Air Transportation Cost Models

Dr. Antonio Trani
Professor
Virginia Tech

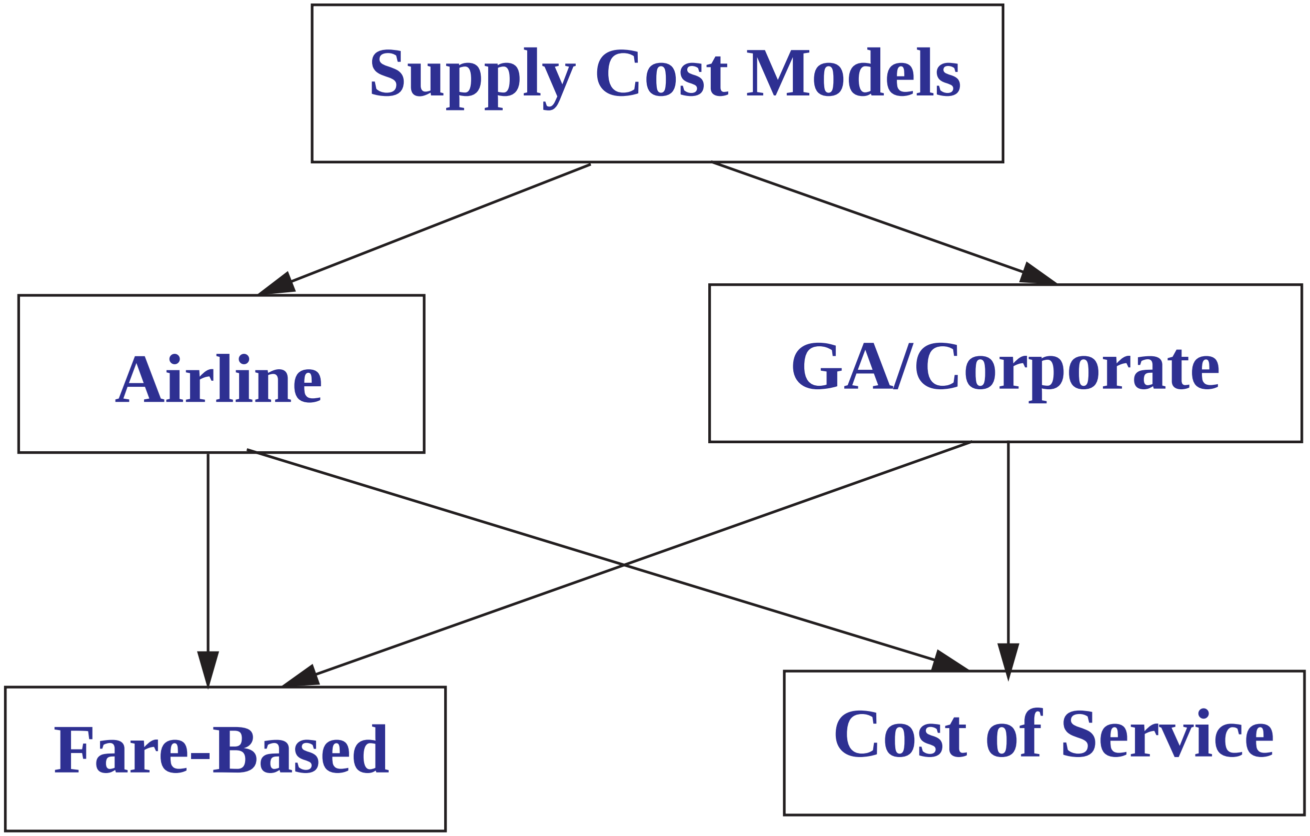
Material Presented in this Section

- Review of aircraft cost models (supply costs in air transportation)
- How supply of service affects the operational economics of the air transportation service
- Apply aircraft performance functions to derive supply relationships
- Cost development models
- Case study: low-boom aircraft

Aircraft Supply Cost Modeling

- Supply function costs are a very important component in the analysis of air transportation systems
- Supply costs are driven by the economics of the aircraft used, the network structure of the service provider (degree of “hub consolidation”), labor costs, etc.
- Two views of the world to derive supply costs in air transportation:
  - Fare-based models
  - Life-cycle cost models based on actual information about organizational cost components

Taxonomy of Air Transportation Supply Models



Fare-Based Models

- Look into the public record and attempt to capture the average fare paid by users in a given air transportation segment
- No attempt made to evaluate individual costs of providing service
- Fares vary dramatically in NAS (specially for airline-type operations)
- These models have appeal because they are simple to derive once you have good access to the fare data
- Best sources of data: airline bookings, DOT BTS DB1B data (go to http://transtats.bts.org)

Fare-Based Models

- We provide you with a sample fare-based model developed at Virginia Tech to predict commercial airline costs across NAS
- This work is part of an integrated transportation systems assessment plan to evaluate new NASA concepts like SATS - Small Aircraft Transportation System
- The model has also been used in mode split analysis calibration for the FAA NAS Strategy Simulator (recently)

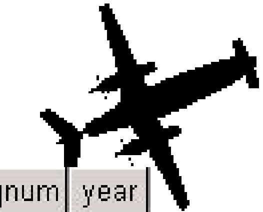
What is the DB1B Database?

- A 10% sample of tickets sold in the country by carriers
- Only a sample (so be aware of possible errors in low density markets)
- Collected by DOT and published by the Bureau of Transportation Statistics (BTS) at http://transtats.bts.org
- Three types of records are collected:
  - Coupon
  - Market
  - Ticket

Brief Summaries of Each Record

- **Coupon Record**
  - Operating carrier, origin and destination airports, number of passengers, fare class, coupon type, trip break indicator, gateway indicator, and distance
- **Market Record**
  - Includes such items as passengers, fares, and distances for each directional market
- **Ticket Record**
  - Reporting carrier, prorated market fare, number of market coupons, market miles flown, and carrier change indicators

Sample Coupon Records



coupo	dest	distanc	farecla	itinid	mktid	opcar	origin	passen	quarter	seqnum	year
4	ATL	576.0	Y	200011000075	200011856239	DL	BWI	1.00	1	3	2000
4	JAX	270.0	Y	200011000075	200011856239	DL	ATL	1.00	1	4	2000
4	ATL	270.0	X	200011000076	200011856240	DL	JAX	1.00	1	1	2000
4	BWI	576.0	X	200011000076	200011856240	DL	ATL	1.00	1	2	2000
4	ATL	576.0	Y	200011000076	200011856241	DL	BWI	1.00	1	3	2000
4	JAX	270.0	Y	200011000076	200011856241	DL	ATL	1.00	1	4	2000
4	ATL	270.0	X	200011000077	200011856242	DL	JAX	1.00	1	1	2000
4	BWI	576.0	X	200011000077	200011856242	DL	ATL	1.00	1	2	2000
4	ATL	576.0	Y	200011000077	200011856243	DL	BWI	1.00	1	3	2000
4	JAX	270.0	Y	200011000077	200011856243	DL	ATL	1.00	1	4	2000
4	ATL	270.0	Y	200011000078	200011856244	DL	JAX	1.00	1	1	2000
4	BWI	576.0	Y	200011000078	200011856244	DL	ATL	1.00	1	2	2000
4	ATL	576.0	X	200011000078	200011856245	DL	BWI	1.00	1	3	2000
4	JAX	270.0	X	200011000078	200011856245	DL	ATL	1.00	1	4	2000
4	ATL	270.0	Y	200011000079	200011856246	DL	JAX	1.00	1	1	2000
4	BWI	576.0	Y	200011000079	200011856246	DL	ATL	1.00	1	2	2000
4	ATL	576.0	X	200011000079	200011856247	DL	BWI	1.00	1	3	2000
4	JAX	270.0	X	200011000079	200011856247	DL	ATL	1.00	1	4	2000
2	LAS	1055	X	20001100008	20001185729.0	AA	DFW	1.00	1	1	2000
2	DFW	1055	X	20001100008	20001185730.0	AA	LAS	1.00	1	2	2000
5	ATL	270.0	X	200011000080	200011856248	DL	JAX	1.00	1	1	2000
5	BWI	576.0	X	200011000080	200011856248	DL	ATL	1.00	1	2	2000
5	COS	1504	N	200011000080	200011856248	--	BWI	1.00	1	3	2000

Sample Market Records

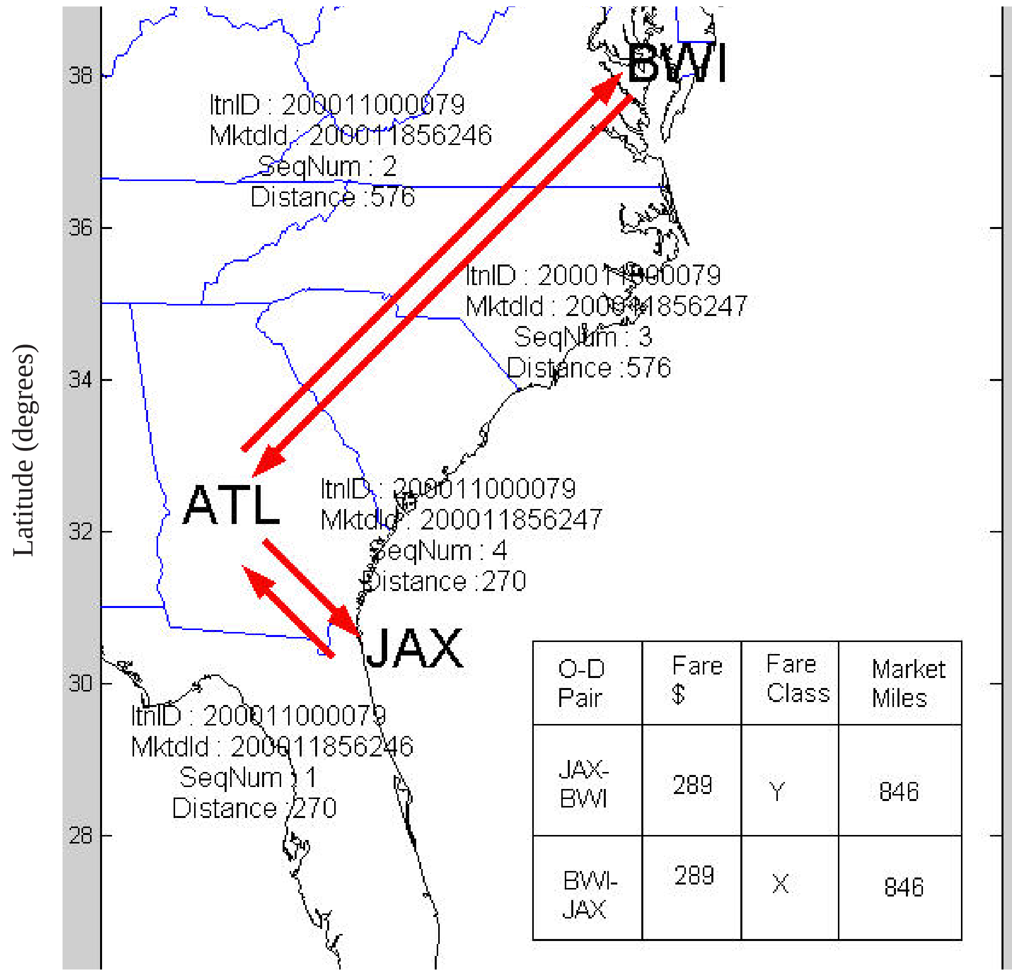
carr	dest	itinid	mktfare	mktid	mktmile	origin	pass	quarter	year
DL	JAX	200011000072	172.00	200011856233	846.00	BWI	1.00	1	2000
DL	BWI	200011000073	194.00	200011856234	846.00	JAX	2.00	1	2000
DL	JAX	200011000073	194.00	20001185[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2000
DL	BWI	200011000074	197.00	20001185[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2000
DL	JAX	200011000074	197.00	200011856237	846.00	BWI	1.00	1	2000
DL	BWI	200011000075	212.00	200011856238	846.00	JAX	1.00	1	2000
DL	JAX	200011000075	212.00	200011856239	846.00	BWI	1.00	1	2000
AA	DFW	2000199955.0	275.00	20001185624	1055.0	LAS	1.00	1	2000
DL	BWI	200011000076	218.00	200011856240	846.00	JAX	1.00	1	2000
DL	JAX	200011000076	218.00	200011856241	846.00	BWI	1.00	1	2000
DL	BWI	200011000077	257.00	200011856242	846.00	JAX	1.00	1	2000
DL	JAX	200011000077	257.00	200011856243	846.00	BWI	1.00	1	2000
DL	BWI	200011000078	245.00	200011856244	846.00	JAX	1.00	1	2000
DL	JAX	200011000078	245.00	200011856245	846.00	BWI	1.00	1	2000
DL	BWI	200011000079	289.00	200011856246	846.00	JAX	1.00	1	2000
DL	JAX	200011000079	289.00	200011856247	846.00	BWI	1.00	1	2000
DL	COS	200011000080	1.00	200011856248	846.00	JAX	1.00	1	2000
DL	JAX	200011000080	1.00	200011856249	1455.0	COS	1.00	1	2000
AA	LAS	2000199956.0	276.00	20001185625	1055.0	DFW	1.00	1	2000
DL	BWI	200011000081	54.00	200011856250	846.00	JAX	1.00	1	2000

Fare Information

Summary of Information Contained in DB1B Records

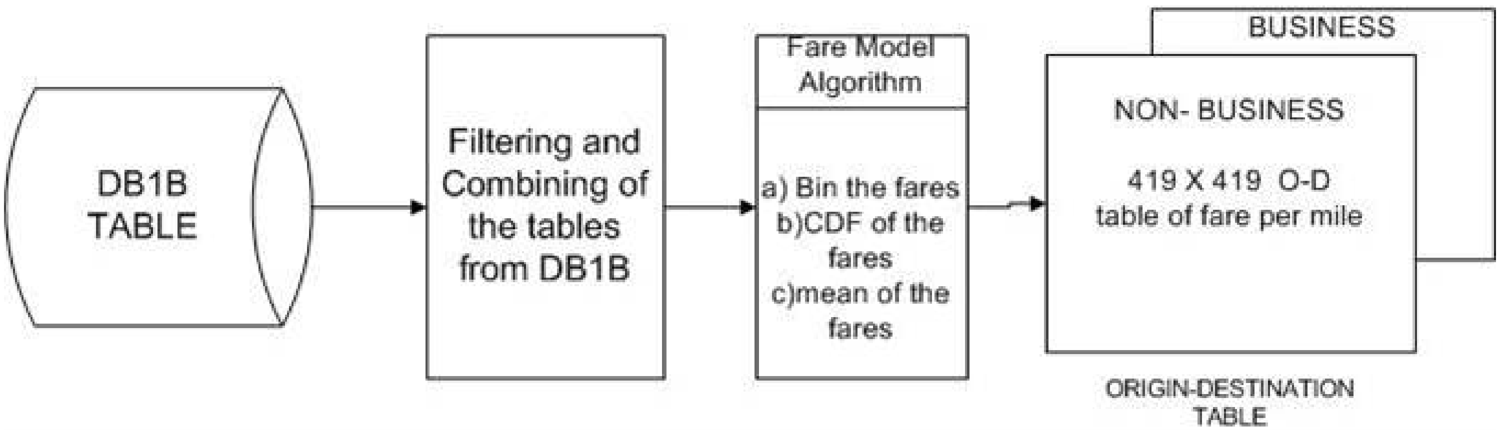
		TABLE TYPE	
FIELD	COUPON	MARKET	TICKET
Itinerary ID	Y	Y	Y
Market ID	Y	Y	
Year	Y	Y	Y
Quarter	Y	Y	Y
Sequence number	Y		
Coupons	Y	Y	Y
No of Passengers	Y	Y	Y
Fare Class	Y		
Market fare		Y	Y
Distance	Y	Y	Y
Origin	Y	Y	Y
Destination	Y	Y	
Carrier	Y	Y	Y
Itinerary yield			Y

