N91-22155

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# 21ST CENTURY PROPULSION

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NASA Symposium
"Vision 21"
Space Travel for the Next Millenium

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VJY446 M15AA

## SPACE TRAVEL IN THE NEXT MILLENIUM?

- How do we predict the future?
  - We do so by examining the past
    - — We predict the near future by examining the immediate past and extrapolate into the far future by studying the more distant past
  - We also use a lot of imagination
- Constraint: In the use of our imagination, we are constrained to obey the "known" laws of physics

- Ray of hope: The laws of physics are known to have been through many evolutionary and revolutionary changes. In fact, they are in a continuous state of flux

- Example: For many centuries physics was taught with the atom being exactly what the word means, INDIVISIBLE. Now , of course, atom is just a name and its splitting is history.

3

## GOALS FOR THE 21ST CENTURY

- Expanded space travel and establishment of permanent manned outposts

- Lunar and Mars outposts represent the most immediate future in space travel and both have history from the very recent past

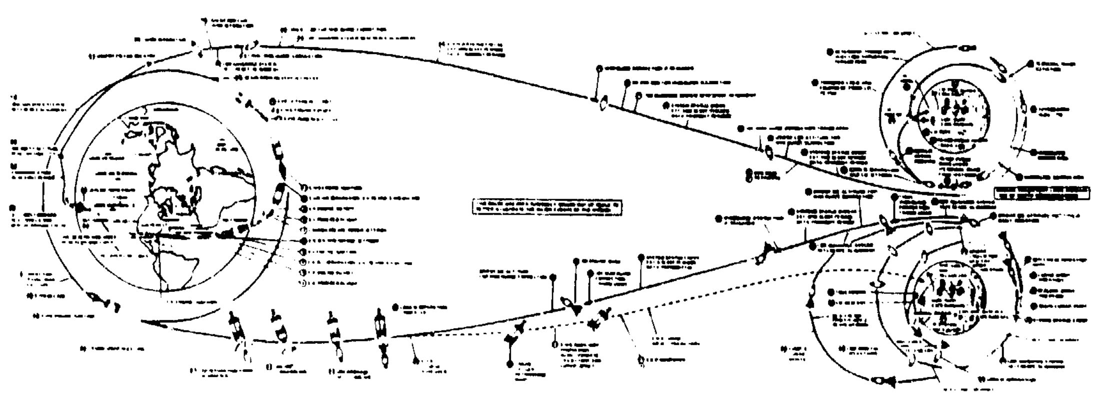
VJY449.1 M15AA

## LUNAR OUTPOSTS

- The Apollo program was successfully conducted with chemical propulsion
  - It was necessary to advance from the liquid oxygen/alcohol propellants of the V-2 to liquid oxygen/liquid hydrogen of the Saturn V upper stages in 15 years

VJY450 M15AA

## APOLLO 16 MISSION PROFILE



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VJY451:M15AA

## MARS OUTPOSTS

- Trips to Mars were planned and vehicles were designed for landings and returns
  - Unmanned 1984
  - Manned 1988
- Trade studies compared chemical cryogenics ($O_2/H_2$) with direct nuclear thermal propulsion using the NERVA engine
- The following charts summarize the trades and vehicle designs conducted between 1965 and 1973

ON TO MARS (REVISITED)


C. BOEHMER



Presented to
2nd AIAA/JPL International Conference
on Solar System Exploration
Pasadena, California
22-24 August 1989



