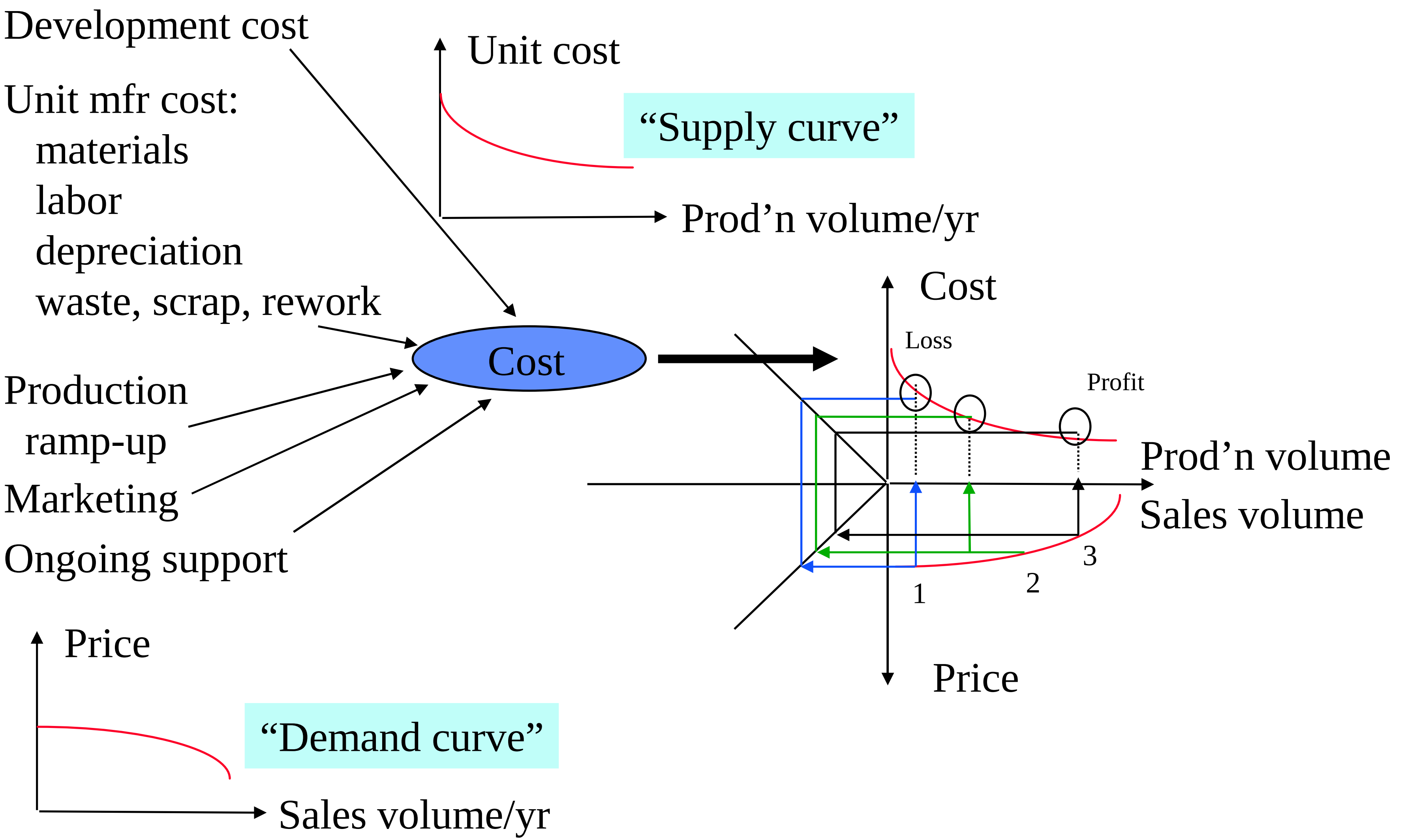
# Economic Analysis of Assembly Systems

- Goals of this class
  - understand the basics of economic analysis
  - unit cost of assembly by different resources
  - return on investment
  - particular properties of assembly systems

# Cost and Price Considerations



# “Price Has Nothing to Do with Cost”

- Price is about value
- Value is often perceived and can be influenced
- Direct value involves functions and ilities
- Perceived value involves or is influenced by
  - Marketing
  - Perceived quality
  - Number of choices available even if most will not be taken
- Value > Price > Cost, otherwise no sales or no profit

# Cost Analysis is a Murky Area

- Engineers need to know the basics of cost analysis for three reasons
  - so they can make sound technological choices
  - so they can judge the suitability of a supplier’s bid
  - so they can argue effectively with accountants
- “Don’t ask us how we do investment justification. We just fill out a form and after a while an answer comes back Yes or No.”
- “MAPI means ‘makes a project impossible’”
  - MAPI = Manufacturing and Allied Processes Institute

