National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Assessment of In-flight Anomalies of Long Life Outer Planet Missions

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Topics

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  - **Anomalies by Time**
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  - **Assessment of Corrective Actions**
- **Lessons Learned**
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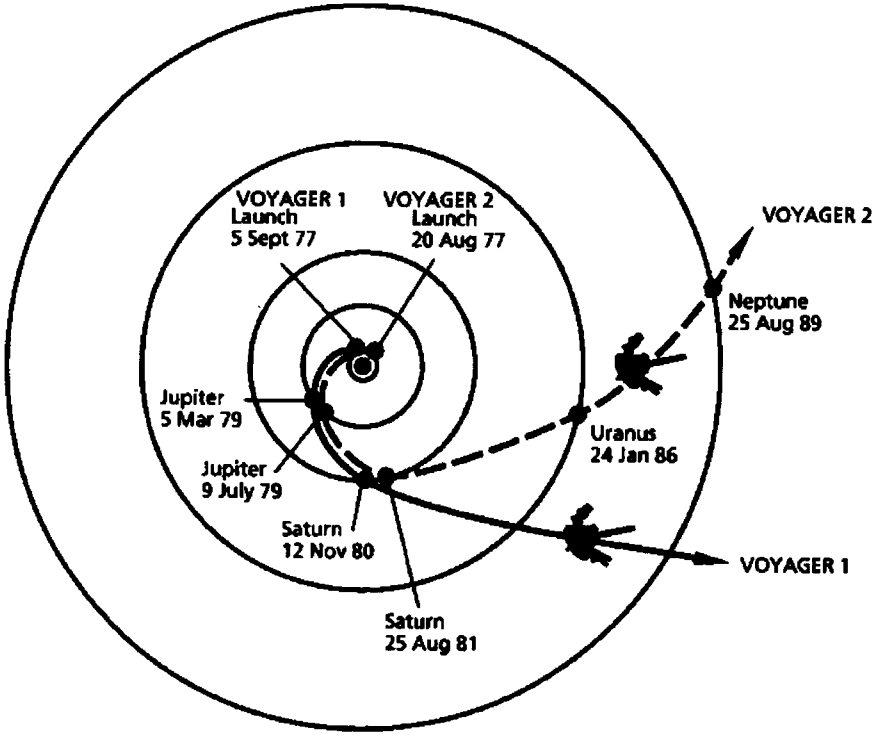
Objectives

- **Analyze in-flight anomaly reports for outer planet spacecraft to gain a better understanding of the technology and management approaches needed to build machines that can fly to the edge of the solar system and into interstellar space**
- **Determine if redundancy was utilized, the type utilized (block vs. functional), and which phase of the flight it was applied**
- **Determine the relationship between the number of anomalies and the occurrence of major flight events**
- **Identify long life mission planning and management issues that must be addressed for future missions**

