Predictability in Space Launch Vehicle Anomaly Detection Using Intelligent Neuro-Fuzzy Systems

JPL *JSC* *McDonnell Douglas* *Lockheed*

Joint Effort

JPL Team

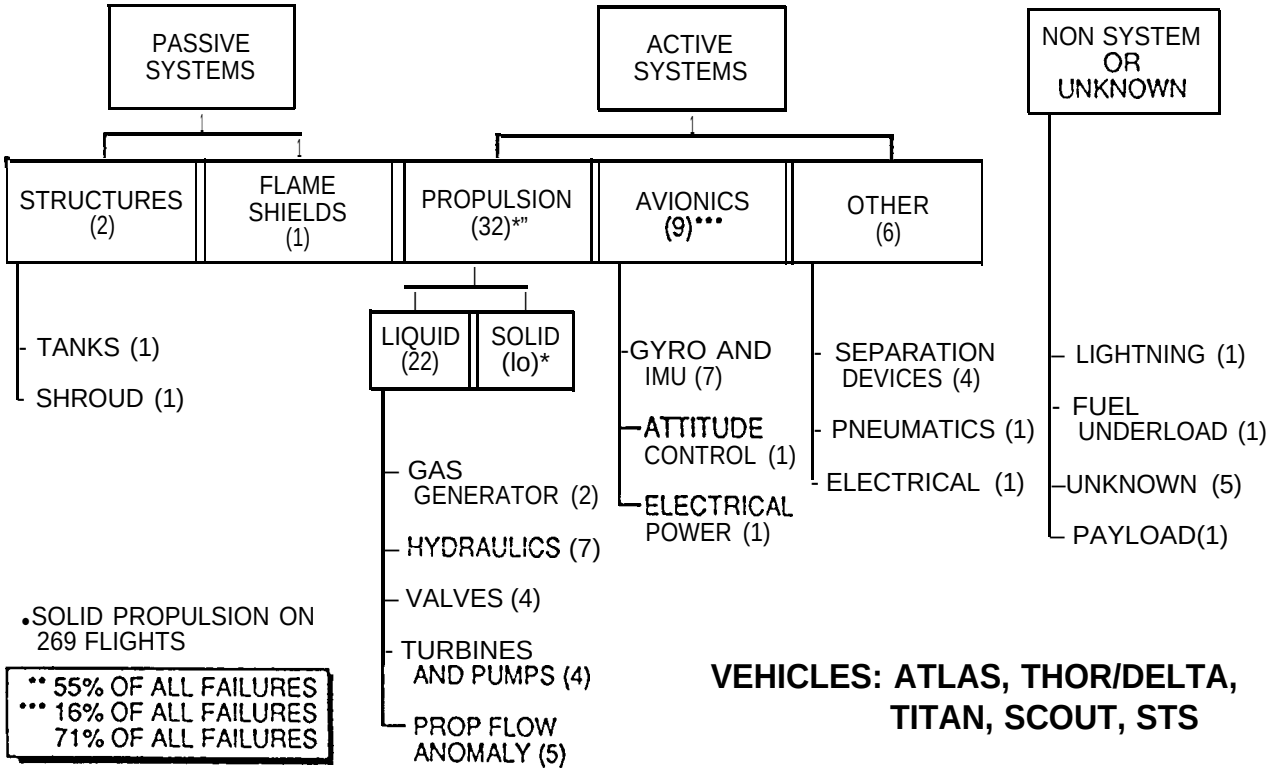
Sandeep Gulati
Raoul Tawel
N. Toomarian
A. Thakoor
J. Barhen
T. Daud

Jet Propulsion Laboratory
Center for Space Microelectronics Technology
Pasadena, CA

