Using State-of-the-Art Technology Trends to Assess Space System Cost Risk

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Overview

- The Problem
- Hypothesis: Technology trends over time can be used to predict space system cost
- Analytical approach
- CER Development
- Validation and Model Application

The Problem

- JPL Advance Planning Office studying future Mars architecture scenarios
- Needs a tool to assess system level cost sensitivity to technology insertion and launch date

Hypothesis

- Technology trends over time can be statistically quantified using representative space system performance parameters
- A technology metric can be formulated that represents a proposed systems risk ranking in relation to the predicted state-of the-art at a chosen point in time
- Metric can then be used to derive an objective multivariate regression model to trade performance, schedule and cost

Approach/Methodology

- Data assembled for NASA earth and planetary orbiters from 1964 to present
  - Performance and design parameters, mass properties, cost, launch date, mission type
- Technology Index
  - Plotted suspect parameters by launch date to assess initial trends
  - Promising trends investigated for multi-variate prediction model for launch date
  - Defined state-of-art as step function
  - Define technology index as difference between proposed launch date and predicted launch date

Approach/Methodology (cont.)

- CER Development
  - Multi-variate regression approach using technology index as input along with normal cost drivers, mass, power, mission type etc.
  - "Best" model selected using statistical measures of fit, R^2, t-values, residual analysis and engineering judgement
  - Validate using proposed missions and dummy time-line and technology choices

Technology Index Parameters

- System attributes investigated

Mass Properties
Structure Mass Fraction
Payload Mass Fraction
On-orbit dry mass

ADACS/C&DH
Pointing Knowledge
Pointing Accuracy
Data Storage
Max Data Rate
Data Rate/C&DH Mass
Data Storage/Max Data Rate

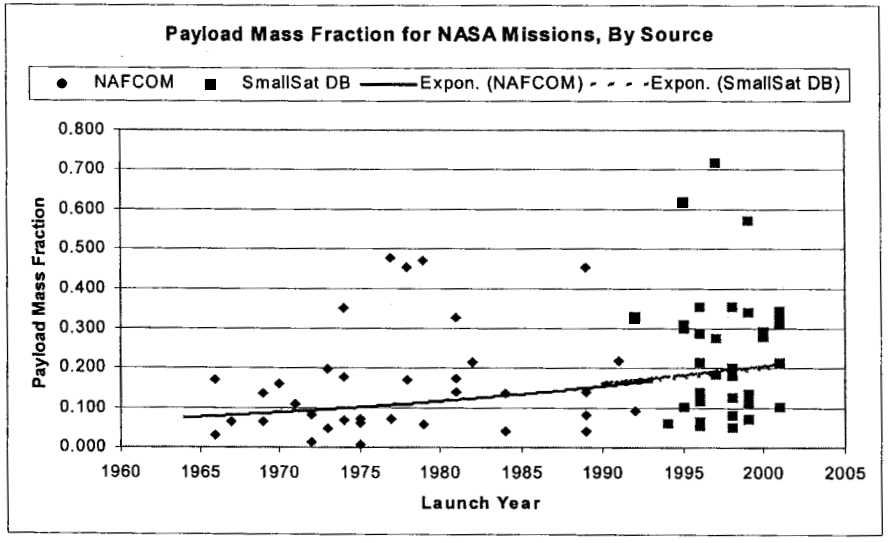
Power
Battery Capacity
Battery Capacity/EPS Mass
EPS Mass Fraction
Solar Array Area
SA Area/EPS Mass
BOL Power/SA Area
BOL Power/EPS Mass
BOL Power

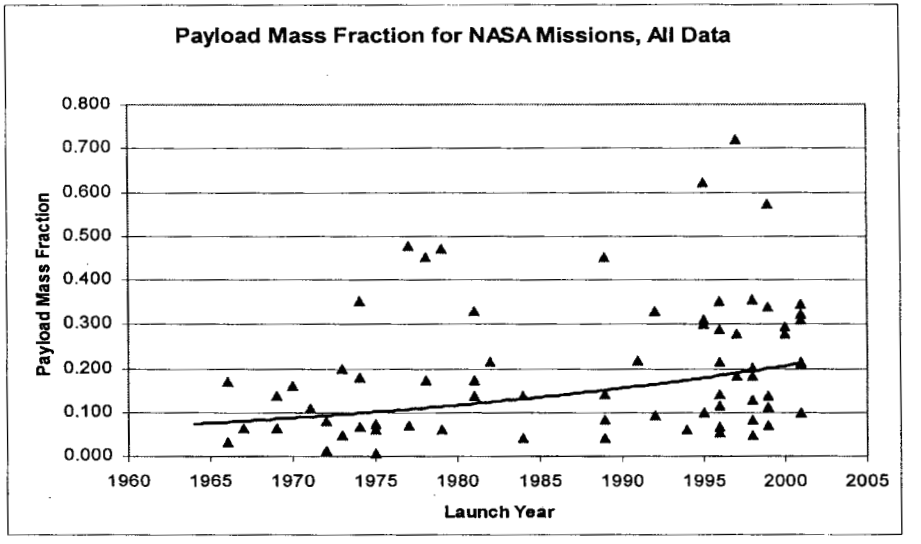
Mission Design
Design Life
Planetary/Earth Orbiting
Large Sat/Small Sat