# Kinds of Cost Categories

- Fixed cost = what you pay to set up (usually investment in facilities)
- Variable cost = what you pay that depends on how many you make per unit time
  - Labor, both direct and indirect (maintenance, supervisors)
  - Materials cost: what you buy that you add value to
  - Expendables: energy, lubricants, tool bits, etc
  - Scrap, rework
- Institutional cost = all other costs of doing business
- In many cases, labor is a fixed cost, due to contracts or the inability to lay people off for short periods when business fluctuates

# Cost Distribution in Engine Plants

Image removed for copyright reasons.
Source:
Figure 18-1 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

# Sources of Cost in the Supply Chain

Image removed for copyright reasons.
Source:
Figure 18-3 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

Source: Daimler Chrysler via Munro and Associates

# A Small Problem

- Fixed costs are usually expended all at once, usually before production starts
- Variable costs are incurred as production runs
- How should these two kinds of costs be combined to provide a true picture of the cost per unit?
- The usual method is to allocate the fixed costs to the units by choosing a time period during which the investment is “recovered”
- unit cost = variable cost

  + Some_Fct (fixed cost, # of units made in some time period)

# Cash Flows Over Time

Image removed for copyright reasons.
Source:
Figure 18-4 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

# Payback Period Method

- A payback period P is selected (arbitrarily?)
- The fixed cost is allocated equally to each unit made during P:
- unit cost = variable cost

  + fixed cost / (P Q)

where Q = quantity made per year

P = a number of years

# Internal Rate of Return Method

- The payback period is replaced by an investment horizon H and an interest rate r
- This is equivalent to a mortgage for H years at interest rate r
- The annual payment A and the annual cost factor $f_{AC}$ for an initial investment $I_o$ are (for zero salvage value):

$$A = I_0 \left[ \frac{r\left(1 + r^H\right)}{\left(1 + r^H\right) - 1} \right] \qquad f_{AC} = \frac{A}{I_0} = \left[ \frac{r\left(1 + r^H\right)}{\left(1 + r^H\right) - 1} \right]$$

# Unit Cost Based on IRoR

- unit cost = variable cost

  + $f_{AC}$ *fixed cost /Q

where Q = quantity made per year

$f_{AC}$ = fraction of fixed cost paid per year, based on:

r = IRoR (ranges from 15% to 35%)

H = investment horizon (ranges from 2 to 5 years or more)

# Annualized Cost Factor vs r

Image removed for copyright reasons.
Source:
Figure 18-5 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

# Simplified Unit Cost for Manual Assembly

$$COST_{UNIT\ MANUAL} = \frac{A\$ \quad \#\,People}{Q}$$

$$\#\,People = \left\lceil \frac{T\,N\,Q}{2000 * 3600} \right\rceil$$ [largest integer]

Q = annual production volume

T = assembly time per part, sec

N = number of parts per unit

A$ = annual cost of a person

$A\$ = \overline{L}_H * 2000$

$L_H$ = labor cos t, $ / hr

2000 = hours per shift year

3600 = sec / hr

(assumes no investment required)

# Simplified Unit Cost for Fixed Automation

$$C_{UNITFIXED} = \frac{f_{AC}\, N\, S\$}{Q}$$

where Q = annual production volume, units / year

$f_{AC}$=fraction of machine cost paid for per year

S\$ = cost of one station in the machine

(assumes one station per part)
(also assumes no people required)

# Simplified Unit Cost for Flexible Automation

$$C_{UNITFLEX} = \frac{f_{AC} I}{Q} + \frac{L\$}{Q}$$

where $I =$ total investment in machines and tools

L$ = annual cost of workers associated with the system

$I$ = # MACHINES * $ / MACHINE + # TOOLS * $ / TOOL

$$\text{\# MACHINES} = \left[ \frac{T\ N\ Q}{2000 * 3600} \right]$$

$$\text{\# TOOLS} = N$$

$$L\$ = w\ \bar{L}_H\ \text{\# MACHINES} * 2000$$

where w = number of workers / station

Combining the above yields:

$$C_{UNIT\ FLEX} = \frac{f_{AC}}{Q}\left[ \text{\# MACHINES} * \$\ /\text{MACHINE} + \text{\# TOOLS} * \$\ /\ \text{TOOL} \right] + \frac{L\$}{Q}$$