JPL

INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS

742 TOTAL FLIGHTS (1966-87), 58 failures

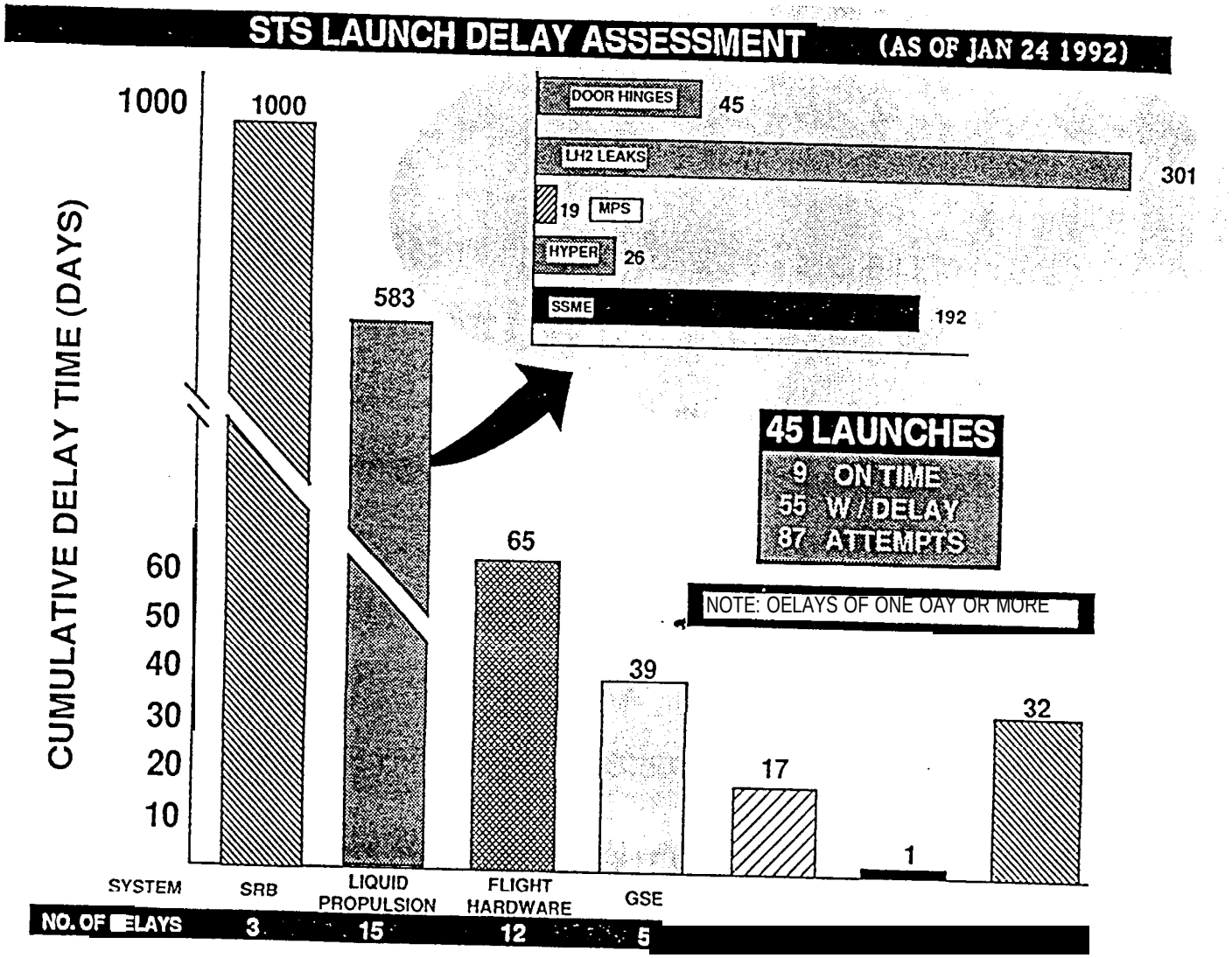


VEHICLES: ATLAS, THOR/DELTA, TITAN, SCOUT, STS

Where The Flight Failures Have Been In Launch Vehicles

JPL

INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS

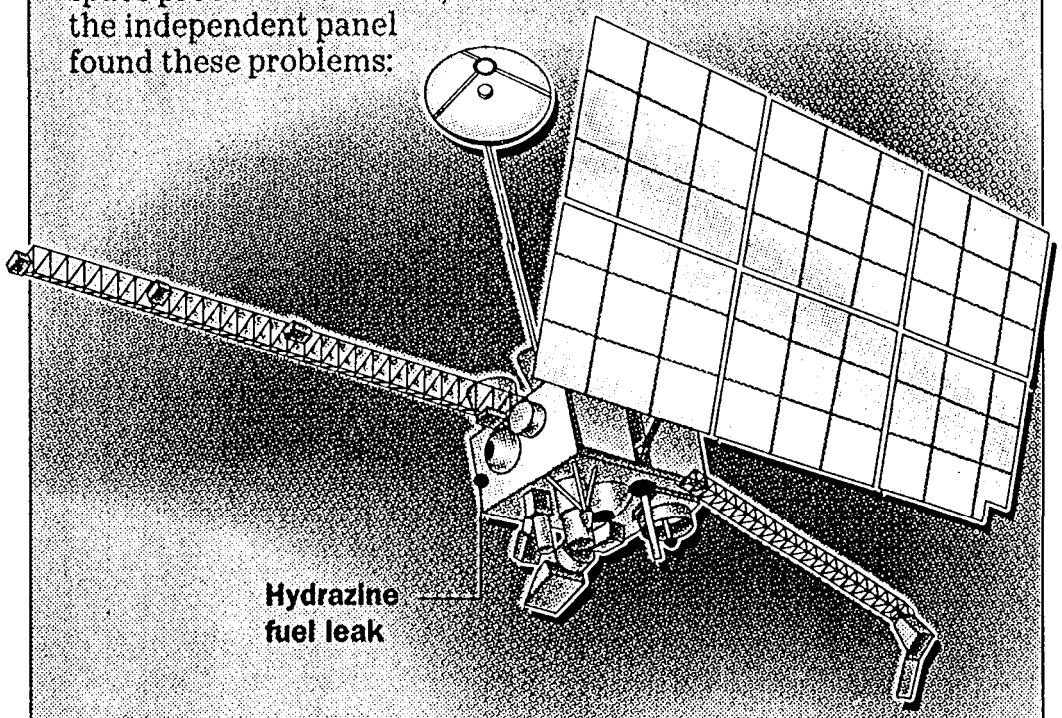


JPL

Failure of Mars Probe Blamed on Fuel Leak

Troubled Spacecraft

A federal panel Wednesday announced the findings of its inquiry into the Aug. 21 disappearance of the $980 million Mars Observer spacecraft. Exactly what happened to the space probe is not known, but the independent panel found these problems:



- **Mechanical flaw:** A leak of volatile hydrazine fuel may have caused an explosion when the spacecraft's tanks were pressurized.

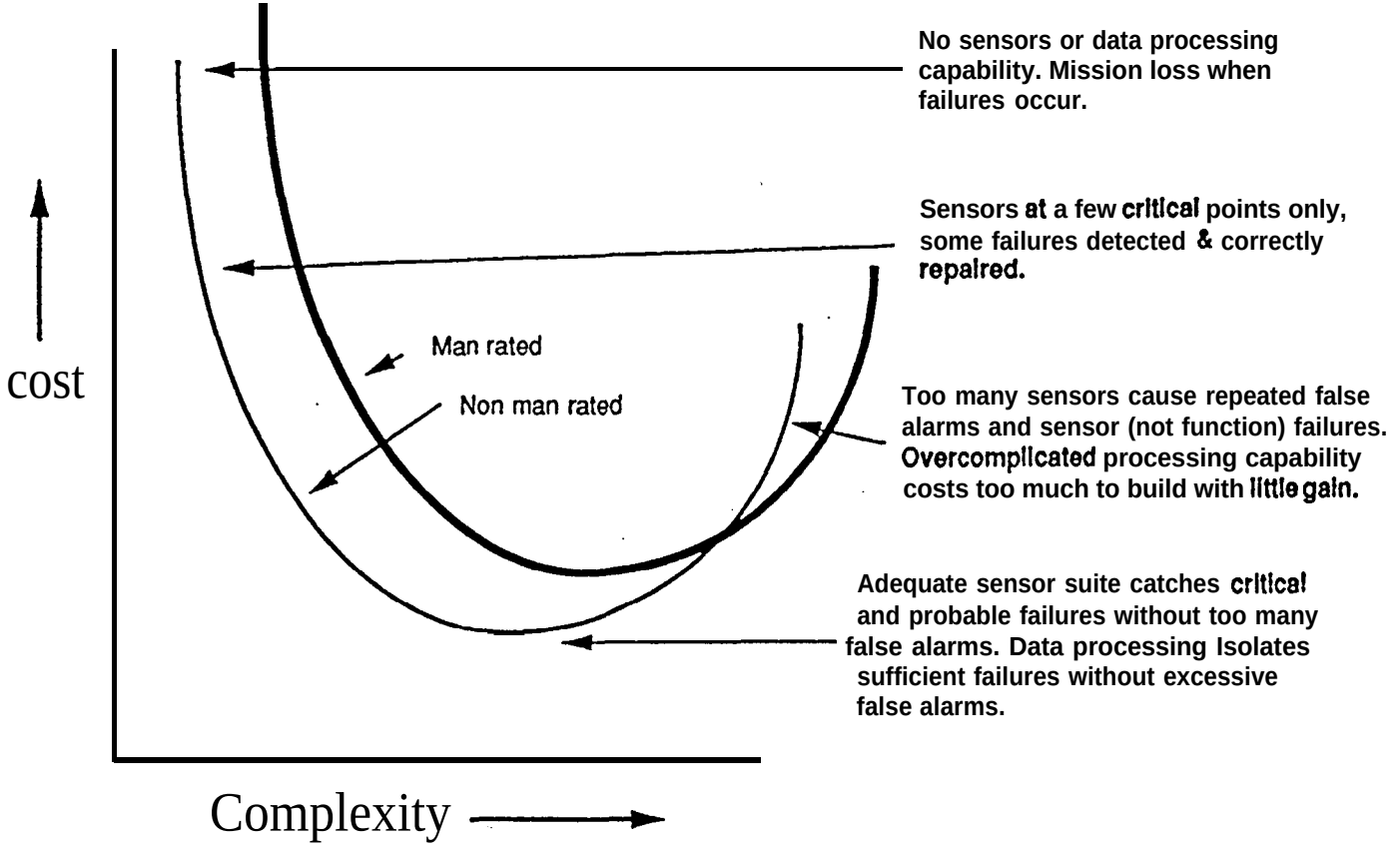
- **Design flaw:** NASA engineers used technology that had been developed for operation in near-Earth orbit but was unsuitable for the more extreme conditions of interplanetary space.

- **Management flaw:** Project managers at the Jet Propulsion Laboratory did not exercise sufficient control over continuing changes in the spacecraft's design and its scientific instruments.

Source: NASA

Los Angeles Times

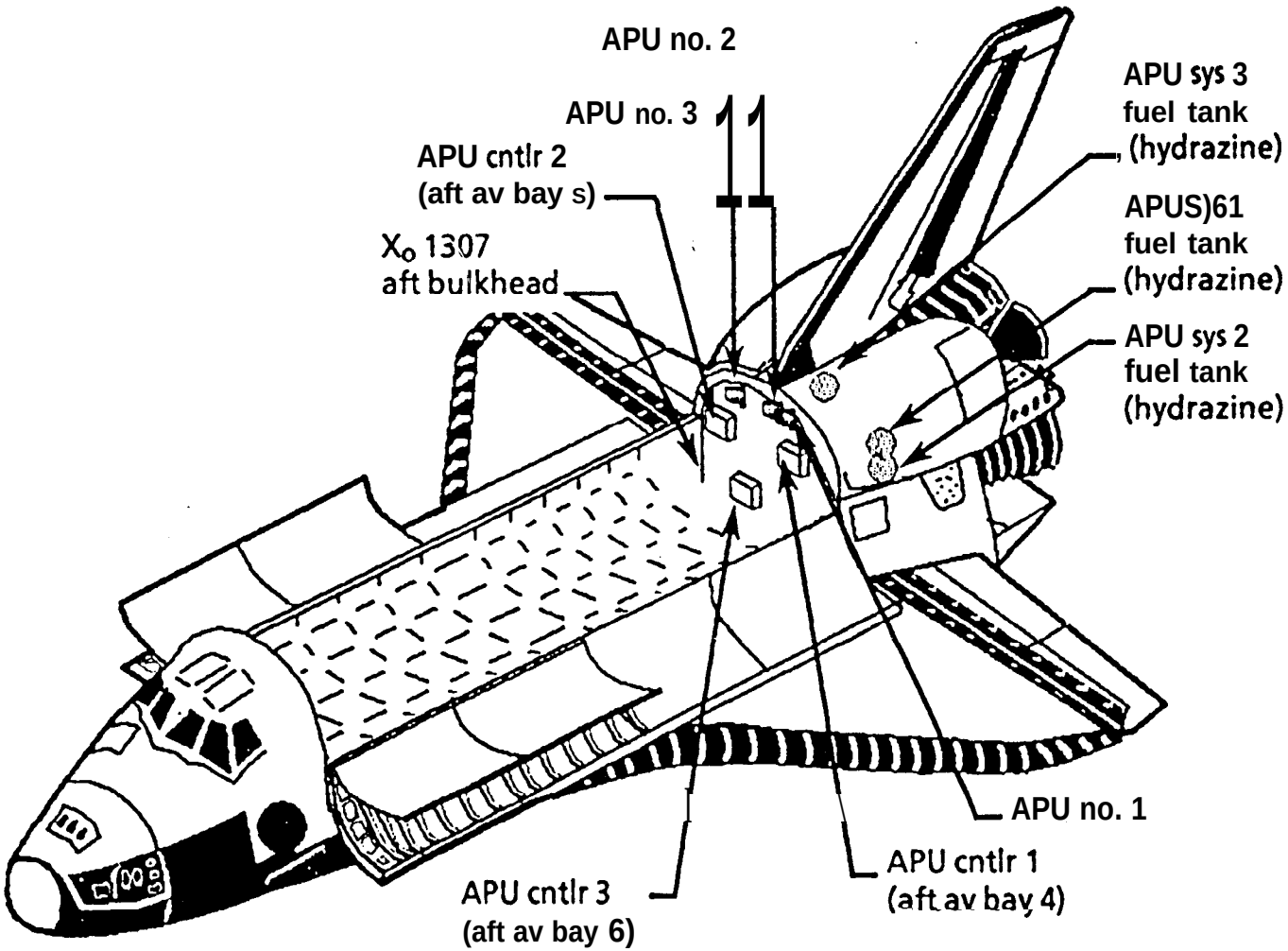
INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS



VHM COST OPTIMIZING CURVE

JPL

INTELLIGENT N'EUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS



TARGET HMS - STS Auxillary Power Unit Location

JPL

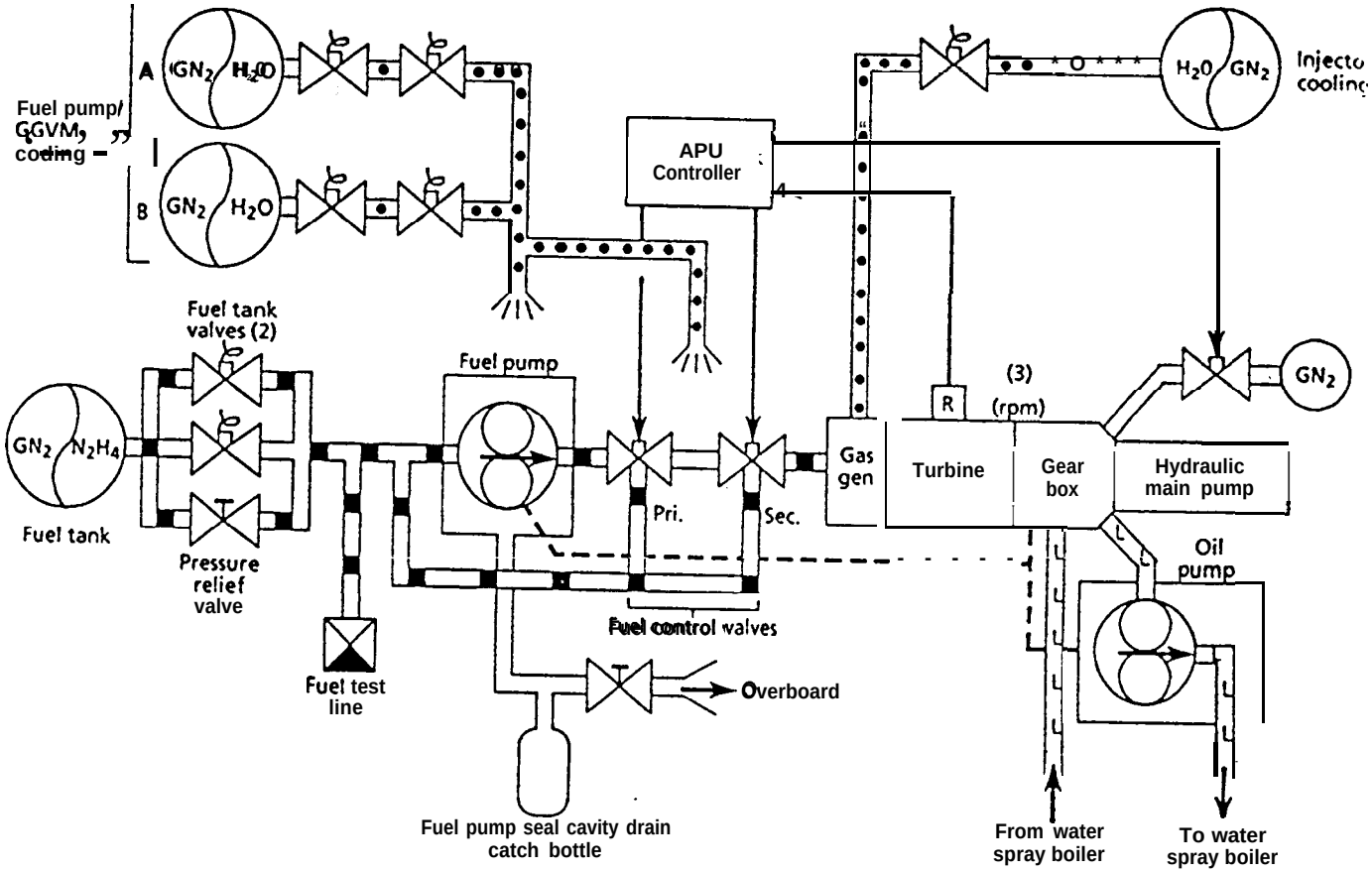
AUXILIARY POWER UNIT

- Provide power for the Orbiter hydraulic systems
  - liquid hydrazine -------> mechanical shaft power

- Hydraulic systems
  - actuate the Orbiter aerosurfaces
  - throttle and steer Orbiter main engines
  - deploy and steer landing gear
  - apply landing gear brakes

- Operation Cycle
  - t-5min to OMS-1 burn
  - deorbit burn and entry to just before landing

INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS



TARGET HMS - STS Auxillary Power Unit

JPL

INTELLIGENT NEUROPROCESSORS FOR LAUNCH VEHICLE HEALTH MANAGEMENT SYSTEMS

TECHNOLOGY ISSUES

- Engineering alarm limits - critical thresholds which define the acceptable range of engineering values on any telemetry channel

  - determined manually: hardcopy ISOE data, design information on spacecraft, rules of thumb

  .Overreliance on domain experts leading to wide thresholds creating a range of undetected anomalies

  - monitoring of individual sensors via redlining approach

- Access only to snapshots of telemetry due to exploitation of low sensor acquisition rates. Further degradation due to noisy and incomplete data

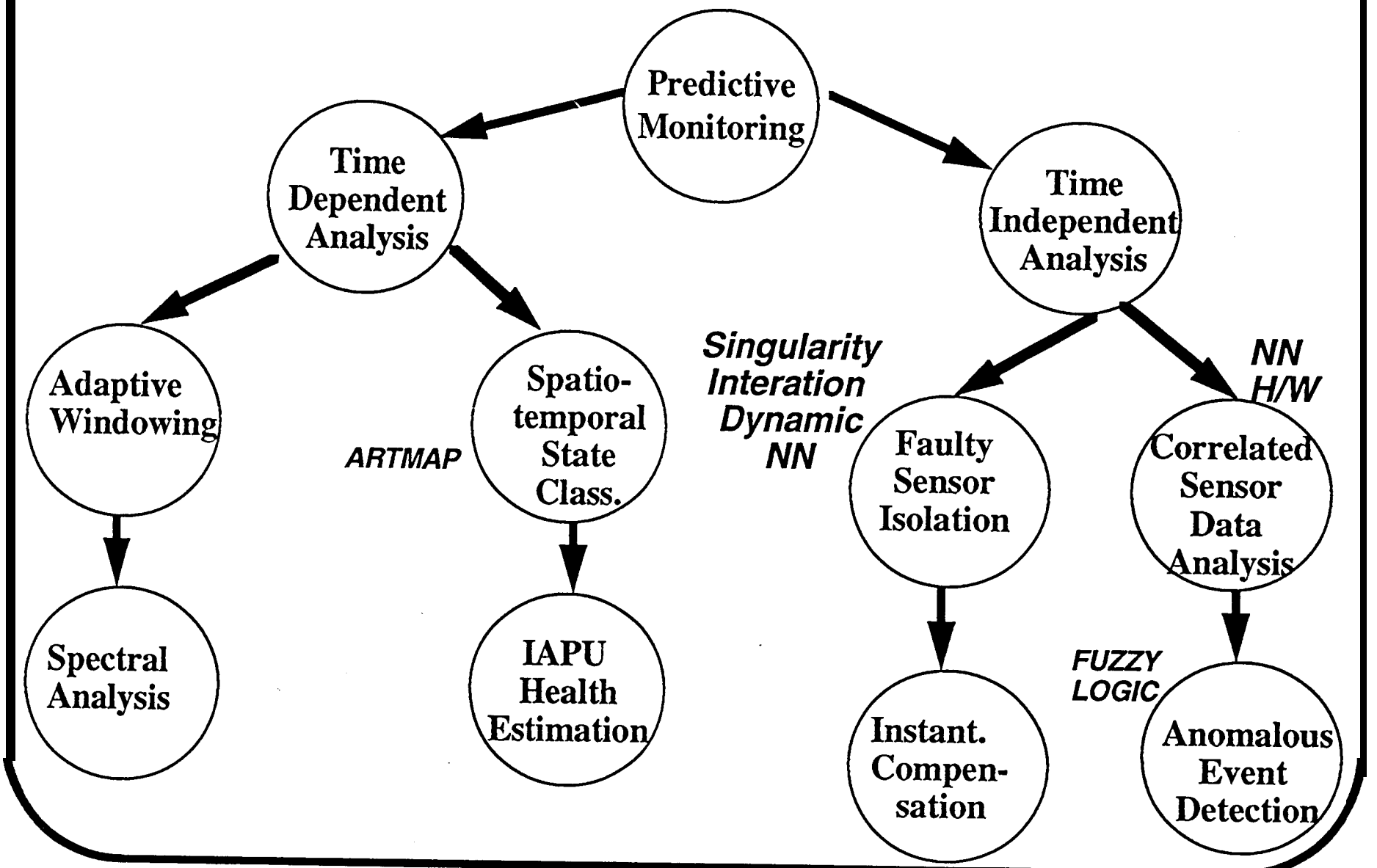
- Specific diagnostics can be executed only if they were preconceived and preprogrammed

