Department of Aeronautics and Astronautics
School of Engineering
Massachusetts Institute of Technology

Graduate Program (S.M., Ph.D., Sc.D.)

Field: Air Transportation Systems
Date: September 4, 2007

1. Introduction and Purpose

The graduate program in the Department of Aeronautics and Astronautics at M.I.T. provides educational opportunities in a wide variety of aerospace-related topics through academic subjects and research. The purpose of this document is to provide incoming masters and doctoral level students guidance in planning the subjects they will take during their graduate program. The focus of this document is Air Transportation Systems. The suggestions outlined here are to be understood as guidance and not as a mandatory, rigid framework. The final decision as to which subjects are taken and in what sequence is to be decided between each student and their academic advisor and/or doctoral committee. In addition to these recommendations, the official S.M. and doctoral degree completion requirements must be taken into account during the design of a graduate program[1].

2. Motivation for studying Air Transportation Systems

Since Charles Lindbergh's first solo non-stop flight across the Atlantic Ocean in 1927 air transportation has become a major driver for global travel and commerce. Initially, major cities were connected by only a few pioneering airlines and the focus was on transportation of passengers and air mail. Gradually, with the advent of the jet aircraft, specifically the Boeing 707, air transportation has expanded at a dramatic pace.

The sustained growth of air transportation since the 1960s has led to new generations of wide and narrow body aircraft, and the emergence of new market segments such as business aircraft for corporate travel. The air shipment of parcels (e.g. DHL, FedEx, UPS and other carriers) has increased enormously in recent years and is a major enabler of decentralized supply chains and commerce.

With this expansion, however, have come a number of systems engineering challenges, all requiring further research and development of advanced methods:

Capacity Constraints: As the number of commercial flights increases along with the number of passengers carried per year, a number of capacity constraints are affecting the efficiency of the air transportation system, as well as its ability to expand further. The

[1] Refer to the S.M., Ph.D. and Sc.D. degree requirements in Aeronautics and Astronautics section of the MIT Bulletin, or to http://web.mit.edu/aeroastro/academics/grad/index.html

two main constraints are airport runway constraints (the number of takeoffs and landings that can be performed per hour), as well as enroute air traffic control constraints. Air transportation experts and researchers are investigating the effects of these capacity constraints as well as potential ways of removing bottlenecks from the air transportation system, either through improved infrastructure and technology or by adoption of new procedures.

Safety and Security: The terrorist attacks of September 11, 2001 have demonstrated in a tragic way that large commercial aircraft are vulnerable to targeted attack and that such vulnerabilities must be mitigated through improved security at airports, in aircraft themselves, as well as by developing best practices. Additionally, while the number of aircraft accidents and fatalities has decreased significantly since the 1960s further improvements in air safety need to be achieved in light of the growth in air traffic volume and density.

Environmental Impacts of Aviation: Airports around the world, led by Heathrow in London (UK) and several other Western European airports, are imposing increasingly stringent regulations to limit the impact of noise, NO_x and particulate emissions on the local population surrounding airports. One way to reduce the impact of aviation is to develop a new generation of more environmentally friendly aircraft.

As urban areas expand, airports that used to be well outside city limits are increasingly surrounded by urban areas. This requires the careful development of new approach procedures that will minimize the noise footprint of aviation in urban areas. It also requires a more integrated approach to airport planning and management and a more deliberate and strategic approach to stakeholder interactions. There is also a desire to understand environmental impacts at a global scale and develop phenomenological and parametric models of air transportation at such scales. This is currently one of the aims of the PARTNER consortium, in which MIT is the leading institution.

Economics and Evolution of Airlines: Since the airline deregulation of 1978, U.S. airlines have faced many challenges and experienced great year-to-year variability in terms of profitability and industry health. This has manifested itself through mergers and consolidation and through the disappearance of some of the major airlines of the past (PanAm, TWA, Eastern). While some of the traditional airlines are struggling, newer low-cost airlines (Southwest Airlines, Jet Blue) have made significant inroads in restructuring the industry and challenging traditional business models. A thorough understanding of airline economics and of interactions with government regulations, market demand and technology is required to make contributions in this important area.

