NASA

Launch Pad Vibroacoustics Research at NASA / KSC

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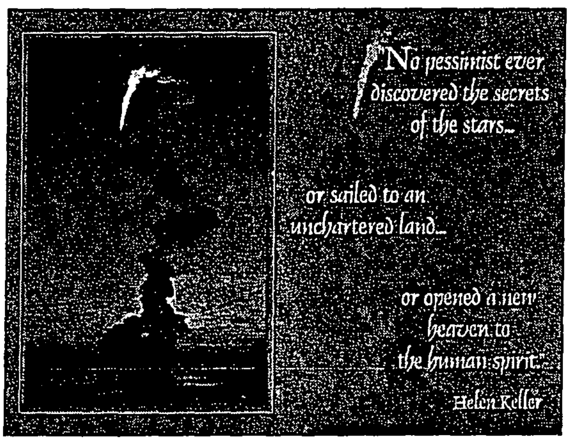
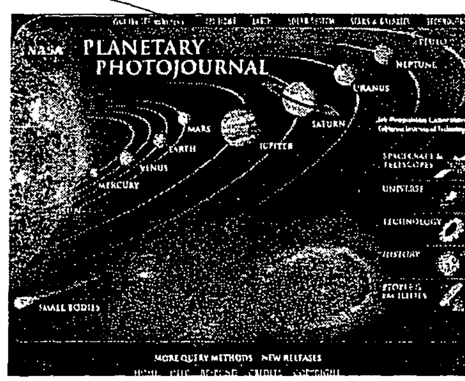
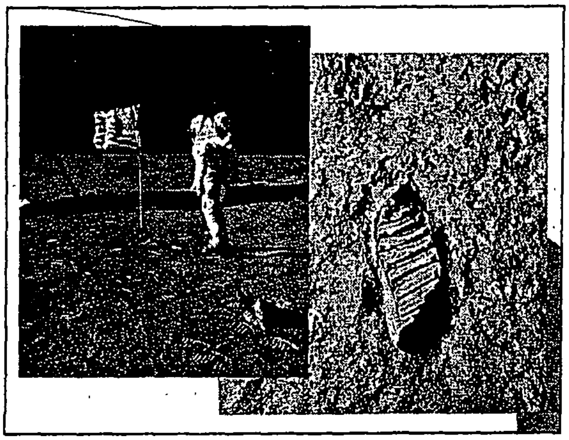
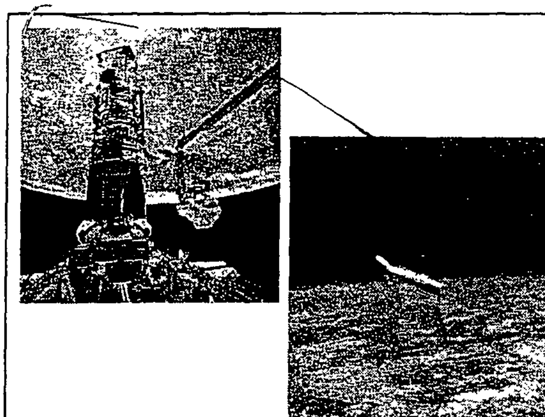
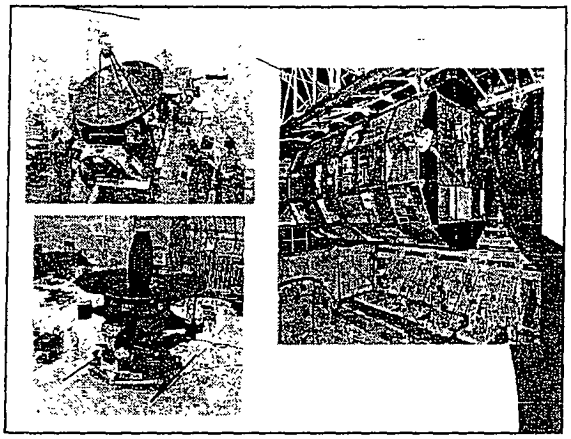
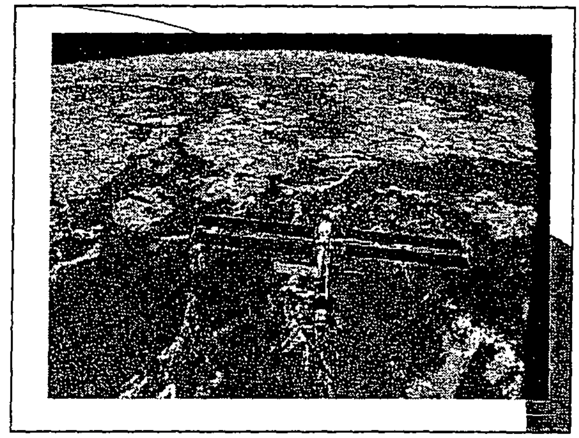


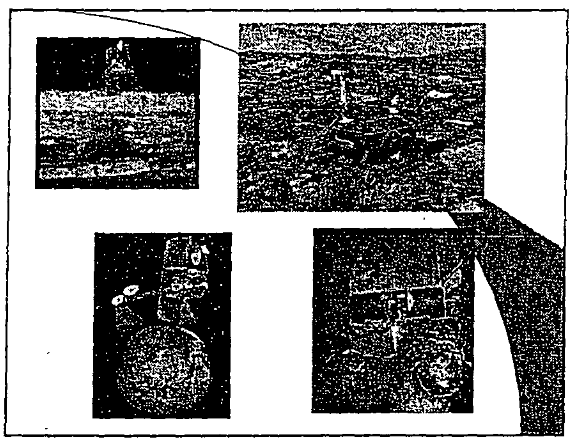


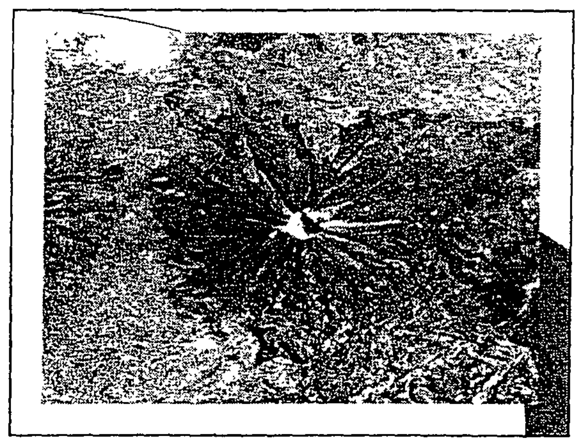


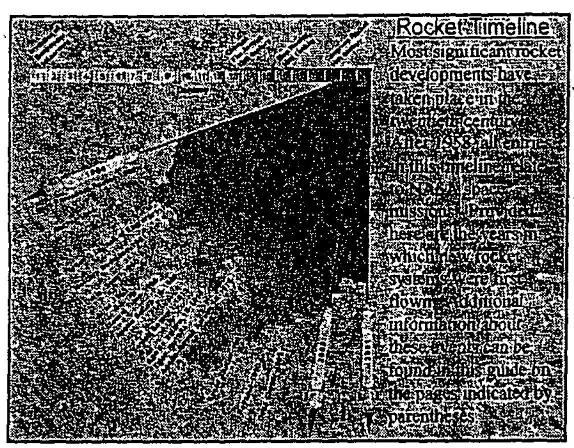


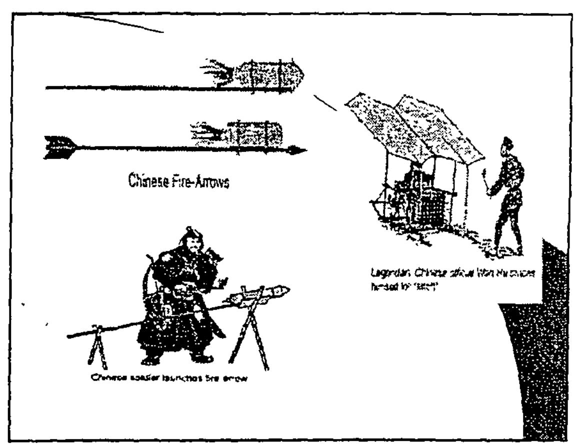


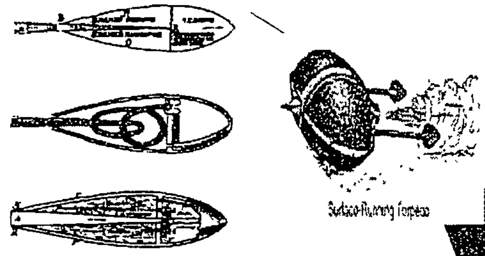




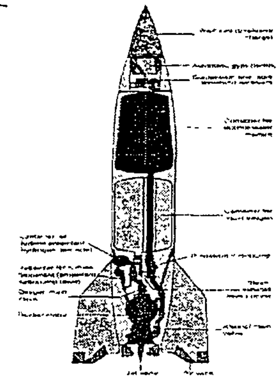



Rocket Timeline
Most significant rocket developments have taken place in the twentieth century. After 1958, all entries in this timeline relate to NASA space missions. Provided here are the years in which new rocket systems were first flown. Additional information about these events can be found in this guide on the pages indicated by parentheses.


Chinese Fire-Arrows
Chinese soldier launches fire arrow

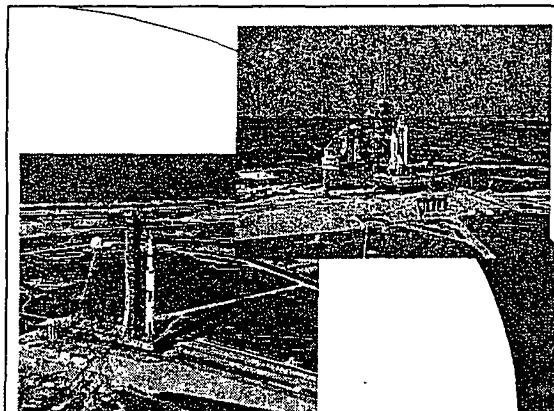


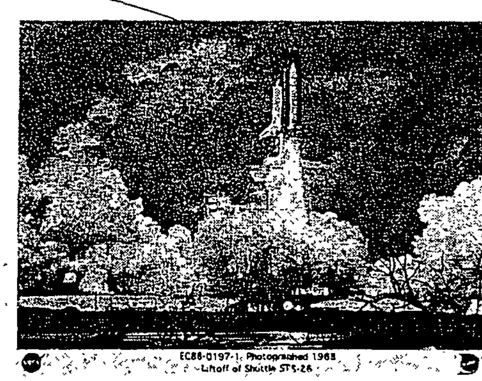
Tsiolkovsky Rocket Designs



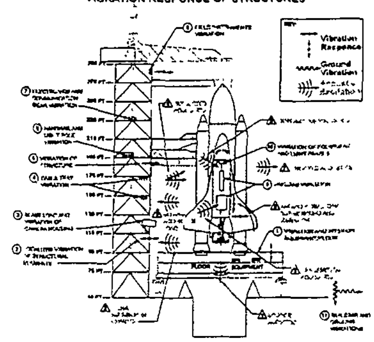
Rocket Noise and KSC

- KSC's role as a premier launch site dictates reliability and availability of pad and ground support equipment
- Structural vibration is consequent to launch acoustics, both air-borne and structure-borne
- Resonance is always present, due to wide band acoustic excitation
- Noise and Vibration measurements are key to launch readiness



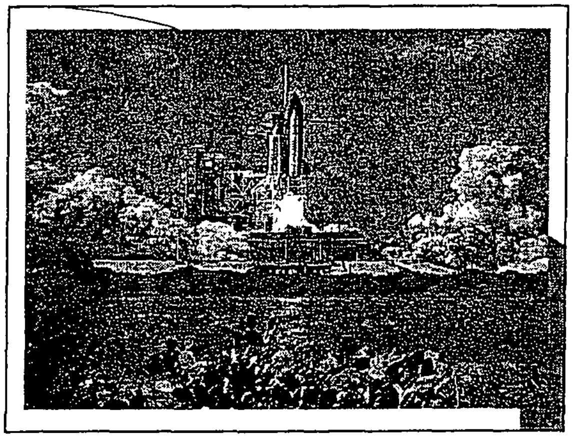


ROCKET LAUNCH-INDUCED NOISE AND VIBRATION RESPONSE OF STRUCTURES



Characteristics of Noise

- Space Shuttle launch environment (plume pressures, acoustics, strains, vibration) are random, nonstationary, non-gaussian, and wideband
- Amplitude and frequency vary widely
- Significant variability exists between short duration and long duration data collection and processing thereof
- Large sample size needed (we have over 100 launches)