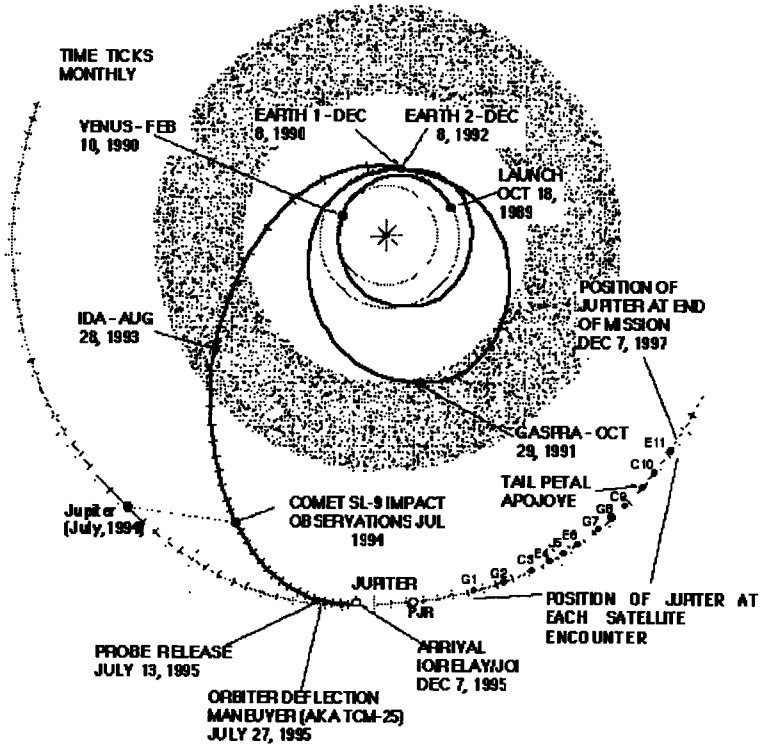
Mission Summaries

	VOYAGER	GALILEO
Launch Dates	**Aug-Sept 1977**	**October 1989**
Encounters	**Jupiter 1979** **Saturn 1980-81** **Uranus 1986** **Neptune 1989**	**Venus 1990** **Earth 1990-91** **Asteroids 1991-1993** **Jupiter December 1995**
Current Distance **Sun to spacecraft** **June 2004**	**91 AU Voyager 1** **73 AU Voyager 2**	**Mission completed** **September, 2003** **Jupiter impact** **s/c destroyed**