Sample Information Provided by Combining DB1B Records



O-D Pair	Fare $	Fare Class	Market Miles
JAX-BWI	289	Y	846
BWI-JAX	289	X	846

Sample Procedure to Obtain a Fare-based Model



Requires a good data mining software (to handle large records such as SAS, SPSS, or even Matlab)

Fare-Based Models

RESULTS FROM DB1B

This is the total number of records in the combined file OD_Combined_2000_1

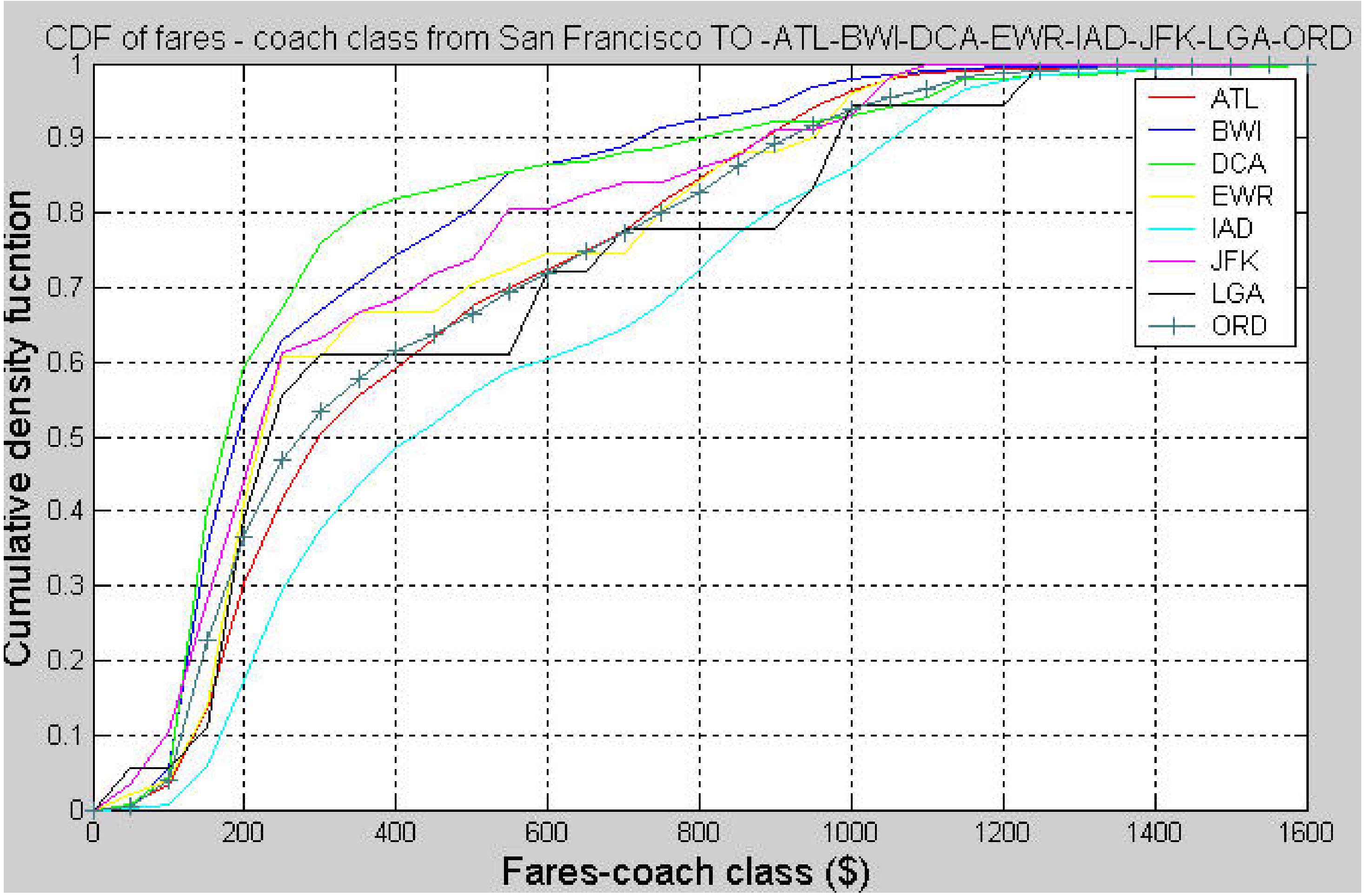
Total from the Table(i.e Records)	**3757457**	
		Percentage in the table
X(Restricted coach class)	2683563	**71.41965963**
Y(Unrestricted coach class)	623212	**16.58600484**
N	58461	1.555866108
C(unrestricted business class)	6919	0.184140497
D(restricted business class)	4698	0.125031371
F(Unrestricted First class	101285	**2.695573096**
G(Restricted first class)	243082	**6.469322204**
U(Unkown)	35318	0.939944223
Total	**3756538**	
Difference(Records which are unkown)	919	

Coach

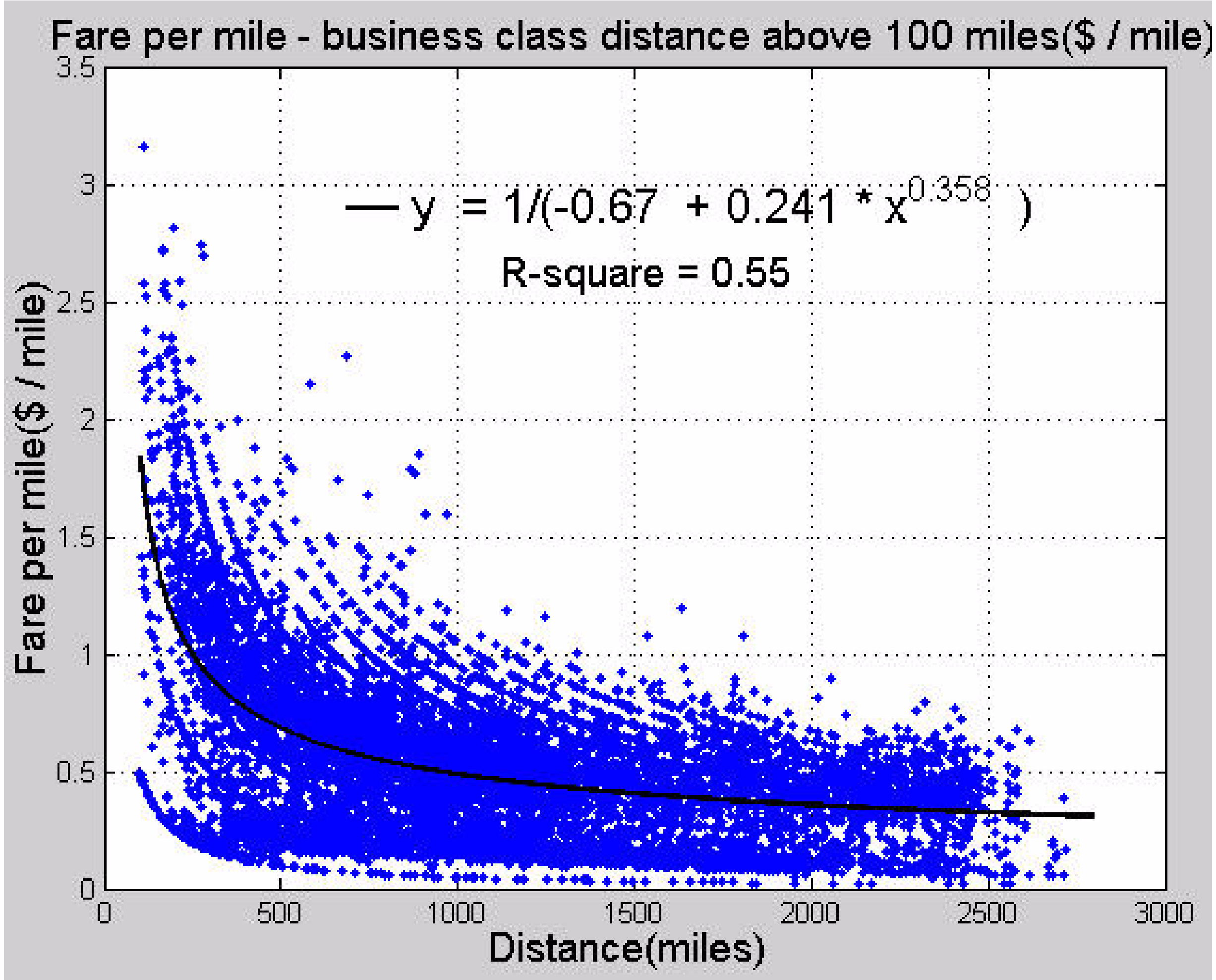
Business
First Class

DB1B records (first quarter 2000)

Sample Fares Extracted from DB1B



First and Business Class Fares in NAS



Virginia Tech Fare-Based Models (Commercial Airline Service in the year 2000)

Coach (general model) For distance > 50 miles

fare = distance / $(-0.14 + 0.039 * \text{distance}^{0.654})$

R-square = 0.76

Coach (above 100 statute miles) For distance > 100 miles

fare = distance / $(-0.26 + 0.027 * \text{distance}^{0.727})$

R-square = 0.78

Business (general model) For distance > 50 miles

fare = distance / $(-1.599 + 0.617 * \text{distance}^{0.262})$

R-square = 0.46

Business (above 100 statute miles) For distance > 100 miles

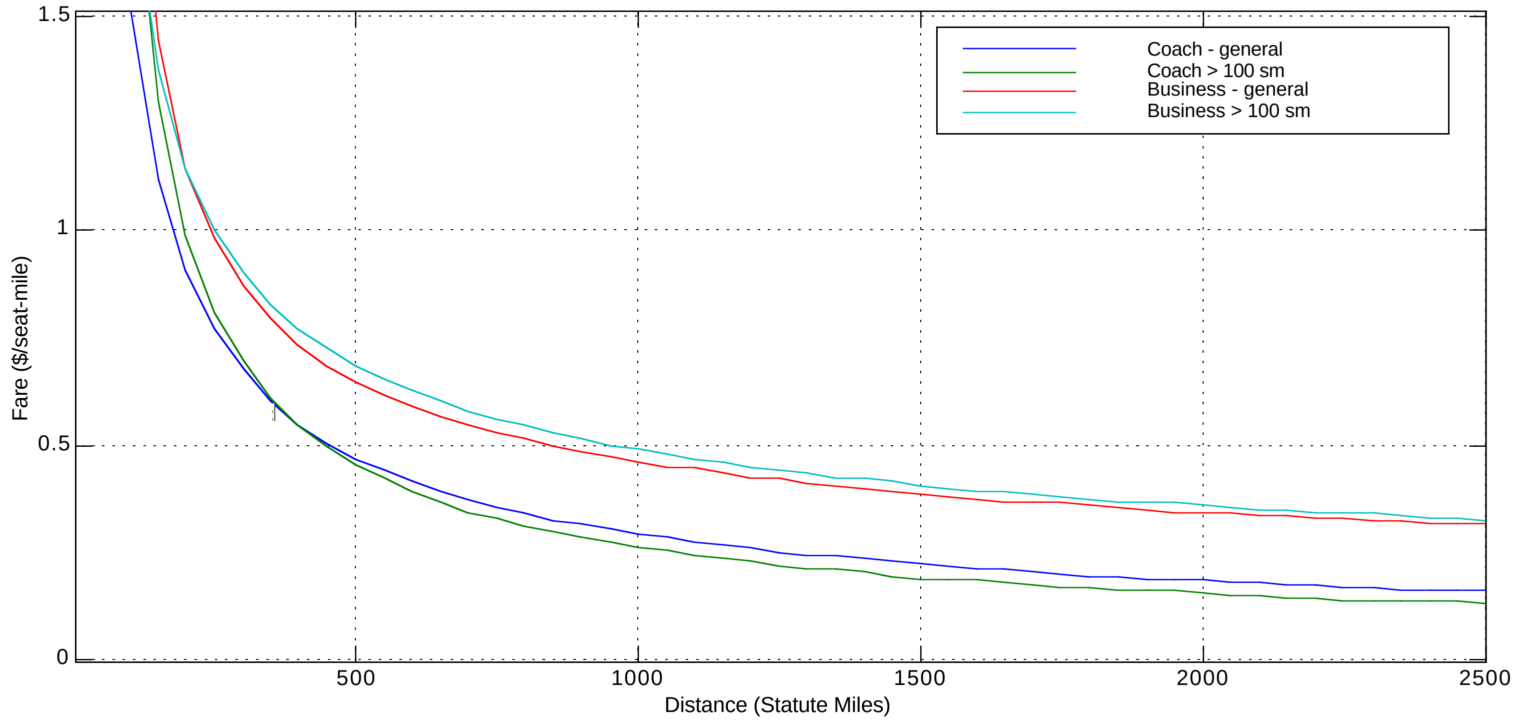
fare = distance / $(-0.67 + 0.241 * \text{distance}^{0.3508})$

R-square = 0.55

Coach fares (54,300 OD pairs), Business and First Class fares (13,200 OD pairs)