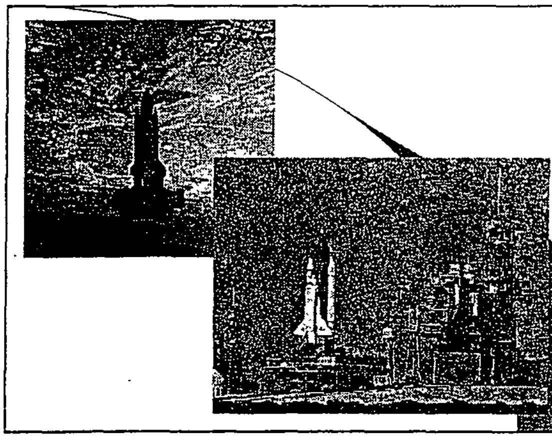


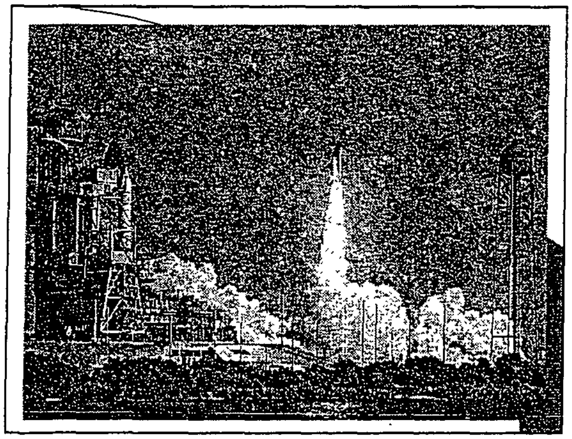
Noise...Generation

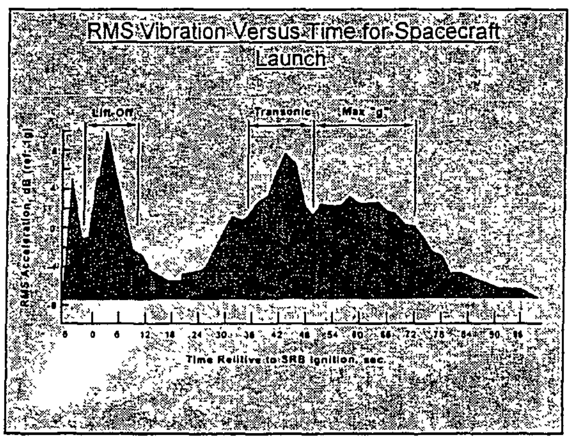
- Space Shuttle noise: 180 dB ~ 2.8 psi
- Space Shuttle Lift-off:
  - Creates intense noise
  - Noise source is supersonic exhaust
  - Turbulent eddies created due to mixing of hot gases with ambient air...lead to shock
  - Shock strongest source of noise (see 5)

Noise...Impact

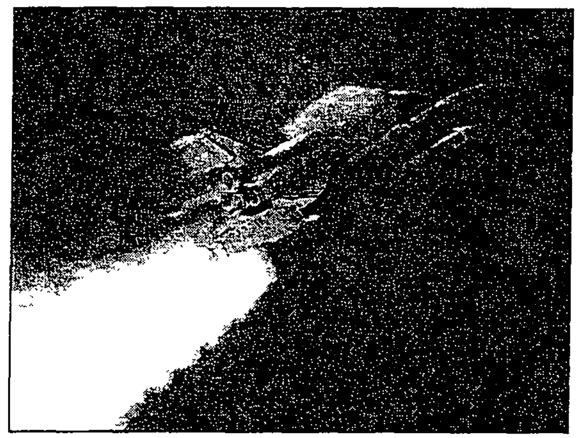
- Vibroacoustics effect on the vehicle and its' valuable payload
- Effect on Astronauts inside vehicle
- Influence on pad and ground structures
- Impact on wildlife and ecosystem in close proximity of the pad
- Physiological and psychological effect on humans and surrounding community
- Sonic boom related issues

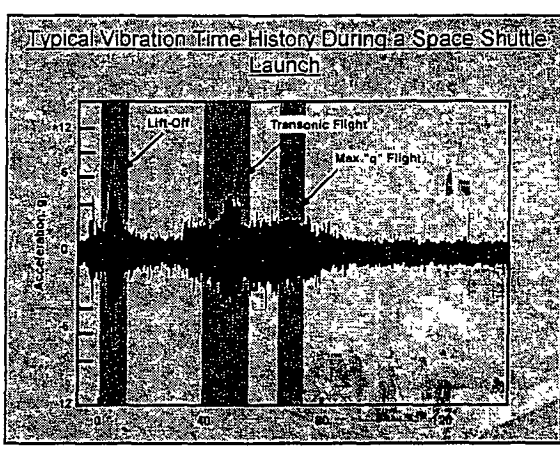




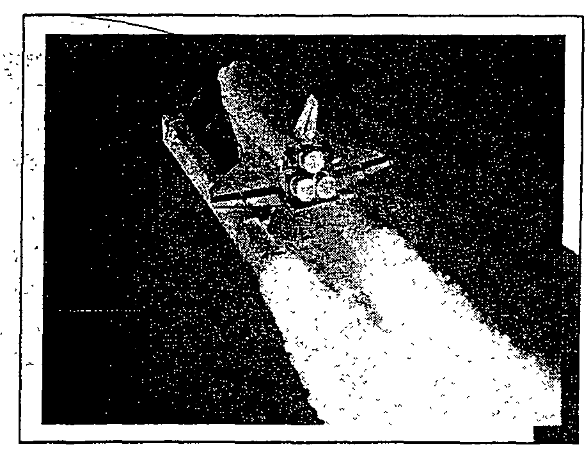


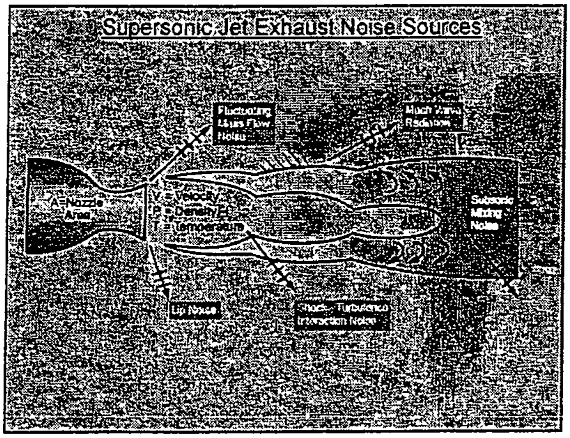
RMS Vibration Versus Time for Spacecraft Launch
Lift-Off
Transonic
Max "q"
RMS Acceleration, dB (ref. 1g)
Time Relitive to SRB Ignition, sec.

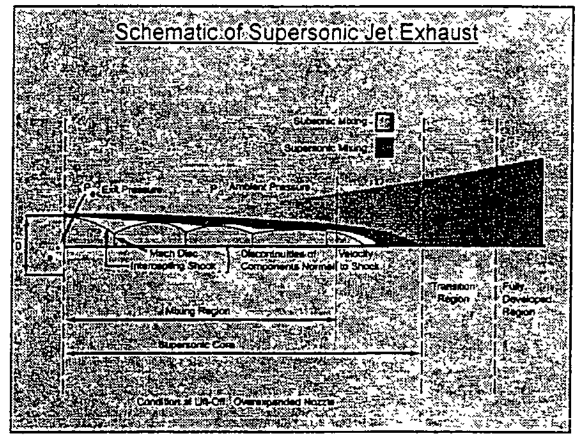


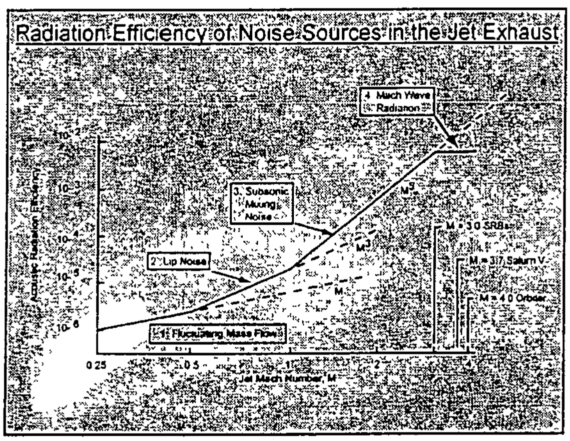


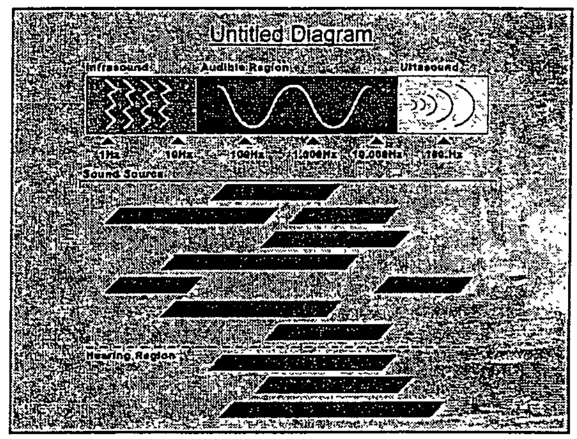
Typical Vibration Time History During a Space Shuttle Launch
Lift-Off
Transonic Flight
Max. "q" Flight
Acceleration, g

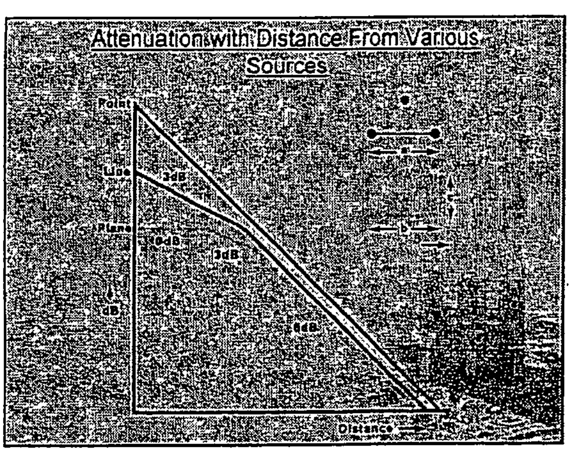


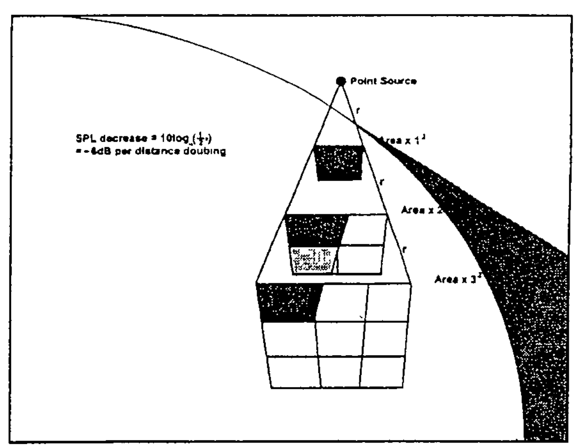

Supersonic Jet Exhaust Noise Sources
Fluctuating Mass Flow Noise
Mach Wave Radiation
Subsonic Mixing Noise
Lip Noise
Shock - Turbulence Interaction Noise

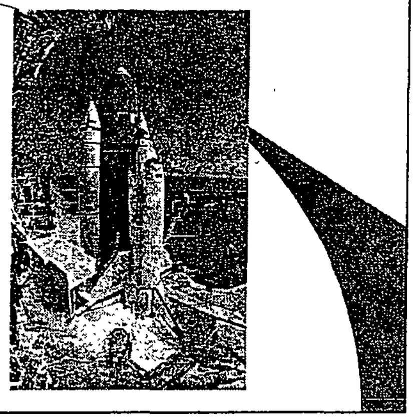

Schematic of Supersonic Jet Exhaust
Subsonic Mixing
Supersonic Mixing
Ambient Pressure
Mach Disc Intercepting Shock
Discontinuities of Velocity Components Normal to Shock
Transition Region
Fully Developed Region
Mixing Region
Supersonic Core
Condition at Lift-Off: Overexpanded Nozzle


Radiation Efficiency of Noise Sources in the Jet Exhaust
4. Mach Wave Radiation
3. Subsonic Mixing Noise
2. Lip Noise
1. Fluctuating Mass Flow
M = 3.0 SRBs
M = 3.7 Saturn V
M = 4.0 Orbiter
Jet Mach Number, M
Acoustic Radiation Efficiency