MISSION TRAJECTORIES



Voyager



Galileo

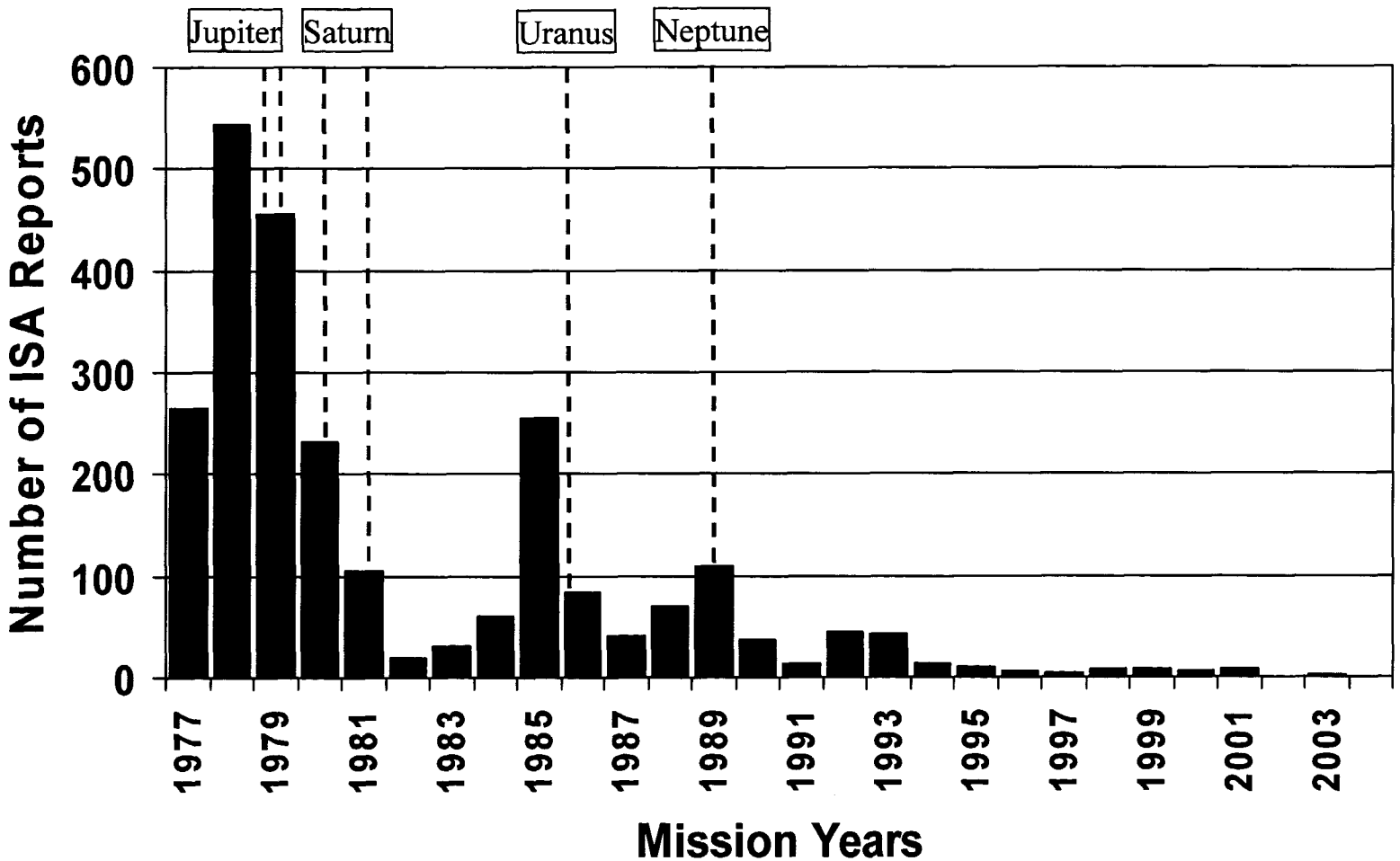
In-flight Anomaly Reporting

- **Incident Surprise Anomaly (ISA) Reports**
  - **Documents anomalies during flight that occur on the spacecraft or the spacecraft ground support system**
  - **Process**
    - **Problem described**
    - **Verification**
    - **Corrective Action Taken**
    - **Review and Approval**
    - **Closure**
  - **Voyager and Galileo Electronic ISAs Evaluated**

Redundancy Usage

Spacecraft	Number	Time of Occurrence	Redundancy Applied
Voyager 1	2	10 years	Block
		15 years	Block
Voyager 2	4	0 years (at launch)	Block
		7 month	Block
		4 years	Block
		22 years	Block
Galileo	1	1.5 years	Functional

Voyager Incident Surprise Anomaly Quantities by Year



Voyager ISA Trends

- **Trends indicates when anomalies are likely to occur**
  - **Beginning of the mission**
    - **Shakedown of spacecraft in flight**
    - **Anomalies decreases after first couple of years**
  - **Increase with major encounters**
    - **Changes to inactive instruments due to radiation and aging**
    - **More activity = More anomalies**
- **Voyager anomaly reporting**
  - **Follows closely with planetary encounters**
    - **Peaks at outset and before Uranus and Neptune visits**
  - **Overall decrease with increasing time**
    - **Due to less activity**
    - **Opposite from expected trends due to radiation and aging**