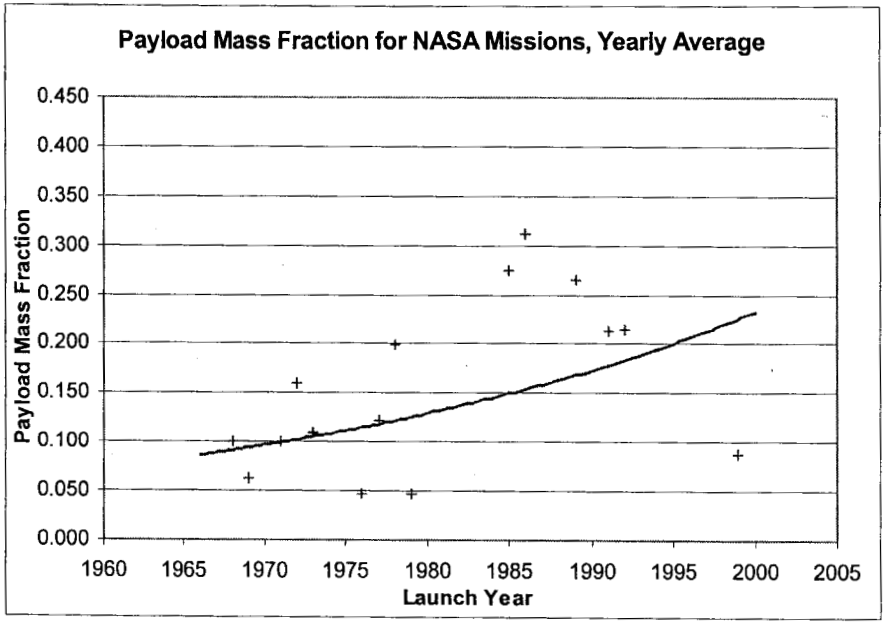
Technology Index Data Set

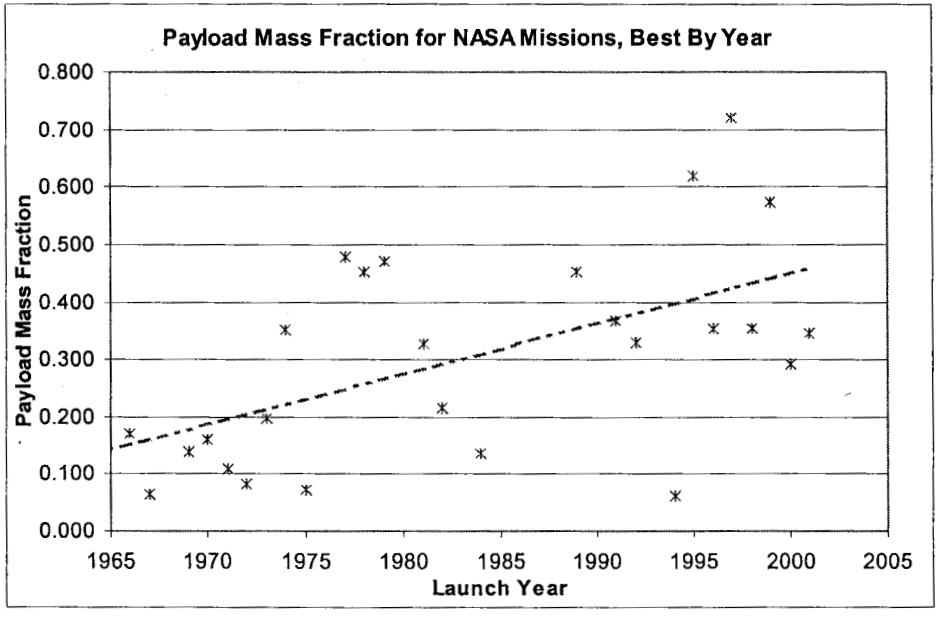
ACE
ACRIMSAT
ACTS
AE-3
AEM-HCMM
AMPTE-CCE
ATS-1
ATS-2
ATS-5
ATS-6
CLARK
CLEMENTINE
COBE
CRRES
DE-1
DE-2
Deep Space 1
EO-1
ERBS
FAST
FUSE
Galileo Orbiter
Galileo Probe
GENESIS
GRACE
GRO
HAWKEYE
HEAO-1
HEAO-2
HEAO-3
HETE
HETE II
ICESat
IMAGE
JASON-1
LANDSAT-1
LANDSAT-4
LEWIS
Lunar Orbiter
Lunar Prospector
Magellan
MAGSAT
MAP
Mariner-10
Mariner-4
Mariner-6
Mariner-8
Mars 98 (MCO)
Mars 98 (MPL)
Mars Global Surveyor
Mars Observer
Mars Odyssey
Mars Pathfinder
METEOR
MICROLAB (Orbview-1)
NEAR
OSO-8
OTA
PEGSAT
Pioneer Venus Bus/Orbiter
Pioneer Venus Large Probe
Pioneer Venus Small Probe
Pioneer-10
POLAR
QuickTOMS
S3
SAC-B
SAMPEX
SEASTAR (Orbview-2)
SME
SMS-1
SNOE
SSM
STARDUST
Surveyor
SWAS
TIMED
TIROS-M
TIROS-N
TOMS-EP
TOPEX
TRACE
UARS
VCL
Viking Lander
Viking Orbiter
Voyager
WIND
WIRE
XTE

Technology Trends – Mass Properties

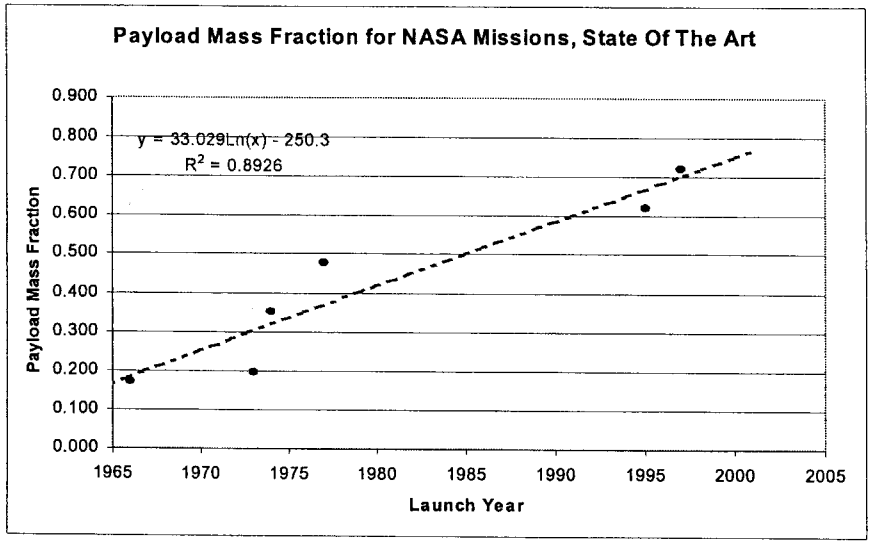


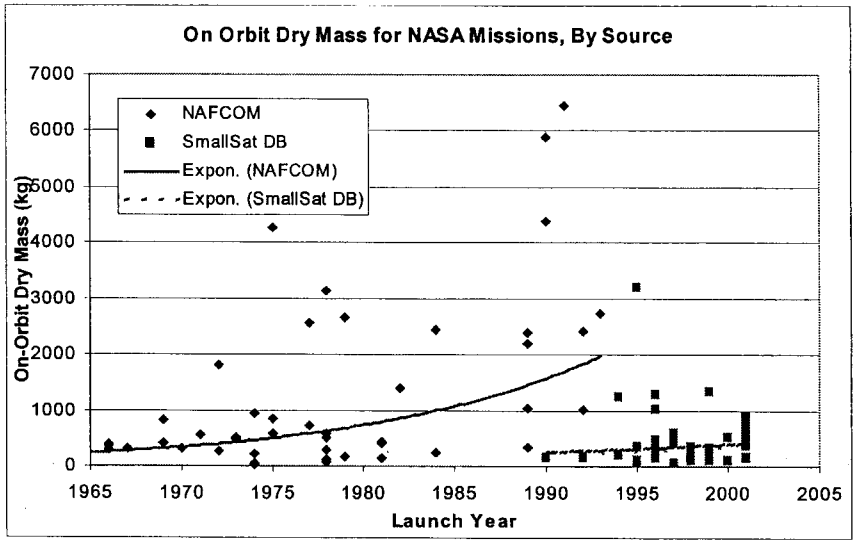


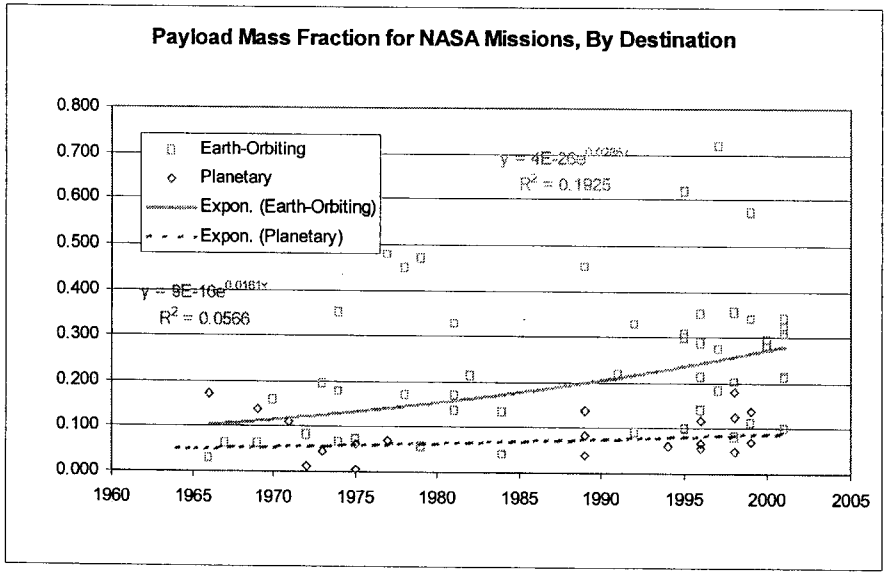


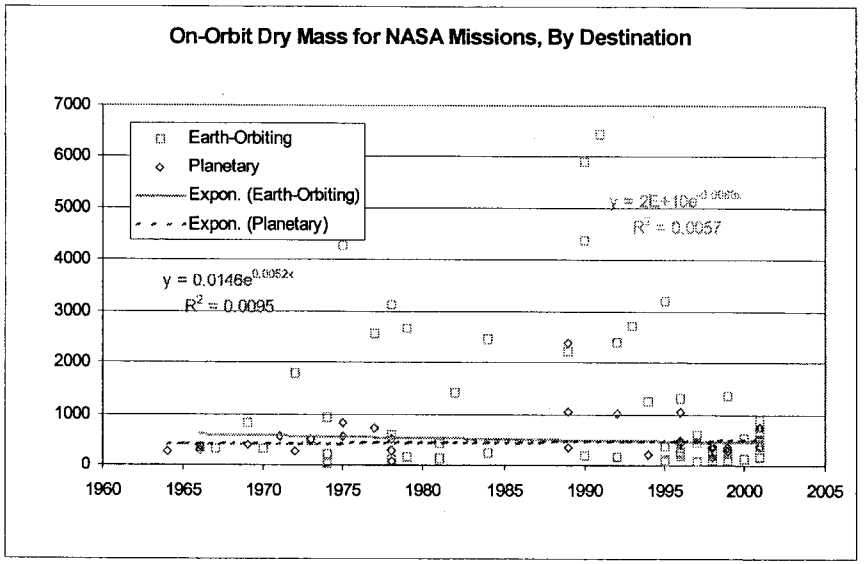


Technology Trends – Mass Properties (cont.)