  - cannot currently correlate effects between multiple sensors in real-time
  - fault-detection to engine catastrophe time can be as short as 0.1 sec.

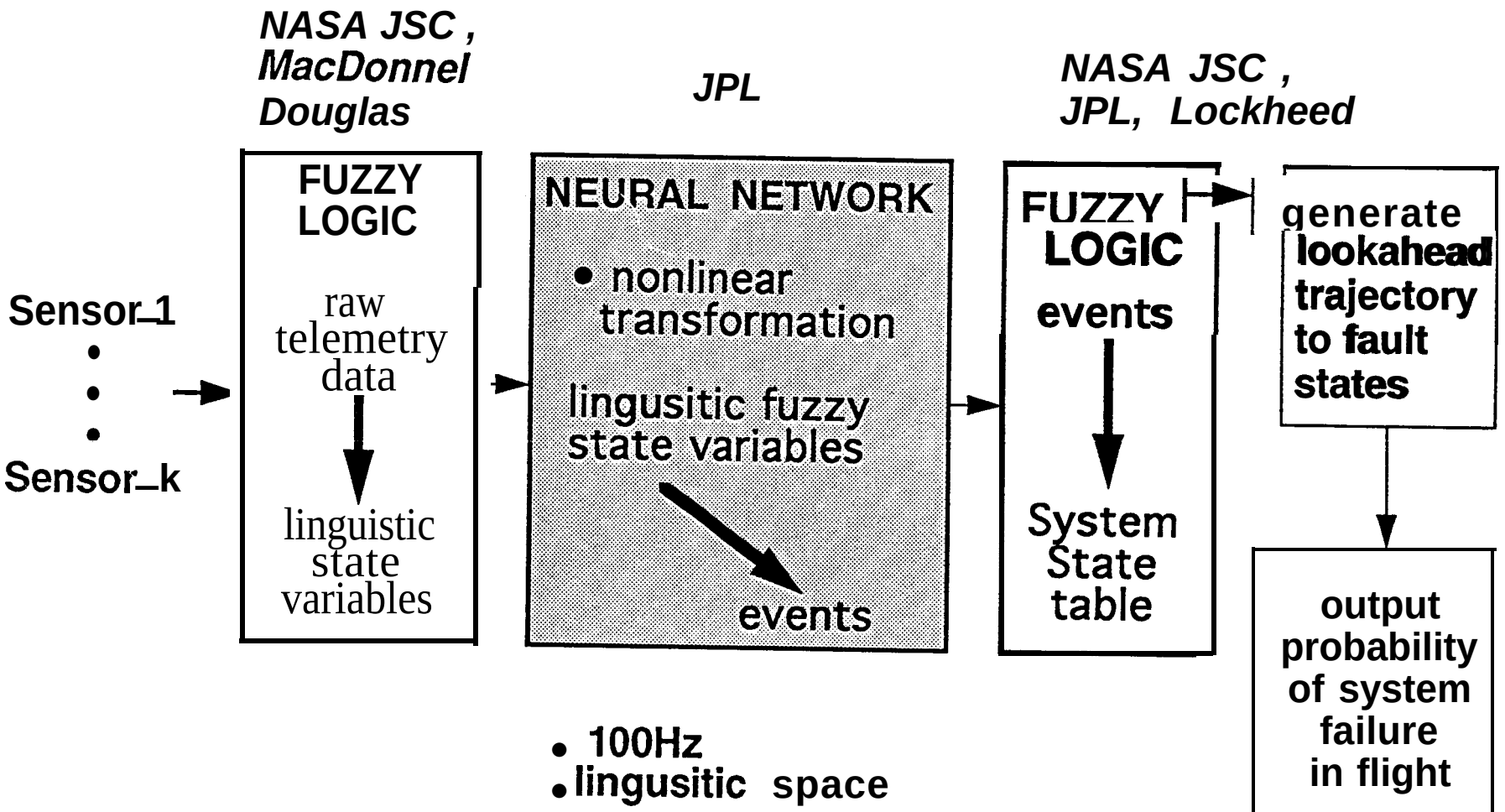
- fault-detection to engine catastrophe time can be as short as 0.1 sec.

JPL

INTELLIGENT NEURO-FUZZY SYSTEM for STS APU Health Monitoring



Integration of Neural Networks & Fuzzy logic



INTELLIGENT NEURO-FUZZY SYSTEM for IAPU Health Monitoring

CAPABILITIES TARGETED FOR DEMONSTRATION: DEMO-1

- detection of all red-line errors currently identified

- real-time correlation of data from multiple, heterogeneous sensor:

  - faster-than-real-time anomaly propagation to determine probability of failure
  - both with (NN s/w) and without (NN h/w) time-lags

- ease of augmenting expert-generated APU fault knowledge base without need to redesign the system

- isolating failed sensors as against failed subsytem / system
  - reconstruct suspect information and minimize disruption of diagnostic process

*** • synergistic integration of fuzzy logic and neural networks for real-time diagnostic applications

STS / IAPU HEALTH MONITORING

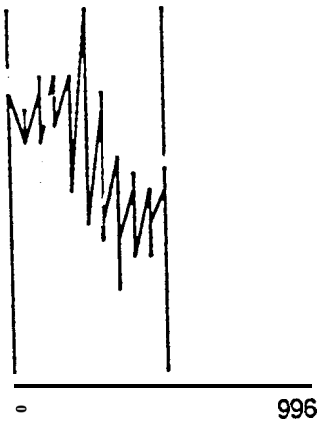
- Startup & mode-switch phases particularly difficult to monitor due to highly complex& nonlinear nature of IAPU dynamics

- reduced engine / teststand damage during test firings
  = typically damage 1 APU every 2 weeks

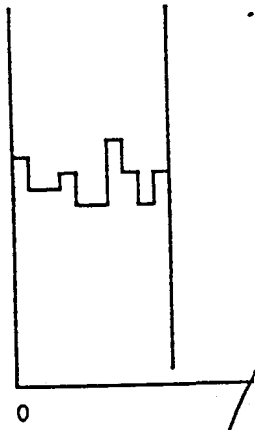
- facilitate post-test diagnostic process
  - tool for APU knowledge engineering

