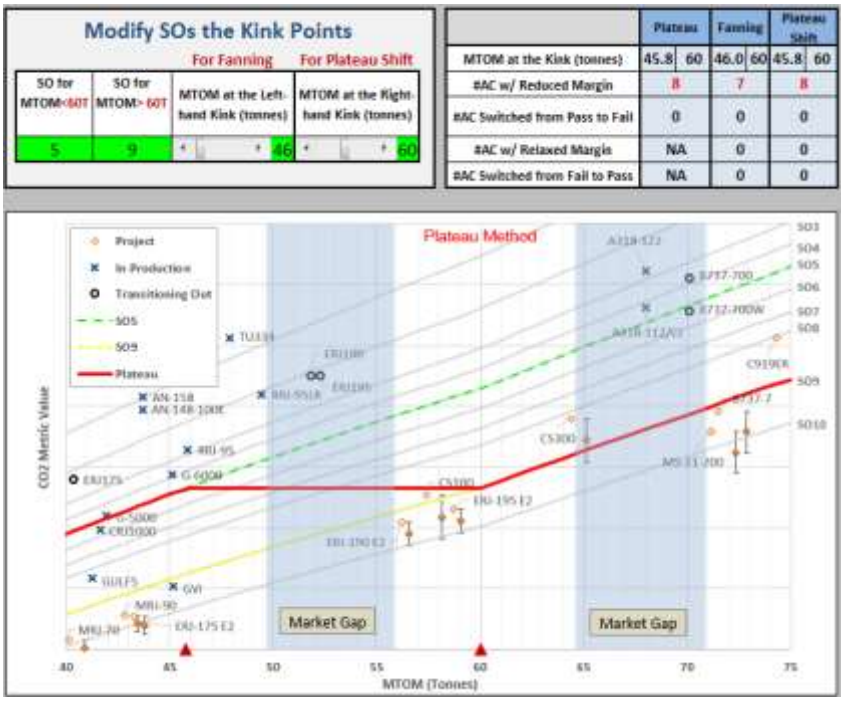


*Figure 5: Decision Support Tool for Connecting SOs*

## Milestone(s)

- A14 supported U.S. policy maker to reach agreement with other CAPE members on the carbon standards for commercial aircraft at CAEP meeting
- A14 supported U.S. policy makers leading up to the July 2015 Steering Group Meeting in Montreal, Canada
- A14 is completing an extensive cost benefit analysis in order to inform the U.S. position for the development of an aircraft CO2 standard
- A14 to inform U.S. policy makers leading up to Feb 2016 CAEP CO2 standard decision
- Provide materials to support MDG/FESG and WG3 meetings during October 2015

## Major Accomplishments

- The U.S. and 22 other countries reached agreement on the first-ever global carbon standards for commercial aircraft
- CAEP consensus on a functional CO2 Standard metric
- Systematic analysis process utilizing the FAA environmental tool suite
- Technical and data driven input into CAEP process
- Cost benefit analysis to inform U.S. policy makers and FAA team

- Future fleet evolution studies for CAEP and NextGen

## Publications

**CAEP Reports**

- Guidance on Connecting CO2 Stringency Options (CAEP 10 IPXX Connecting SOs)
- COST-BENEFIT ANALYSIS… (CAEPx_SGx_IPxx_Cost-Benefit Analysis of CAEP10 CO2 Stringency Options)
- CO2 main analysis: Cost… (CAEPSG.201x.WPx.en_FESG-MDG)
- INVESTIGATION OF PRICE… (IP0x_MDG-FESG-STG-0x)
- POST-PROCESS IMPLEMENTATION OF PRICE… (IP0x_MDG-FESG-STG)
- CO2 MAIN ANALYSIS… (CAEPSG.201x.WP.x.3.en_MDG-FESG)
- CO2MAIN ANALYSIS: FUEL PRICE… (IP0x_MDG-FESG-STG-0x)
- CO2MAIN ANALYSIS: FUEL PRICE… (WP0x_MDG-FESG-STG-0x)
- Technology review… (CAEPx_WGx_CO2_WP0x)
- CO2 MAIN ANALYSIS: FRAMEWORK… (CAEPx_WGx_CO2-x_IP0x)
- CO2 MAIN ANALYSIS: FRAMEWORK… (presentation)

## Outreach Efforts

- Participation at ICAO CAEP meeting in Montreal Canada, February 2016
- Participation at ICAO CAEP Steering Group 10 in Montreal Canada, July 2015
- Participation in ICAO CAEP MDG/FESG Meetings
  - Savannah, Georgia (January 2015)
  - Cologne, Germany (April 2015)
- Participation in ICAO CAEP WG3 Meetings
  - Belfast, United Kingdom
  - Washington D.C., U.S.A.
- Extensive interaction with Volpe
- Extensive support of interaction with Stakeholders
  - Manufacturers, Operators, NGOs, EPA
- Within ASCENT
  - Collaboration with ASCENT Projects 20, 21, and 24A on environmental impact modeling to assess value of the standard
  - Collaboration with ASCENT Projects 11A and 11B on fleet modeling
  - Collaborating with Volpe on the GHG modeling in AEDT2b

## Awards

None

## Student Involvement

Graduate students have been involved in all aspects of this research and have been key members of the team.

GT: Robert Moss (M.S. April 2015, employed), Fatma Karagoz (M.S. April 2015, transitioned to another project)
MIT: Edward Mugica (M.S. May 2015, employed), Morrisa Brenner (estimated: M.S. ’17, PhD ’20)
BAH: None

## Plans for Next Period

None. Project is completed.