McDonnell Douglas Space Systems Company

MCDONNELL DOUGLAS


## HISTORY

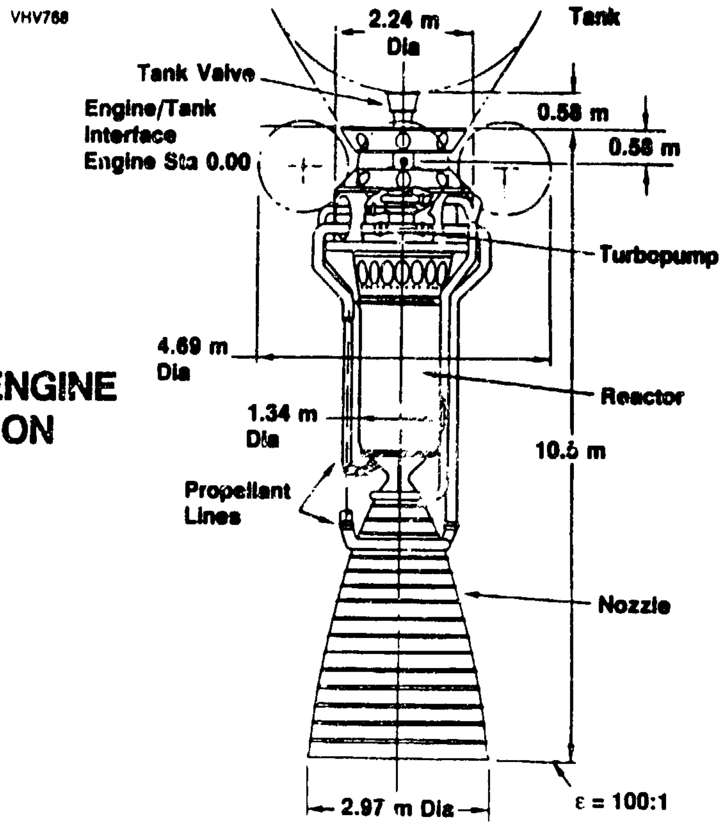
Nuclear Engine

- KIWI - A (Los Alamos) 1957-1960
- KIWI - B (Los Alamos) 1961-1964
  - KIWI-B4E Aug 1964
    - 940 MW, 10-min, restart
- Phoebus (Los Alamos) 1965-1968
  - 4100 MW, 30-min
- NRX (Aerojet/Westinghouse) 1964-1967
- XE-1 (Aerojet/Westinghouse) 1969

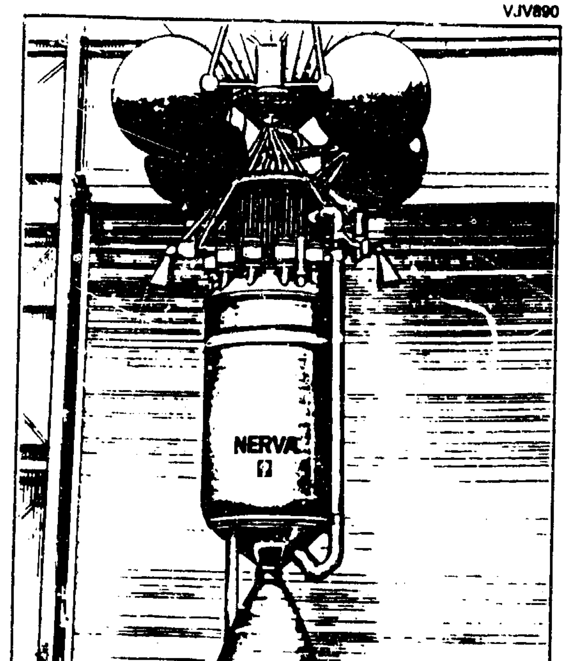
Nuclear Stage

- Douglas Aircraft 1965-1969
- McDonnell Douglas 1969-1973
  - Nuclear Flight Definition Study
    - Saturn derivative
    - Shuttle
  - Nuclear Stage System Definition Study
    - Propulsion module
  - Reusable Nuclear Shuttle (RNS)
    - Lunar
    - LEO-GEO
    - Earth – Mars