Figure 1 shows seasonal revenue distribution trends in the airline industry as an example of economic air transportation analysis

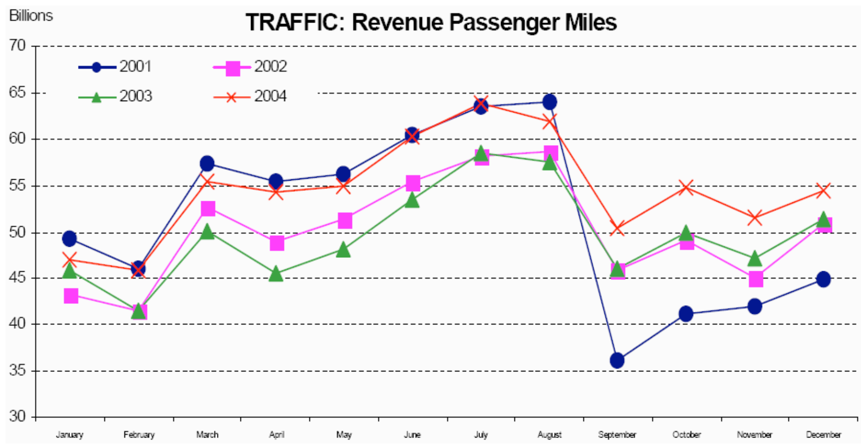

Figure 1**:** Revenue distribution of airlines (U.S.) 2001-2004 (source: P. Belobaba)

Study of airline operations and networks is increasingly global. New airlines are also emerging in Europe (Fig. 2) and Asia and their growth and evolution can be studied using network analysis and graph theory.

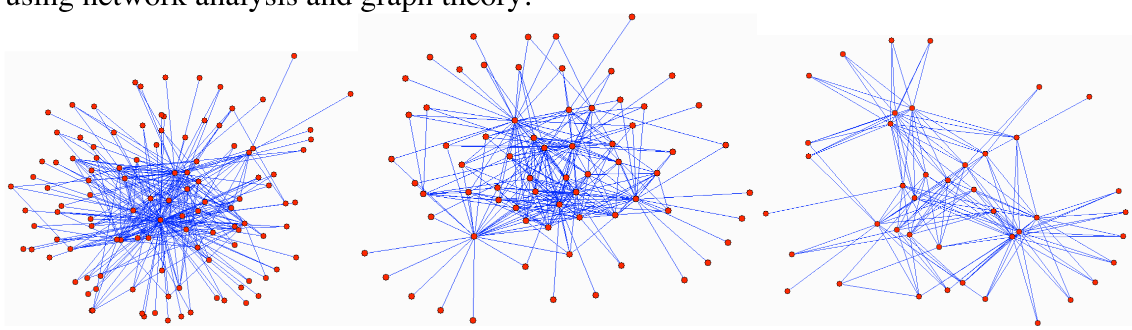

Figure 2: Example of airline route networks (2005 timetable), from left to right for Ryanair, EasyJet and SkyEurope. All three airlines exhibit interesting, transitions from star to multiple hub-and-spoke topologies (source: G. Bounova).

3. What are Air Transportation Systems Engineers?

One of the challenges facing air transportation systems engineers is that they must understand the interaction of a number of complex, interrelated domains. This interdisciplinary focus is essential to future success as a researcher or practitioner in this area. Below we list what we feel are the main disciplines that are necessary to master air transportation as a field. Different individuals will choose to place special emphasis in one or two of these areas, but some familiarity with all of them is necessary.

First, they must understand <u>aircraft technology and design</u> with an eye towards operational issues. Each type of aircraft is characterized by a set of specifications such as range, capacity and takeoff and landing length. These specifications drive the way in which aircraft are used to transport passengers and/or cargo as part of a larger transportation network. The aircraft also consume fuel, and produce noise and chemical emissions. For the most part students in Air Transportation will not focus directly on the design of aircraft, but rather on the implications of the aircraft's technical, economic and operational characteristics in a larger context.

Infrastructure aspects are also crucial since they relate to the abovementioned capacity constraints. The planning and design of new airports is a major technical, economical and policy challenge. Airport runway and taxiway layout, optimization of approach and departure procedures and integration with the local economy and ground transportation systems must all be considered. The air traffic control system (ATC) is also a major part of the infrastructure. Radar systems and navigational aids (such as GPL, VOR, NDB etc) have been used for decades, but their modernization and upgrading has lagged behind the best available technology due largely to policy and economic challenges. How can a major infrastructure be upgraded, when its day-to-day operations cannot be disrupted? These are major questions needing to be addressed by air transportation engineers.