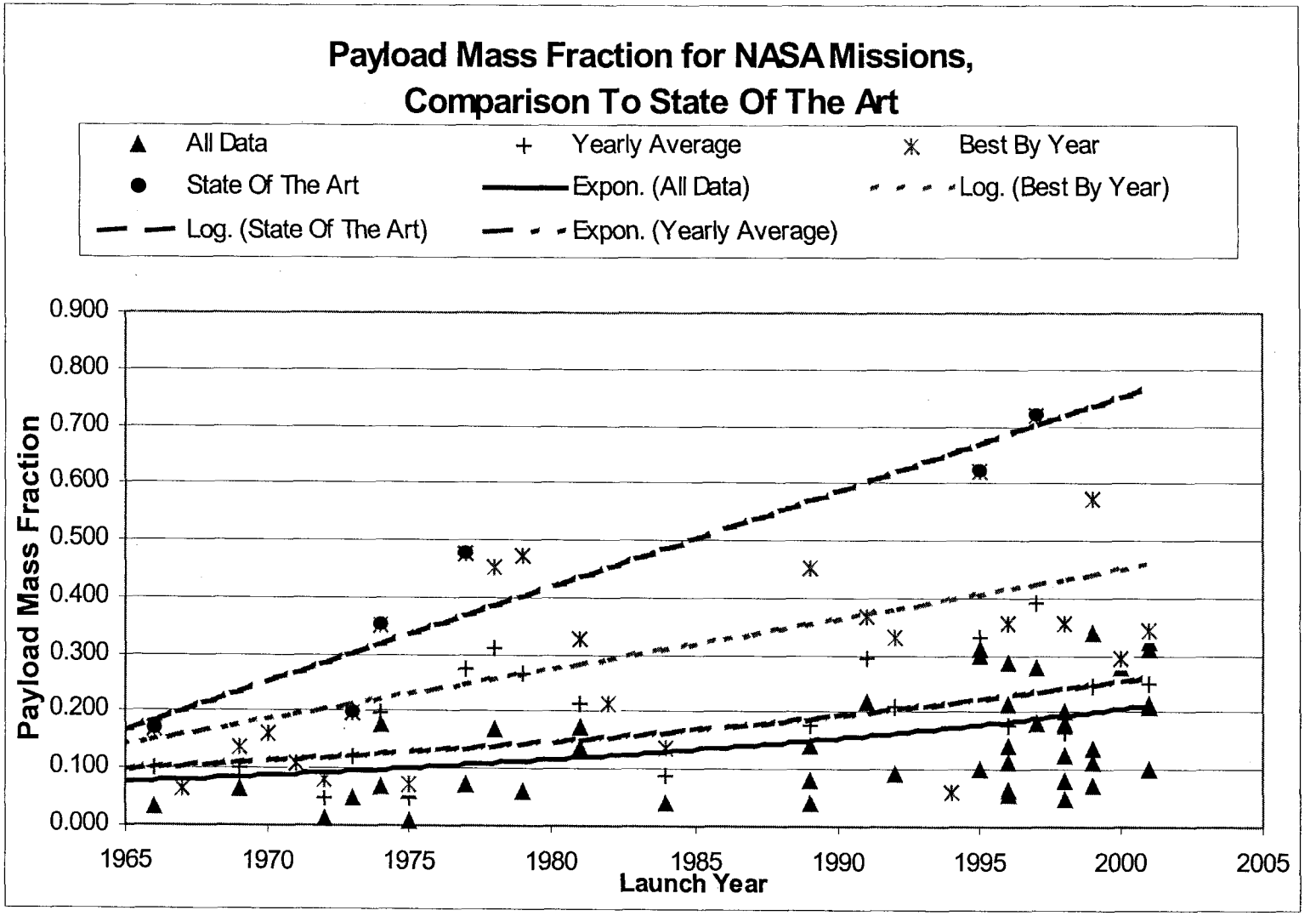




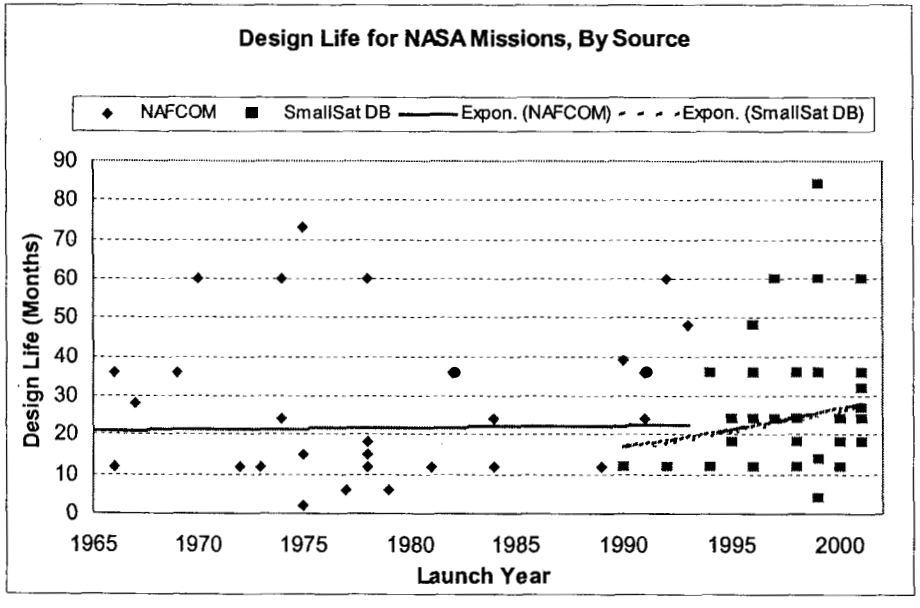


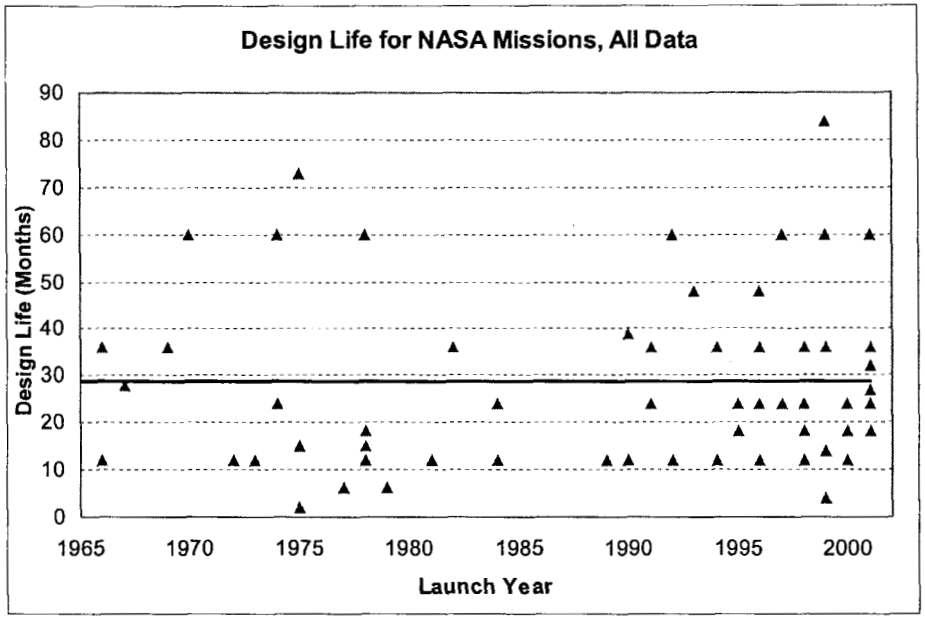


Technology Trends – Mass Properties (cont.)