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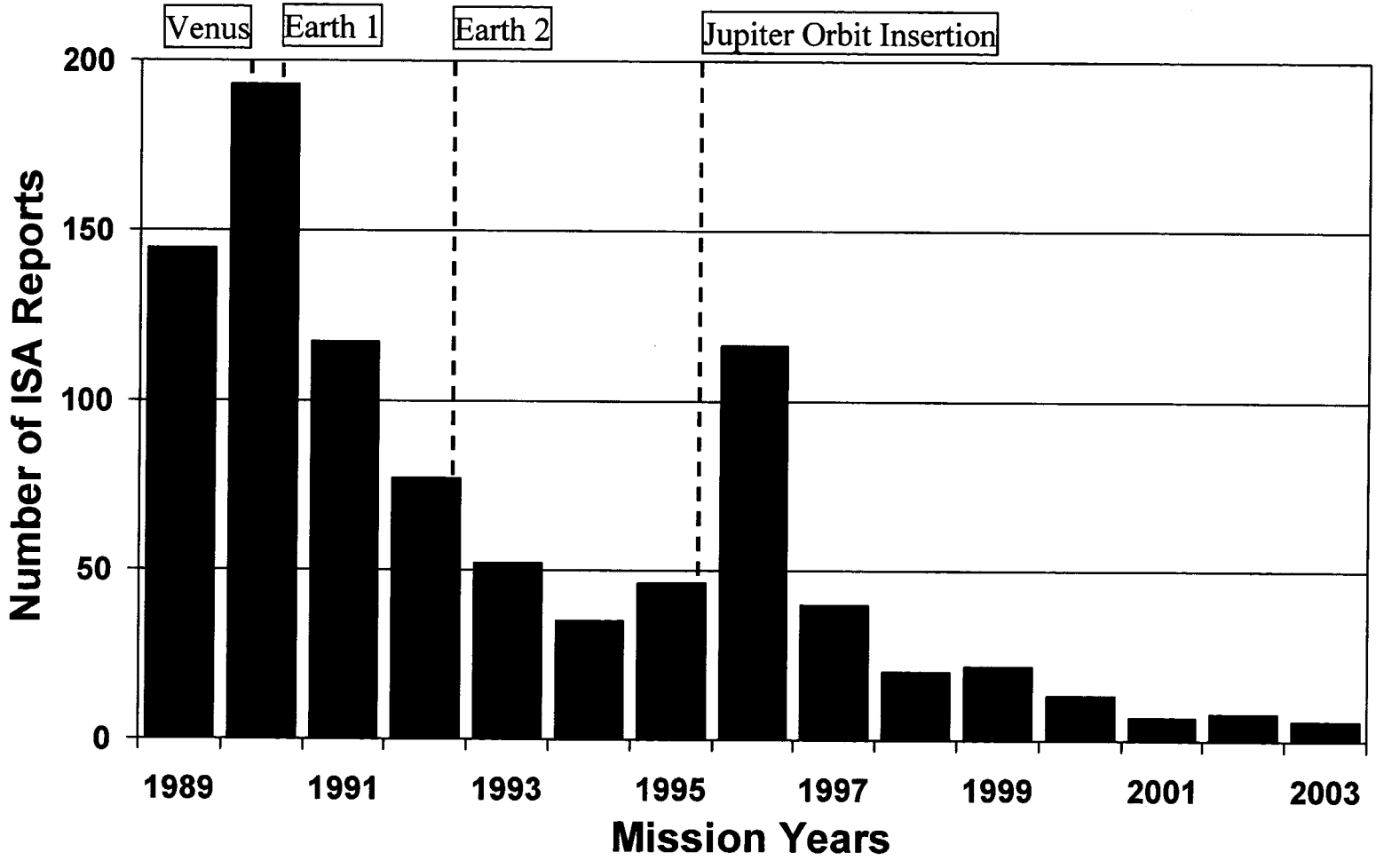