## NERVA FLIGHT ENGINE CONFIGURATION




## FULL SCALE MOCKUP OF NR-1 FLIGHT ENGINE, RATED AT 1500 MW, AND 75,000 LB THRUST



VJO075.3 M2BZ

# NUCLEAR ROCKET REACTOR TESTING

## LASL (LANL)

| | Date | Power Level (MW) | Run Time (min) |
|---|---|---|---|
| KIWI - A | July 1959 | 70 | 5 |
| KIWI - A′ | July 1960 | 85 | 6 |
| KIWI - A3 | Oct 1960 | 100 | 5 |
| KIWI - B1A | Dec 1961 | 300 | 1 |
| KIWI - B1B | Sept 1962 | 900 | 1 |
| KIWI - B4A | Nov 1962 | 500 | 0 |
| KIWI - B4D | May 1964 | 1020 | 1 |
| KIWI - B4E | Aug 1964 | 940 | 10 |
| TNT | Jan 1965 | — | — |
| Phoebus - 1A | June 1965 | 1090 | 11 |
| Phoebus - 1B | Feb 1967 | 1500 | 30 |
| Phoebus - 2A | June 1968 | 4100 | 13 |
| Pee Wee - 1 | Dec 1968 | 500 | 40 |
| NF - 1 | June 1972 | 434 | 108 |

12

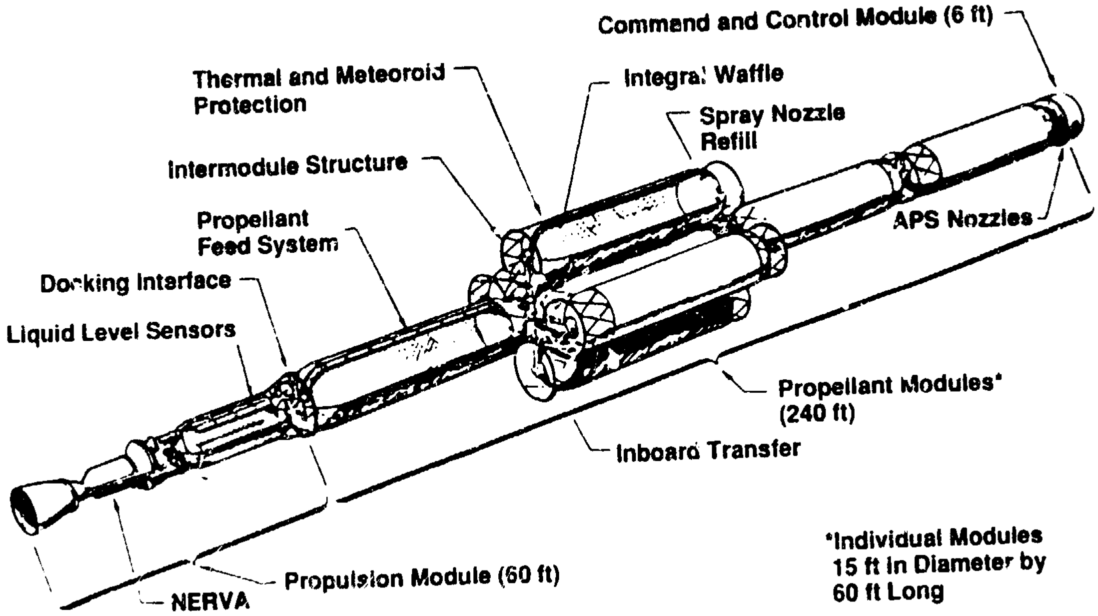
VJO076.2 M2BZ

# NUCLEAR ROCKET REACTOR/ENGINE TESTING WESTINGHOUSE/AEROJET

| | Date | Power Level (MW) | Run Time (min) |
|---|---|---|---|
| NRX - A2 | Sept 1964 | 1100 | 5 |
| NRX - A3 | April 1965 | 1100 | 17 |
| NRX - EST | March 1966 | 1100 | 28 |
| NRX - A5 | June 1966 | 1100 | 30 |
| NRX - A6 | Dec 1967 | 1100 | 60 |
| XE | Mar 1969 | 1100 | 10 |