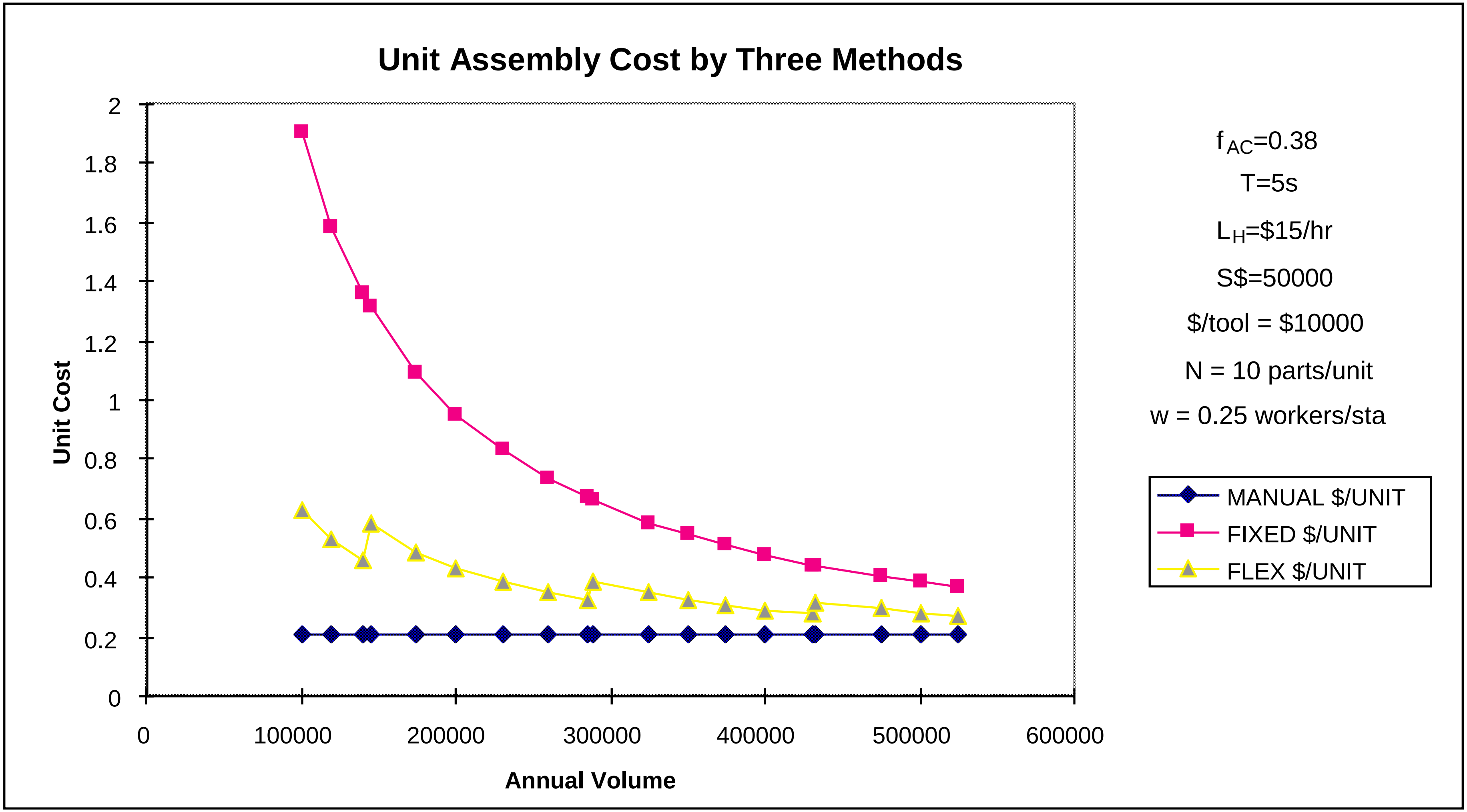
$$C_{UNITFLEX} - \frac{f_{AC}\ \$/\ \text{MACHINE}\ T\ N}{2000 * 3600} + \frac{f_{AC}\ \$/\ \text{TOOL}\ N}{Q} + \frac{w\ T\ N\ \bar{L}_H}{3600}$$

# Conclusions from Unit Cost Models*

- Cost is linearly proportional to number of parts N
  - one reason for fixation on part count reduction
- Cost of flexible automation grows with the "price-time product": $/machine * T
  - shows that cost and time can be traded
- Other costs grow as part, station, and tool count grow
  - floor space
  - support staff
  - line downtime (see System Design chapter)

*P. M. Lynch, "Economic-Technological Modeling and Design Criteria for Programmable Assembly Machines," MIT ME Dept PhD Thesis, June 1976

# Unit Cost Example



# Unit Cost Example - 2

Image removed for copyright reasons.
Source:
Figure 16-5 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

# More Detailed Cost Model

Image removed for copyright reasons.
Source:
Figure 18-9 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.