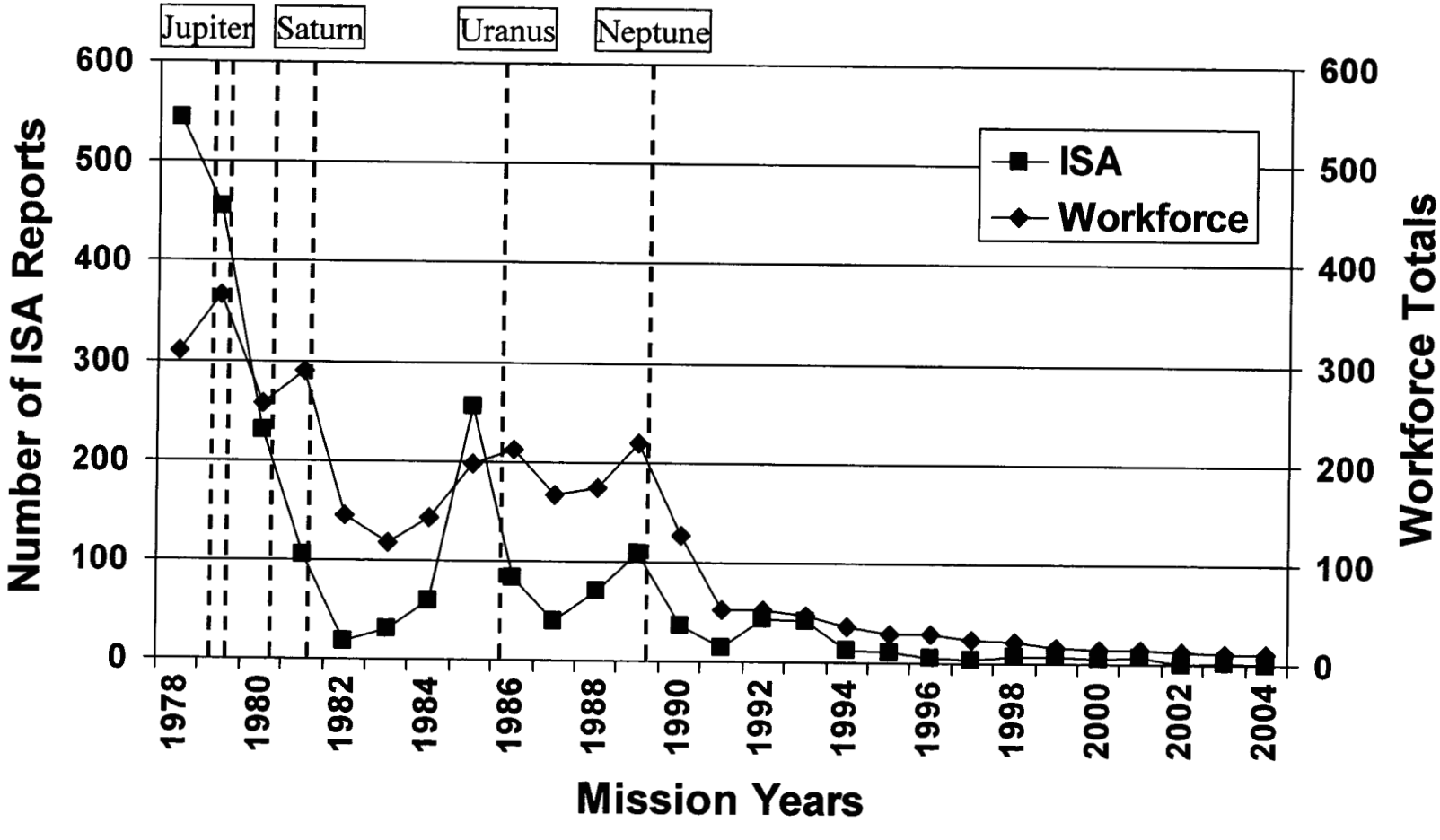
Galileo Incident Surprise Anomaly Quantities by Year