# CLASS 3 MULTI-MODULE RNS

VJV872.1




# CLASS 1 SINGLE-MODULE HYBRID RNS

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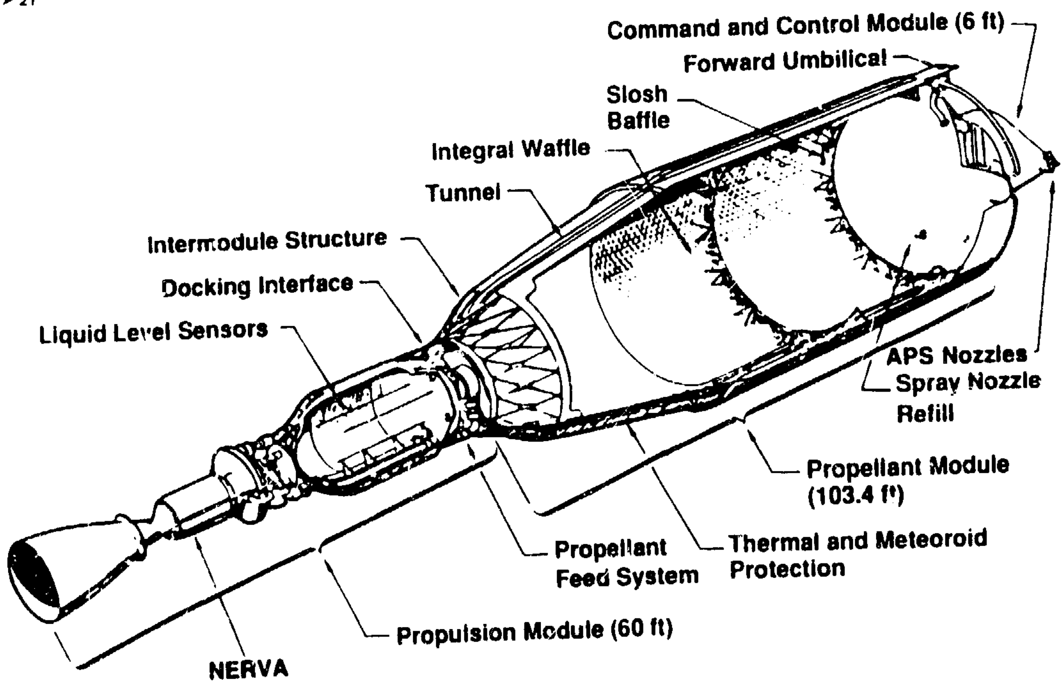
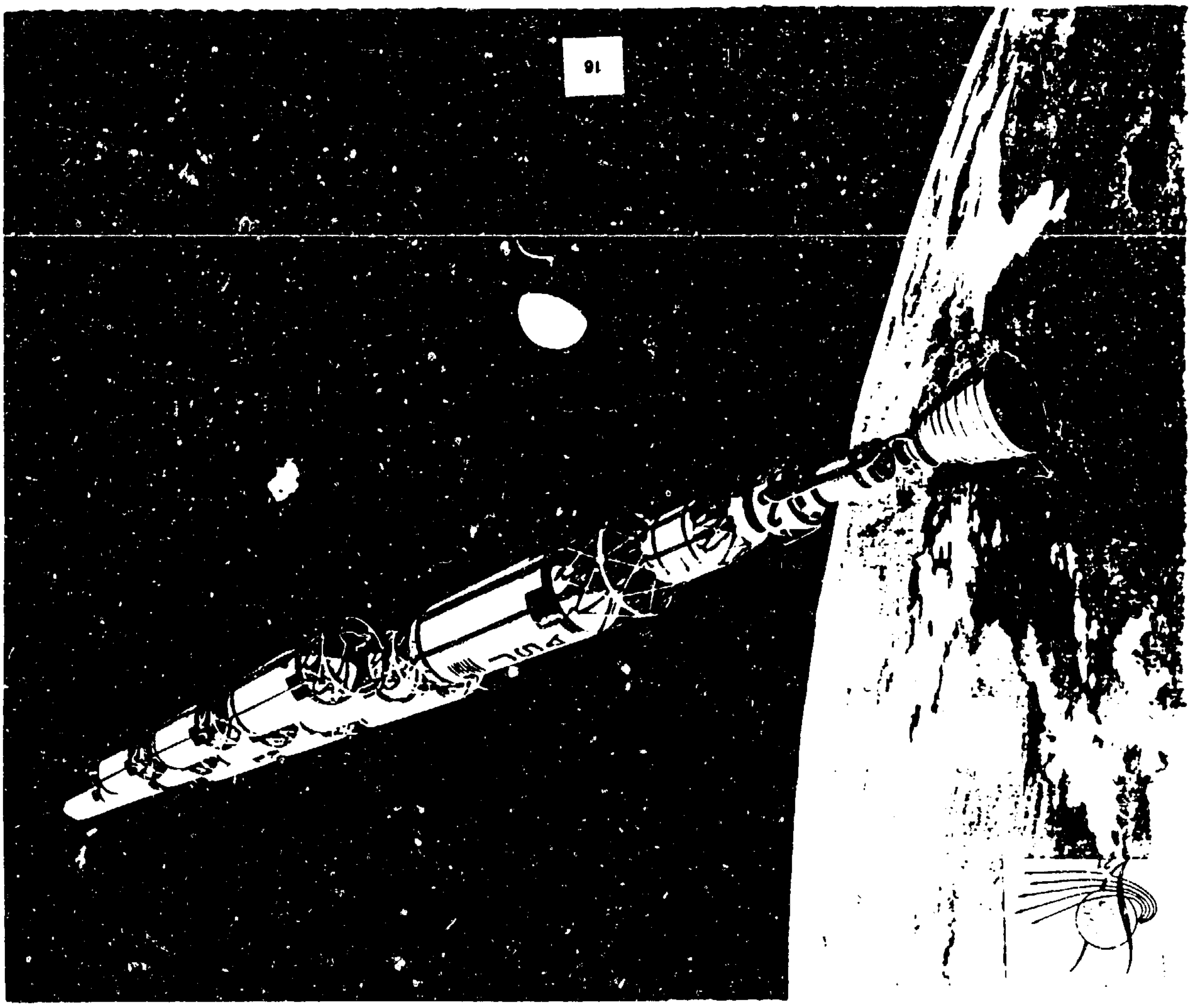