# Caveats About Examples

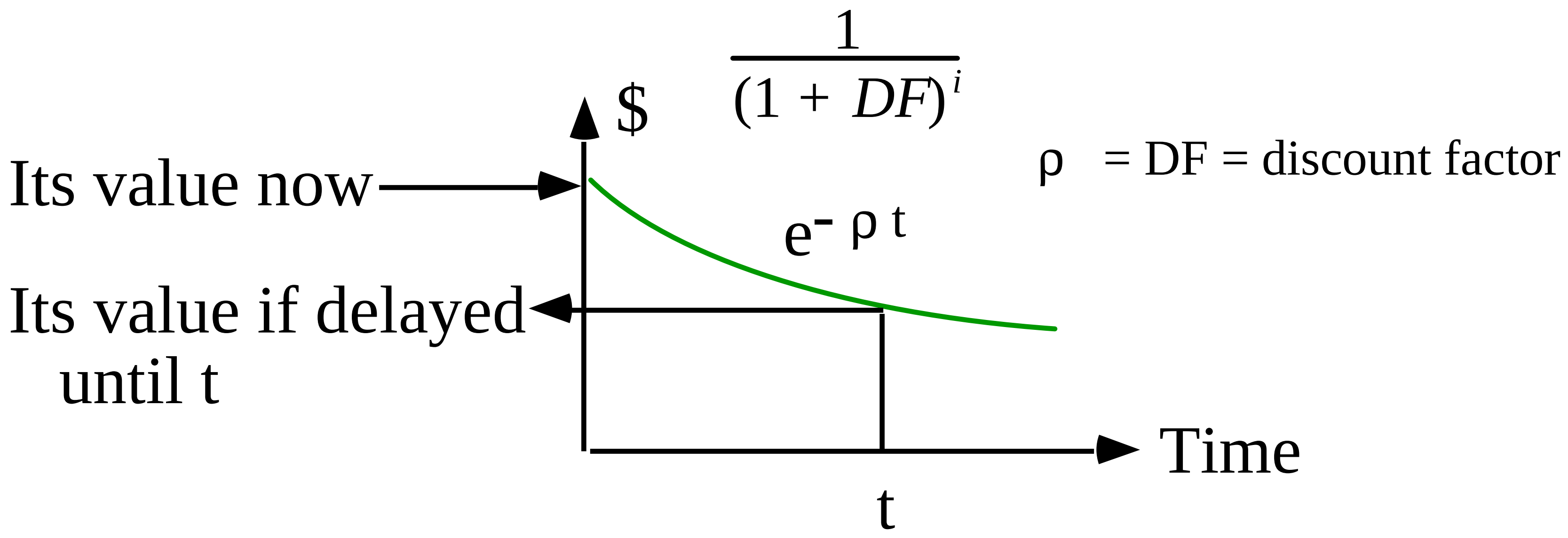
- If T = 2 s, then Q = 3.6 million, or else the line runs only part of one shift
- If # people > # of parts or operations, then extra people are needed for one shift operation
- If Q > 7.2 Million / T, then a 2nd or 3rd shift is needed

# Discounted Cash Flow Analysis

- AKA net present value calculation
- More detailed and sophisticated than unit cost comparisons
- Seeks to determine if an investment is “good”
- Based on comparing return on investment
  - a base case is compared to an alternate
  - the alternate requires upfront investment
  - it creates a saving stream over time, which is discounted to “present value”
  - do the savings justify the investment?