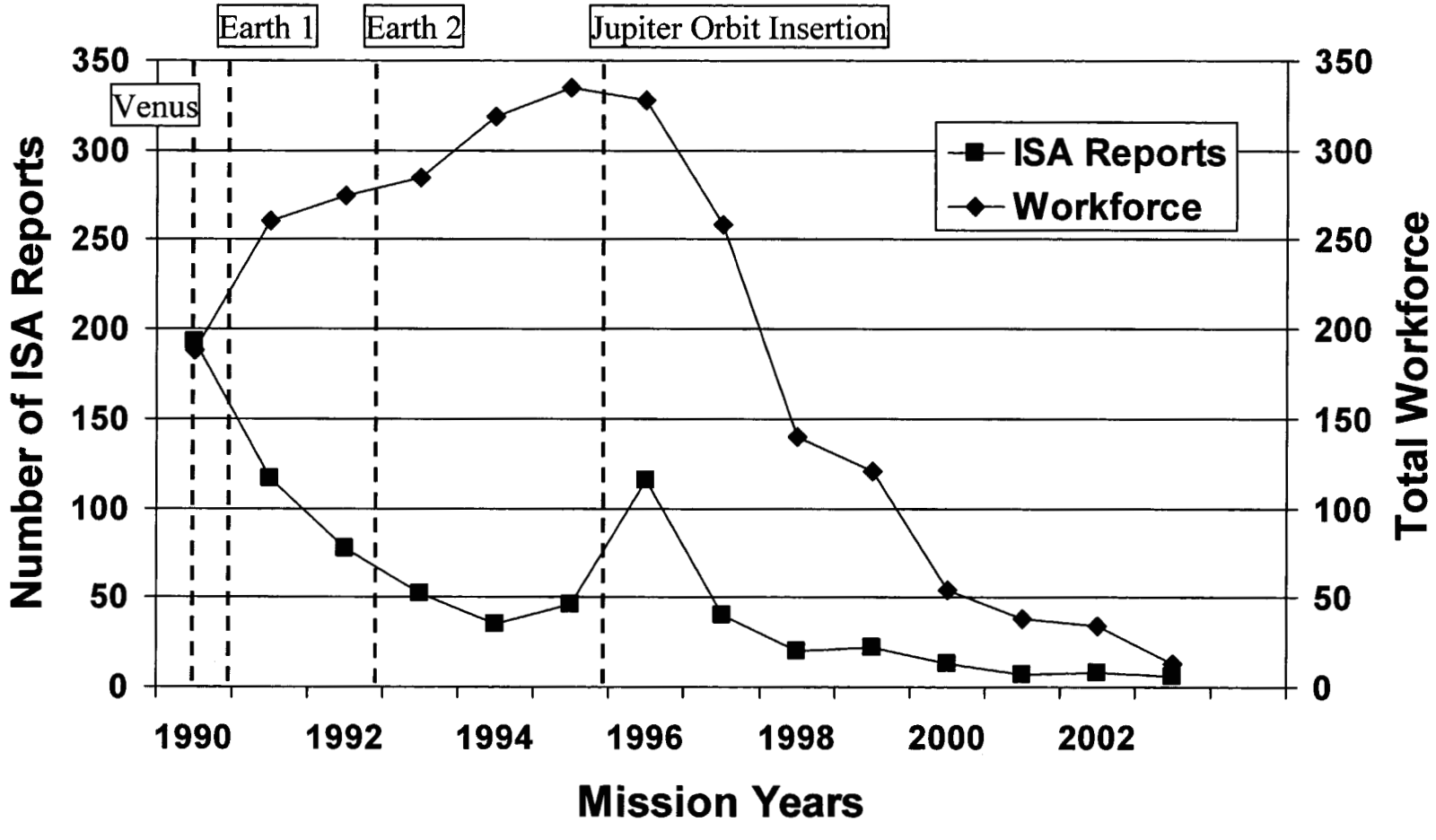
Galileo ISA Trends

- **Similar to Voyager trends**
  - **Major encounter increases**
    - **Before and during encounter**
    - **Instrument reactivation**
    - **More activity**
- **Peaks in anomaly reporting**
  - **Venus and first Earth encounter**
  - **Post Jupiter orbit insertion**
    - **Multiple encounters with planet and various moons**
    - **Adjustments to Jupiter environment**
- **Overall decrease with time**
  - **Unexpected since spacecraft degrades with time**
    - **Harsh environment**
    - **Fewer available instruments over time**