## NUCLEAR STAGE DESIGN/PROGRAM CONSIDERATIONS

VJX042 M1CV

- ❑ Structure
- ❑ Propulsion
  - Auxiliary
  - Nuclear
- ❑ Electrical
  - Power
  - Guidance/Navigation
  - Control
  - Communications
- ❑ Thermal Control
- ❑ Radiation Protection
  - Configuration
  - Shielding
- ❑ Propellant Control
  - Pressurization
  - Chilldown

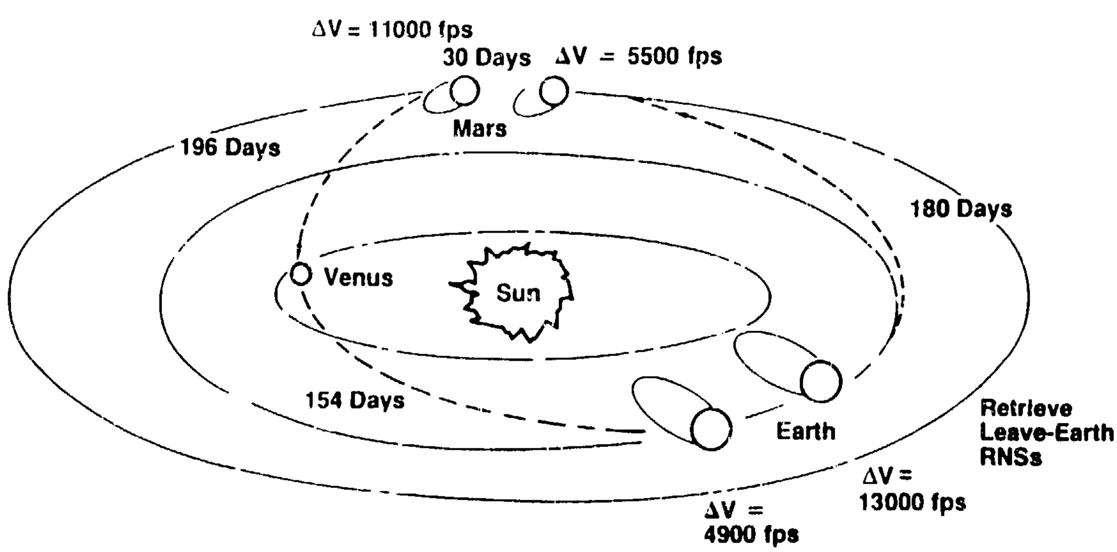
# NUCLEAR STAGE DESIGN/PROGRAM CONSIDERATIONS
(Continued)