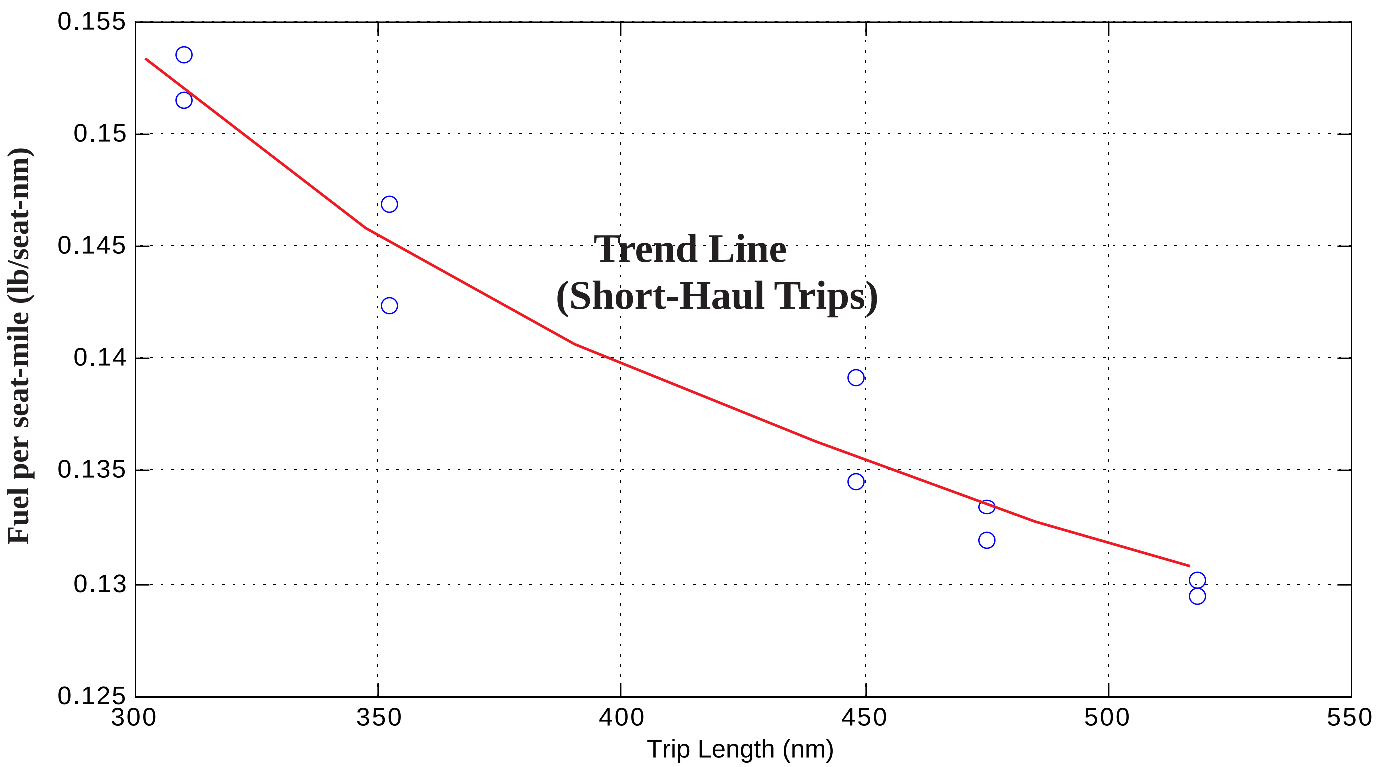
Source: DOT DB1B year 2000 data (all 10% samples)

Fare Based Models (Graphical)



Models are restricted to distances above 100 miles
Source: DB1B data (12 million records, year 2000)

Sample Airline Fuel Cost Function



Life Cycle Cost (LCC) Models

- An attempt to derive specific cost components of the service
- Each cost category is modeled as a state variable (an accumulator over time) with cost activities modeled over a long period of time (life cycle)
- Logistic support and maintenance actions are considered in the analysis

Sample General Aviation (GA) LCC Model

- Life-cycle GA models developed for NASA Langley Research Center
- Two types of models:
  - Generic model to predict cost for any size and weight given an engine technology
  - Specific GA aircraft models

GA technologies considered:

- SE = single engine
- ME = multi-engine piston and turboprop
- Jet = jet engine aircraft

General Costs Categories Considered in the Model

- Variable costs (fuel, maintenance hrs., parts, miscellaneous)
- Fixed costs (hull insurance, liability, software, miscellaneous)
- Periodic costs (engine overhaul, paint, interiors, flight deck upgrades)
- Personnel costs (captain and first officer - if applicable)
- Training costs (crew training and recurrent training, maintenance training)

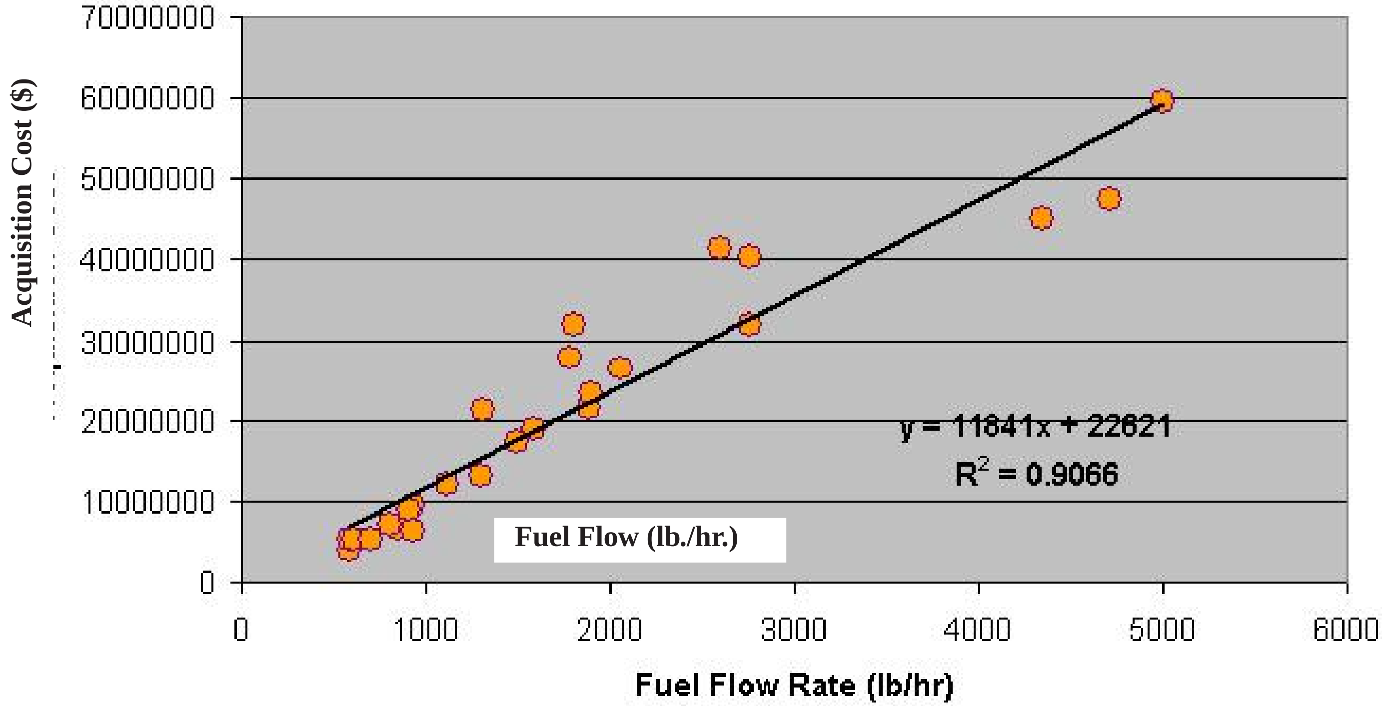
General Costs Categories Considered in the Model (continuation)

- Facilities costs (hangar space, office lease, miscellaneous)
- Depreciation cost (amortization of aircraft value)

Data Sources: Business and Commercial Aviation and ARG/US data (years 2001-2003)

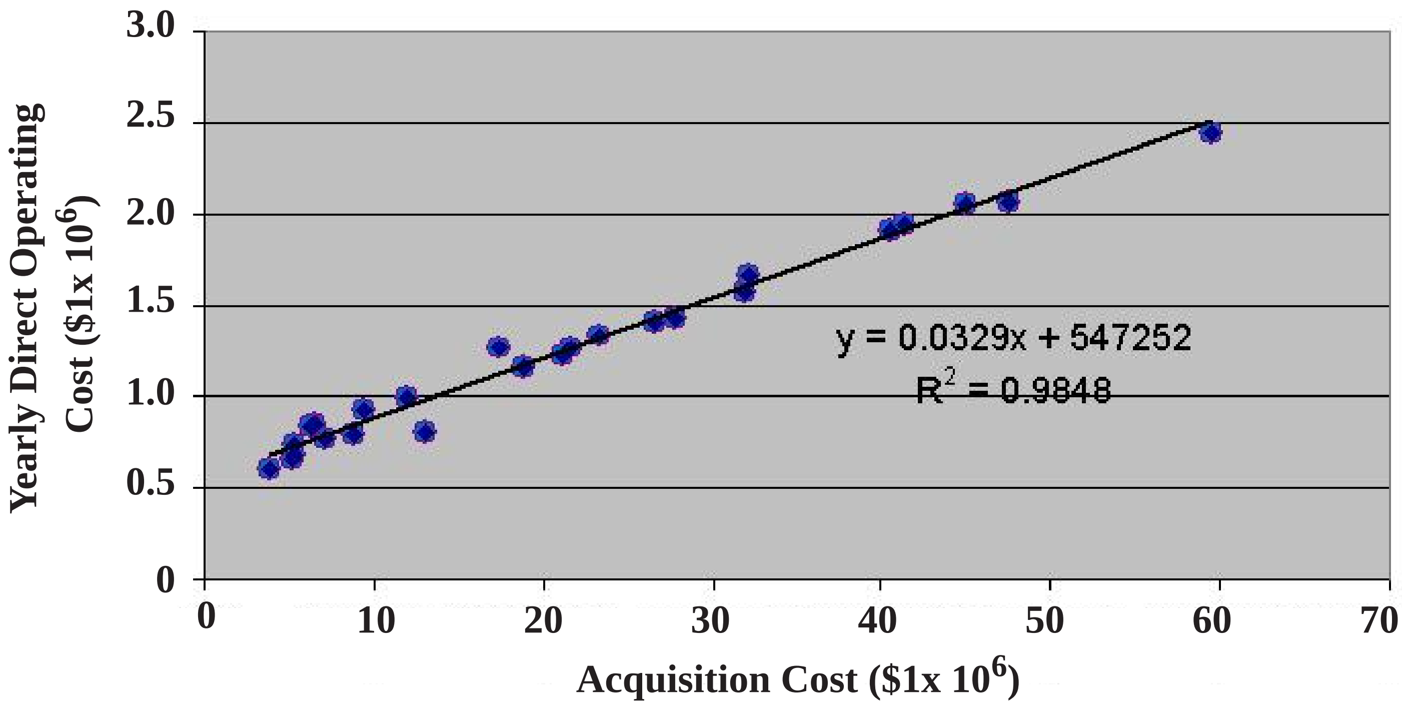
Generic LCC GA Cost Model

- Derives costs from fundamental relationships such aircraft design and operational parameters



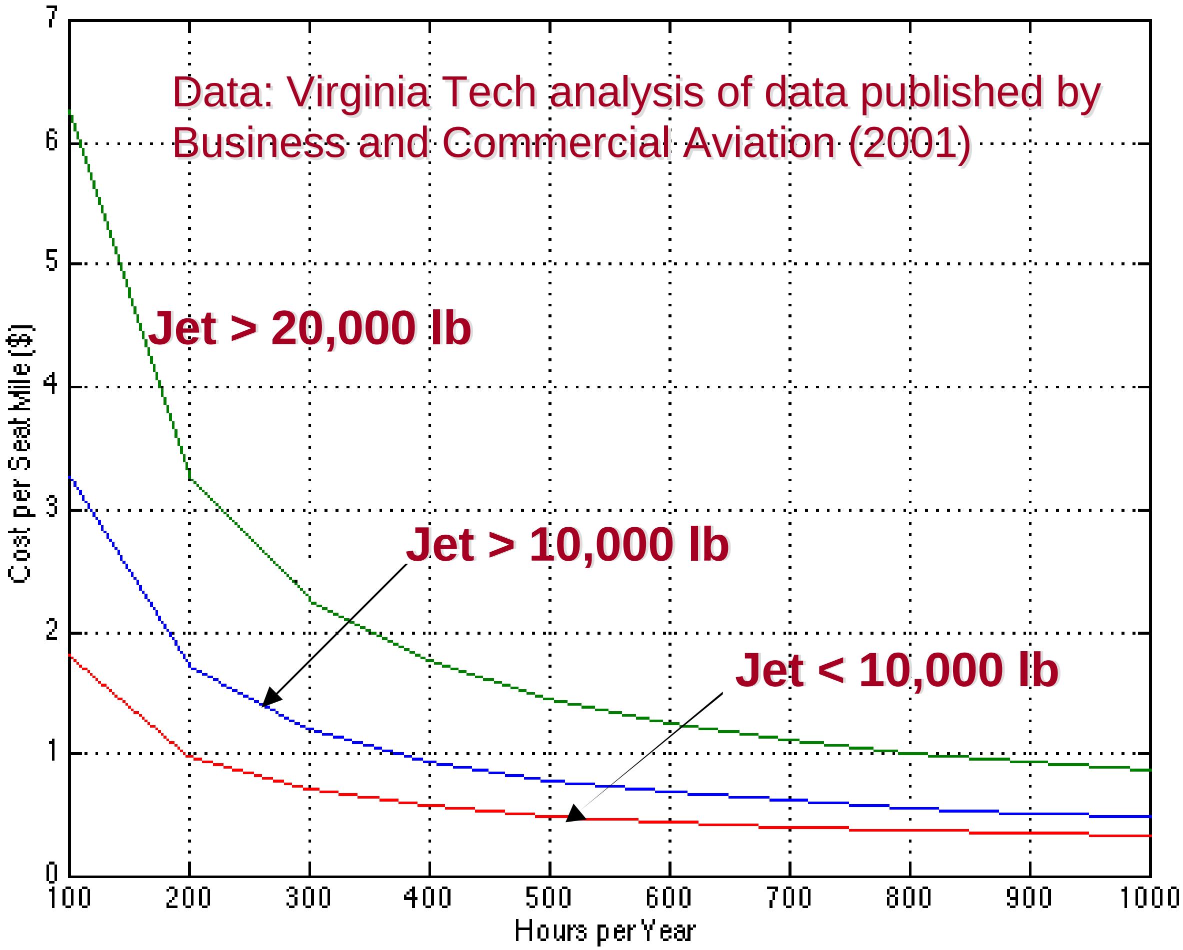
Sample Generic GA Cost Model

Assumption: 600 hours of operation per year



Source of aircraft prices: Business and Commercial Aviation (2001)