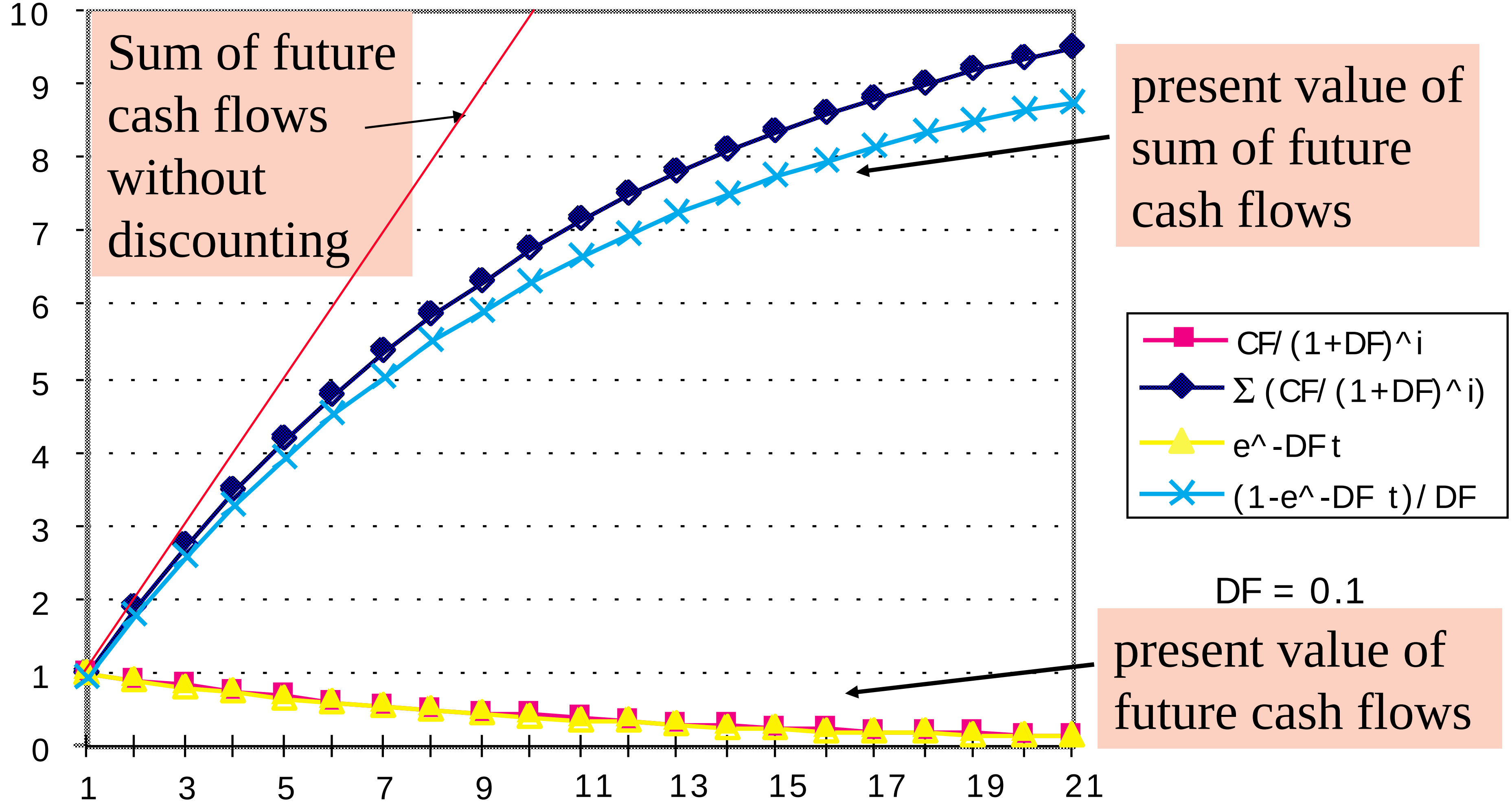
# Discounting Future Cash Flows

Money is a two-dimensional quantity ($,t)



# Two Cash Flow Formulas

Takeaway: The early cash flows contribute the most.



# Comparison Analysis

- Base case
  - fixed costs
  - labor costs
  - material costs
- Alternate case
  - fixed costs
  - labor costs
  - material costs

Comparison:
What discount rate makes the discounted sum of future savings in labor and material costs greater than or equal to the difference in fixed cost between base and alternate?

$$\text{Investment}_{\text{alt}} - \text{Investment}_{\text{base}} = \sum_{i=1}^{H} \text{Net savings}_i \,/\, \left(1 + DF\right)^i .$$

Alternatively: set discount rate = cost of borrowing
Choose the alternate investment if NPV > 0

# Discounted Cash Flow (DCF) and Economic Value Added (EVA)

- EVA is very similar to DCF. The discount rate used in EVA is the weighted average cost of capital (WACC)
  - Cost of capital includes interest rate on debt plus expected rate of return on stock (not easy to compute)
- EVA is usually used to value the whole company but is being used more and more to value individual investments
- See http://www.pitt.edu/~roztocki/abc/abc.htm
- See Econ DEMO-Stanley Hammer.xls on MIT Server.

# Zero or Net Present Value Calculations

- Comparing two investments, the savings Sv are considered income
- You pay taxes on the income at tax rate Tx, yielding your net income Ni
- You can claim depreciation Dp on your investment, decreasing your taxable income and lowering your taxes
- The IRS specifies how much you can claim in depreciation each year
  - the net income is: Ni = Sv - Tx(Sv - Dp)
- "present value analysis" spreadsheet on MIT Server finds the discount rate that gives NPV = 0
- Can be used to find NPV for any discount rate