Untitled Diagram
Infrasound
Audible Region
Ultrasound
1Hz
10Hz
100Hz
1,000Hz
10,000Hz
100kHz
Sound Sources
Hearing Region


Attenuation with Distance From Various Sources
Point
Line
Plane
3dB
6dB
Distance


Point Source
SPL decrease = 10log
= -6dB per distance doubling



Noise...SSME Ignition

- Loud roar and heavy vibrations in the cockpit ~ driving a car down a railroad track or sitting close to speakers at a rock concert
- SSME's produce close to a million pounds thrust; since rocket is held to the pad via bolt/nut arrangement
- Noise is LOUD and teeth-rattling

Sounds...SRB Ignition

- Noise and vibration increase significantly; one cannot simulate such noise and shaking in the laboratory
- Vibrations and noise are not so bad that Astronauts cannot read instruments; noise does not prevent them from hearing fellow Astronauts (they use intercom for communication)

Noise....in Space

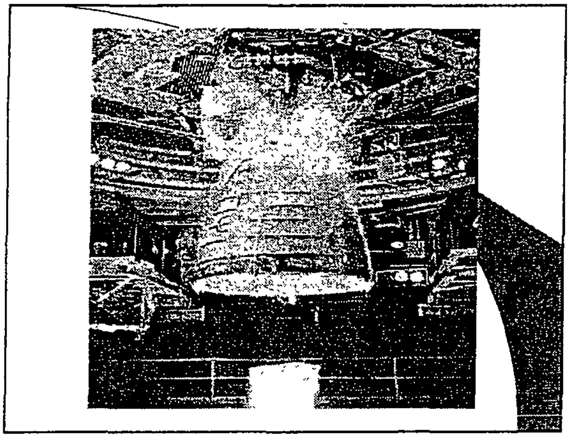
- Sound does not travel in vacuum, so it is not possible to talk in space. During EVA, Space walkers use radio
- Explosions occurring outside cannot be heard inside
- Talking inside Space Shuttle or ISS is same as on Earth; Air inside Shuttle is similar to ground
- N_2 = 80%, O_2 = 20%, Sea Level pressure = 14.7 psi similar to Earth

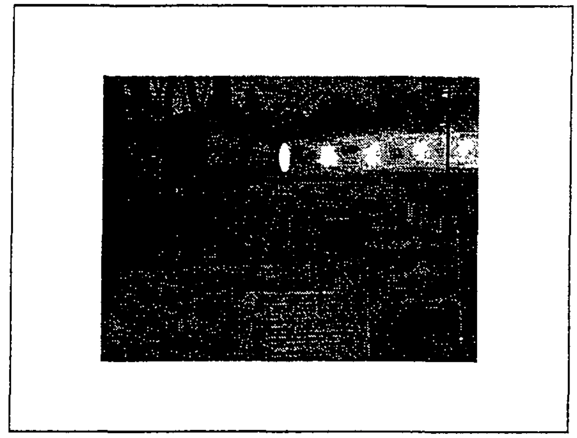
Noise at and during Liftoff

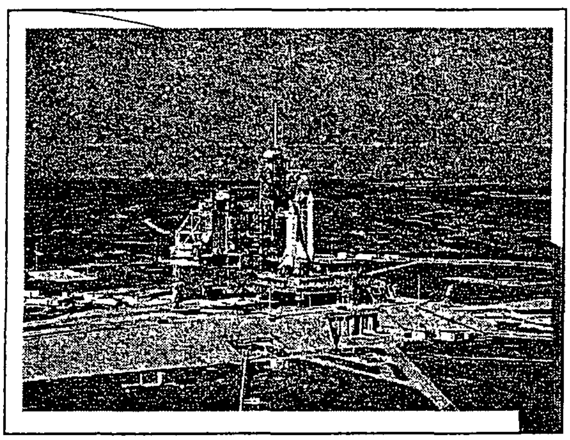
- Vibrations steadily increase up to Mach 1, the speed of sound, where shock waves add to the shaking; vibrations moderate as the Shuttle rises into thinner air as it ascends
- When SRB's burn out and are separated a dramatic change occurs; marked by a bang due to explosive bolts being fired; noise and vibration end at last

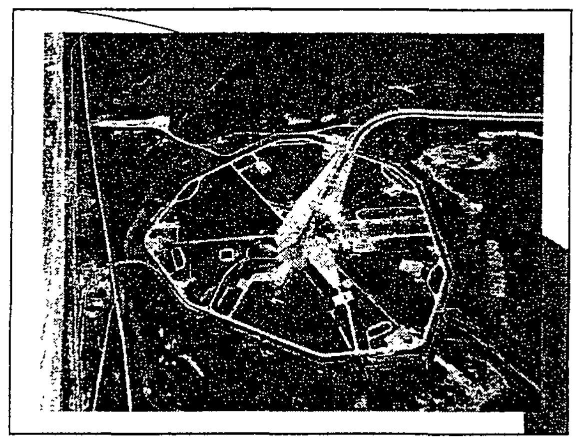
Noise at and during Liftoff

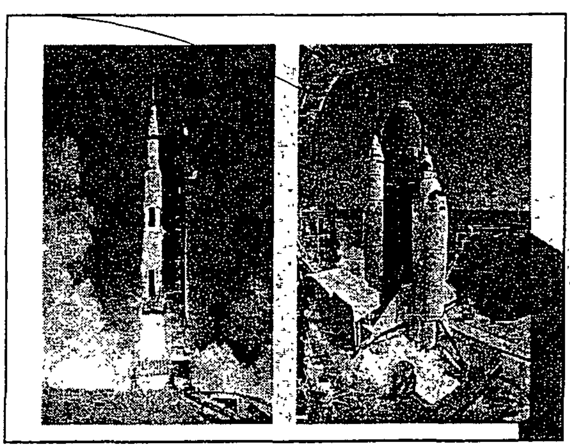
- SRB separation occurs around 25 miles; air is very thin here for wind noise or shock waves to shake the Astronauts
- SRB separation occurs 2 minutes after liftoff (after T-0 seconds)
- Even though SSME's are still operating there is virtually no noise or vibrations during the rest of the ascent until External tank ejection (around 8.5 minutes after liftoff

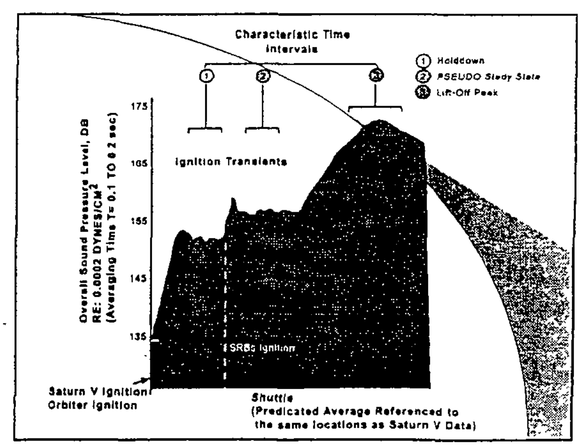


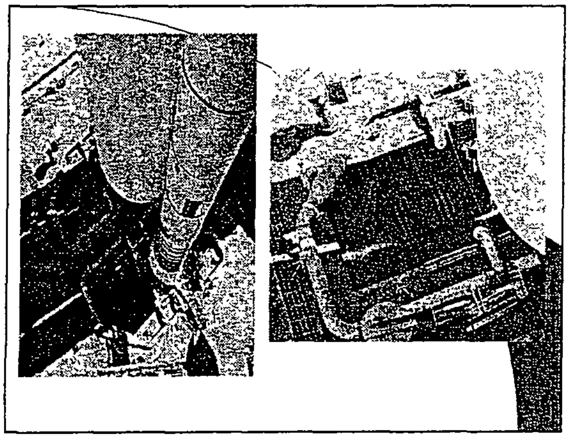


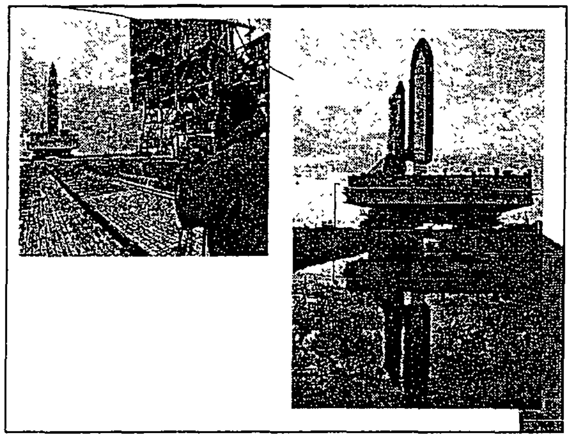


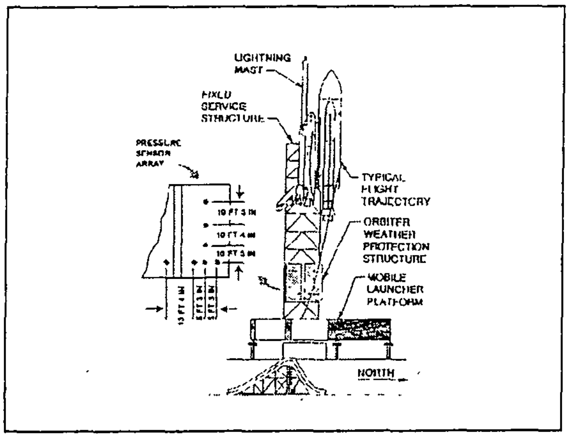


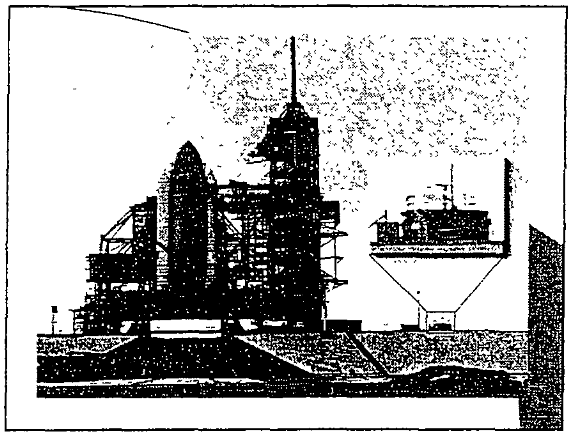


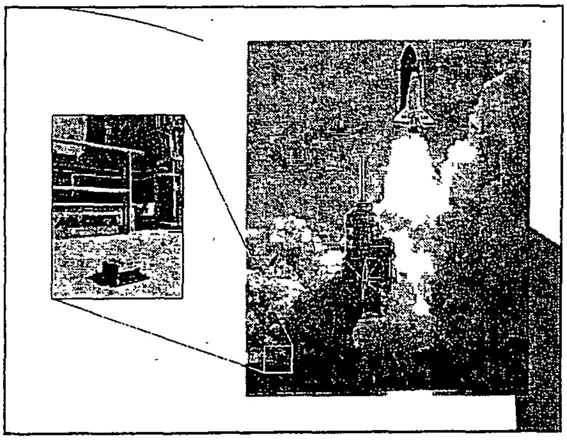

Characteristic Time Intervals
1 Holddown
2 PSEUDO Stedy State
3 Lift-Off Peak
175
165
155
145
135
Ignition Transients
Overall Sound Pressure Level, DB RE: 0.0002 DYNES/CM²
(Averaging Time T= 0.1 TO 0.2 sec)
SRBs Ignition
Saturn V Ignition
Orbiter Ignition
Shuttle
(Predicated Average Referenced to the same locations as Saturn V Data)









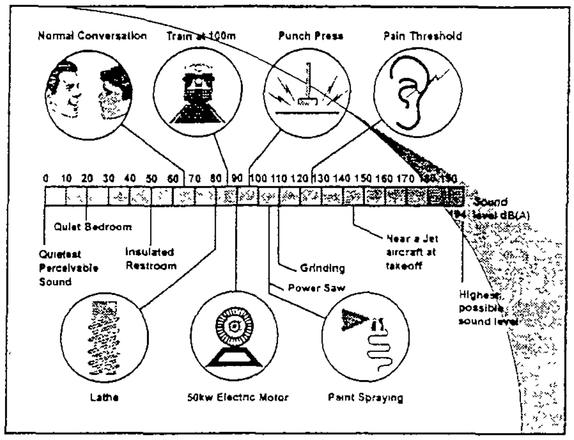


Noise...Characterization

- Typical: Time history, OASPL, and FFT
- At NASA, we use Probability Density Distributions, Power Spectral Density, Cross-Power Spectral Density, Pressure Correlation Lengths, Coherences, etc.
- AJ factors – Vibroacoustic coupling between the sound field and structure of consequence