Sample Results of the Generic Aircraft Model



Aircraft Specific Cost Models

- Employed when one individual aircraft or technology is to be evaluated in great detail
- Considers actual costs (if available) or scaled costs from other aircraft if the technology is not mature
- An example model provided in the following pages was developed to help NASA Langley establish baseline costs for new generation of very light business jets like the Eclipse 500 and Safire

Aircraft Specific Cost Model (Eclipse 500)

Eclipse 500 PW 610F Cost Model (by A.A. Trani)

This model estimate the total ownership cost for an Eclipse 500 aircraft. The model uses preliminary data extrapolated from the Business and Commercial Aviation Operations Planning Guide

Cost Metrics

Total Cost Per Hour	1,012.17
Cost Per Mile	3.039550
Cost per Seat Mile	1.085554
Fuel Expense	193.283582

Annual Costs

Annual Variable Cost	144,948.47
Annual Amortization C...	44,411.0
Annual Fixed Costs	42,792.0
Annual Hangar and Offi...	49,800.0
Annual Periodic Costs	43,666.7
Annual Personnel Costs	68,750.0
Annual Traning Cost	10,500.00

Total Annual Cost

Annual Costs of Opera...	404,868.1

Jet Fuel Cost per Gallon: 1.5000 – 3.5000; U; 2.5000

Number of Pilots: 0 – 2; U; 1

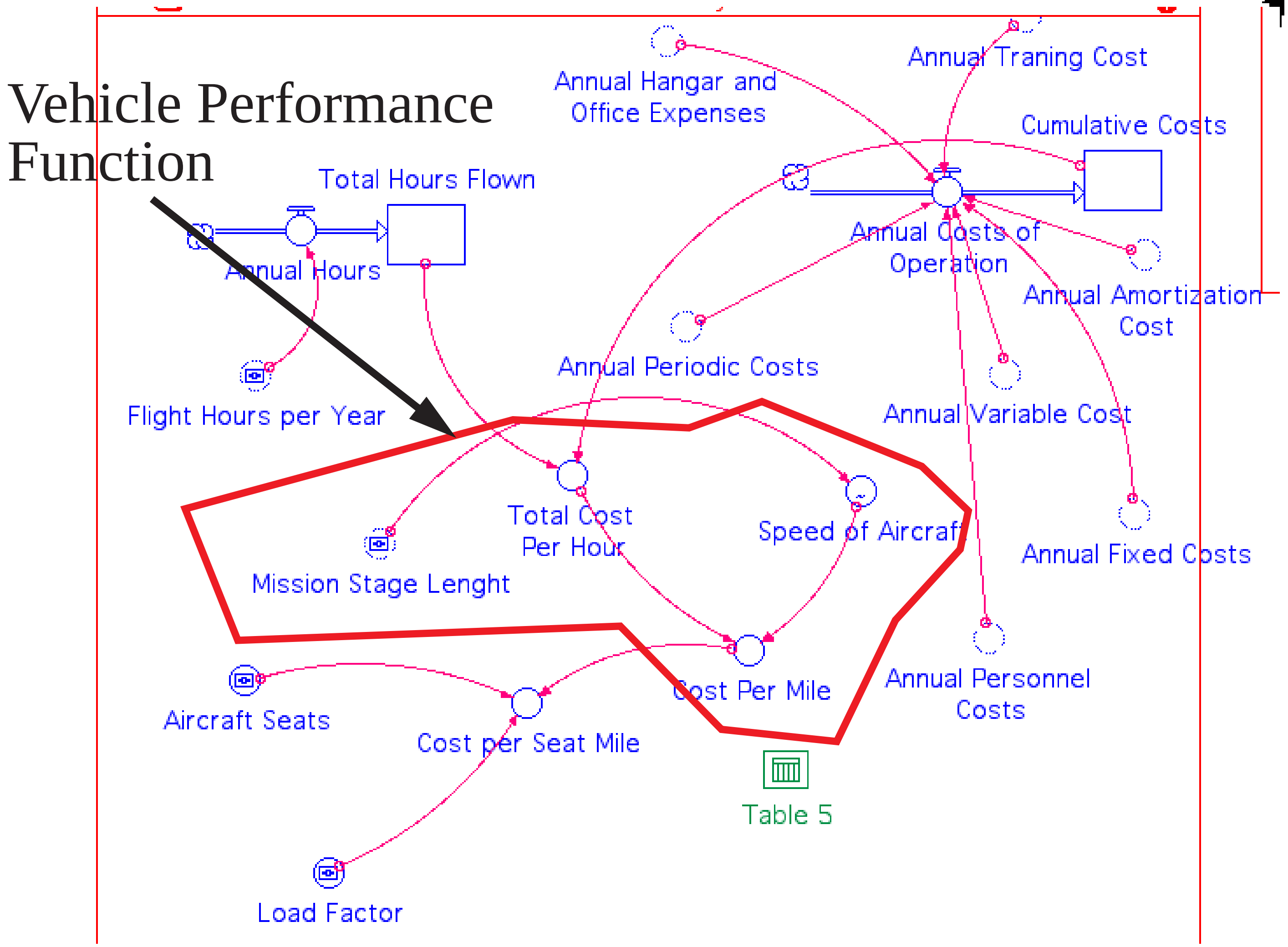
Load Factor: 0.3000 – 1.0000; U; 0.7000

Flight Hours per Year: 150.00 – 1000.00

Percent Resale Value: 0.3500 – 1.0000

Interest Rate: 0.05000 – 0.15000

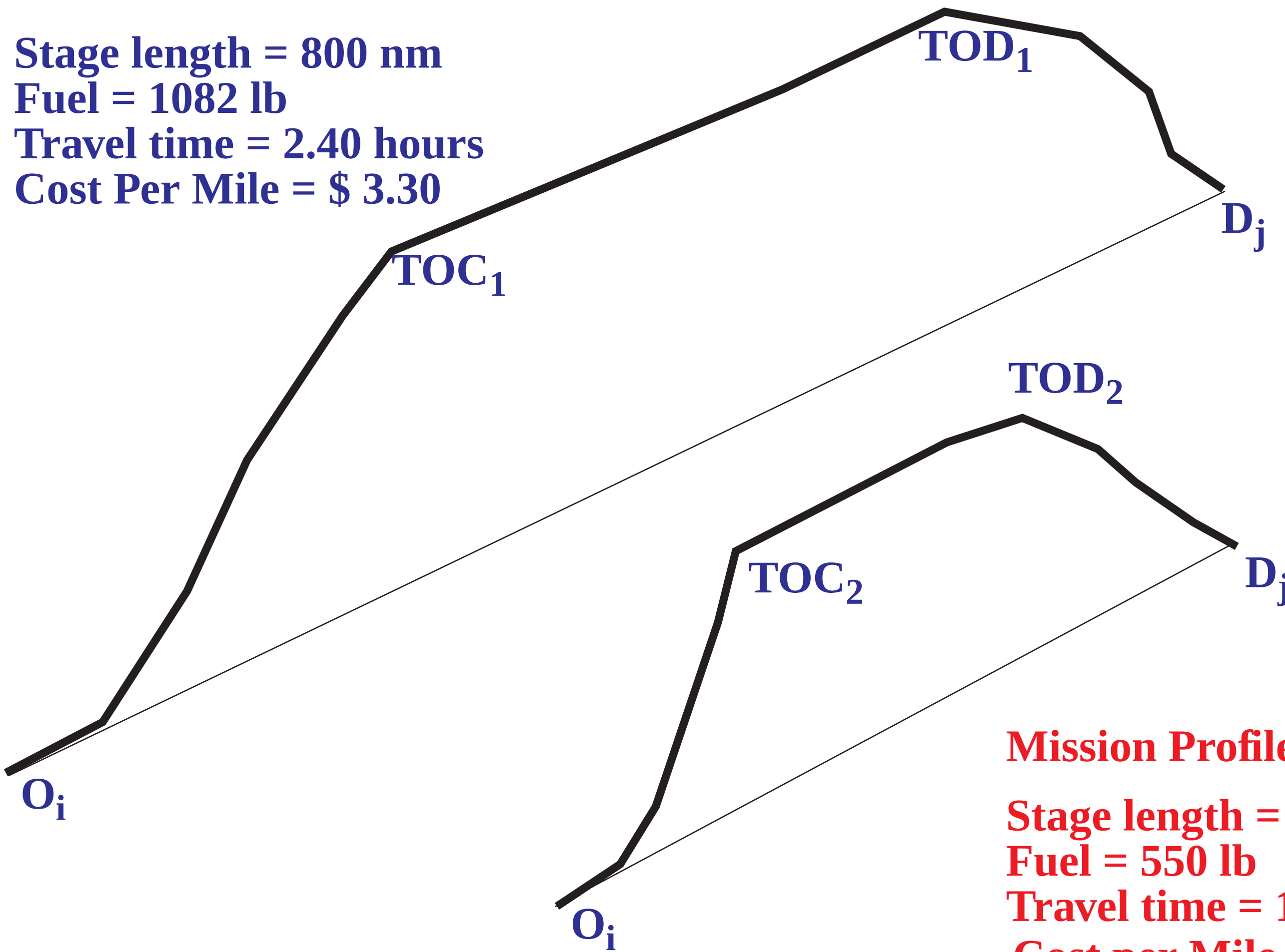
Modeling Partial Causal Diagram



Vehicle Performance Functions

Mission Profile 1

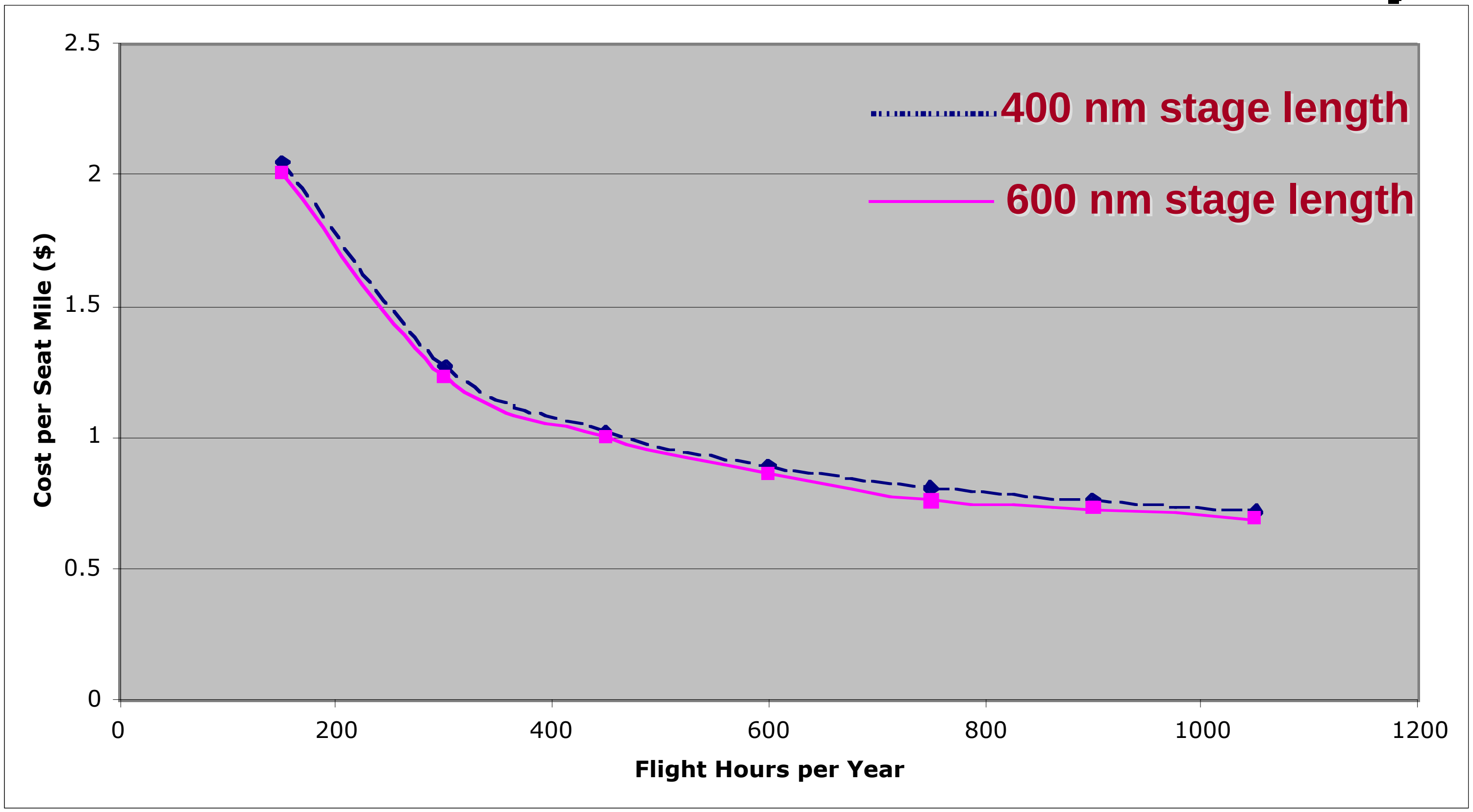
Stage length = 800 nm
Fuel = 1082 lb
Travel time = 2.40 hours
Cost Per Mile = $ 3.30



Mission Profile 2

Stage length = 250 nm
Fuel = 550 lb
Travel time = 1.00 hours
Cost per Mile = $ 4.10

Sample Aircraft Specific Model



1 Professional Pilot, $2.5/gallon fuel cost, 70% load factor

Eclipse 500 with Pratt and Whitney 610F Engines

Summary of Costs of Air Transportation Supply

- Corporate Jet aircraft

  - 50-350 cents ASM

- Regional turboprop aircraft (EMB-120, ATR-72)