Graph(1-8) | Graph(9-16) | Zoom | Quitzoom | Data | Quit

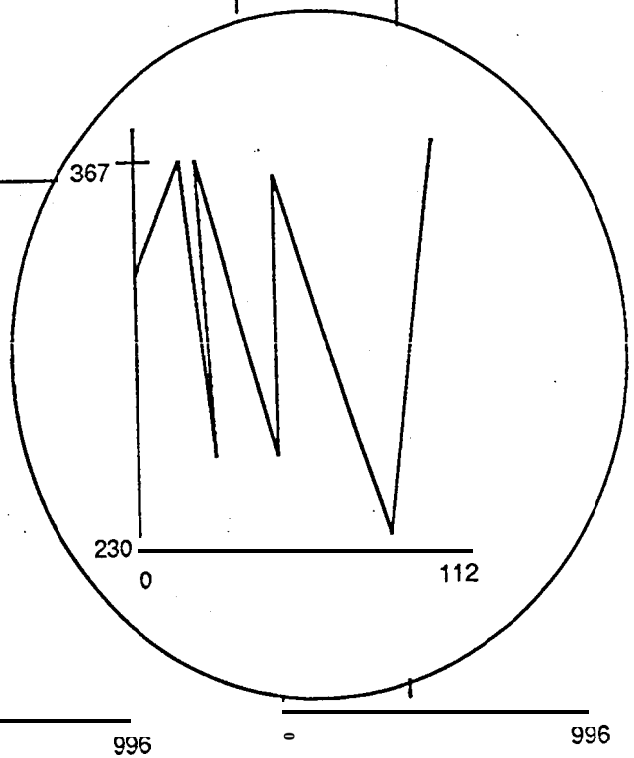
V46T0180A
APU FU LN GN2 PRESS



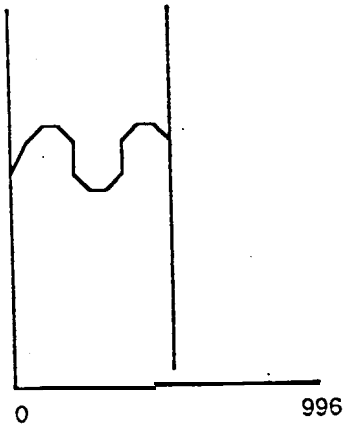
V46T0130A
APU 1 FU TK SKIN TEMP



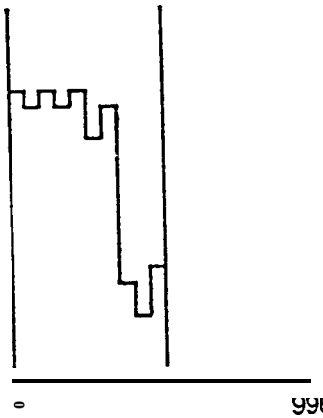
V46T0102A
APU 1 FU TK TEMP



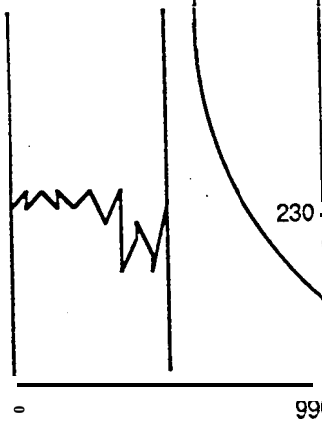
05A
APU 1 FU LN OUT PRESS



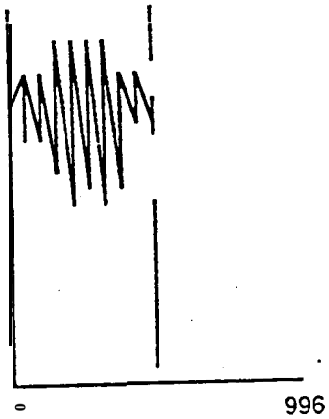
V46P0190A
APU 1 FU PMP DRN LN P-1



V
APU 1 F



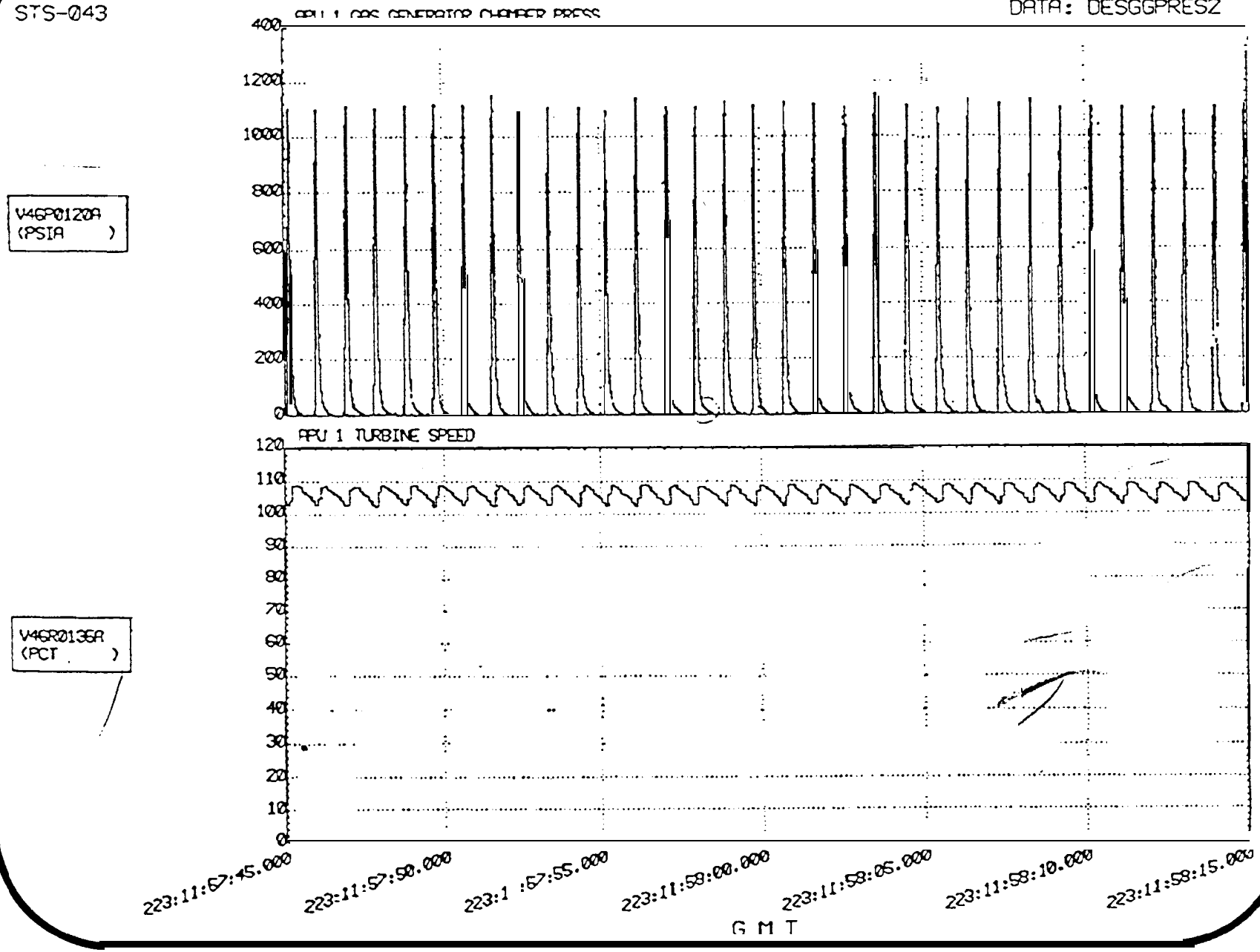
V46P0110A
APU 1 FU PMP IN PRESS