Rocket vs. Common Noise

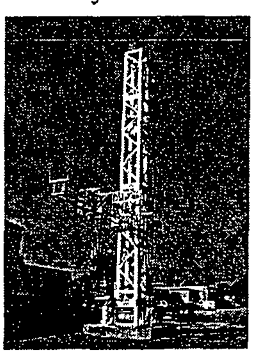
- 0 dB - Threshold of hearing
- 55 dB - Normal conversation
- 85 dB - Exposure must be < 8 hours
- 140 dB - Jet Engine (Pain threshold)
- 158 dB - Australian Cicada at 3 feet
- 180 dB - Shuttle lift-off at 10 feet
- 194 dB – Highest noise level (14.7 psi)

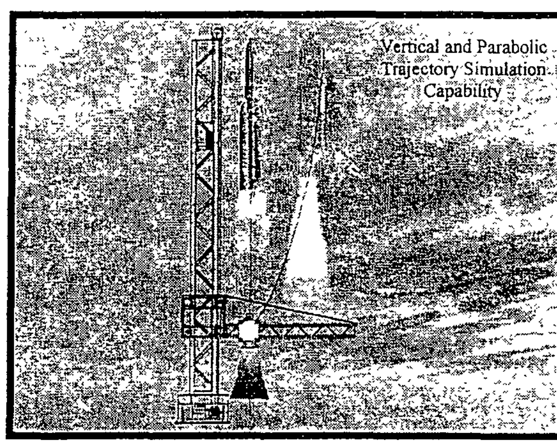


Loudness : Records

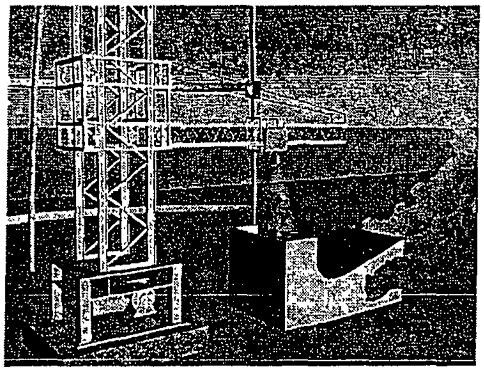
- 188 dB: Loudest Animal Sound
- 182 dB: Loudest Instrument
- 158 dB: Loudest Insect
- 145 dB: Loudest Animal
- 128 dB: Loudest Scream
- 122 dB: Loudest Whistle
- 121 dB: Loudest Shout
- 93 dB: Loudest Snoring

Launch Systems Test bed

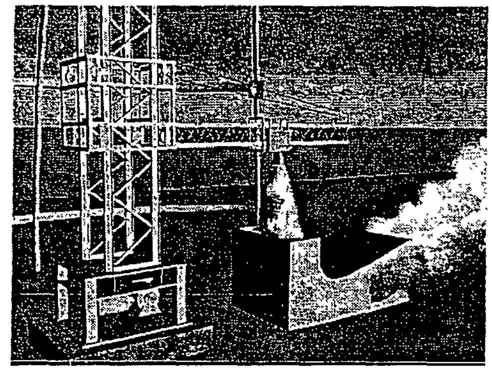


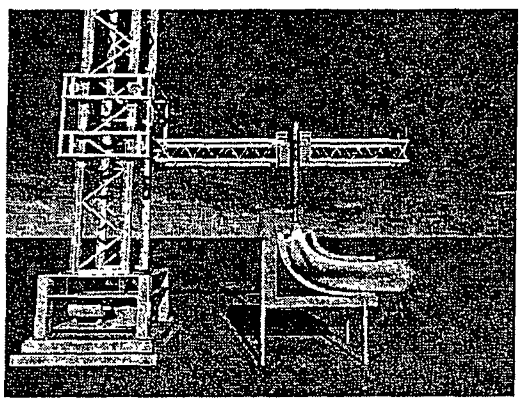


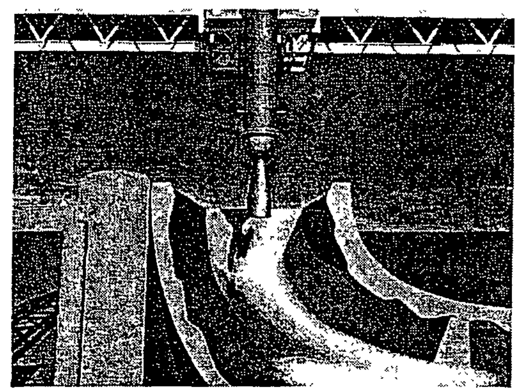
Cold Jet (GN2) Simulation with closed duct

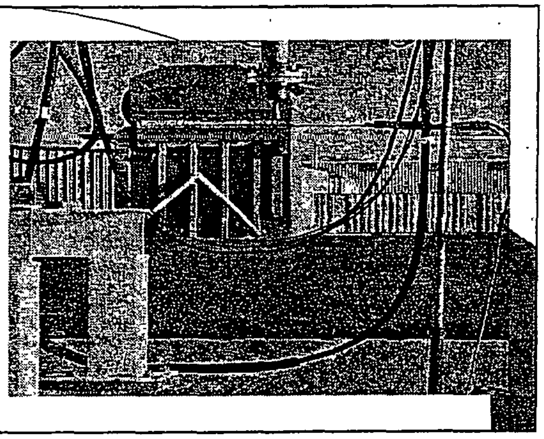


Future Hot Combusting Jet (GH2+GOX) Simulation



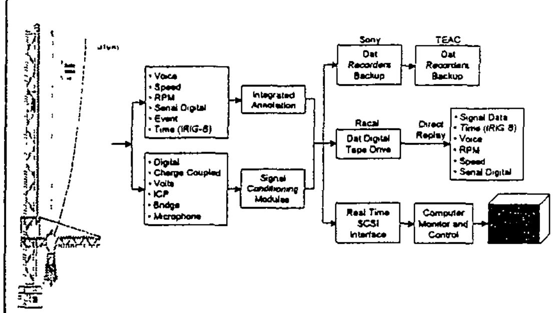


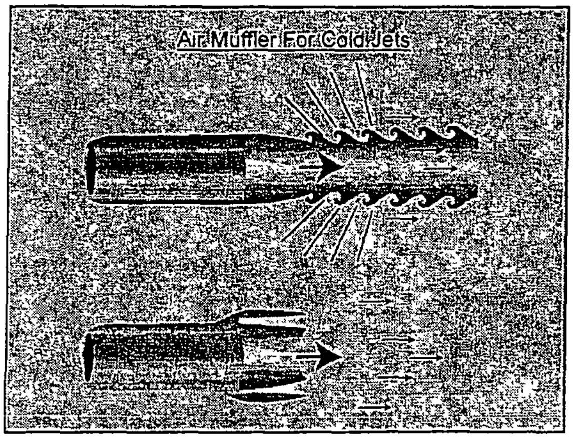


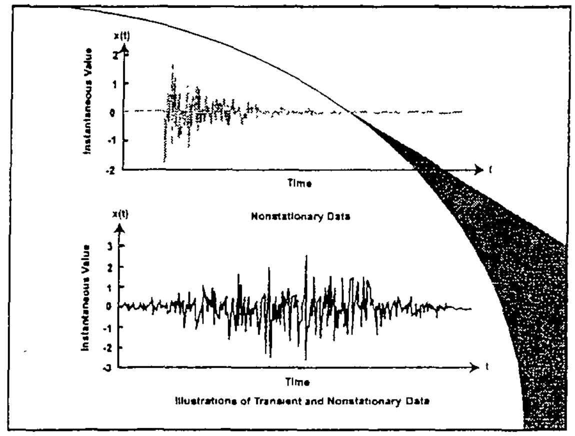


Trajectory Simulation Mechanism

Data Acquisition System





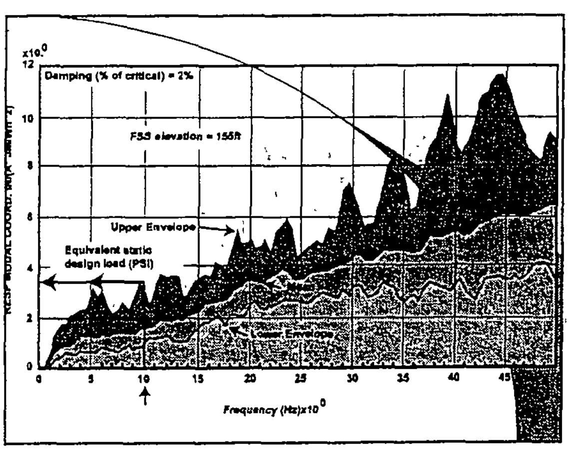


Noise...Design Application

- What you don't hear...hurts you (20 Hz)
- Define acoustic load in terms of Static Equivalent Load (Architectural use)
- Dynamic Load: Enhance SEL analysis by conducting modal tests, response analysis; include considerations for stress, fatigue, and fracture mechanics

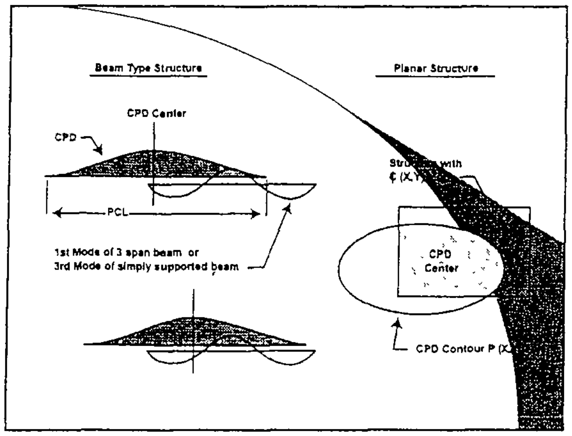
Vibroacoustics Objectives

- Rocket Noise Models
  - Characterize acoustics environment
  - Bridge gap between test and analysis
  - Develop innovative analysis
- Vibration Response Analysis
  - Reliable Structural analysis method
  - Test project for verification
  - Implement system for use



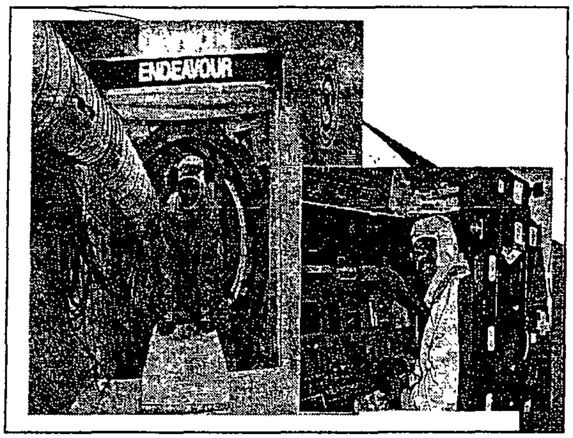
Vibroacoustics....needs

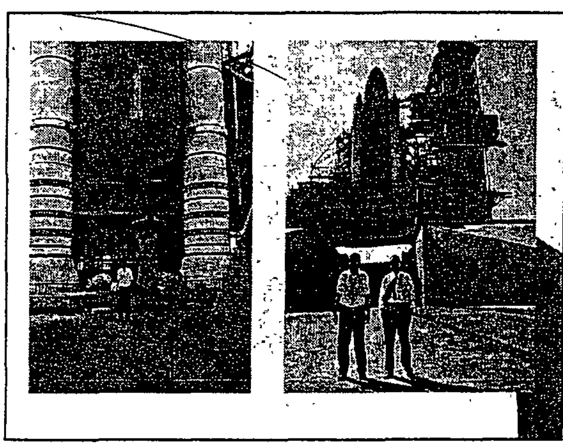
- ESL approach is crude; leads to over design – does not account for higher order modes
- Future launch vehicles have higher mechanical power – no experience
- Lower costs for new structures and modifications of older structures
- New measurement based analysis systems are needed coupled with FEA