  - 9.2 to 11.5 cents per ASM

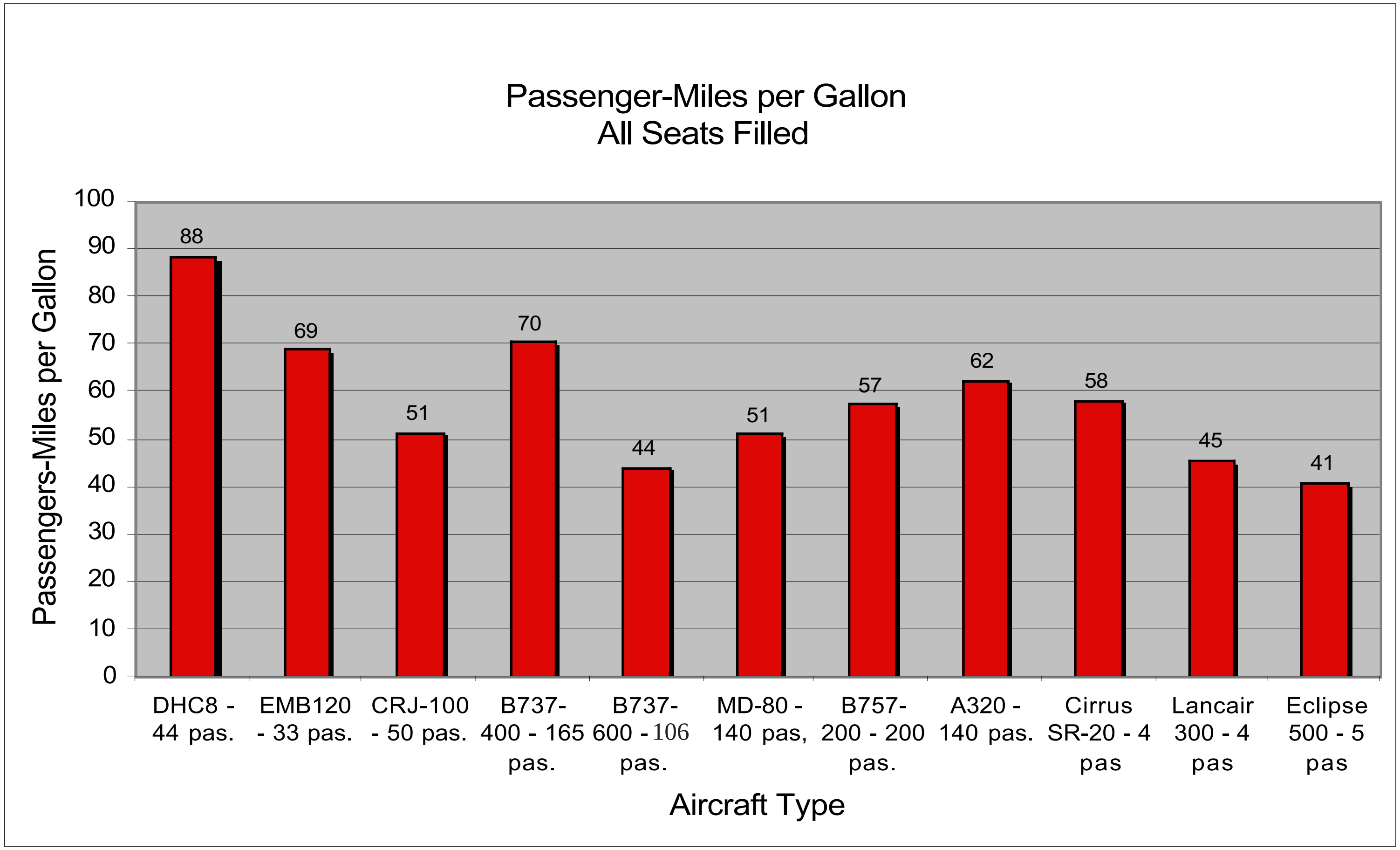
- Regional jets (Bombardier CRJ-200, Embraer 145)

  - 9.5 to14.0 cents per ASM

- Transport aircraft (Boeing 737-800, Airbus A321)

  - 6.1 to 8.2 cents per ASM

Sample Aircraft Fuel Efficiency in Cruise



Remarks

- Transportation supply functions are necessary to understand the dynamic relationships between supply and demand forces in air transportation
- Without adequate supply-based aircraft models, the analysis of NAS impact metrics such as delays, capacity and costs to users is not possible
- Fuel costs is just one component of the total LCC of operating aircraft. Other costs components need to be specified in cost-benefit studies
- We advise the use of LCC cost models in NAS cost-benefit analysis

Where Can I get Information on Airline Operating Costs?

- DOT Form 41, P52 Schedule (available at BTS web site)

DOT Form 41 P52 Schedule - Aircraft Operating Cost

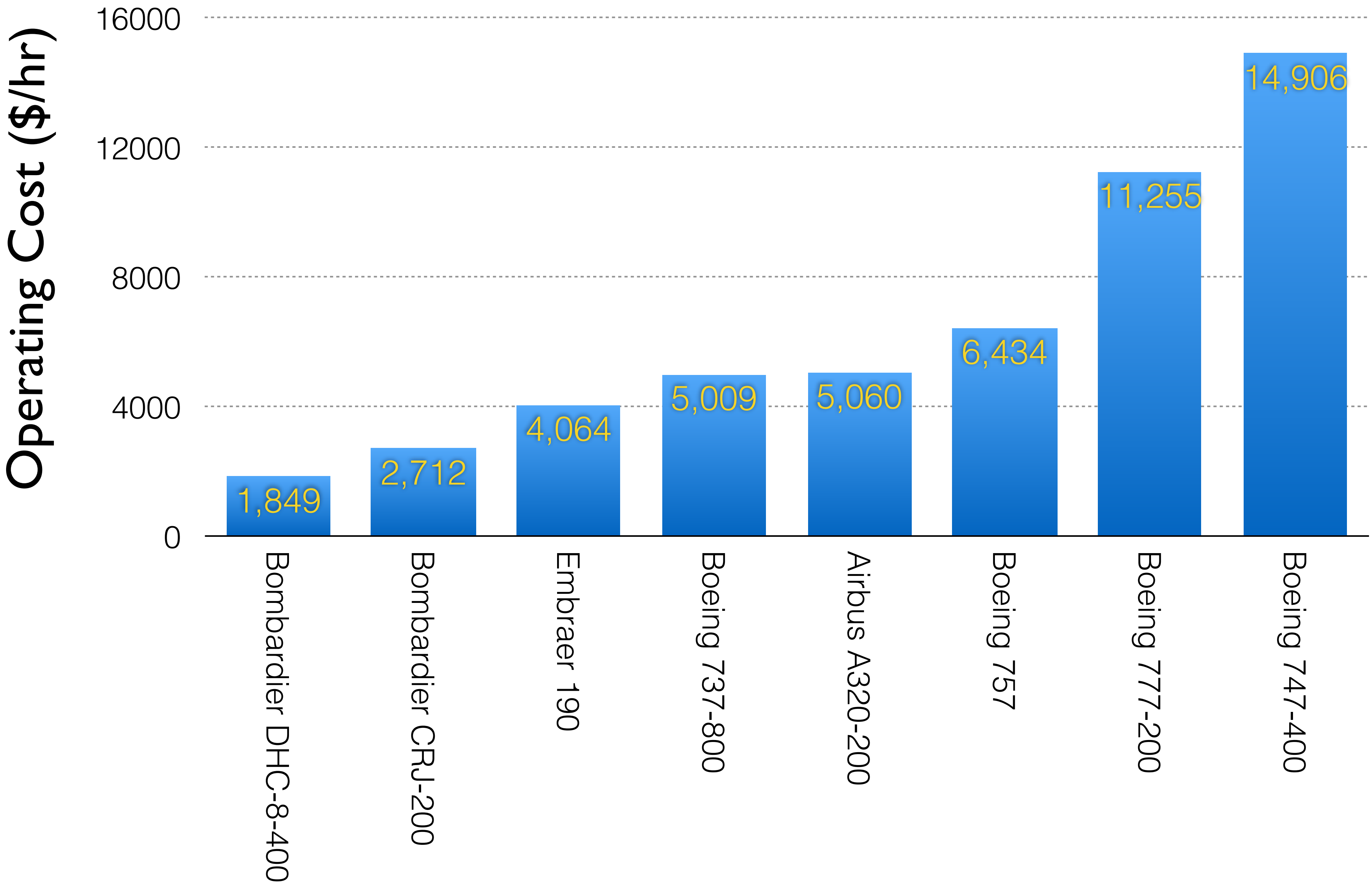
PILOT_FLY_OPS	3434.00
OTH_FLT_FLY_OPS	
TRAIN_FLY_OPS	
PERS_EXP_FLY_OPS	226.00
PRO_FLY_OPS	
INTERCHG_FLY_OPS	
FUEL_FLY_OPS	10107.00
OIL_FLY_OPS	
RENTAL_FLY_OPS	2977.00
OTHER_FLY_OPS	
INS_FLY_OPS	49.00
BENEFITS_FLY_OPS	1116.00
INCIDENT_FLY_OPS	
PAY_TAX_FLY_OPS	200.00
OTH_TAX_FLY_OPS	343.00
OTHER_EXP_FLY_OPS	
TOT_FLY_OPS	18452.00
AIRFRAME_LABOR	563.00
ENGINE_LABOR	-43.00
AIRFRAME_REPAIR	370.00
ENGINE_REPAIRS	977.00
INTERCHG_CHARG	
AIRFRAME_MATERIALS	137.00
ENGINE_MATERIALS	-8.00
AIRFRAME_ALLOW	
AIRFRAME_OVERHAULS	
ENGINE_ALLOW	
ENGINE_OVERHAULS	
TOT_DIR_MAINT	1996.00
AP_MT_BURDEN	1082.00
TOT_FLT_MAINT_MEMO	3078.00
NET_OBSOL_PARTS	19.00
AIRFRAME_DEP	339.00
ENGINE_DEP	155.00
PARTS_DEP	30.00
ENG_PARTS_DEP	14.00
OTH_FLT_EQUIP_DEP	201.00

AIRCRAFT_CONFIG	1
AIRCRAFT_GROUP	6
AIRCRAFT_TYPE	612
AIRLINE_ID	19704
UNIQUE_CARRIER	CO
UNIQUE_CARRIER_NAME	Continental Air Lines Inc.
CARRIER	CO
CARRIER_NAME	Continental Air Lines Inc.
UNIQUE_CARRIER_ENTITY	10220
REGION	L
CARRIER_GROUP_NEW	3
CARRIER_GROUP	3
YEAR	2004
QUARTER	4
f64	
AC_TYPEID	612
AC_GROUP	6
SSD_NAME	BOEING 737-700/LR
MANUFACTURER	BOEING
LONG_NAME	BOEING 737-700/700LR
Average_OperatingCost_per_Hour	2,550.11
Sum_of_Air_Cost	625,322,125
Sum_of_Air_Hours	88,242
Expected_Value_of_Costper_Hour	7,086
OTH_FLT_EQUIP_DEP_GRP_I	739.00
FLT_EQUIP_A_EXP	
FLY_OPS_EXP_I_A	
TOT_AIR_OP_EXPENSES	22288.00
DEV_N_PREOP_EXP	
OTH_INTANGIBLES	
EQUIP_N_HANGAR_DEP	
G_PROP_DEP	
CAP_LEASES_DEP	
TOTAL_AIR_HOURS	8.74
AIR_DAYS_ASSIGN	0.99
AIR_FUELS_ISSUED	7269.00

Example Information

T100 Aircraft Name	T100 Aircraft Code	Hourly_Operating_Cost
Airbus Industrie A300-600/R/Cf/Rcf	691	10,797
Airbus Industrie A-318	644	3,829
Airbus Industrie A320-100/200	694	4,362
Airbus Industrie A319	698	4,039
Airbus Industrie A320-100/200	694	4,362
Airbus Industrie A321	699	4,572
Aerospatiale/Aeritalia Atr-72	442	2,946
Beechcraft Super King Air	458	1,275
Beech 1900 A/B/C/D	405	1,375
Pilatus Britten-Norman Bn2/A Islander	131	380
Mcdonnell Douglas Dc-9-50	650	4,695
Mcdonnell Douglas Dc9 Super 80/Md81/2/3/7/8	655	5,441
Mcdonnell Douglas Dc9 Super 80/Md81/2/3/7/8	655	5,441
Mcdonnell Douglas Dc9 Super 80/Md81/2/3/7/8	655	5,441
Mcdonnell Douglas Dc9 Super 80/Md81/2/3/7/8	655	5,441
Mcdonnell Douglas Dc9 Super 80/Md81/2/3/7/8	655	5,441
Mcdonnell Douglas Md-90	656	4,415
Boeing 717-200	608	4,475

T100 Form 41 Operating Costs (2012)



Commercial Aircraft List Prices (2013)

Aircraft	List Price ($M)		Max. Takeoff Mass (kg)	$ per kg
737-700	76		77,500	980.65
737-800	90.5	106.1 in 2019	79,020	1,145.28
737-900ER	96.1		85,000	1,130.59
737 MAX 7	85.1		72,303	1,176.99
737 MAX 8	103.7	121.6 in 2019	82,200	1,261.56
737 MAX 9	109.9		88,300	1,244.62
747-8	356.9		447,600	797.36
747-8 Freighter	357.5	419.2 in 2019	447,600	798.70
767-300ER	185.8		158,760	1,170.32
767-300 Freighter	188	220.3 in 2019	158,760	1,184.18

source: Aircraft Manufacturer Data

Commercial Aircraft List Prices (2013)

Aircraft	List Price ($M)		Max. Takeoff Mass (kg)	$ per kg
777-300ER	320.2	375.1 in 2019	351,540	910.85
777 Freighter	300.5		347,458	864.85
787-8	211.8		228,000	928.95
787-9	249.5	292.5 in 2019	248,000	1,006.05
787-10	288.7	338.4 in 2019	251,000	1,150.20
A318	70.1		68,001	1,030.87
A319	83.6		75,501	1,107.27
A320	91.5	104.6 in 2019	77,001	1,188.30
A321	107.3	122.5 in 2019	93,002	1,153.74
A319neo	92		76,000	1,210.53