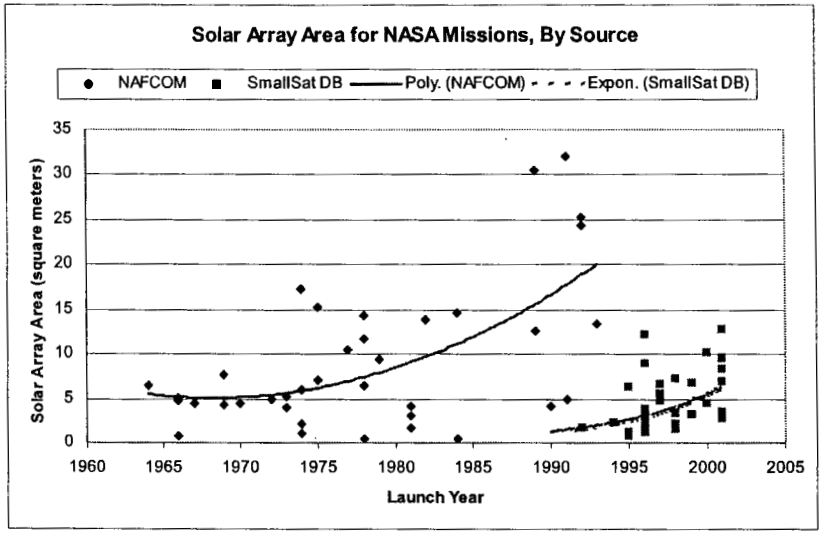


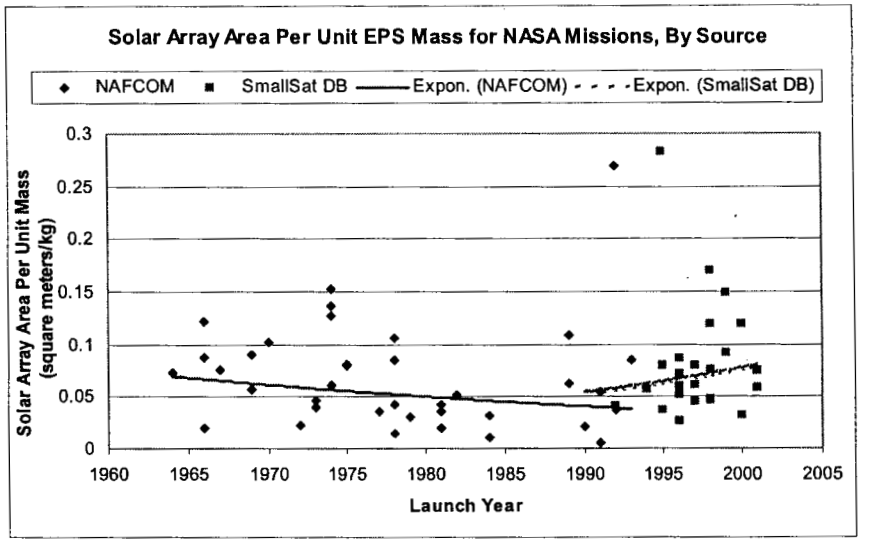
Technology Index – Design Life

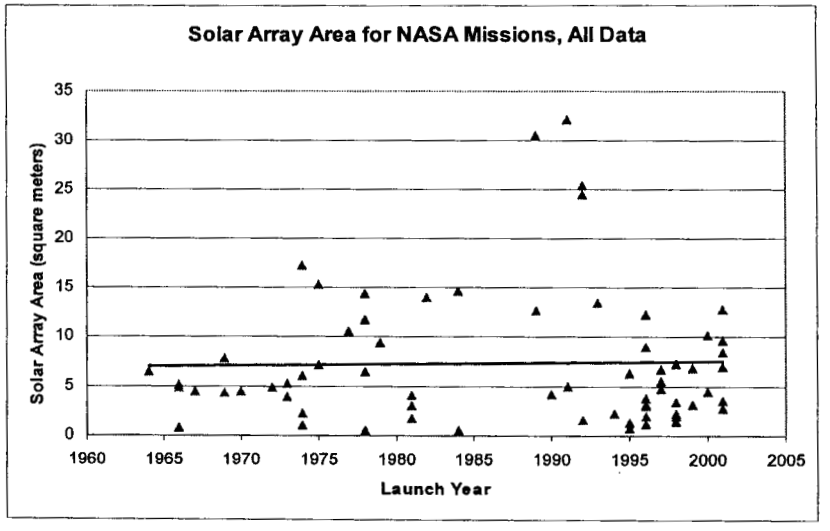


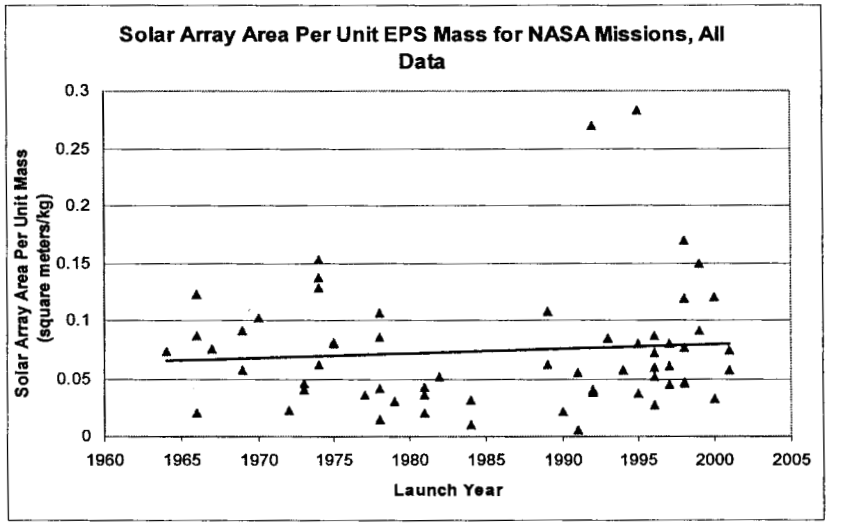


Technology Index – Power/Solar Array Area

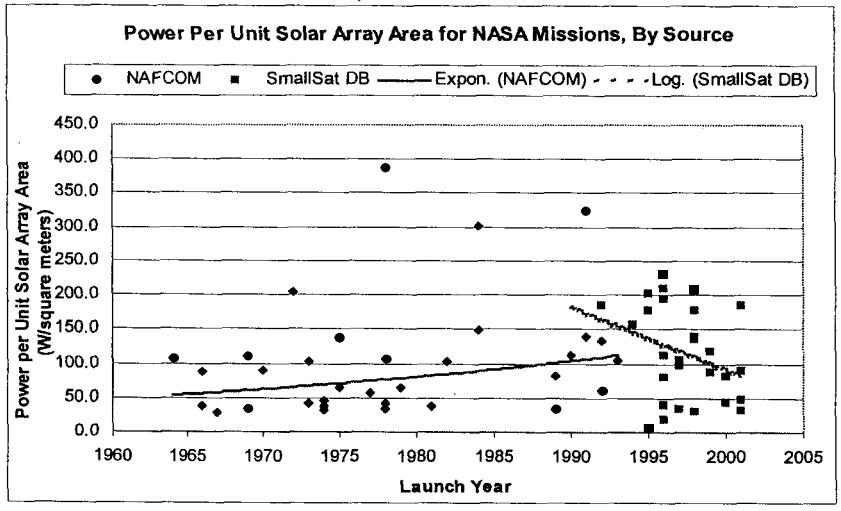


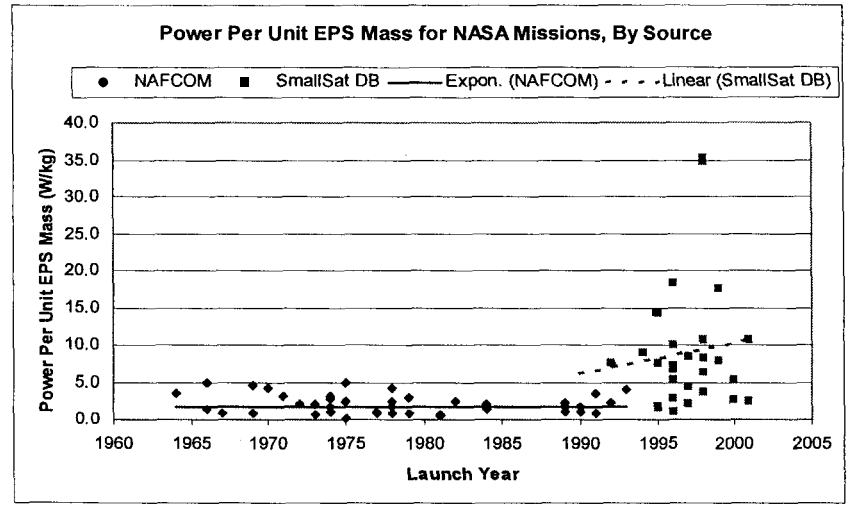