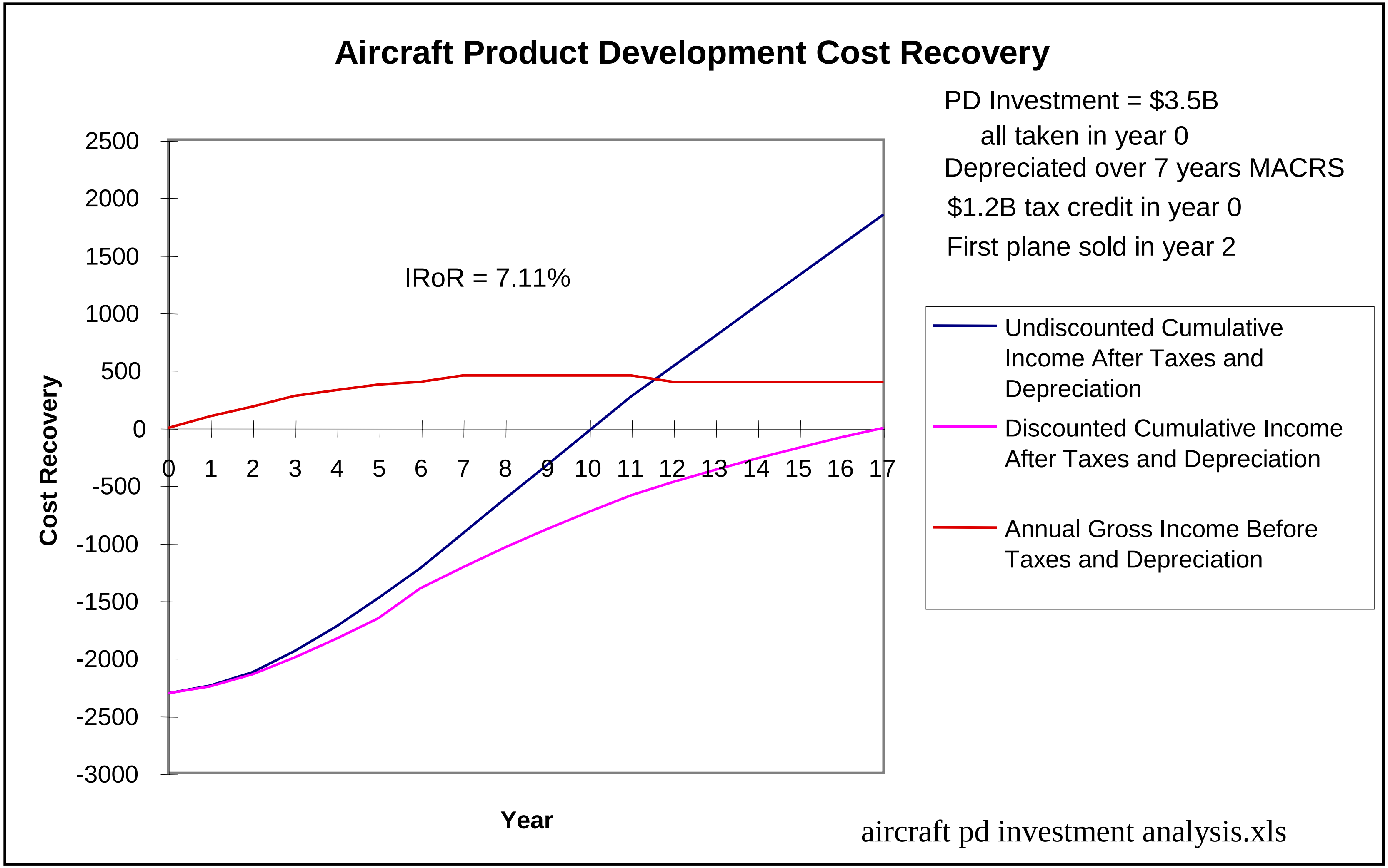
# Zero Present Value Analysis

| | ZERO PRESENT WORTH CASH FLOW ANALYSIS | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 7 | YEARS ECONOMIC LIFE | | 0% | SALVAGE VALUE % OF COST AT END OF ECONOMIC LIFE | | | | |
| | **EXPENSE FORECAST** | | | **INCOME FORECAST** | | | | |
| **YEAR** | **RATIO** | **TAX RATE** | **DEPRECIABLE** | **SAVINGS** | **DEPRECIATION** | **TAX RATE** | **CREDIT** | |
| 0 | 100.00% | 34.00% | 66.67% | | | | | |
| 1 | | | | $100 | 14.29% | 34.00% | | |
| 2 | | | | $181 | 24.49% | 34.00% | | |
| 3 | | | | $198 | 17.49% | 34.00% | | |
| 4 | | | | $150 | 12.49% | 34.00% | | |
| 5 | | | | | 8.92% | 34.00% | | |
| 6 | | | | | 8.92% | SUM OF UNUSED YRS | | |
| 7 | | | | | 8.92% | DEPR= | 31.22% | |
| 8 | | | | | 4.46% | USED FOR SALVAGE VALUE | | |
| | | | | | | OF REMAINING DEPRECIABLE INVESTMEN | | |
| | | | TOTAL INVESTMENT | | $400 | | TAX CREDIT IN YR 0 0N | |
| | | | DEPRECIABLE INVESTMENT | | $267 | | UNDEPRECIATED INVESTMEN | |
| | | | INTERNAL RATE OF RETURN | | 18.41% | RESULT OF | | |
| | | | | | GOAL SEEK | | | |
| | | | | | ON CELL G38 = 0 | | | |
| | | | **PRO FORMA CASH FLOW** | | | | | |
| **YEAR** | **INCOME** | **DEPRECIATION** | **TAXES** | **CREDITS** | **NET** | **DISC NET** | SUM OF UNDISC INC | |
| 0 | ($400) | | ($45) | $0 | ($355) | ($355) | | |
| 1 | $100 | $38 | $21 | $0 | $79 | $67 | $79 | |
| 2 | $181 | $65 | $39 | $0 | $142 | $101 | $221 | |
| 3 | $198 | $47 | $51 | $0 | $147 | $88 | $368 | UNDISC PAYBA |
| 4 | $150 | $33 | $40 | $0 | $110 | $56 | $478 | FOR EX IN FIG |
| 4 | $83 | $0 | $0 | $0 | $83 | $42 | $561 | |
| SALVAGE VALUE IN YEAR 4 | | | | | | | | |
| GROSS INCOME | $713 | $183 | $152 | $0 | $561 | $355 | | |
| NET INCOME | $313 | $183 | $106 | $0 | $206 | ($0) | | |