Knowledge in operations research, economics and policy are essential for tackling major air transportation questions. Airlines typically operate as for-profit firms providing transportation services to passengers and cargo. The modeling of such operations, including the purchase and leasing of new and existing aircraft, the scheduling of aircraft and crews, the monitoring of direct operating costs, as well as the susceptibility to fluctuating fuel prices and government regulations are all crucial aspects with which air transportation professionals have to grapple.

4. Educational Goals in Air Transportation

The overall educational goal of the MIT graduate program in Air Transportation is to prepare students for successful careers as researchers and practitioners in the areas of airline management, air transportation infrastructure design and analysis, as well as air transportation systems architecting.

Successful graduates of the program will have achieved the following objectives:

- They will have gained a fundamental understanding of aircraft technology and design, typically focusing on wide and narrow-body commercial aircraft.

- They will have developed the ability to assess emerging trends, such as the growing use of business jets and the fractional ownership of aircraft.

- They will have exercised this knowledge in the analysis and assessment of a particular air transportation problem, using real world data and interactions with actual stakeholders (airlines, FAA, general aviation, airport operators).

- They will have established breadth in the main areas underpinning air transportation: aircraft and airport design, network modeling, computer simulation, airline economics and management.

- They will have gained experience in the field by applying this knowledge in the context of an actual airline or government organization, e.g., through internships or research interactions.

- They will have generated original research contributions to augment the existing body of knowledge.

To achieve this goal, each student should develop an educational plan with their academic advisor and/or doctoral committee following the guidelines outlined below.

5. Educational Plan in Air Transportation Systems

The educational goals outlined above lead to a proposed recommended Air Transportation Systems program of study. This section proposes a program structure that will accommodate masters and doctoral candidates alike.

Additionally all students have to meet the departmental Mathematics Requirement (see separate document available from the graduate student office) with two graduate level mathematics courses. The department keeps a list of mathematics courses that are acceptable for fulfillment of this requirement.

Overview

An Air Transportation Systems program of study will typically consist of:

(a) A single overview subject;
(b) Two subjects that provide in-depth knowledge in a specialized area.
(c) Two subjects that provide a mathematical/methodological foundation;

These are described in more detail below.

The Overview Subject

16.71J The Airline Industry

[Provides working knowledge of the fundamental issues in air transportation systems: airline economics, planning and operations; international and national regulatory environments; air transportation infrastructure; safety and security; environmental impacts; labor and human resources; interactions among all these elements.]

Specialized Areas

A sequence of at least two subjects in one specialized sub-area of air transportation systems. The following lists approved areas and associated courses. Other combinations of subjects may be approved after consultation with the student's academic and research advisors.

(a) Aviation Infrastructure:

16.72	Air Traffic Control
16.781J	Planning and Design of Airport Systems
ESD.41	Infrastructure Systems

(b) Airline Operations and Management

16.75J	Airline Management
16.77J	Airline Schedule Planning

(c) Air Transportation Systems Architecting

16.886J	Air Transportation Systems Architecting
16.885	Aircraft Systems

(d) Environment and Energy

[To be completed.]

Mathematical / Methodological Foundations

Select at least two subjects. The following subjects are particularly appropriate and recommended. [*Note:* Several of these subjects are also accepted as fulfilling the Department's graduate mathematics requirement noted above.]

1.202J/ESD.212J	Demand Modeling
16.76J/ESD.216J	Logistical and Transportation Planning Methods
6.251J/15.081J	Introduction to Mathematical Programming
6.254	Game Theory with Engineering Applications
15.093J	Optimization Methods
15.082J/ESD.78J	Network Optimization
ESD.34	Systems Architecture
ESD.74	Systems Dynamics for Engineers

This should help a masters student put together a coherent air transportation oriented program, which leads to a S.M. in Aeronautics and Astronautics with emphasis on air transportation. The degree requirement [MIT Catalogue] specifies 66 units, which corresponds to 6 graduate level 12-unit subjects. Doctoral candidates will typically go beyond what is described above in terms of depth and number of units taken, depending on the needs of their particular research topic.

6. Faculty and Staff with Interests in Air Transportation

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Please consult the MIT Aero & Astro web-page for detailed faculty and staff interests:
http://web.mit.edu/aeroastro/faculty/faculty.html