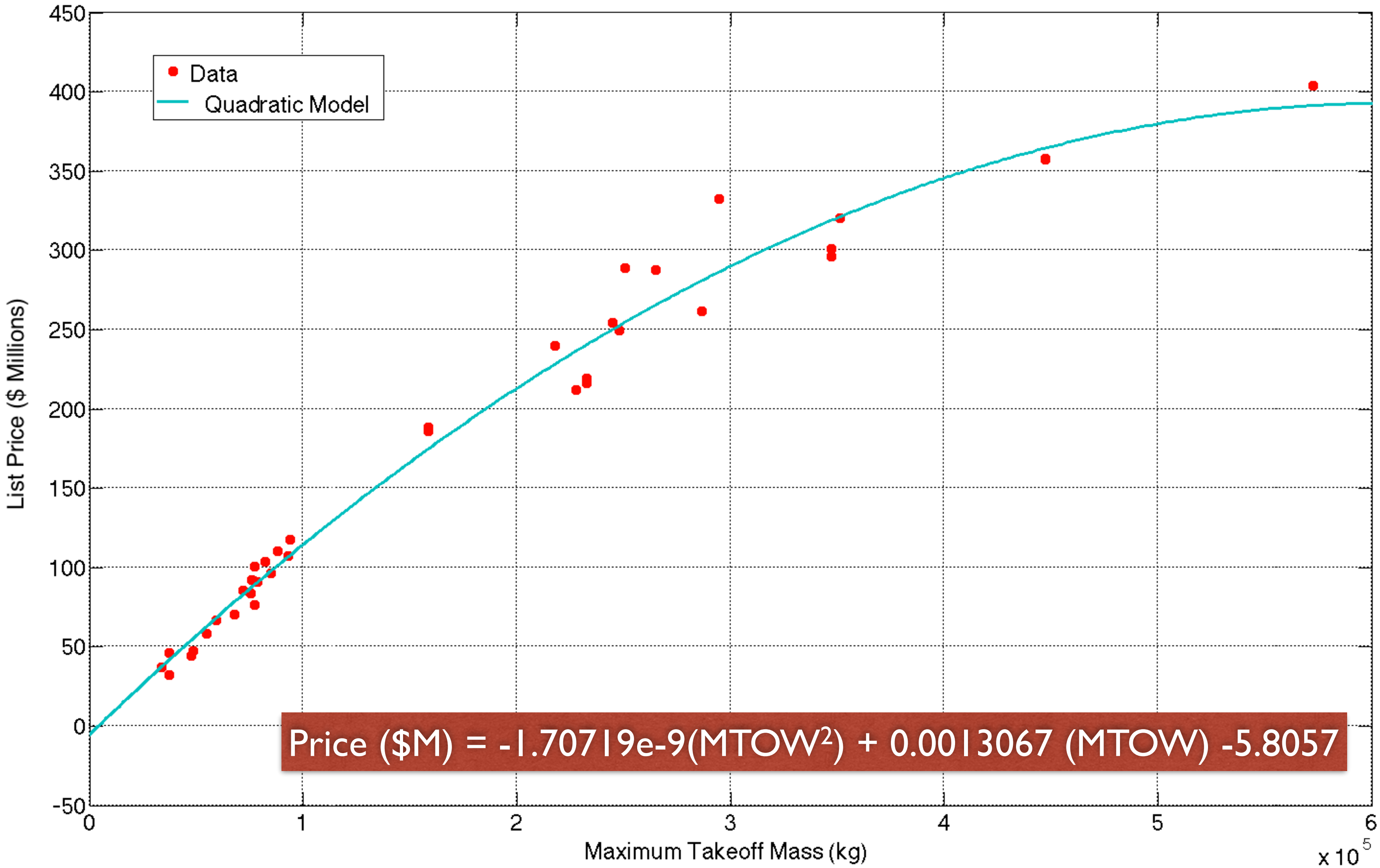
source: Aircraft Manufacturer Data

Commercial Aircraft List Prices (2013)

Aircraft	List Price ($M)		Max. Takeoff Mass (kg)	$ per kg
A330-200	216.1		233,004	927.45
A330-200F	219.1		233,000	940.34
A330-300	239.4		218,000	1,098.17
A350-800	254.3		245,000	1,037.96
A350-900	287.7	317.4 in 2018	265,000	1,085.66
A350-1000	332.1	366.3 in 2018	295,000	1,125.76
A380-800	403.9	445.6 in 2018	573,000	704.89
CRJ-700 Nextgen	37		34,100	1,085.04
CRJ-900 Nextgen	46.2		37,420	1,234.63
E175	32		37,500	853.33
E190	44		47,800	920.50
E195	47		48,750	964.10

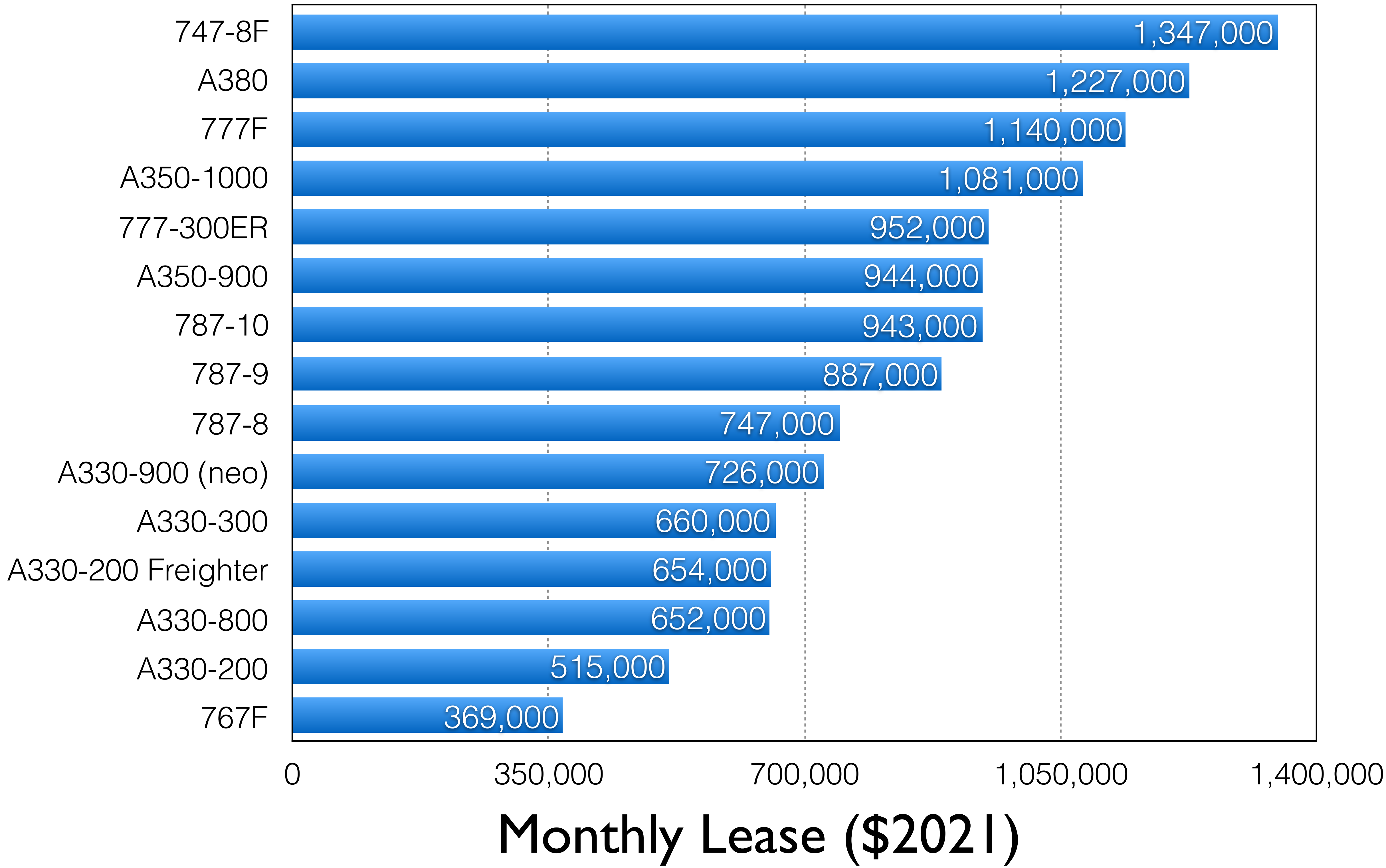
source: Aircraft Manufacturer Data

Commercial Aircraft Price vs. MTOW



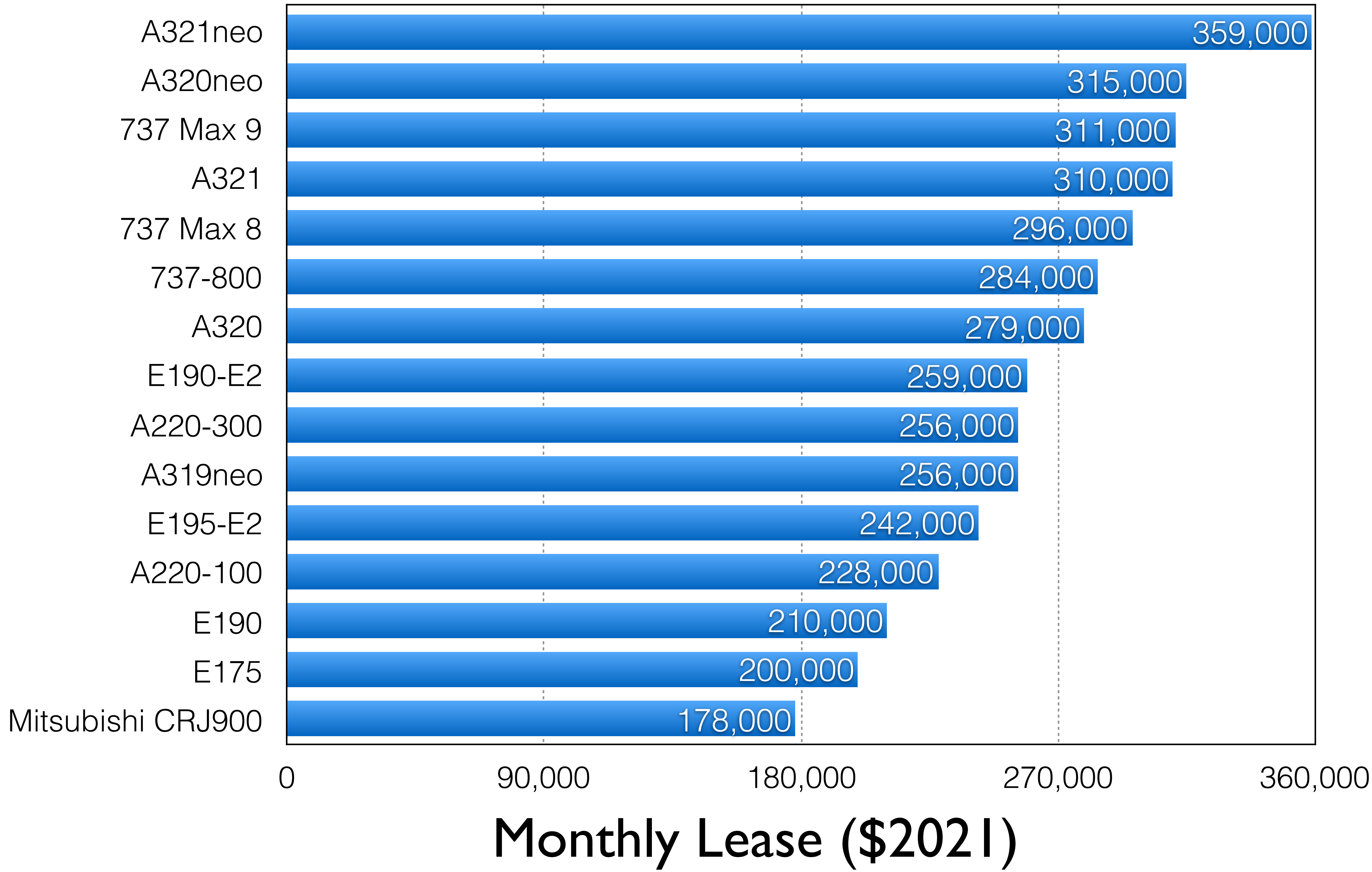
Price ($M) = -1.70719e-9(MTOW^2) + 0.0013067 (MTOW) -5.8057

Commercial Aircraft Lease Rates (2021)



source: AirFinance Journal Magazine July-August 2021, page 45

Commercial Aircraft Lease Rates (2021)



source: AirFinance Journal Magazine July-August 2021, page 45

Aircraft Development Cost Model

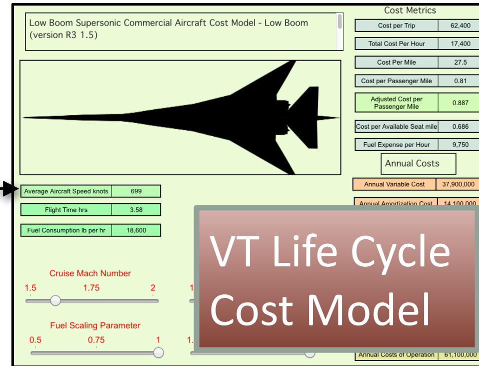
Goal: To Estimate of the Unit Cost of the Developing Aircraft

Aircraft Cost Analysis Workflow

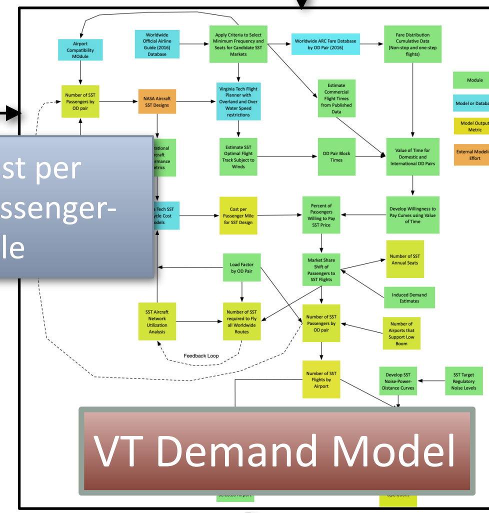
Aircraft design process considers:

- Aircraft range
- Payload
- Runway field length
- Wing loading
- Approach speed
- Mach number
- Aircraft size for airport compatibility

Aircraft TOGW weight and vehicle performance information



Worldwide network operations model



Cost per passenger-mile

Aircraft TOGW
Mach number
Production run

Aircraft cost development model (or equations)

Output information from VT Model

- Airports able to support SST operations
- City pairs served
- Actual demand
- Number of aircraft needed

Feedback

Feedback

Aircraft Cost Development Model

- Nicolai and Raymer's cost categories
  - Airframe engineering
  - Development and support
  - Flight test
  - Engines
  - Avionics
  - Manufacturing labor
  - Material and equipment
  - Tooling
  - Quality control
  - Flight test operations
  - Test facilities
- Model uses L. Nicolai's cost relationships adapted from the DAPCA IV model
- Adaptations made to engine and avionics cost
- Learning curves are different for different activities in the aircraft development cycle

Example of cost equations

$$E = k_1 W^{c_1} S^{c_2} Q^{c_3}$$

$E = \text{Cumulative engineering hours (hrs)}$

$W = \text{aircraft empty weight in pounds}$

$S = \text{aircraft maximum speed (knots) at best altitude}$

k_1, c_1, c_2, c_3 are calibration constants

Sources of model equations:
Nicolai, L. and Carichner, G., Fundamentals of Aircraft and Airship Design, American Institute of Aeronautics and Astronautics, 2010
Raymer, D.P., Aircraft Design: A Conceptual Approach, American Institute of Aeronautics and Astronautics, 2018