Voyager Flight Anomalies vs Workforce



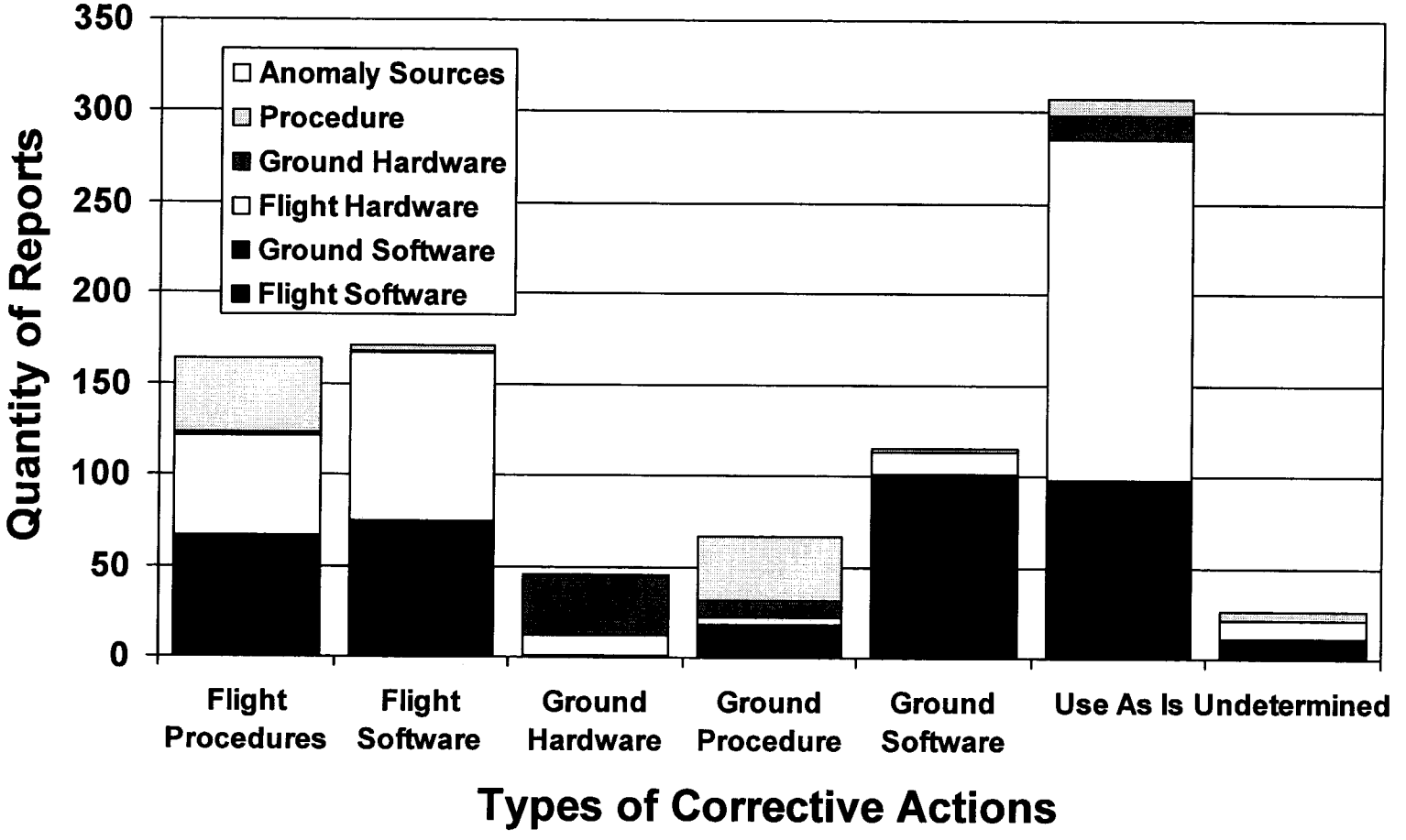
Galileo Flight Anomalies vs Workforce



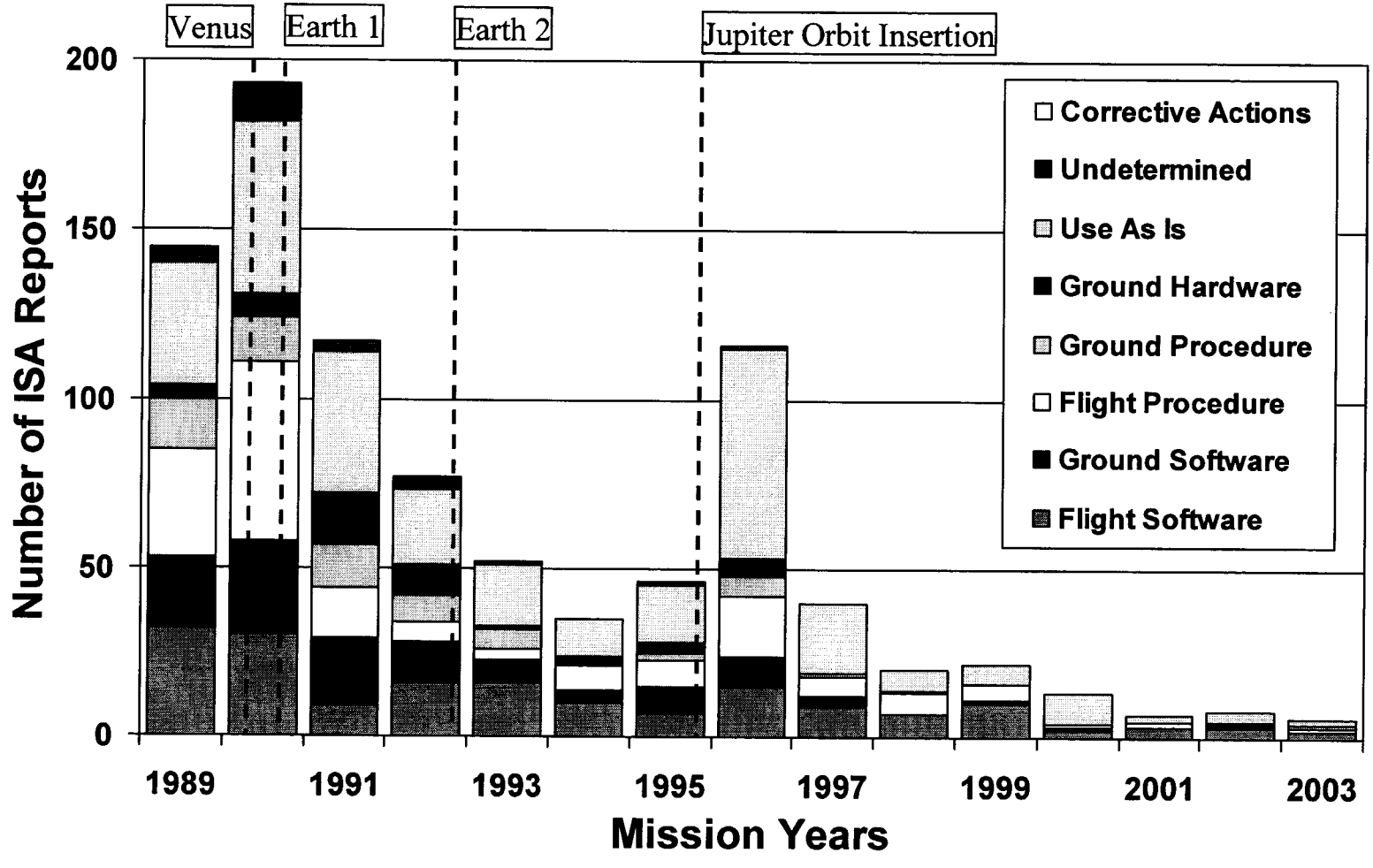
Impact of Workforce on ISA Quantities

- Total workforce includes employees and contractors
- Correlation with ISA reports
  - Voyager mission correlation
    - Follows ISA plot closely
      - Peaks at outset and with planetary encounters
  - Galileo mission correlation
    - Initial divergence
      - Due to early spacecraft difficulties
      - Need to rewrite 80% of spacecraft code
    - Tracks with ISAs after Jupiter orbit insertion
- Overall decrease with time
  - Tracks with ISA reporting
  - Fewer people needed to monitor and control spacecraft

Galileo Types of Corrective Actions with Anomaly Sources



Galileo Types of Corrective Action by Year



Galileo Types of Corrective Action

- **Seven types of Corrective Action identified**
- **"Use As Is" was most common type**
  - **Over 1/3 of all corrective actions**
  - **Essentially taking no action**
    - **Flight hardware problems**
    - **Single events**
- **Software Changes second most common**
  - **Flight software**
    - **Changes to of spacecraft operating software**
    - **Radiated to spacecraft via the Deep Space Network**
    - **Addressed hardware and software issues**
  - **Ground software**
    - **Changes to software run on Earth based computers**

Galileo Types of Corrective Action (cont.)

- **Procedural Changes**
  - **Flight procedure**
    - **Mission Rules**
    - **Spacecraft operating procedure**
  - **Ground procedure**
    - **All others**
- **Ground Hardware**
  - **Changing Earth based hardware**
    - **Mission Control**
    - **Deep Space Network**
- **Undetermined**
  - **Information not available in electronic ISA database**

Lessons Learned

- **Block and/or functional redundancy necessary for successful operation**
- **Robustness in underlying architecture of system design necessary**
- **Knowledgeable experienced cadre of operations personnel must have access to information**
- **Number of anomalies is dependent on mission activity**
- **Corrective actions most frequently noted is "use as is", next is "software update", and third is "procedural change"**

Summary

- **Anomaly reports analyzed for three deep space spacecraft with an accumulated flying time of sixty six years**
- **Redundancy has been used on all of these missions at different phases of the flight**
- **Number of anomalies increased as major flight events occurred**
- **Long life missions planning to include:**
  - **Skill retention for progressively obsolete spacecraft**
  - **Knowledge management for systems and instrument control**