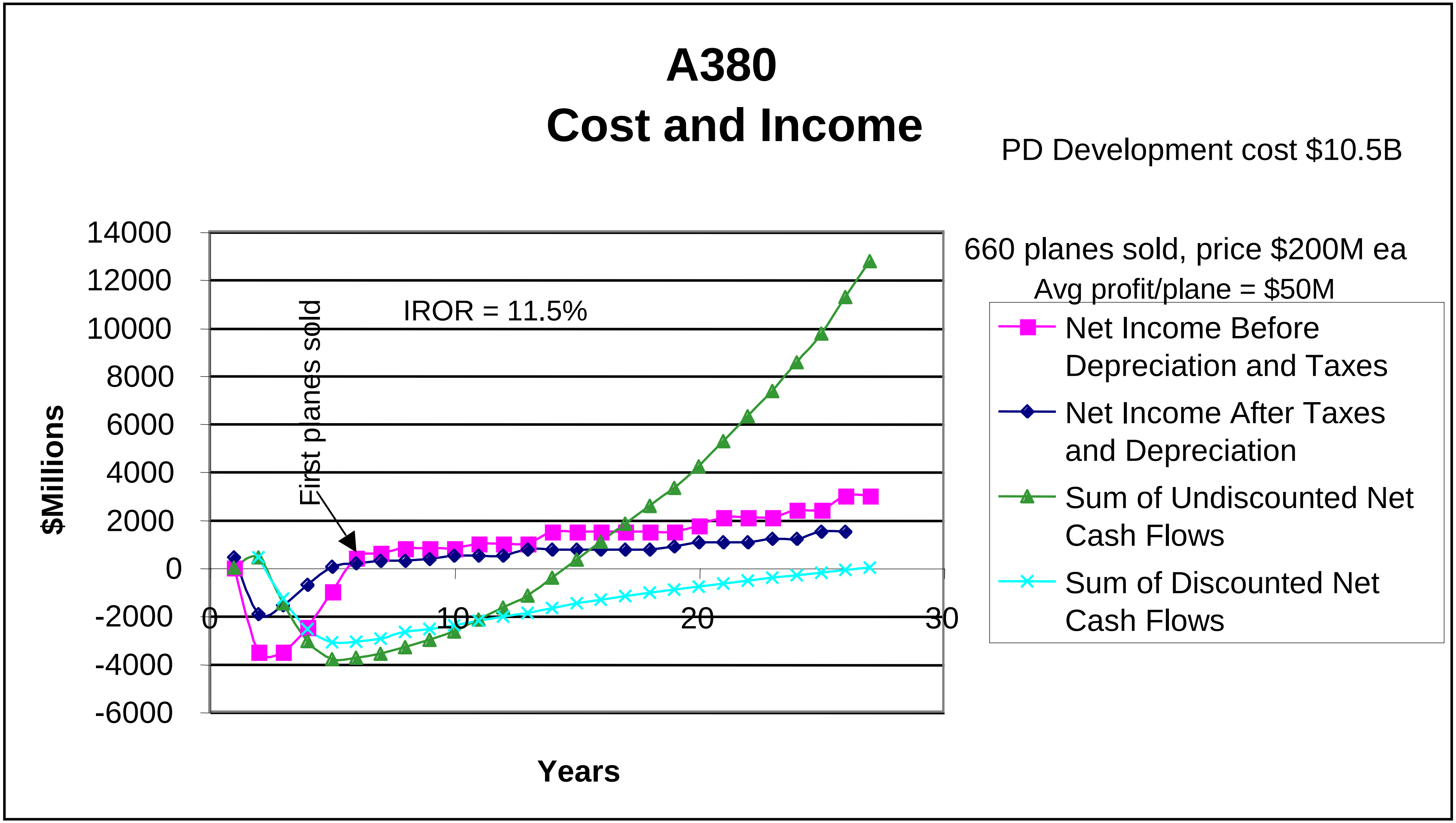
# How to Use this Spreadsheet

- Enter savings, tax rate, depreciation rate
- Goal seek to get zero NPV
- Or
- Put in various discount rates and observe NPV
- NPV > 0 is desired