CEE 5614

Additions to Cost Models

Dr. Antonio A. Trani
Professor
Civil and Environmental Engineering

Spring 2023

A Simple Aircraft Development Cost Model

- Two Matlab scripts to estimate the unit cost of aircraft given four key parameters:
  - Operating empty weight (lbs.)
  - Aircraft maximum speed (knots)
  - Aircraft engine thrust (lbs.)
  - Quantity of aircraft to be produced
- Uses an adaptation of the RAND DAPCA IV model (Nicolai and Carichner)

Aircraft Life Cycle Cost Development Model • Aircraft Production Cost Model • Calculate Engineering Hourly Rates	Files to estimate the unit cost of an aircraft given: producton quantity, speed, empty weight and engine thrust. The function below estimates engineering hourly rates for production, research and development and flight testing.

http://128.173.204.63/cee5614/matlab_files_cee5614.html

Example: Aircraft Development Cost Model

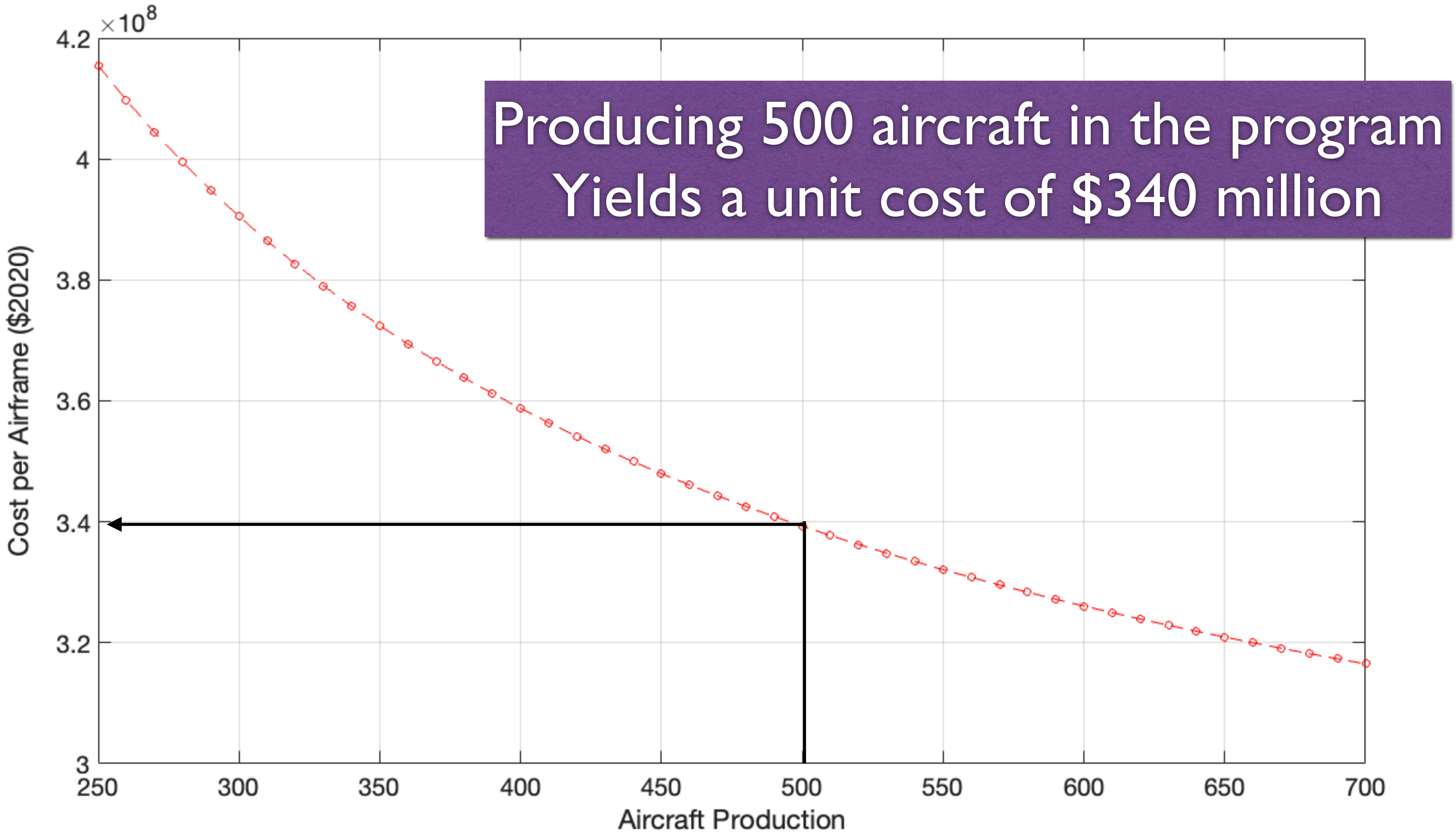
- Estimate the unit cost (in $2020) for an aircraft with the following parameters:
  - Operating empty weight = 370,000 lbs.
  - Aircraft maximum speed = 516 knots
  - Aircraft engine thrust = 115,000 lbs per engine
  - Quantity of aircraft to be produced = 250-700

```
clear
close all
clc

   % Enter the key variables (data shown is similar to a large twin engine commercial aircraft lik
   Qproduction           = 250:10:700;             % unites produced over the life cycle
   MaxSpeed_knots        = 516;                    % knots - maximum speed at cruise altitude
   operating_empty_weight_lb = 370000;             % Pounds
   thrust_surrogate_lb  =  115000;                 % pounds per engine
```

Assume profit margin is 1.15 (15%)

Example: Aircraft Development Cost Model



Functional Form of Cost-Estimating Relationships (CERs)

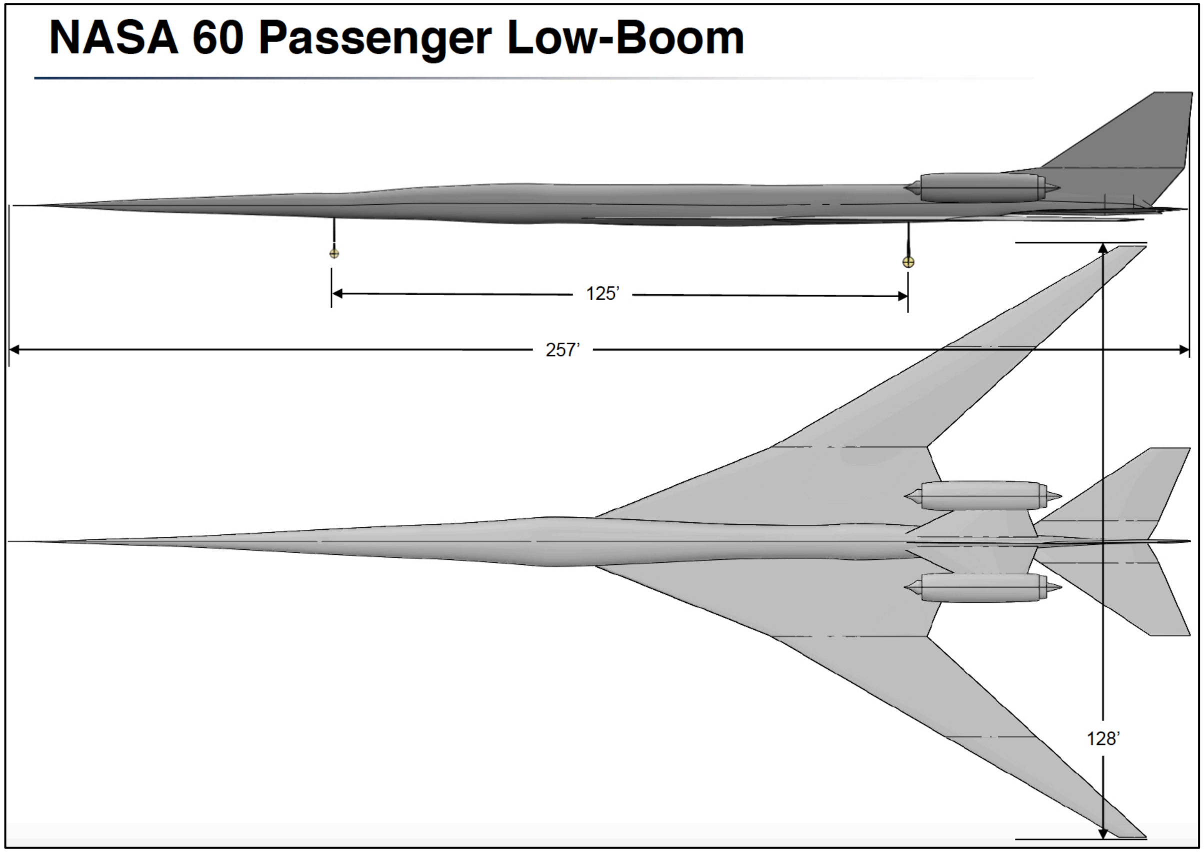
- **Empty weight** (equations in original RAND report use AMPR - American Manufacturer Planning Report) (W) in pounds
  - Nicolai adapted the equations to introduce W as the aircraft empty weight
- **Maximum speed** at best altitude (S) in knots
- **Aircraft quantity produced** (Q)

- Hourly rates are estimated using US Dept. of Labor data and includes:
  - direct labor
  - administrative cost
  - overhead
  - miscellaneous

Activity	Hourly Rate ($2020)	Hourly Rate ($1998)
Engineering	145.5	88.8
Tooling	157.7	94.2
Quality Control	140.0	82.8
Manufacturing	126.3	75.4

Source: Nicolai - Year 1998 is the baseline year of equations

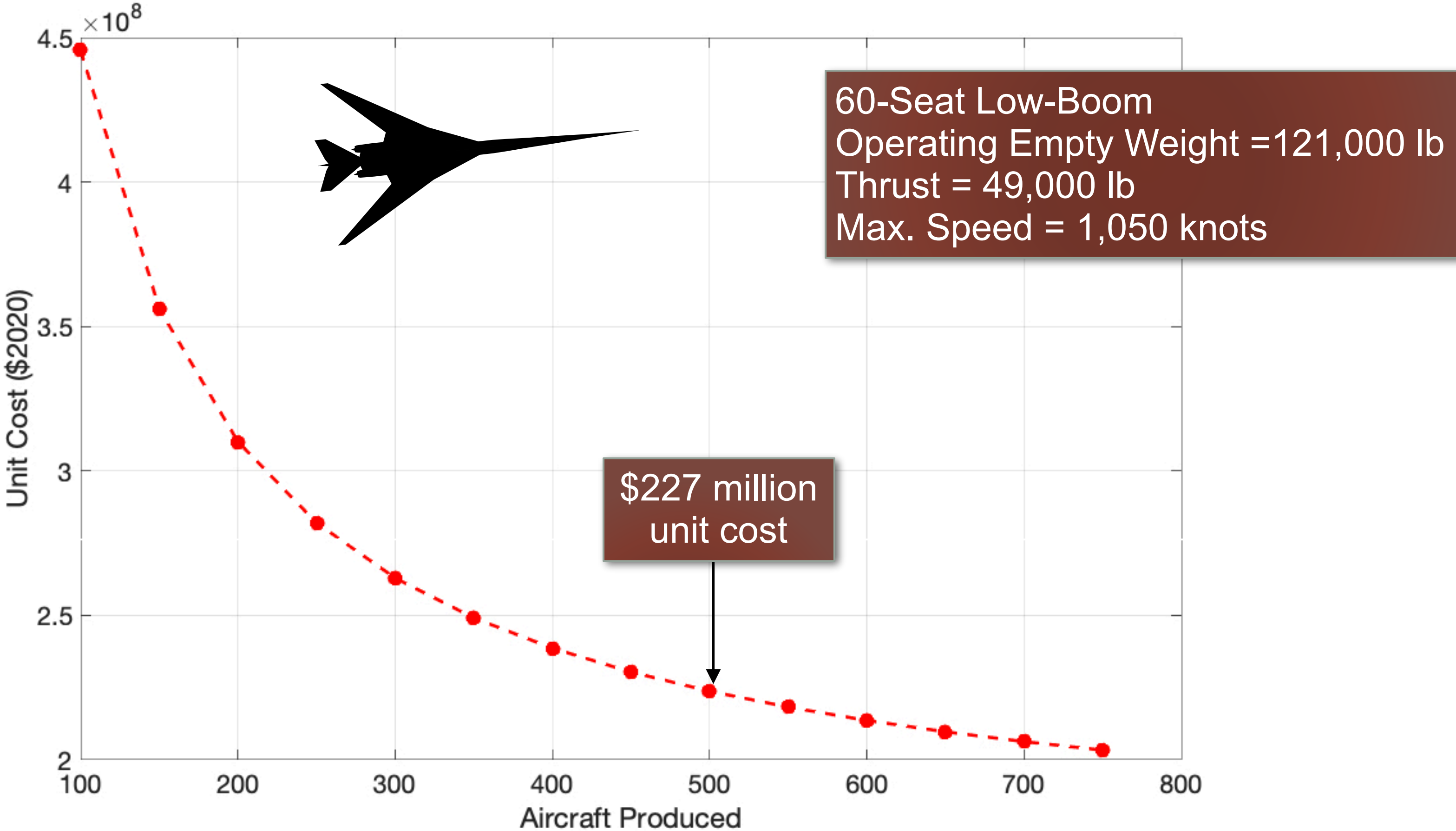
Application to a 60-Seat Low Boom SST Aircraft