SUBSYSTEM: APU
STS-043

APU 1 CHAMBER PRESSURE VS TURBINE SPEED

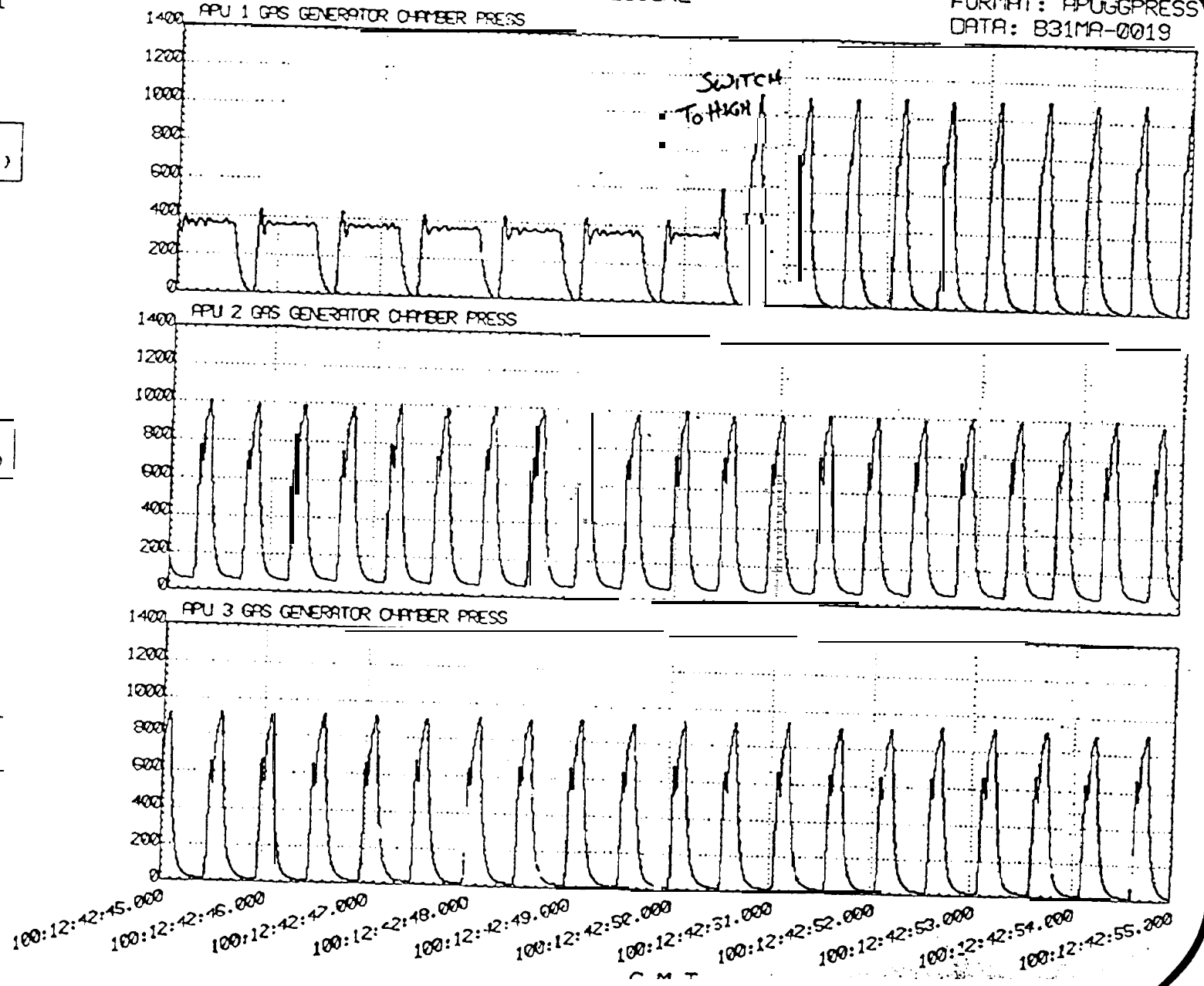
FORMAT: APU1GG-SPD
DATA: DESGGPRES2



SUBSYSTEM: APU
STS-031

APU CHAMBER PRESSURE

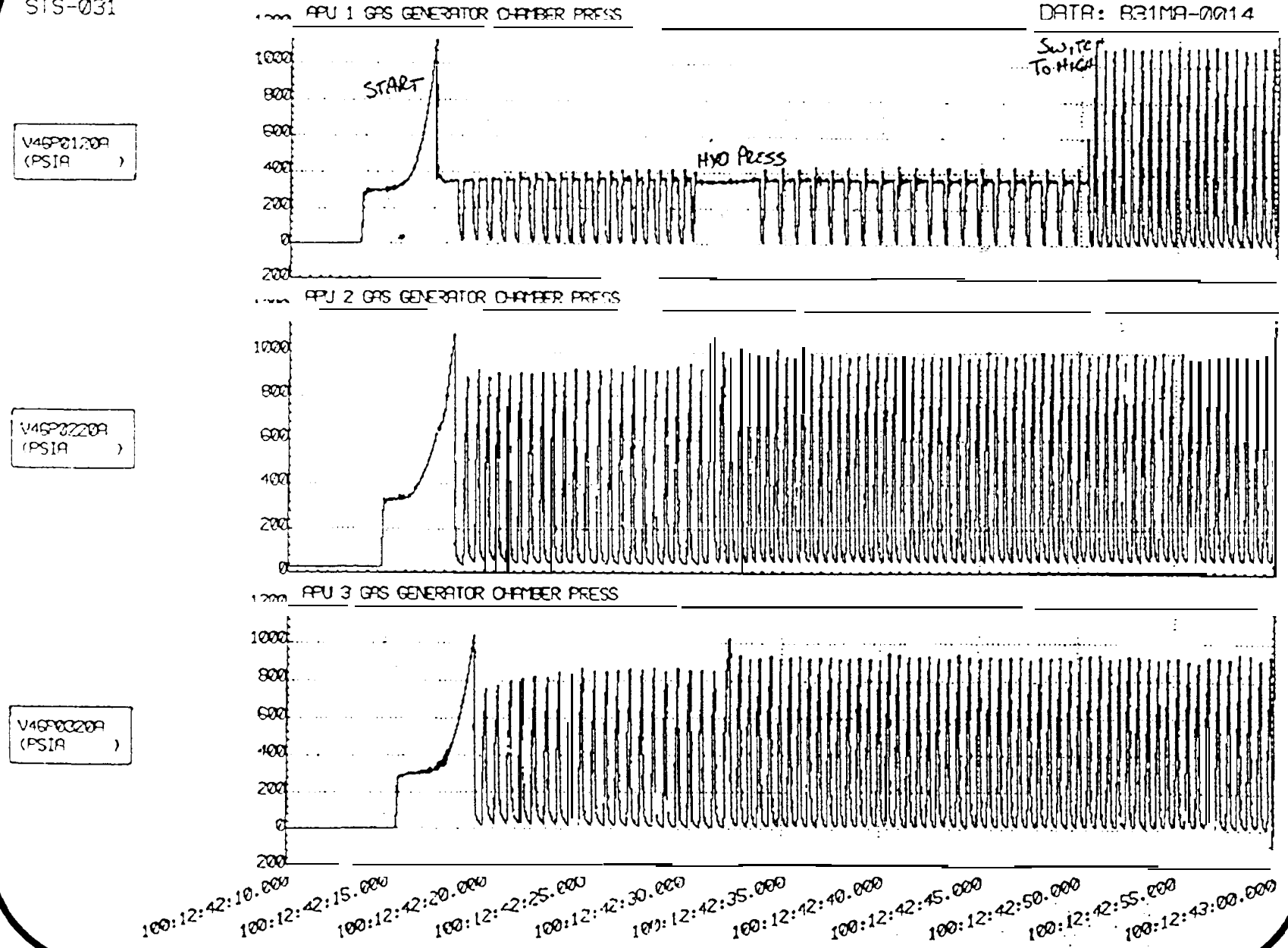
FORMAT: APUGGPRESS
DATA: B31MA-0019



SUBSYSTEM: MER
STS-031

APU GAS GENERATOR CHAMBER PRESURES

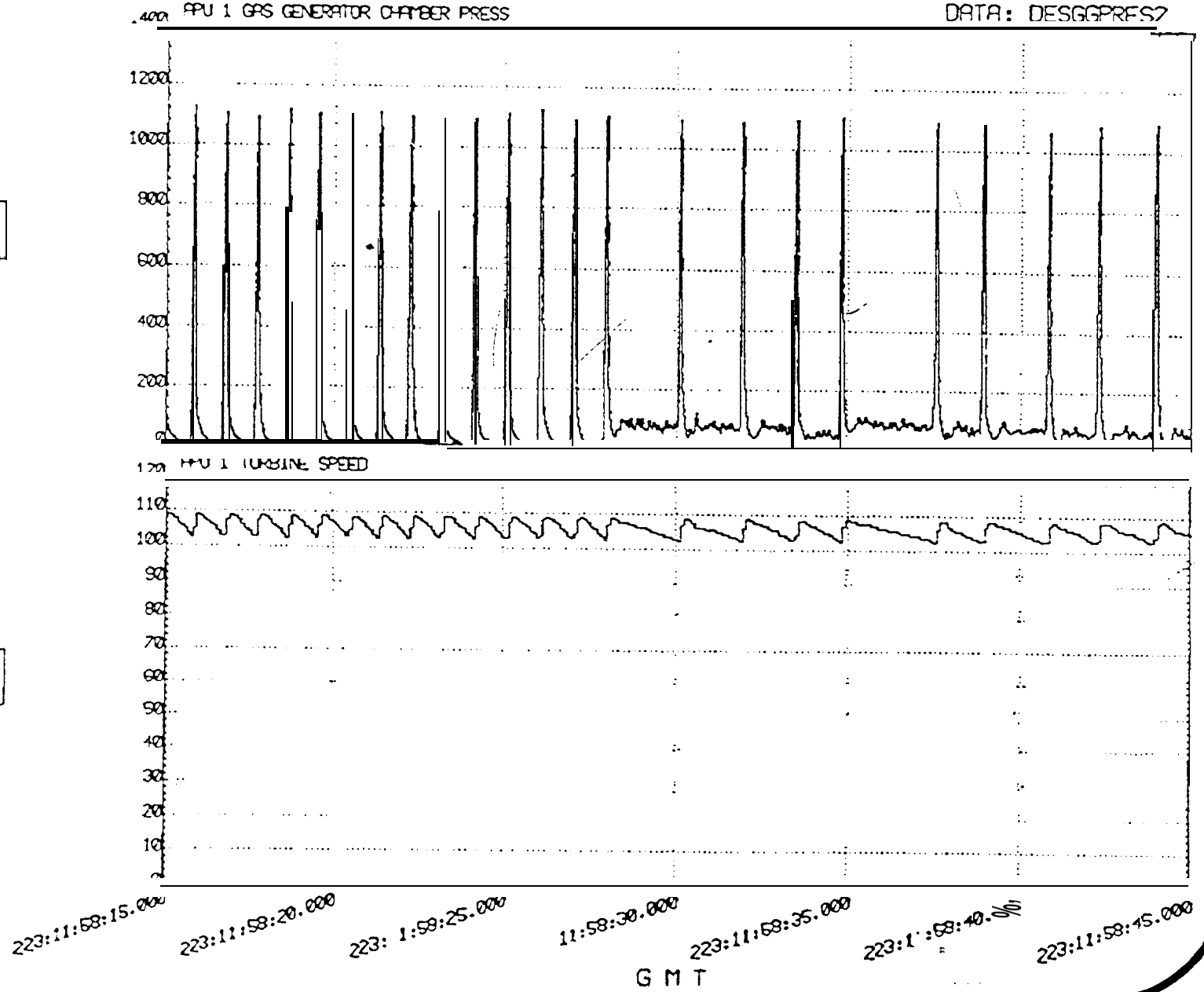
FORMAT: EVT_APU_GG
DATA: B31MA-0014



SUBSYSTEM: APU
STS-043

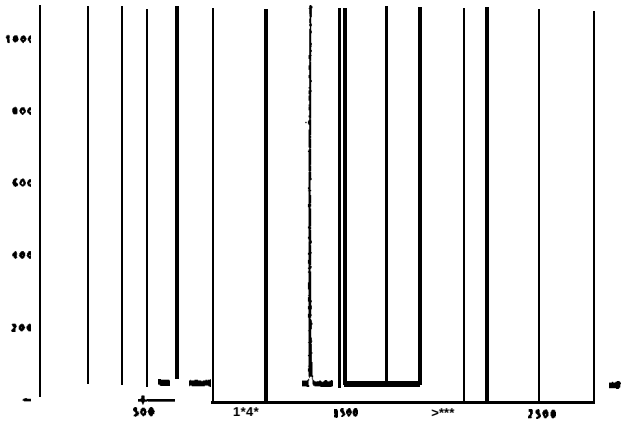
APU 1 CHAMBER PRESSURE VS TURBINE SPEED

FORMAT: APU1GG-SPD