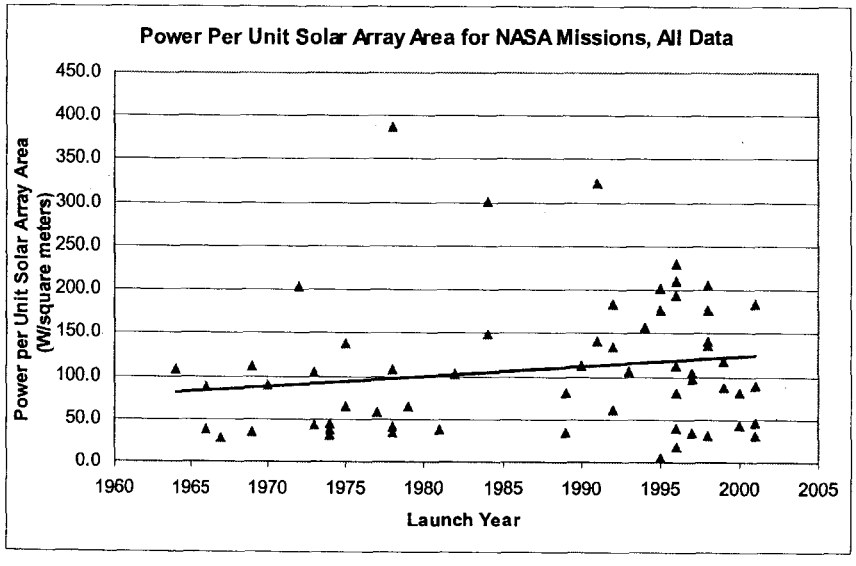


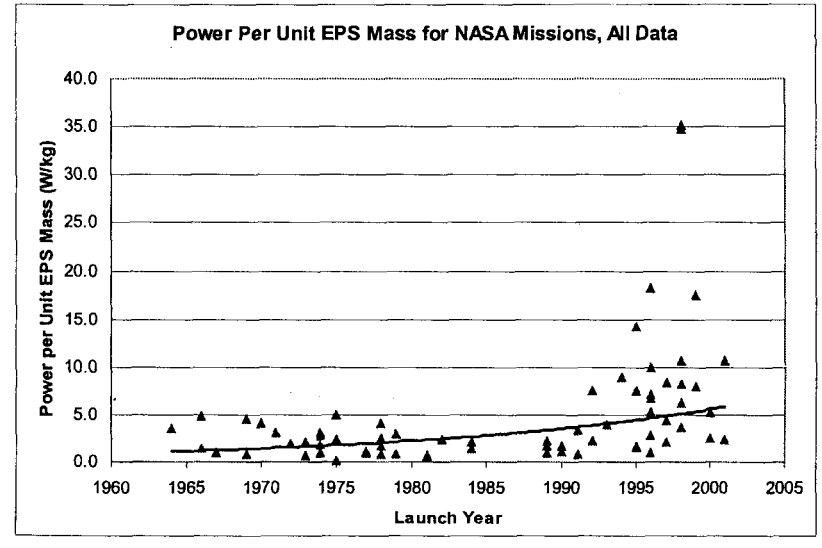


Technology Index – Power

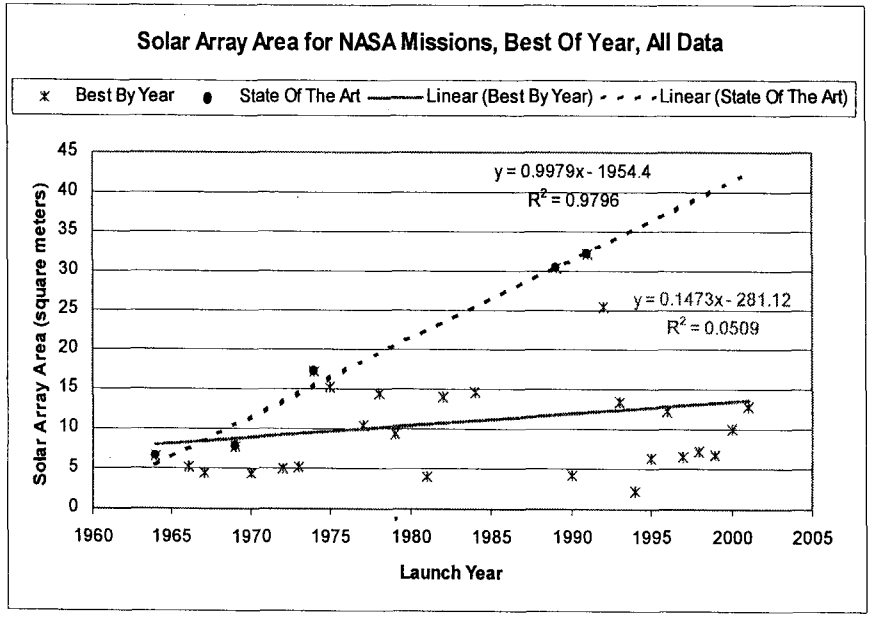


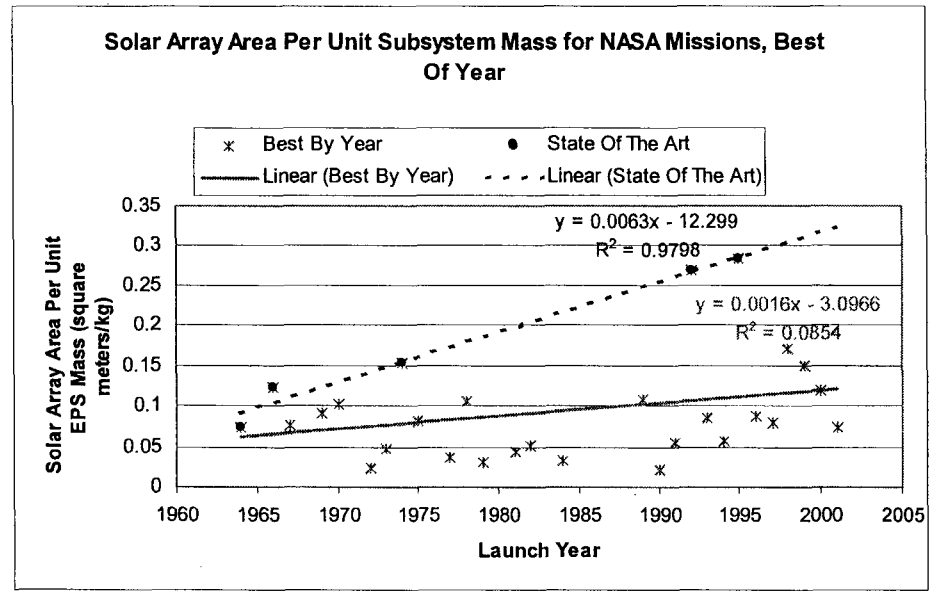




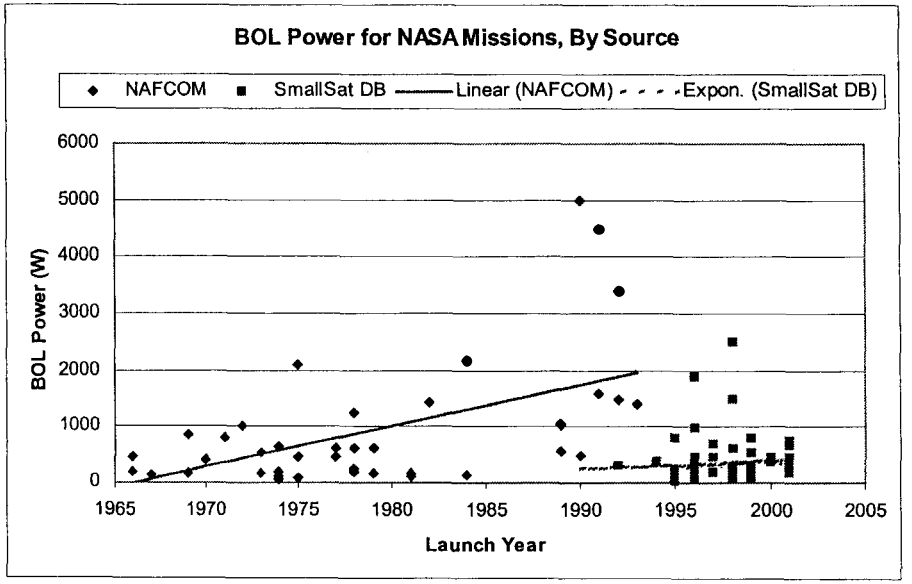


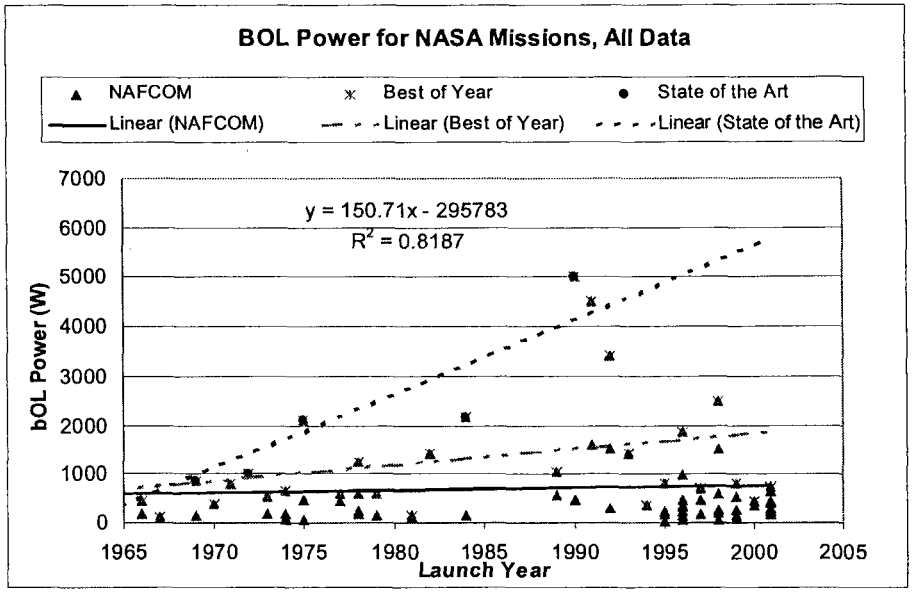
Technology Index – Power/Solar Array Area State of the Art Trends