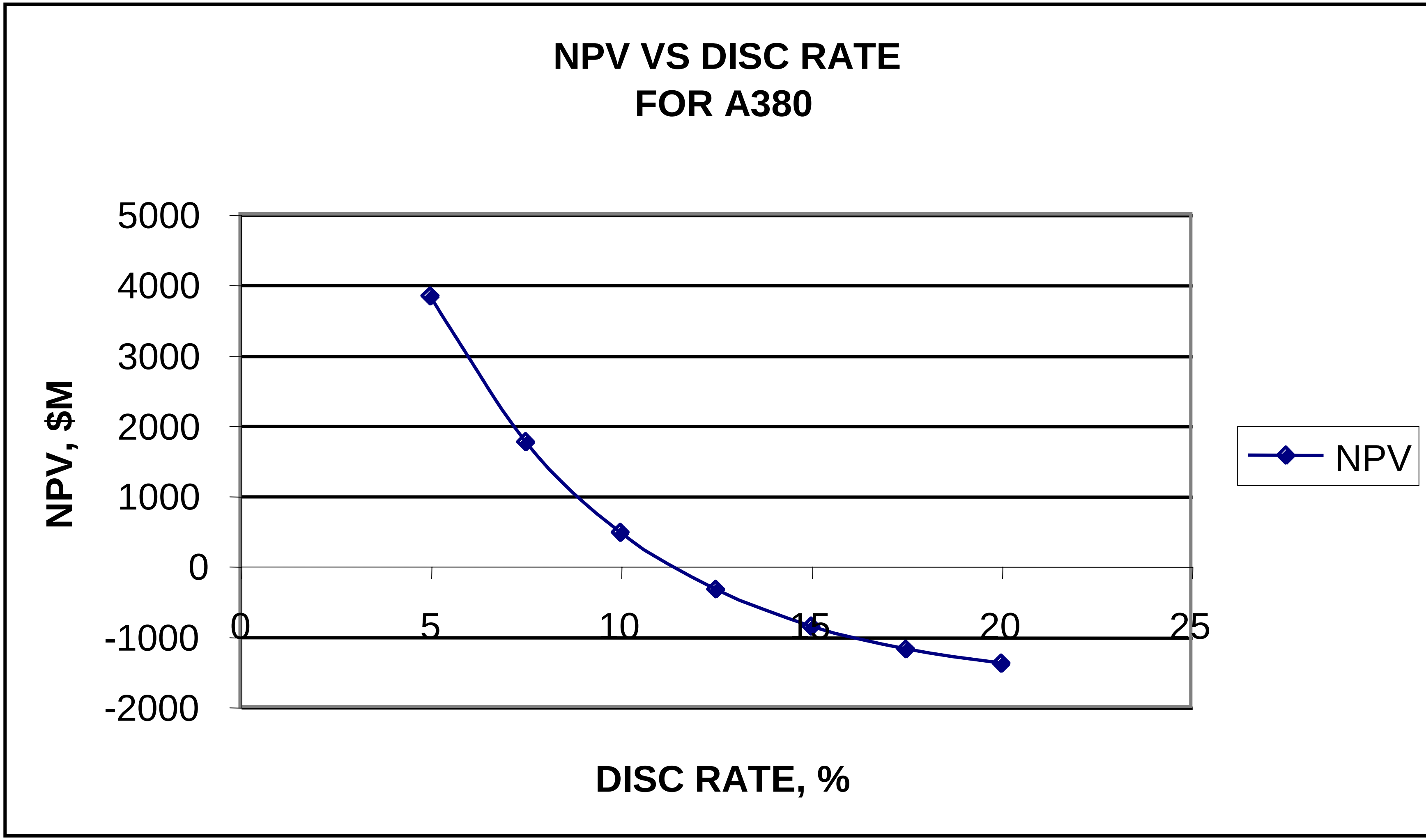
# Aircraft Development Cost Quandry



# A380 Business Case



# NPV vs Discount Rate for A380



# Critiques of DCF

- Target IROR is arbitrary
- The calculations can be gamed
- “Cost” is a slippery quantity
  - People know their expenditures and assume that they know their costs, but these are different even if they add up to the same amount
  - Overheads are allocated arbitrarily and can distort the calculations
  - Activity-based costing is intended to overcome this
  - Robert Kaplan is an EE!

# Summary of Economic-Technical Analysis

Image removed for copyright reasons.
Source:
Figure 18-14 in [Whitney 2004] Whitney, D. E. *Mechanical Assemblies: Their Design, Manufacture, and Role in Product Development*. New York, NY: Oxford University Press, 2004. ISBN: 0195157826.