DATA: DESGGPRES7



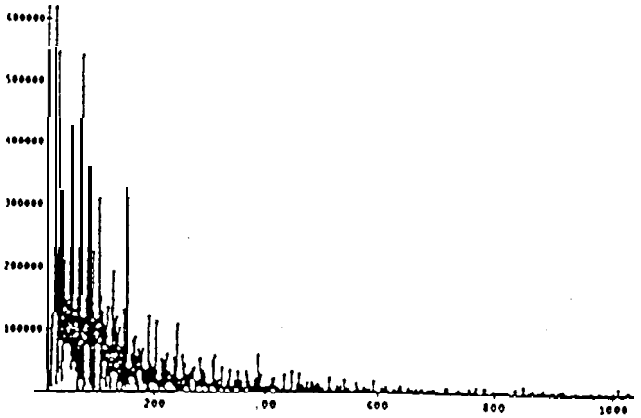
VHM SENSOR DATA WITH CHANGING FREQUENCY AND ADDITIONAL GROUND NOISE

TIME DOMAIN



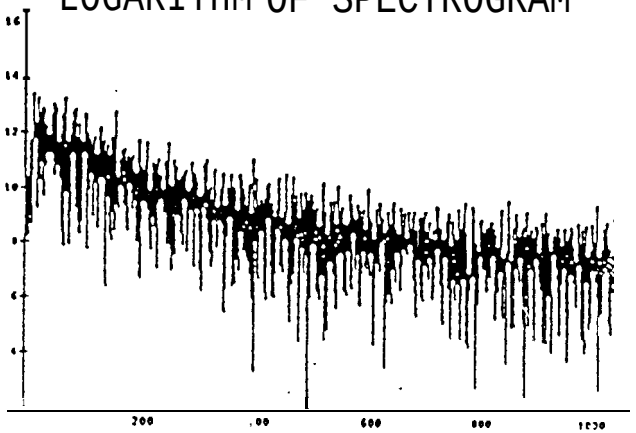
TIME

SPECTROGRAM



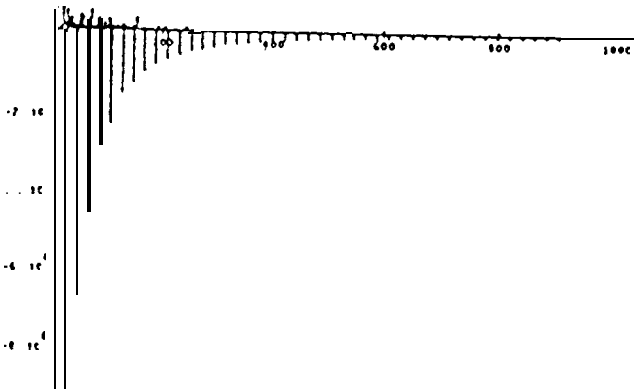
FREQUENCY

LOGARITHM OF SPECTROGRAM



FREQUENCY

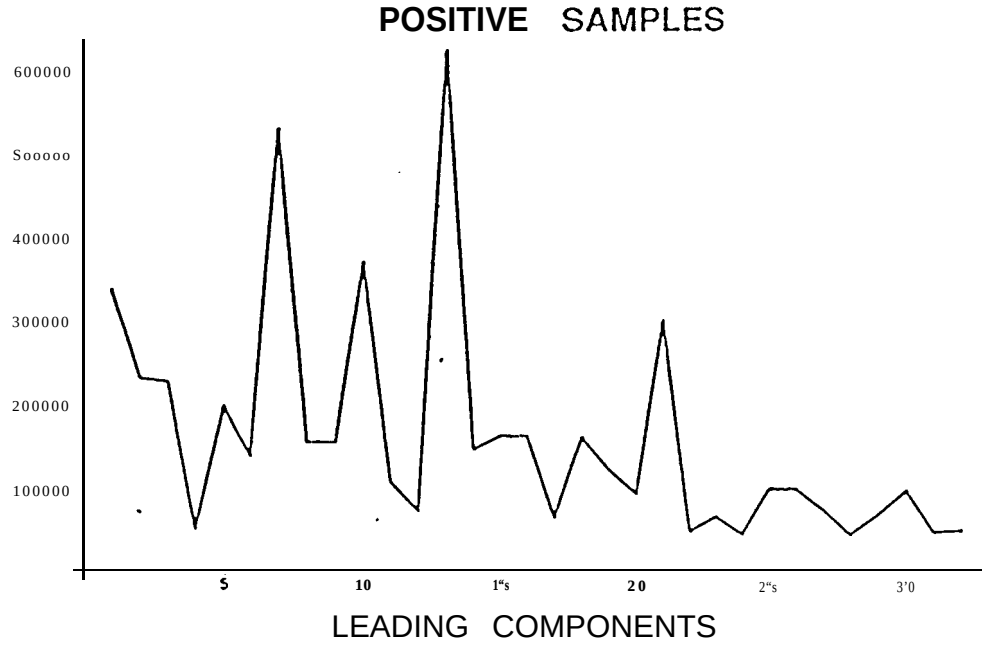
SPECTROGRAM DIFFERENCE

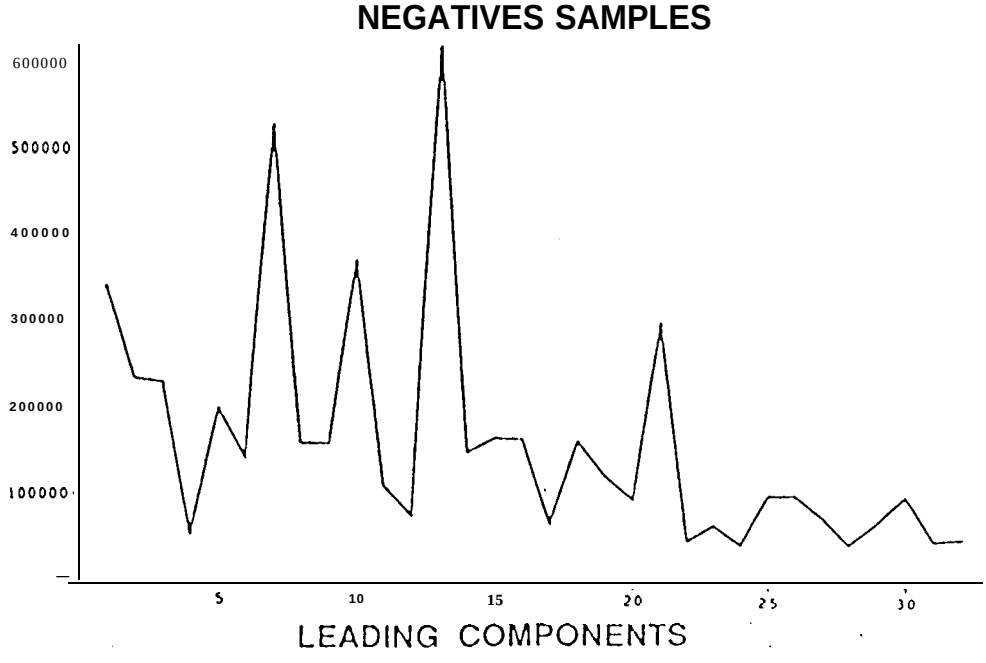


FREQUENCY

SAMPLED SPECTROGRAM DIFFERENCE

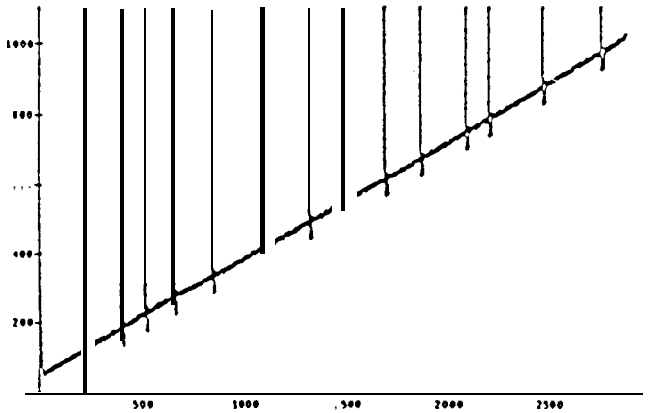