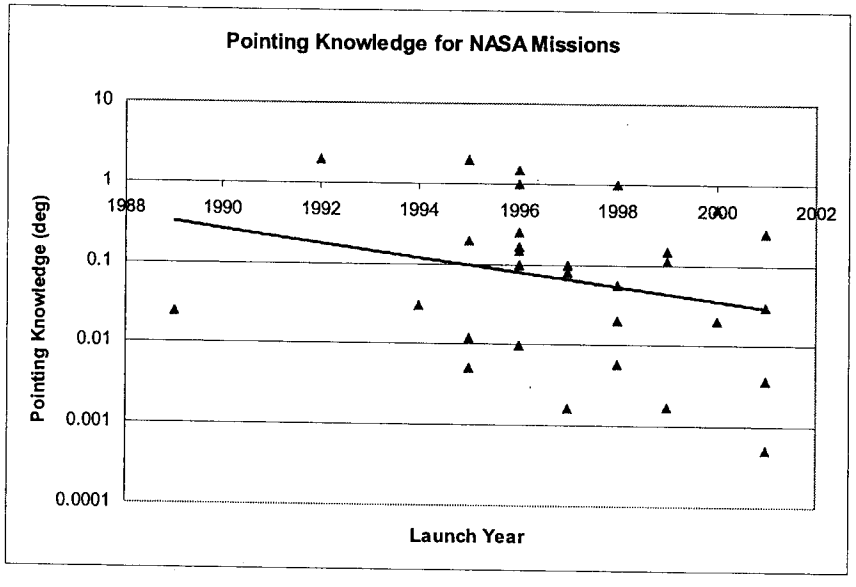


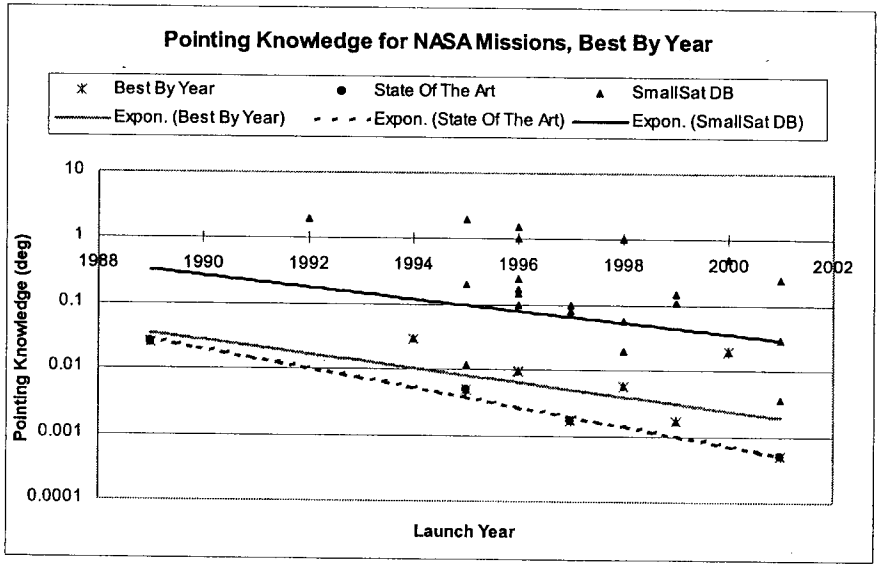
Technology Index – Power



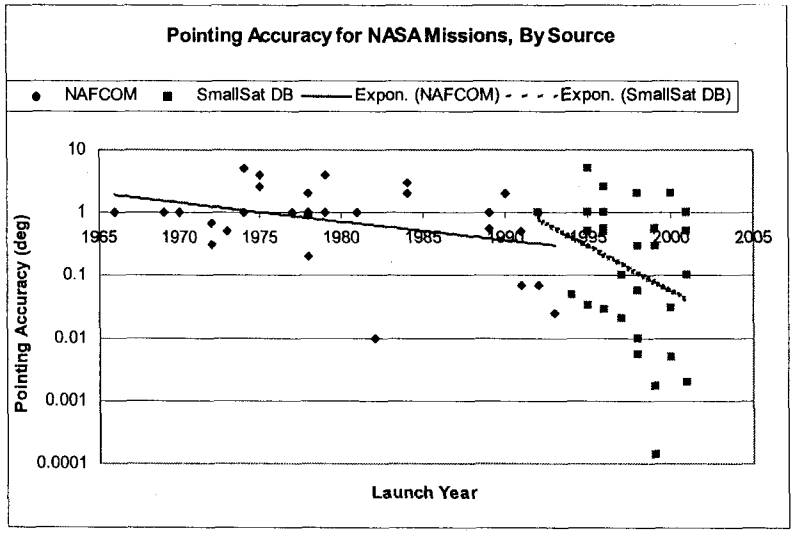


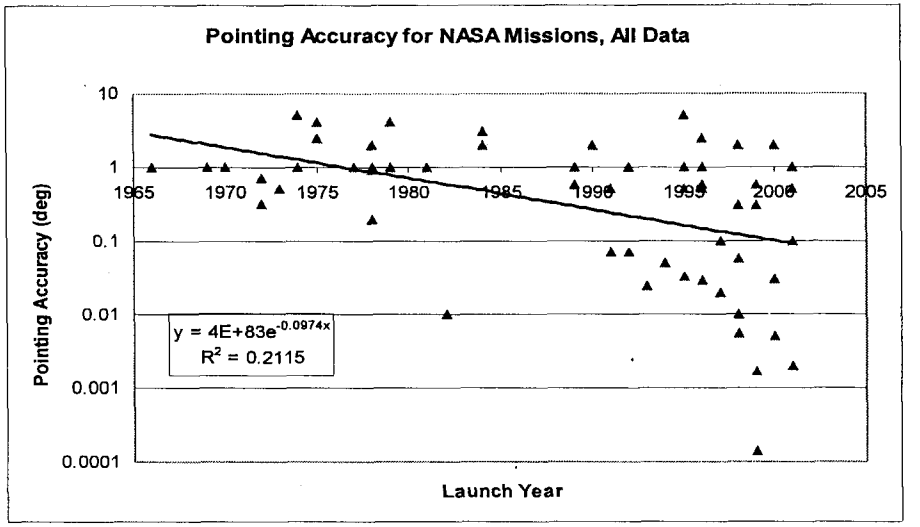
Technology Index – Pointing Knowledge

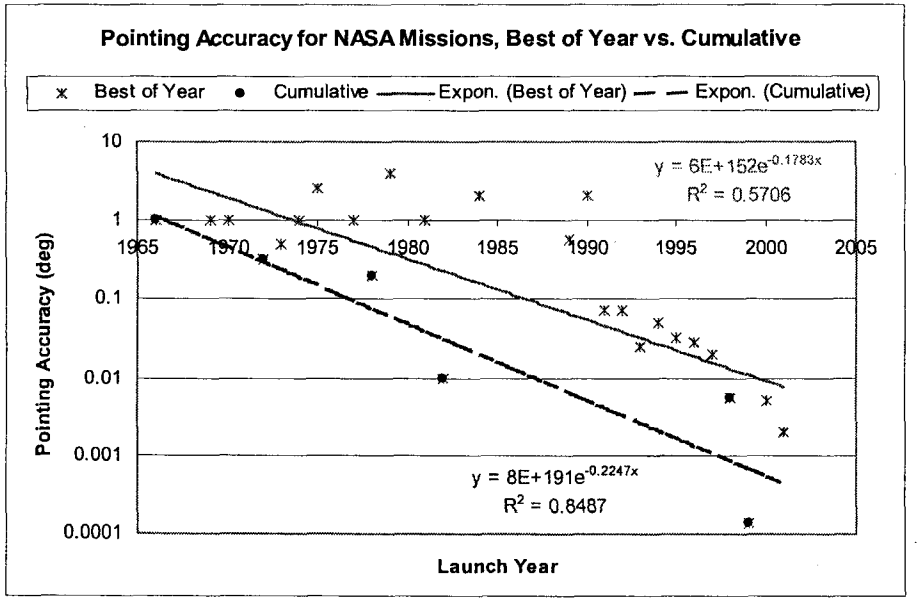




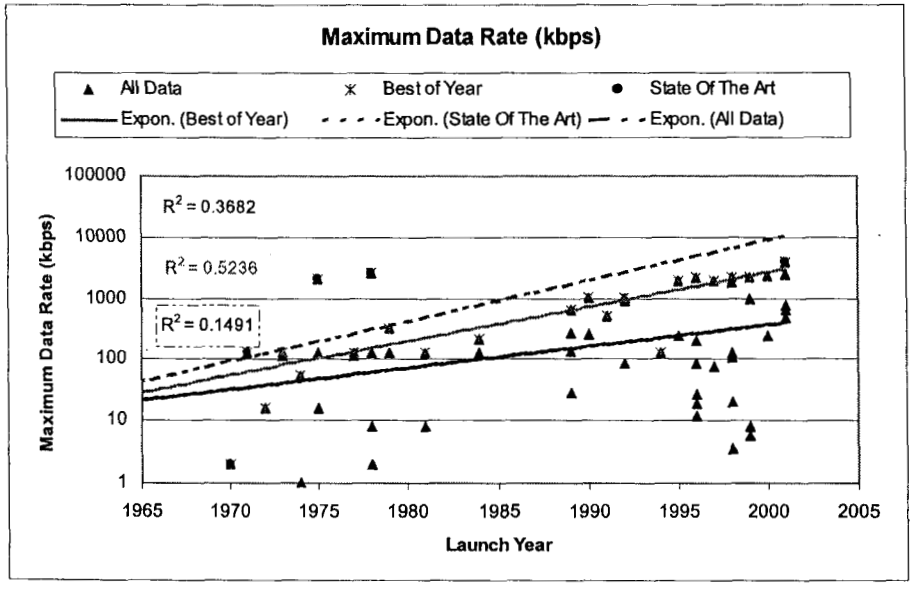
Technology Index – Pointing Accuracy

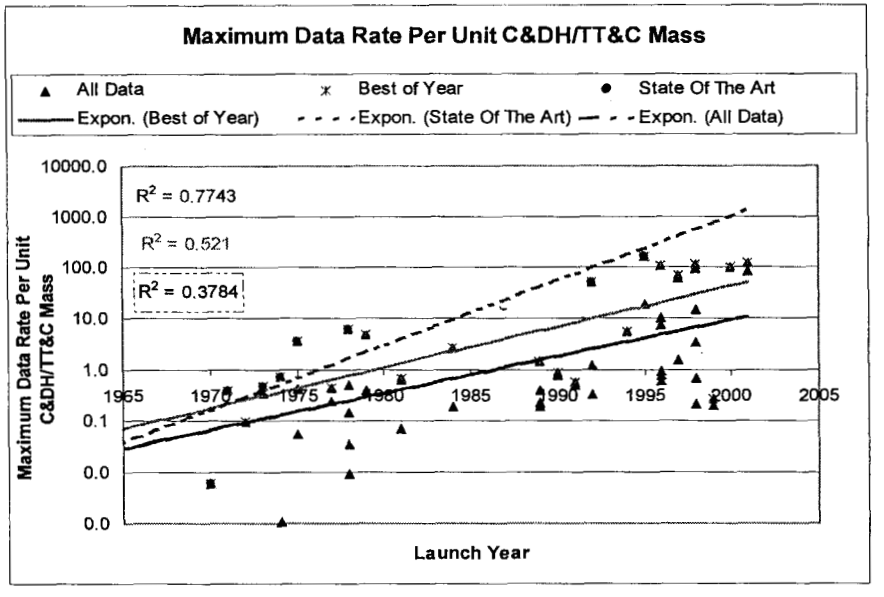






Technology Index – C&DH/TT&C





Technology Risk Multivariate Model

- Formulate candidate multi-variate models that predict launch date based on performance parameters
  - 8 candidates have good diagnostics and broad subsystem coverage
  - Use state-of-the-art data set to represent most stressing risk posture
- Define risk index as difference between predicted and actual launch date
  - Index has negative value since a system rarely pushes state-of-the-art across all measures
  - Index gives a relative value of technology driven risk across quantitative measure of capability at a point in time