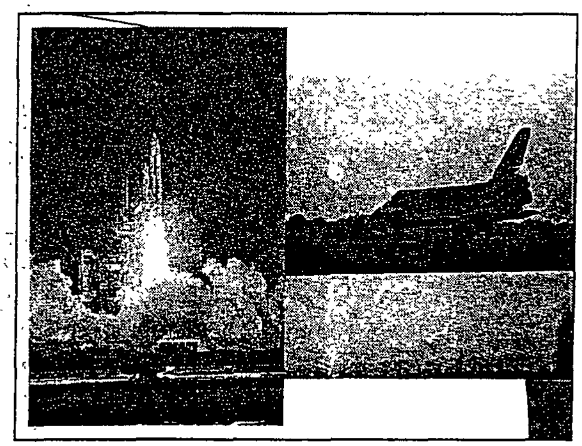


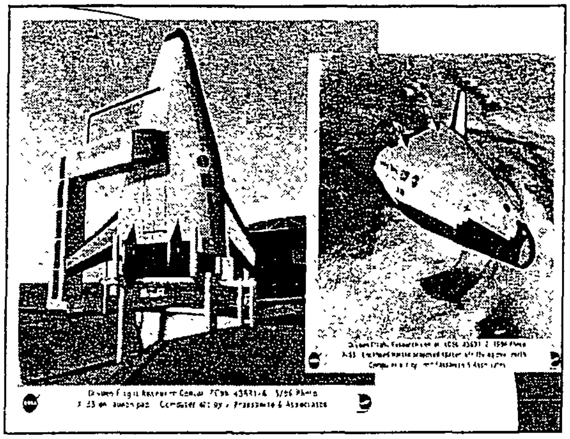
Response Analysis Methods

- Probabilistic Method (1967)
  - Based on classical random vibration
  - Transient – simulated as steady state
  - White Noise PSD, WN decay is CPSD
- Deterministic Method (1987)
  - Based on non-stationary data (Shuttle)
  - Low frequency response analysis - key
  - Response Spectra and PCL, CPD, etc
  - True simulation of rocket response



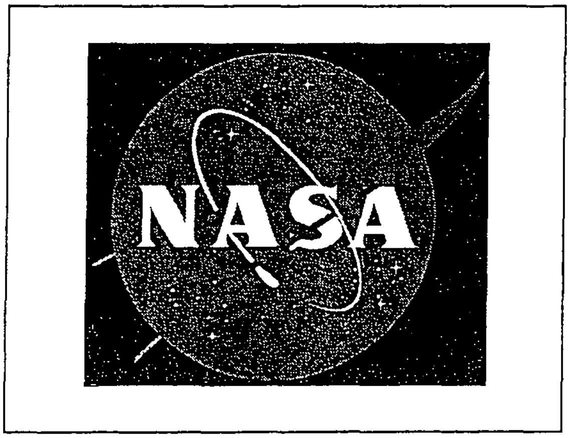






Concluding Remarks

- Critical structures...bridges, oil rigs, aircrafts, rockets, and launch pads all require new techniques for design
- Dynamic loads..aerodynamic, earthquake, ocean waves, acoustic pressures...require random analysis
- Kobe earthquake....similar to water waves overlapping...cancel or additive
- Vibroacoustic coupling, launch exhaust management analysis....state of the art from a Ground Sstructures perspective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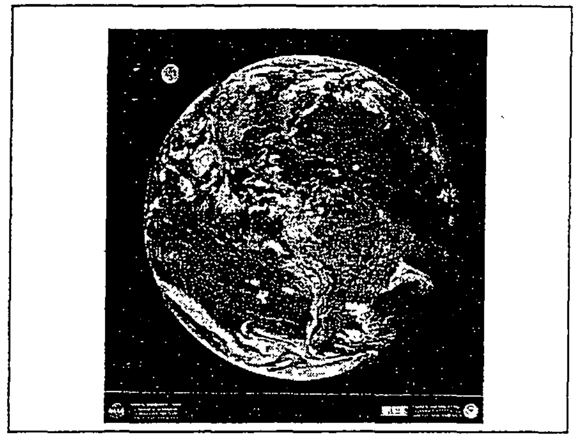
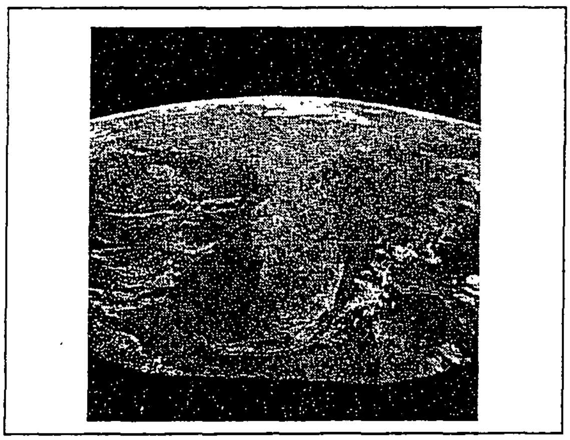
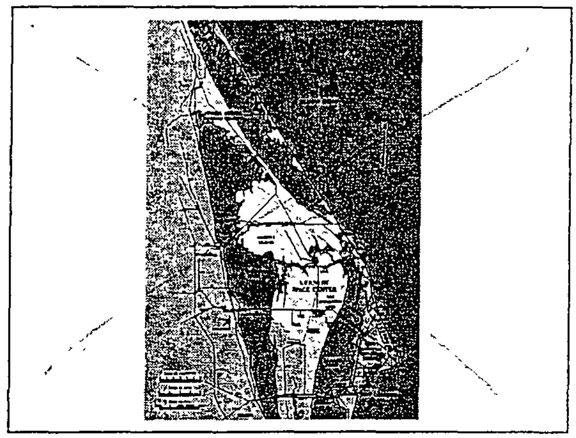
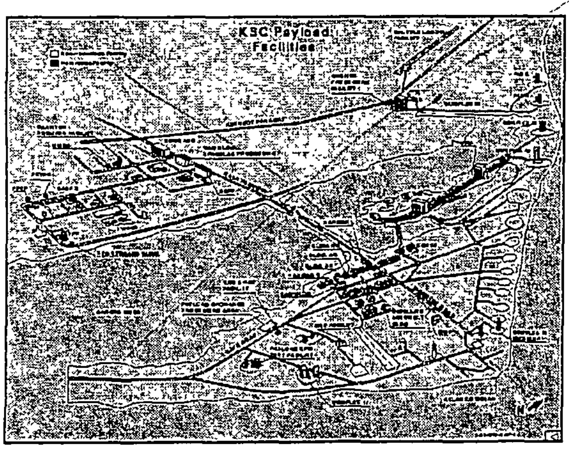
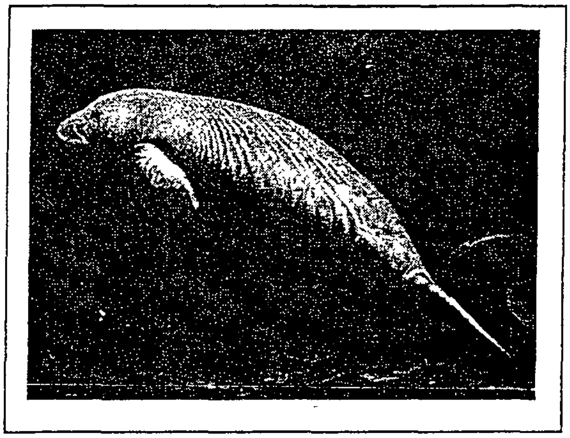
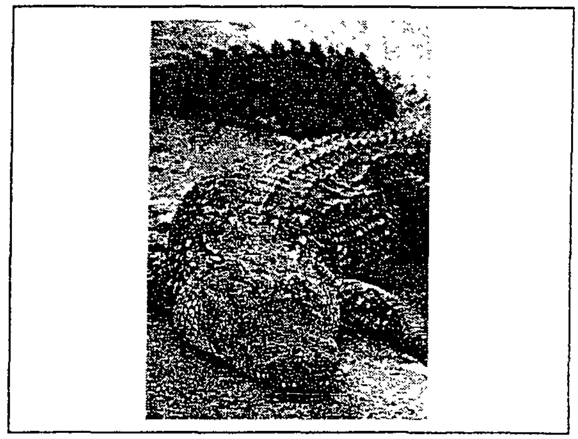


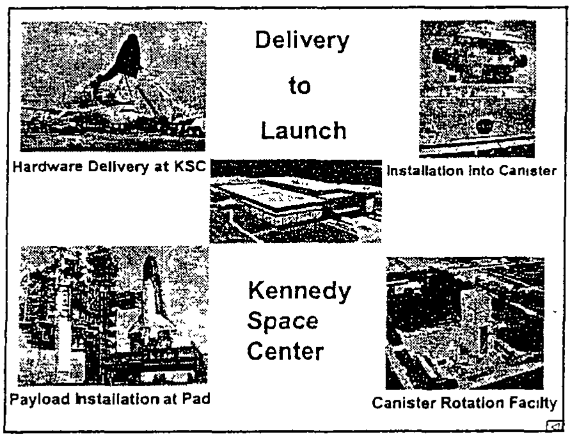




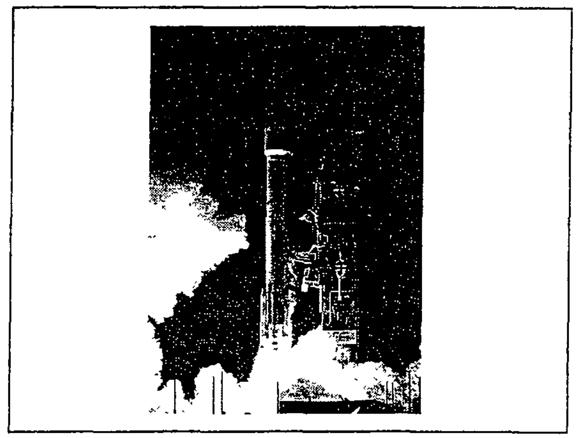

KSC Payload
Facilities

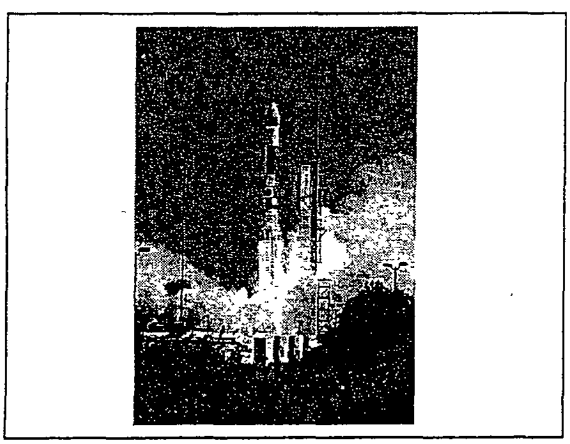


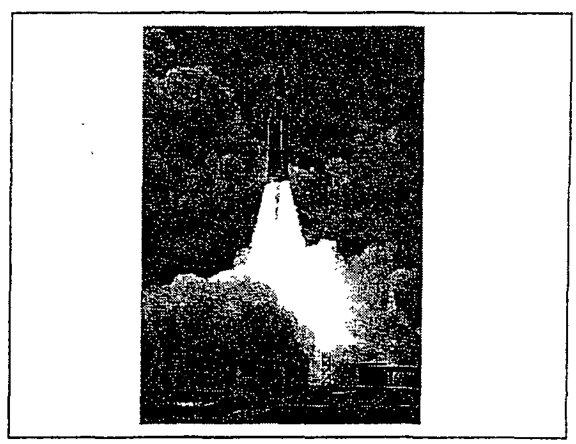


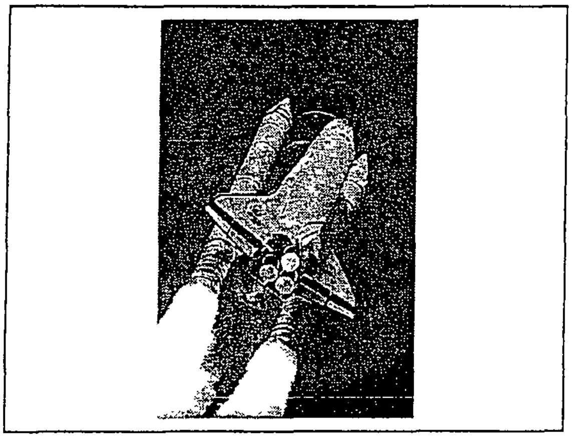


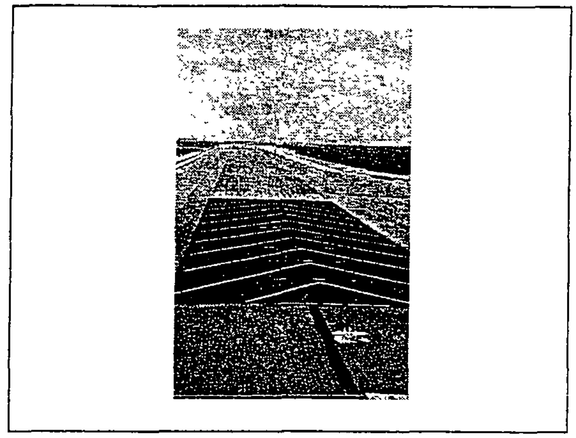
Delivery
to
Launch
Hardware Delivery at KSC
Installation into Canister
Kennedy
Space
Center
Payload Installation at Pad
Canister Rotation Facilty