Source: K. Geiselhart, W. Li, and I. Ordaz, NASA Langley Research Center

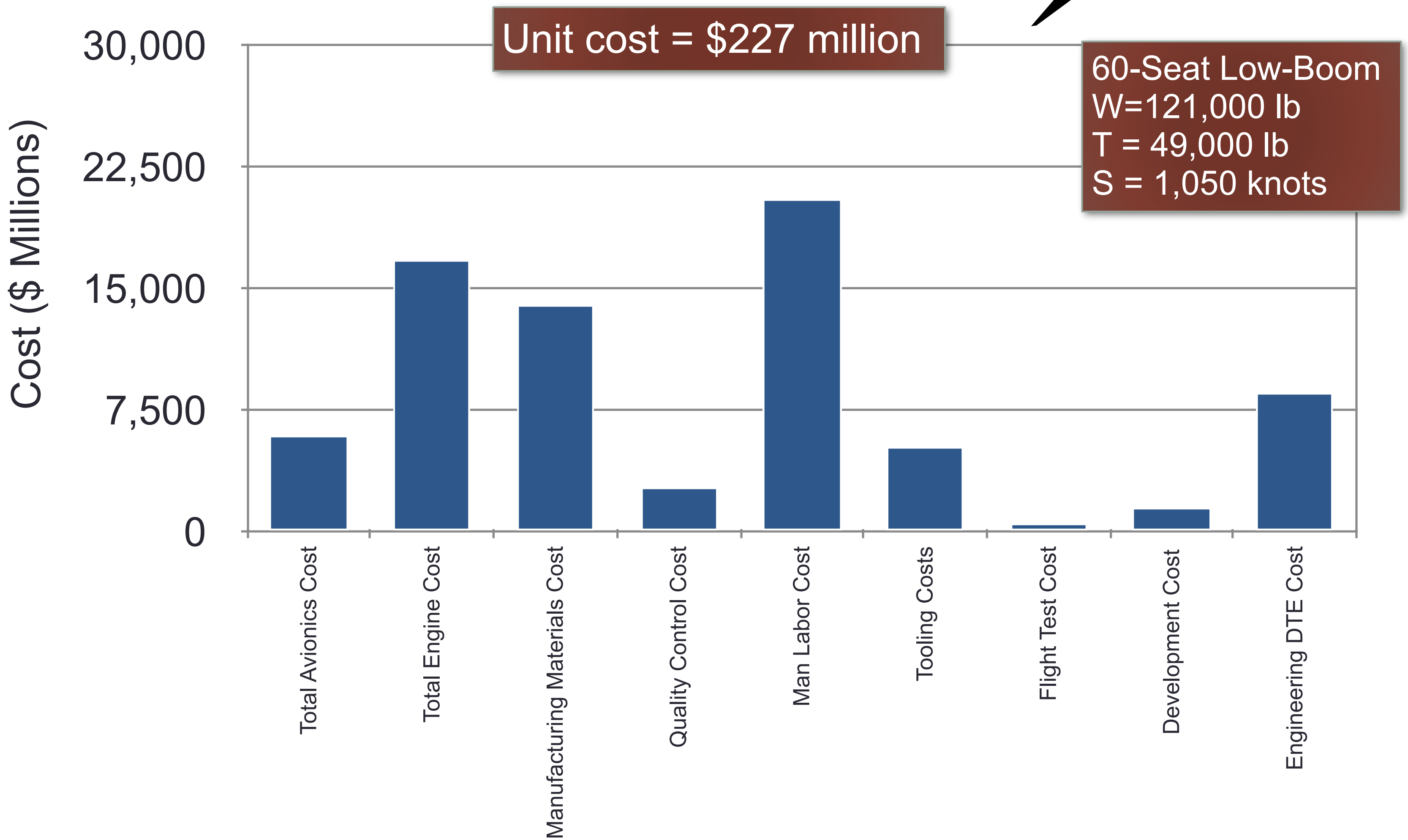
Aircraft Unit Cost Predicted for 60-Seat, Low-Boom Program

- **Assumes 15% profit margin**
- **Aircraft quantity produced** (Q = 100 to 750 aircraft)



60-Seat, Low-Boom Program Costs ($2020)

- **Aircraft quantity produced** (Q = 500 aircraft)

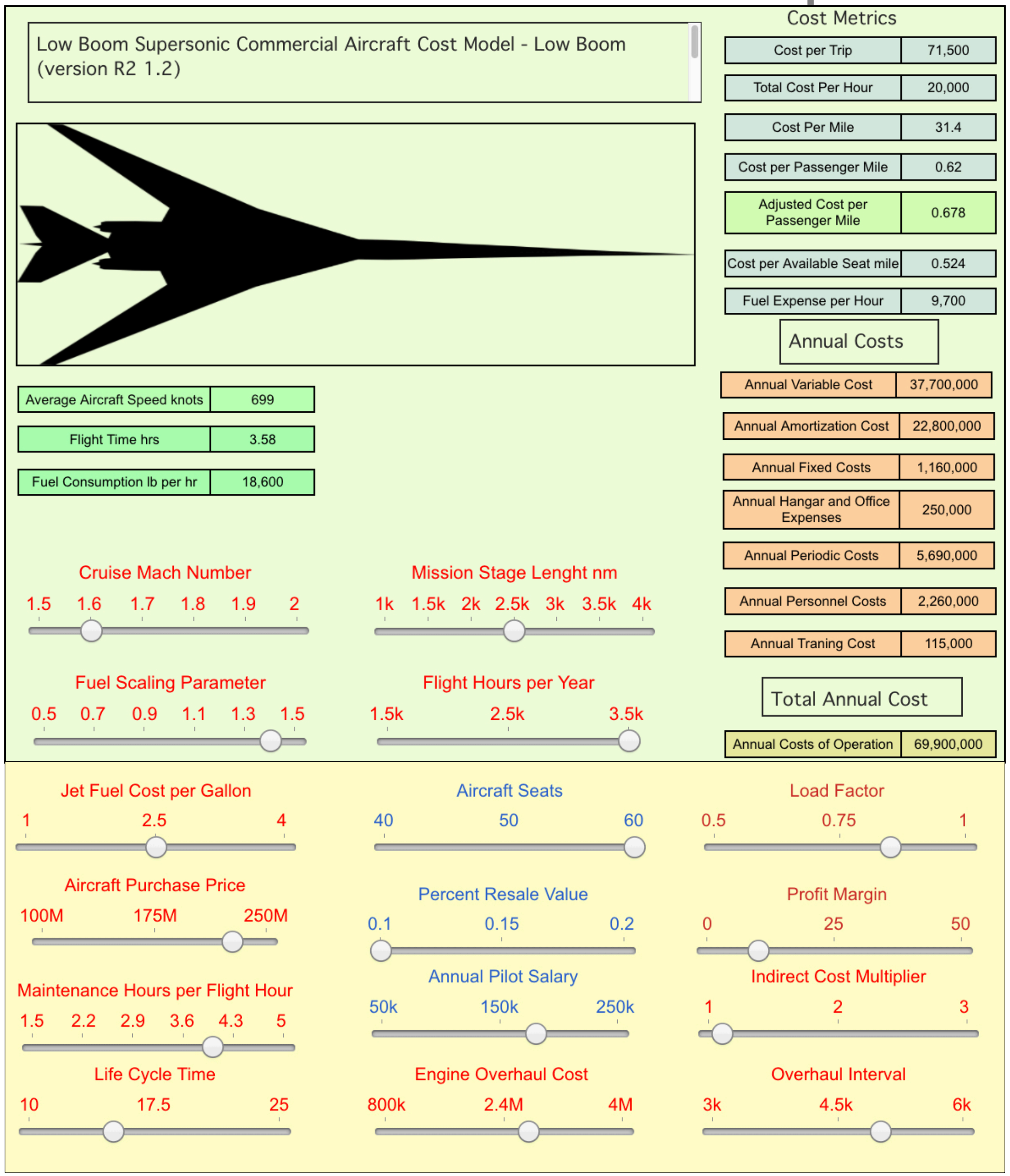


Low Boom Supersonic 40-Passenger Jet Commercial Operation Model Assumptions

- **Aircraft cost 227 million dollars per aircraft ***
- Aircraft seats = 60
- Fuel cost = $2.50 per gallon (airline cost)
- Baseline aircraft utilization - 3,500 hours annually
- Assume fly supersonic at Mach 1.6 overland (Mach 1.8 over water)
- **Overhaul cost = 2.72 million per engine**
- Overhaul interval = 5,000 hours
- Maintenance hours per flight hour = 4.0
- Pilot salaries = $180,000 per pilot (+30% benefits)
- Crew : Two pilots and two cabin crew
- Load factor = 75%
- 10% adjustment cost for airline administrative costs
- **Fuel burn scaling factor = 1.4 (compared to 40-seat low Boom aircraft)**

*** Using Model 2 aircraft development cost equations**

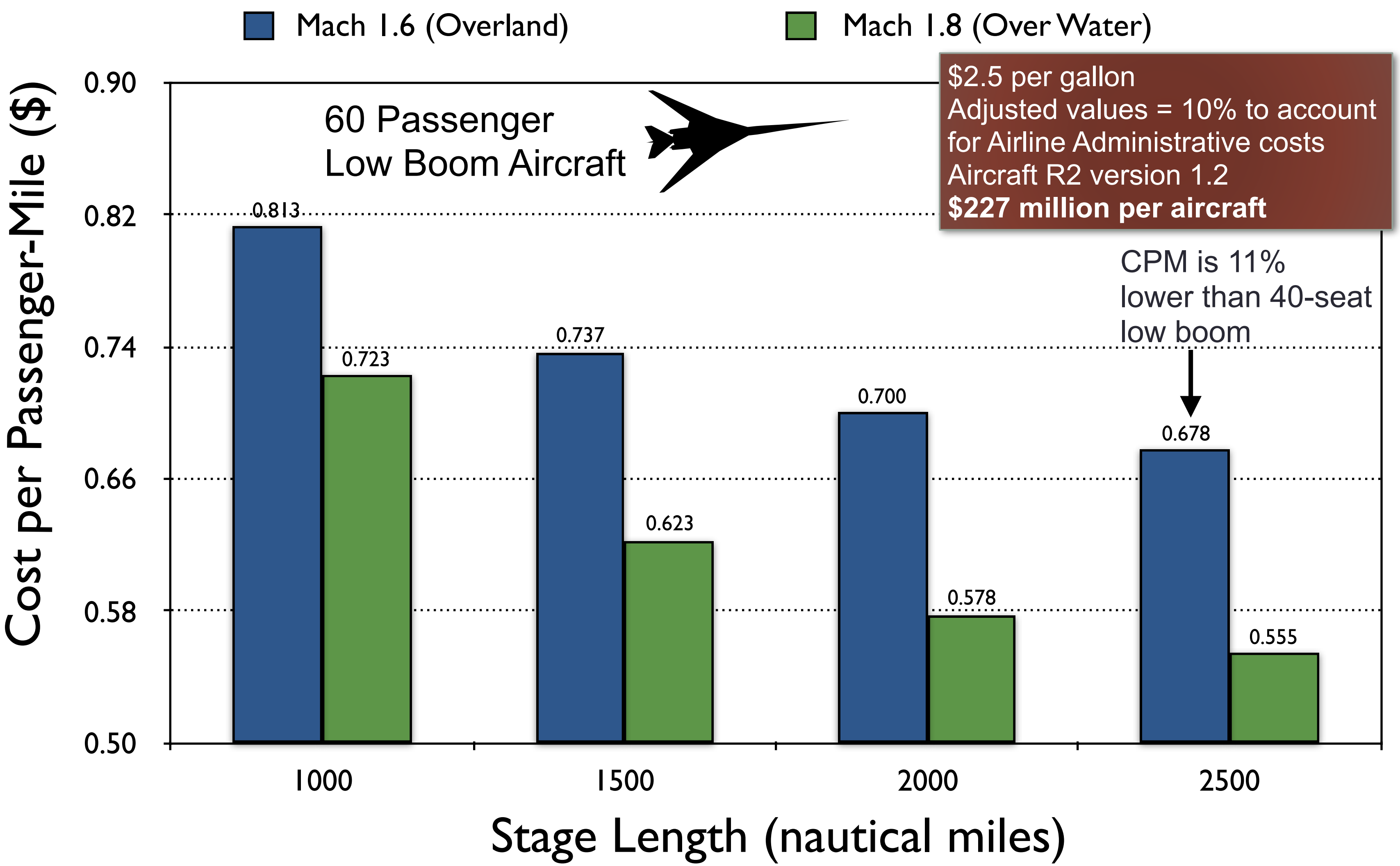
Low Boom 60 Supersonic Aircraft



- Assumptions:

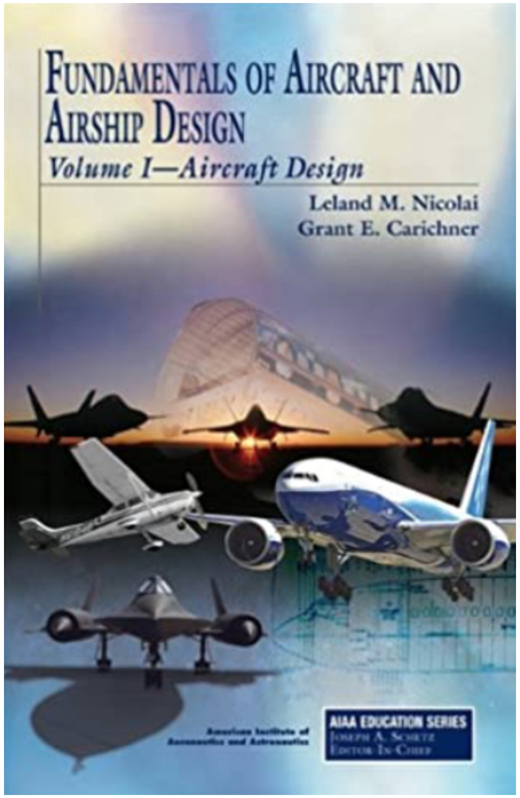
- $227 million dollar/ aircraft
- 1.4 fuel scaling factor compared to optimized 40-seat low boom
- 85% load factor (U.S. Continental)
- $2.72 million in overhaul cost (per engine)

60 Seat Low Boom SST Cost per Passenger Mile: Typical Short Missions
85% Domestic Routes Load Factor



Cost Equations Used to Model Aircraft Development Cost

Adapted from Nicolai, L. and Carichner, G., Fundamentals of Aircraft and Airship Design, American Institute of Aeronautics and Astronautics, 2010



Example of the Aircraft Development Cost Equations

```
% Airframe engineering cost

% Calculate the engineering hours

EHours_DTE          = 4.86 * Wempty_lb .^0.777 .* MaxSpeed_knots .^ 0.894 .* Qdevelopment .^ 0.163;
EHours_Total        = 4.86 * Wempty_lb .^0.777 .* MaxSpeed_knots .^ 0.894 .* Qtotal.^ 0.163;
EHours_Production  = EHours_Total  - EHours_DTE ;

% Estimate the hourly rates for all four activities (cost)

[hourlyRateTooling,hourlyRateEngineering,hourlyRateManufacturing,hourlyRateQC] = calculateHourlyRates(yearOfAnalysis);

EngineeringDTE_Cost          = EHours_DTE * hourlyRateEngineering;
EngineeringProduction_Cost   = EHours_Total  * hourlyRateEngineering;
Engineering_DTE_Cost         = EHours_Production  + EngineeringProduction_Cost;

% Development support cost

DevelopmentCost = 66 * Wempty_lb .^0.63 .* MaxSpeed_knots .^ 1.3;          % in 1998 dollars

% Flight test and operations

FlightTestCost = 1852 * Wempty_lb .^0.325 .* MaxSpeed_knots .^ 0.822 .* Qdevelopment .^ 1.21;
```

Adapted from Nicolai, L. and Carichner, G., Fundamentals of Aircraft and Airship Design, American Institute of Aeronautics and Astronautics, 2010