- Risk index is input to system level cost model

Technology Risk Multivariate Model

- Candidate Model Parameters
  - Payload Mass Fraction
  - BOL Power, BOL Power/EPS Mass
  - Pointing Accuracy
  - Data Storage, Data Storage/Max Data Rate, Data Storage/TT&C,C&DH Mass,
  - Max Data Rate, Data Storage/Max Data Rate, Max Data Rate/TT&C Mass
  - Earth/Planetary Orbiting
- Best diagnostics and prediction models include
  - Payload Mass Fraction(%), BOL Power(W), Pointing Accuracy(deg), Max Data Rate/TT&C Mass(Kbps,Kg), Earth Orbiting(Y=1,N=0)

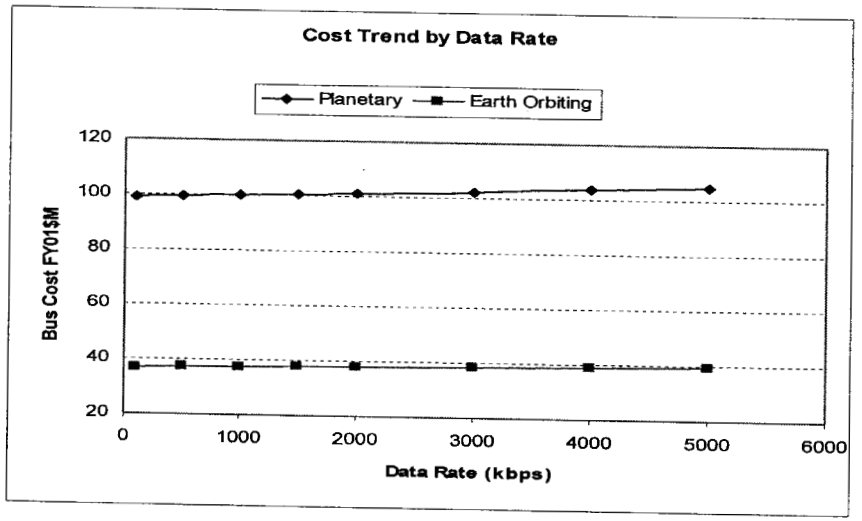
Cost CER development

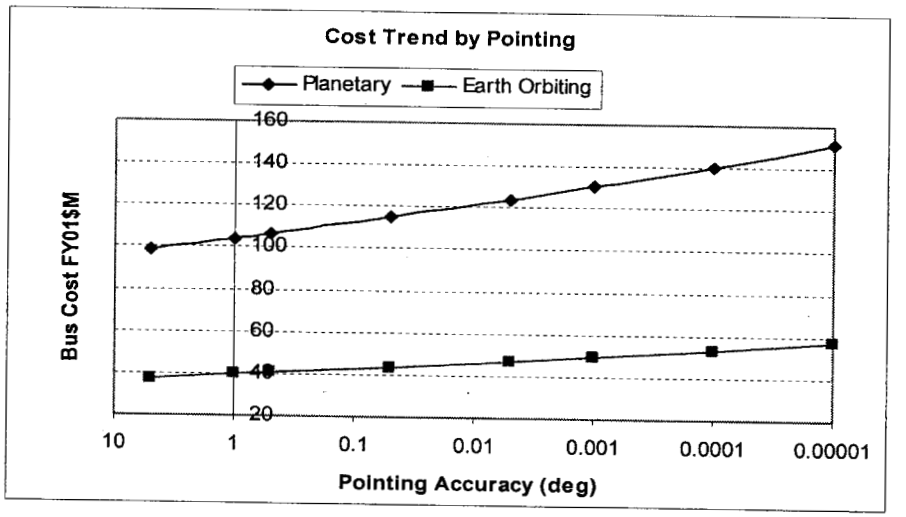
- Recall Risk model output is launch date normalized in months from 1/1/1965
- Risk Index is proposed predicted launch date – proposed launch date
- Risk Index Represents a relative assessment of technology proposed vs. state-of-the-art trend at a future point in time