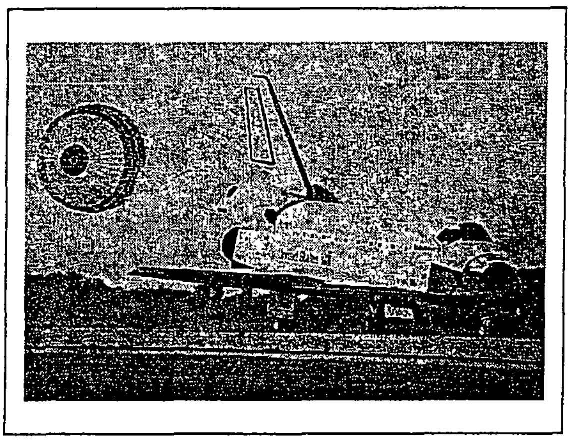


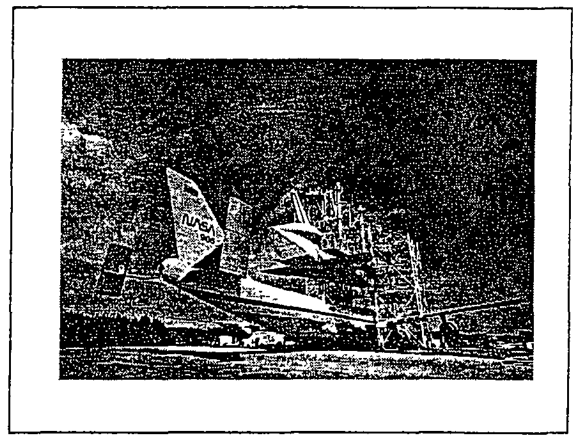


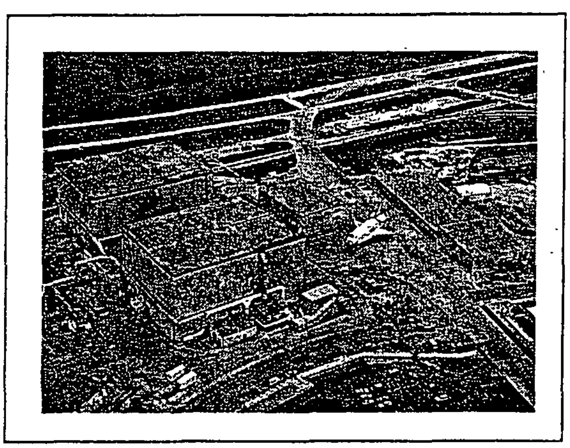


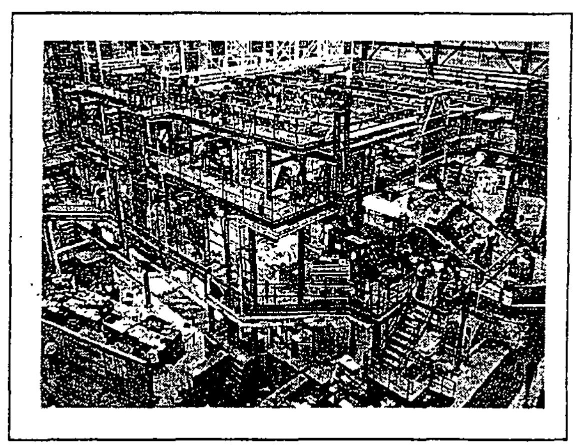


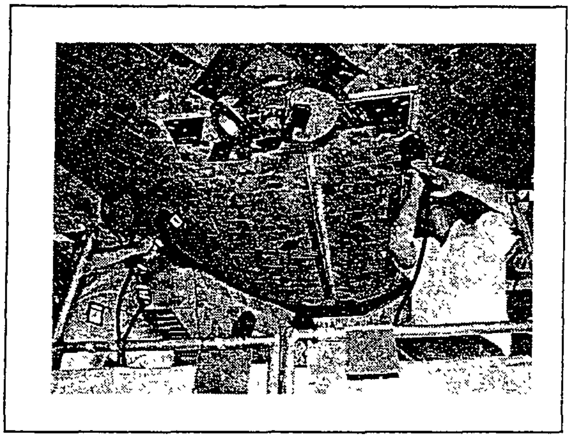
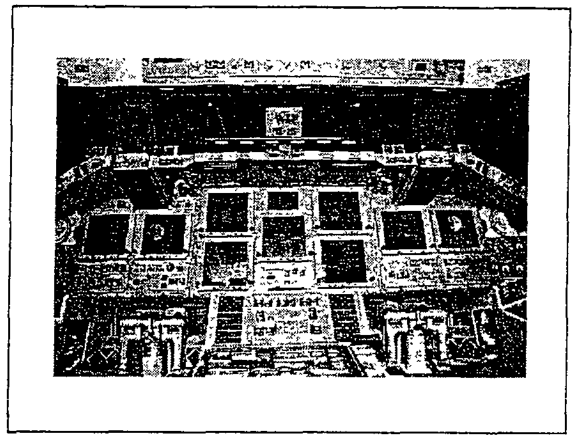
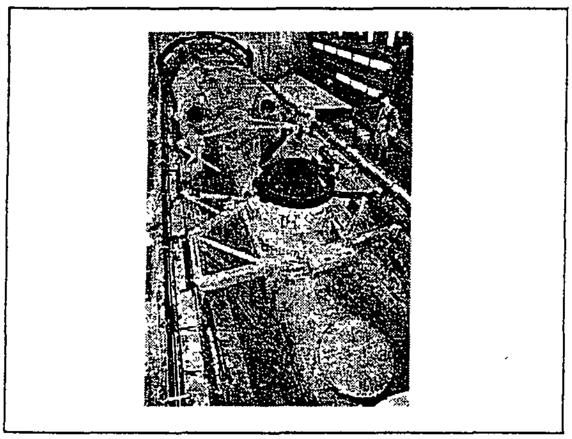
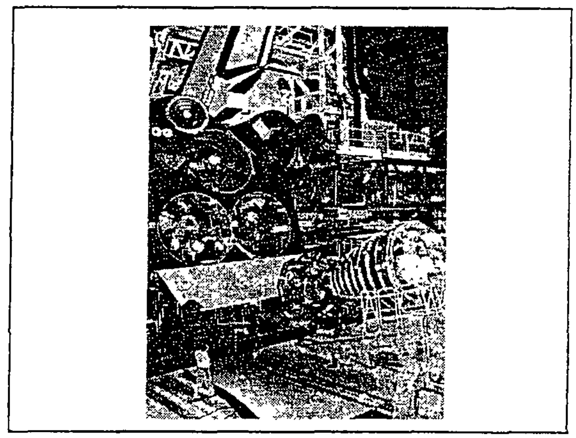
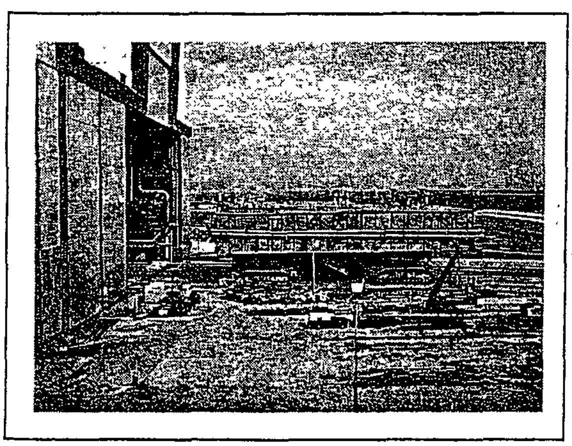
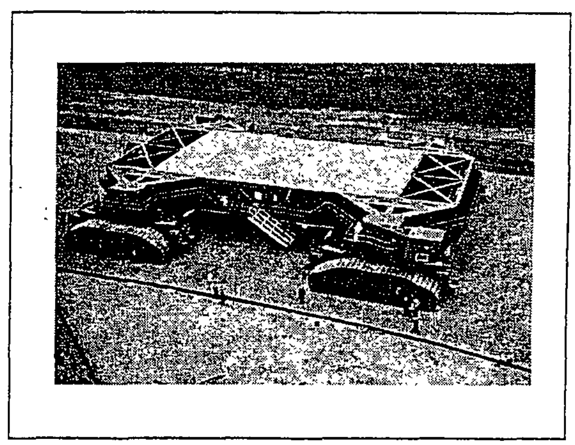