VHM SENSOR DATA WITH VARIATIONS IN FREQUENCY AND GROUND NOISE



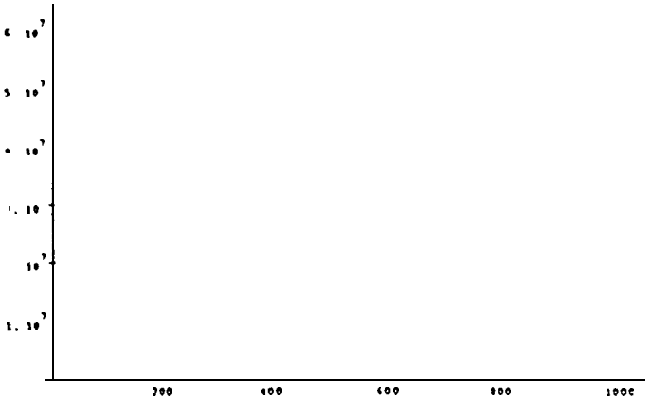


VHM SENSOR DATA WITH CHANGING FREQUENCY AND NOISE BUILDUP

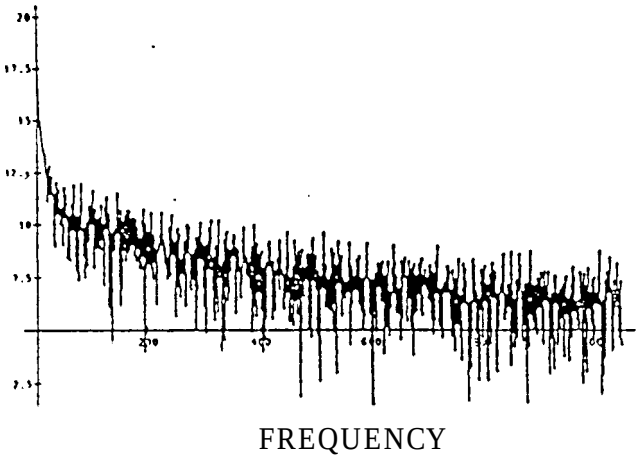
TIME DOMAIN



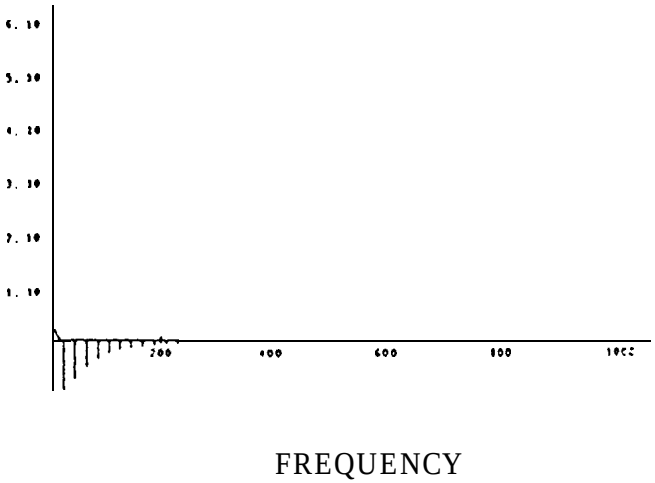
SPECTROGRAM



LOGARITHM OF SPECTROGRAM



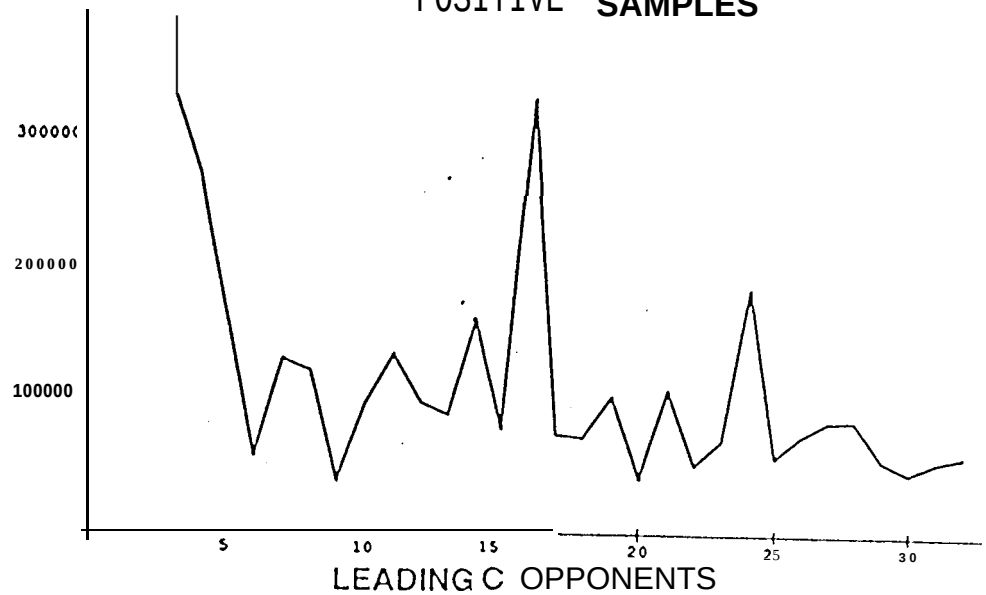
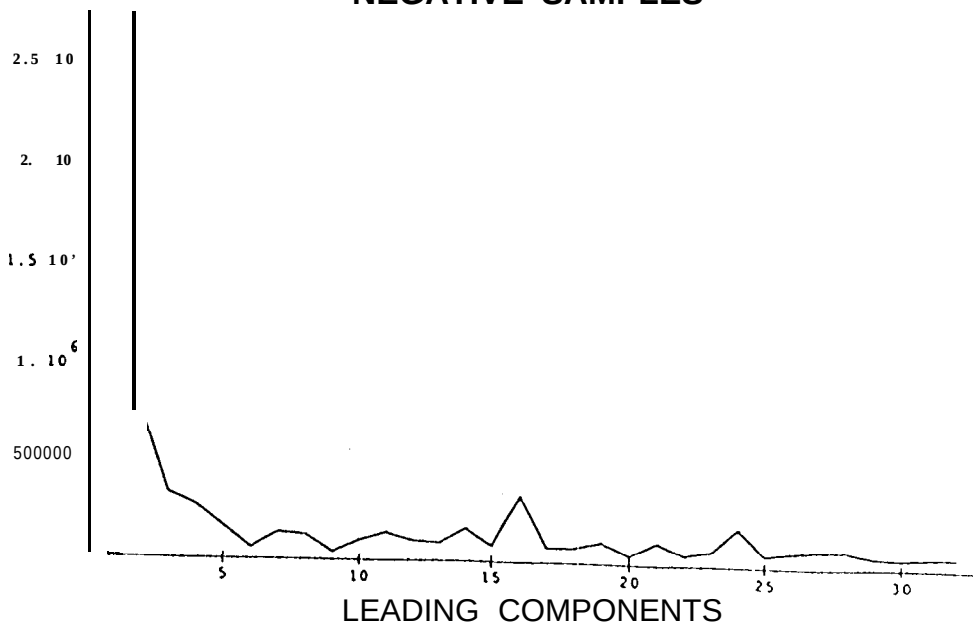
SPECTROGRAM DIFFERENCE



SAMPLED SPECTROGRAM DIFFEREN>

VHM SENSOR DATA WITH VARIATIONS IN FREQUENCY AND BUILDUP NOISE

POSITIVE SAMPLES



NEGATIVE SAMPLES