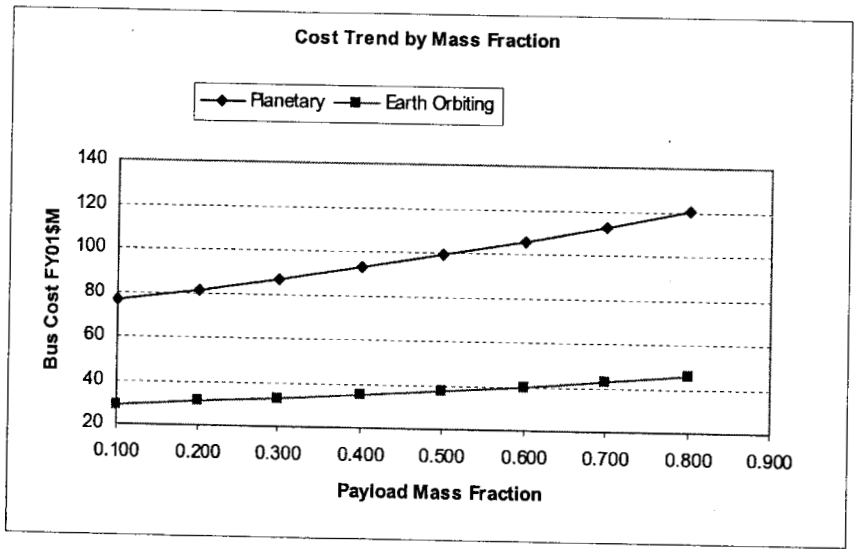
Cost CER development

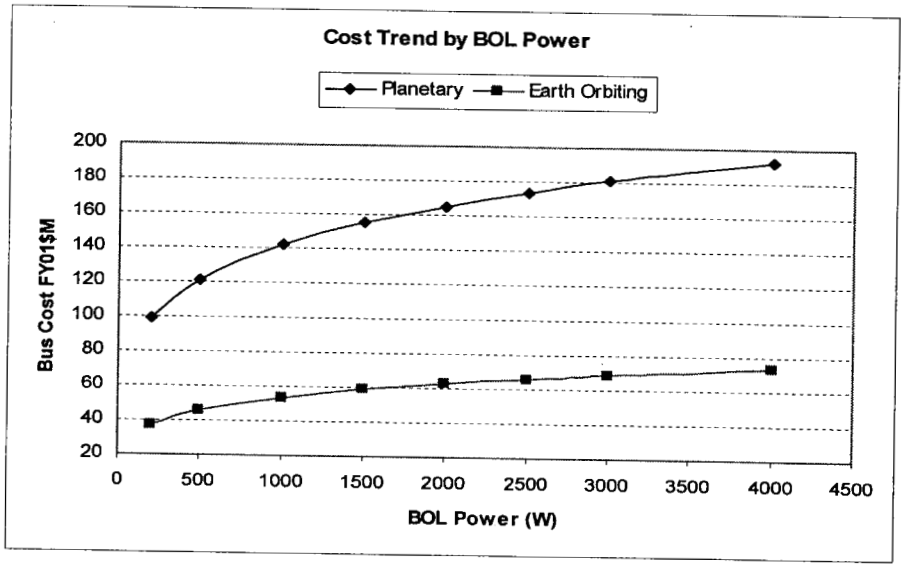
- Build system level bus cost model using risk index as a parameter
- Use same data set as Risk Index with failed missions removed
- Parameters investigated
  - Launch Mass, Dry Mass
  - Power
  - Single/Dual String, Dummy Carrier
  - Risk Index (2 candidates)
- Cost/Risk Model:
  - Bus Cost = f(Bus Dry Mass,Risk Index, Earth Orbiting)
  - Risk Index = f(PL mass fraction, BOL Power, Pointing, Data Rate, TT&C Mass, Earth Orbiting)

Preliminary Cost Model Sensitivity Analysis

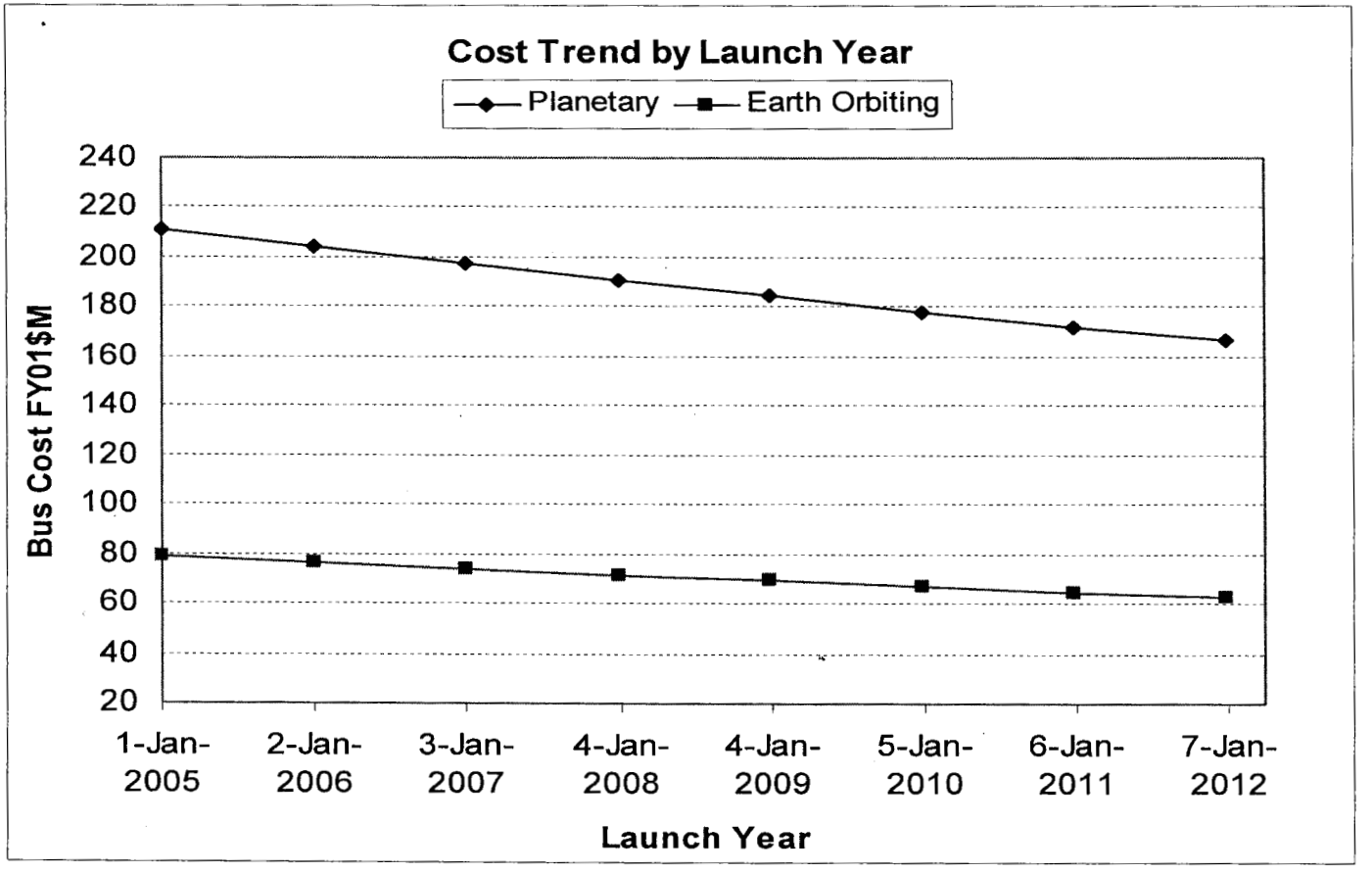








Preliminary Cost Model Sensitivity Analysis



- Note lower cost as launch date is pushed out due to maturing of technology

Summary

- Trends in certain key performance parameters have been statistically identified.
- A link between these trends and cost and schedule has also been shown to exist, and establishes a prediction model useful for performance, schedule, cost trades of Planetary orbiters.
- Initial validation with Europa and Mars 05, and 07 orbiting missions yields good results.
- Cost growth due to push in technology just a piece of the cost-risk puzzle.