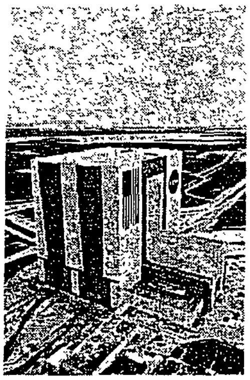


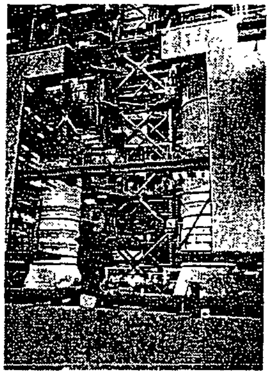


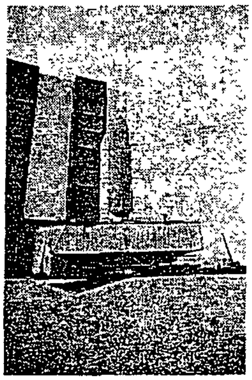


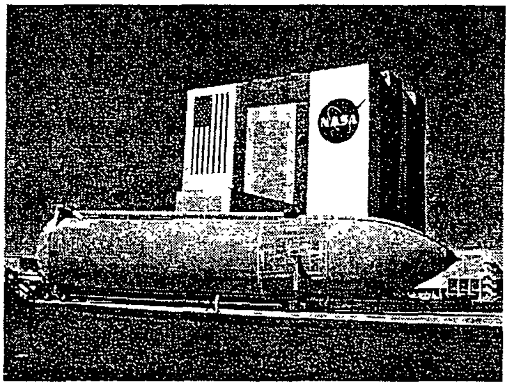


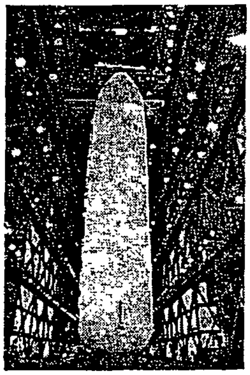







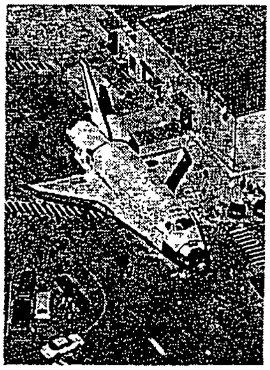


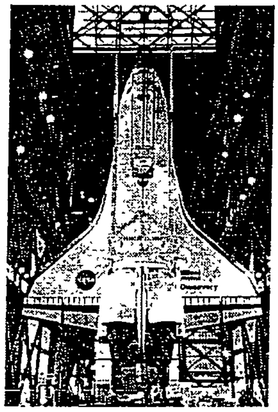


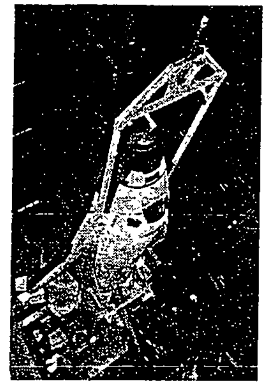


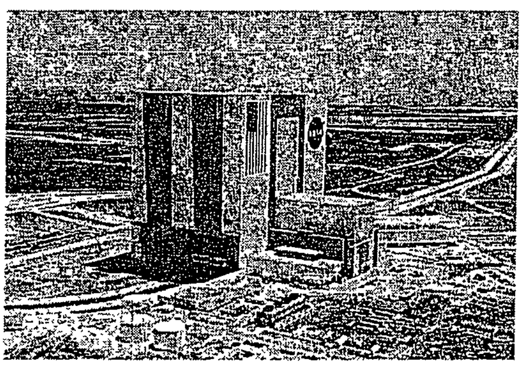


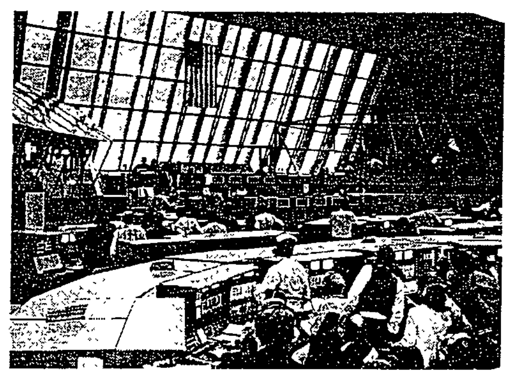


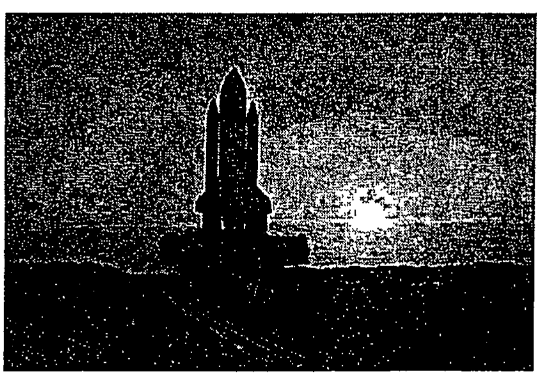


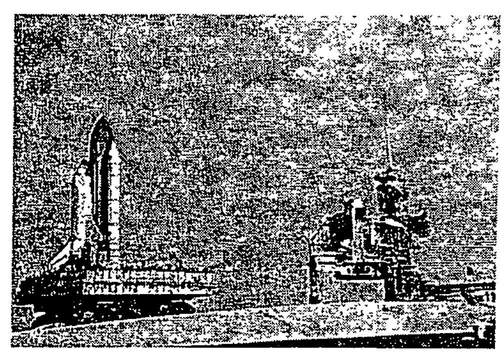


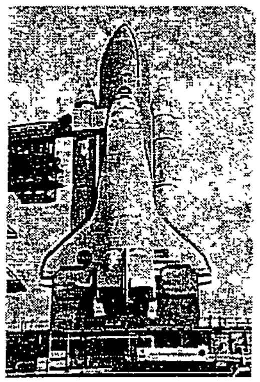
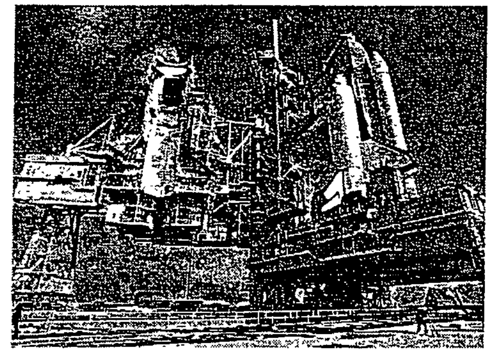
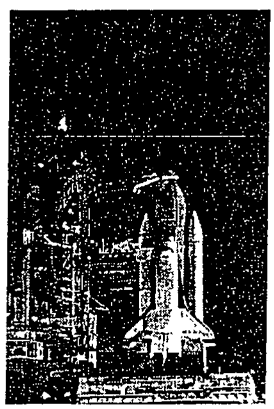


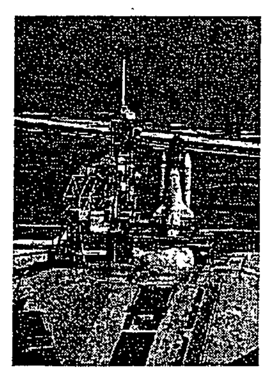


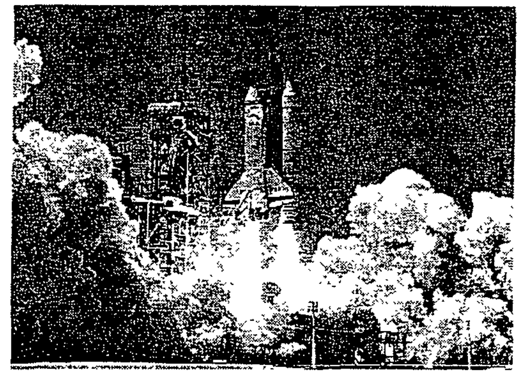
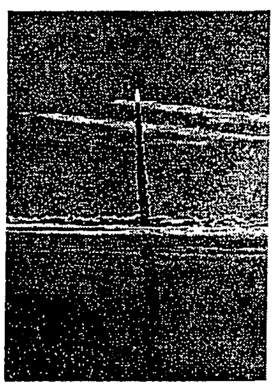


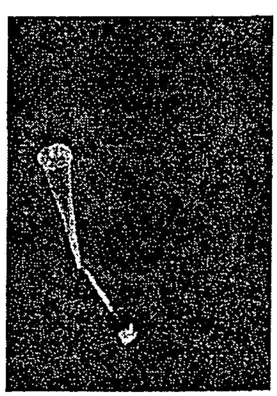
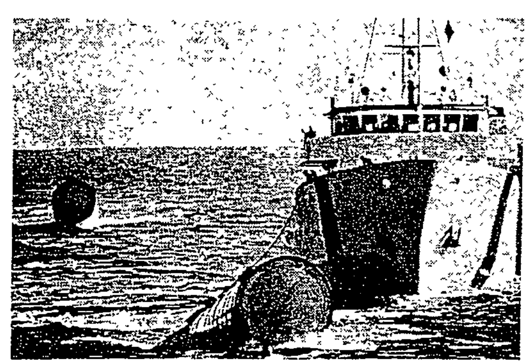


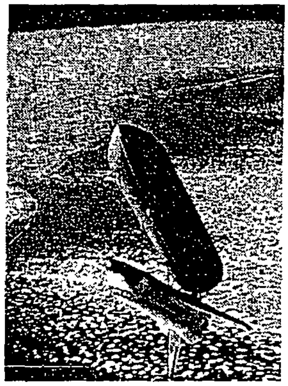


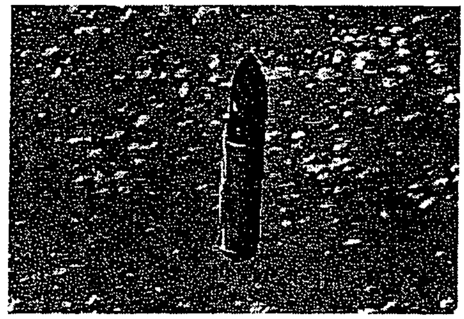




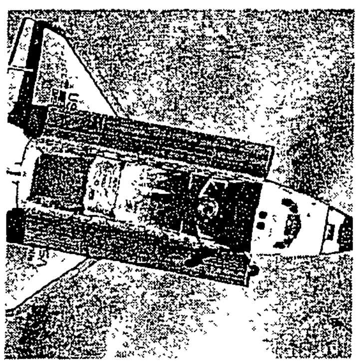



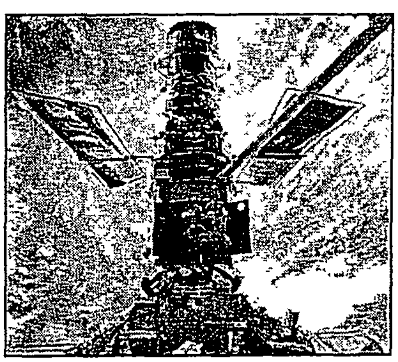




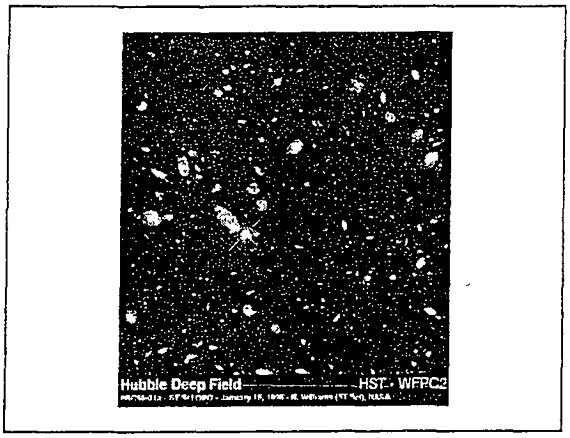


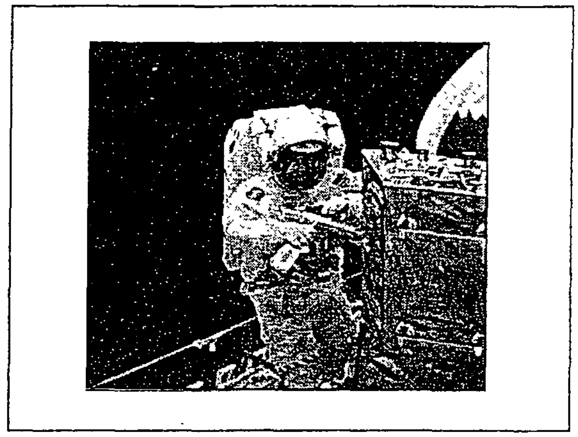


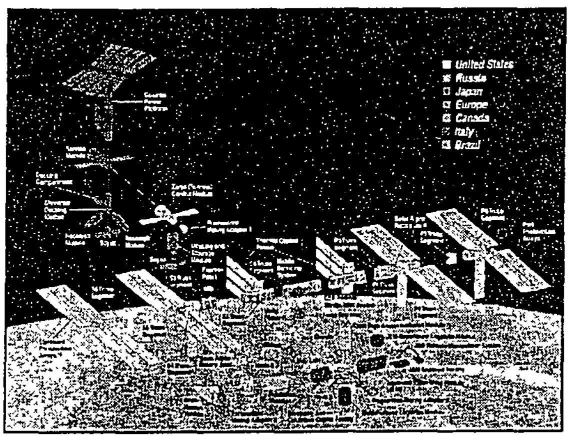





Gaseous Pillars · M16
HST · WFPC2


Hubble Deep Field
HST · WFPC2

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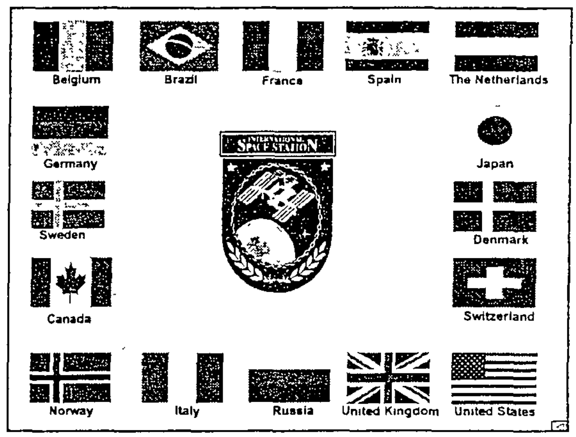
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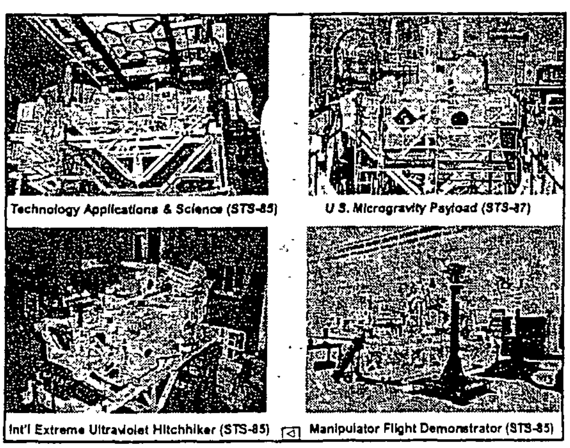
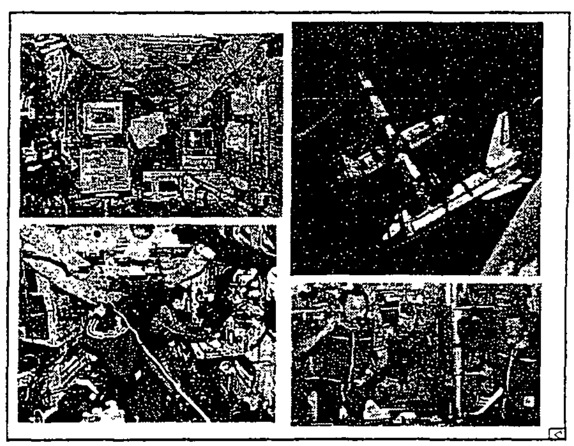
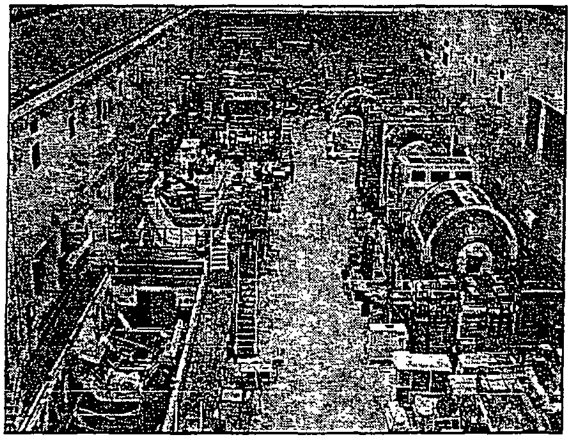
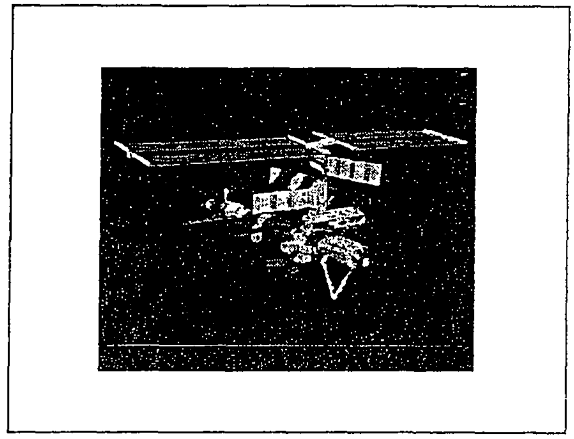
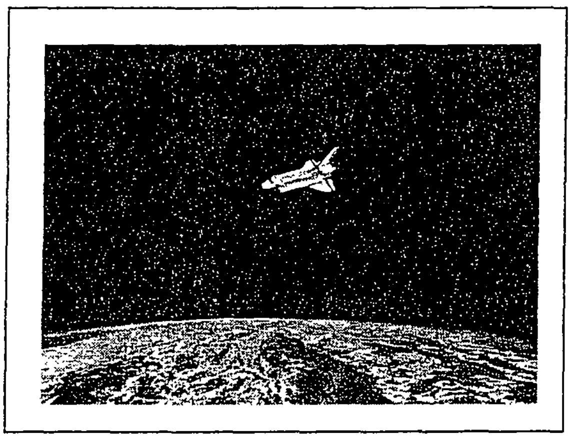
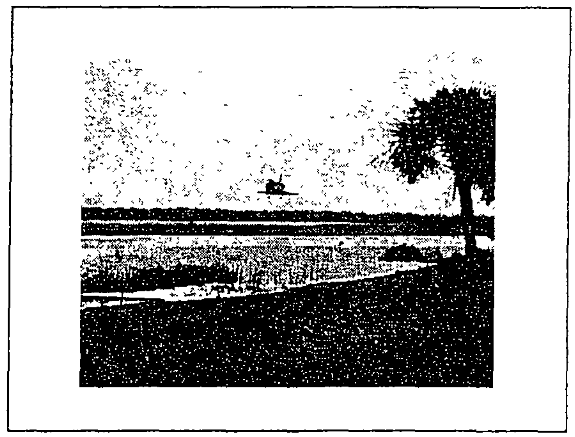
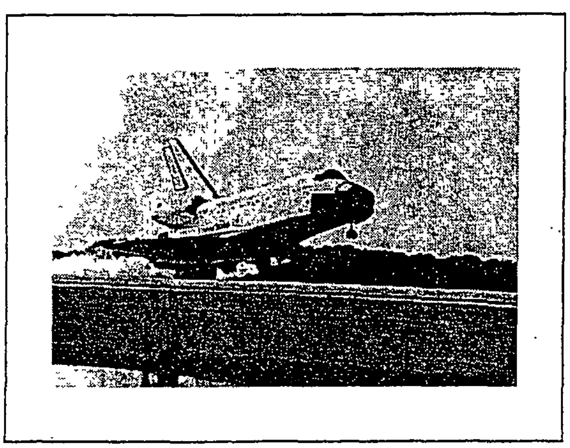
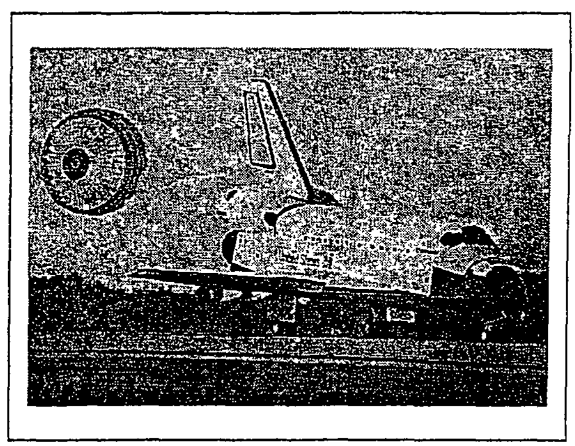
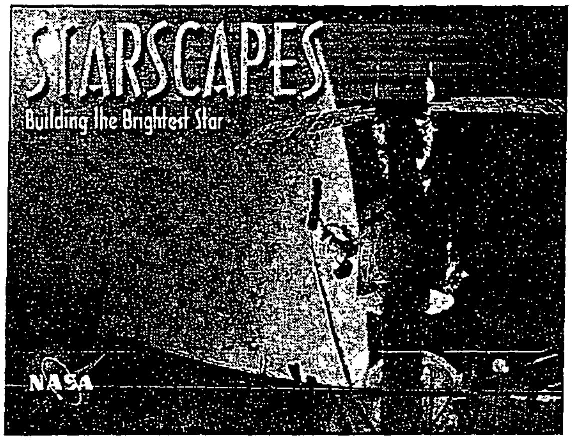
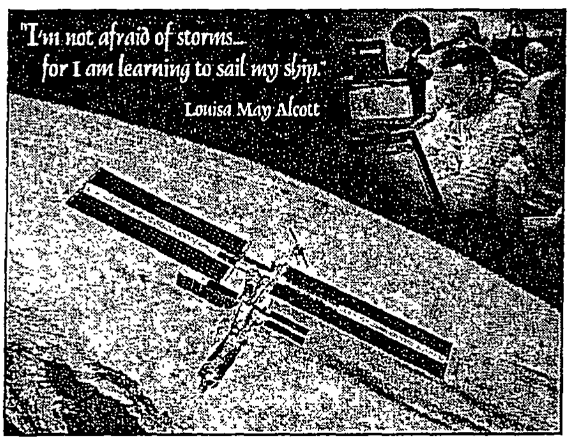

Technology Applications & Science (STS-85)
U.S. Microgravity Payload (STS-87)
Int'l Extreme Ultraviolet Hitchhiker (STS-85)
Manipulator Flight Demonstrator (STS-85)

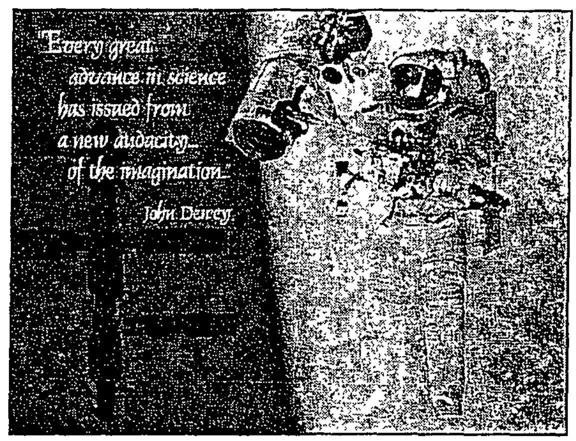


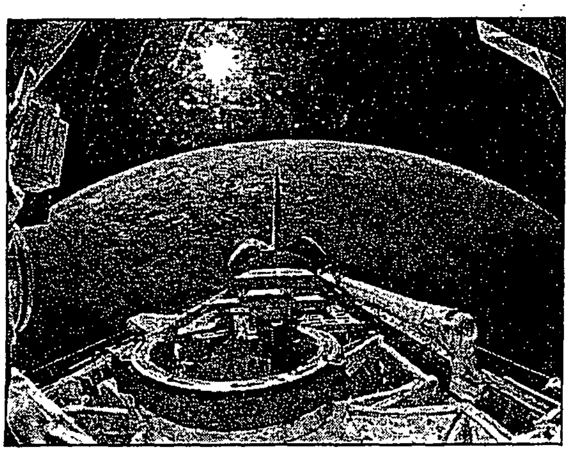








STARSCAPES
Building the Brightest Star
NASA

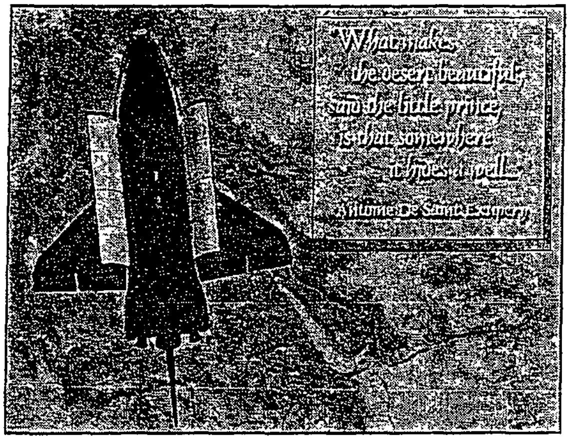

"Smooth seas do not
make skillful sailors."
African Proverb

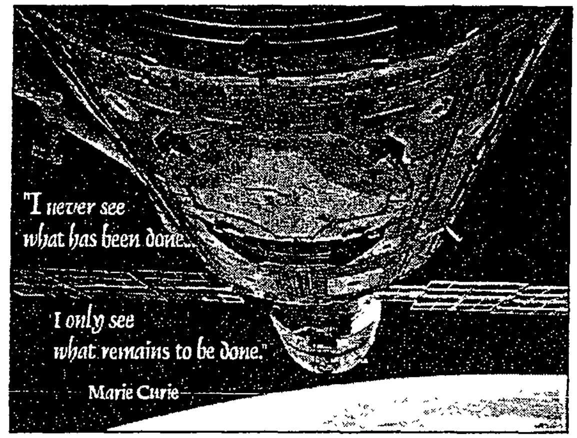

"I'm not afraid of storms...
for I am learning to sail my ship."
Louisa May Alcott

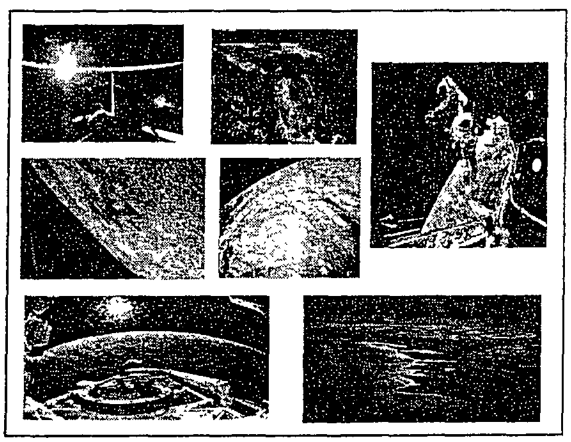

"Every great
advance in science
has issued from
a new audacity...
of the imagination."
John Dewey

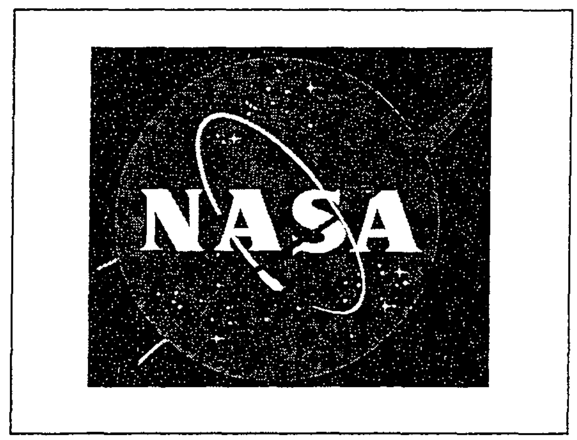



"We must become the change we want to see."
Gandhi


What makes
the desert beautiful,
said the little prince,
is that somewhere
it hides a well...
Antoine De Saint Exupery


"I never see
what has been done...
I only see
what remains to be done."
Marie Curie




NASA