VJX042 M1CV

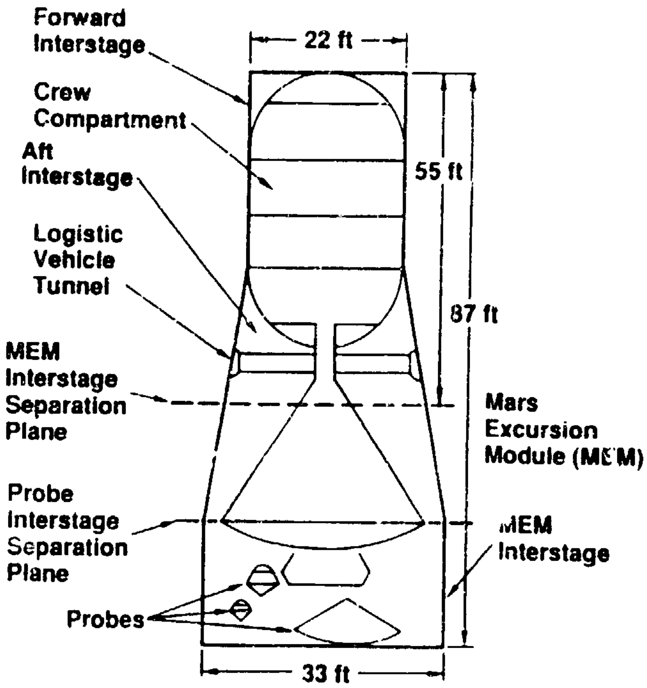
- Weight/Mass Control
- Ground/Orbital Operations
  - Assembly
  - Maintenance
- Safety
- Reliability
- Manufacturing
- Test Plan
  - Component
  - Systems
  - Battleship
- Program Schedule
- Costs

VJV877.1

# 1988 MARS LANDING PROFILE



# MSFC MANNED MARS SPACECRAFT CONCEPT

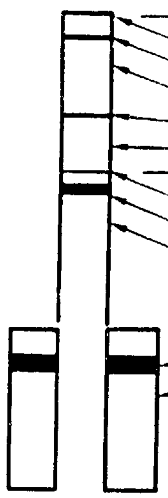



| | Weight (lb) |
|---|---|
| Mission Module | 82,900 |
| Mars Excursion Module | 95,290 |
| Mars Probes | 36,000 |
| Venus Probes | 4,000 |
| Interstages | 21,000 |
| Total Spacecraft | 239,190 |



# PROPELLANT REQUIREMENTS – BASELINE MODE

- 262-nmi Departure Orbit
- 300,000-lb Capacity RNS



| RNS Number | | ΔV (1000 fps) | Wp (1000 lb) | A'Cool (1000 lb) | Wp (%) |
|---|---|---|---|---|---|
| 4 | Arrive - Earth | 4.9 | 36 | 2.5 | 13 |
| | *Midcourse | 0.7 | 10.2 | 0 | 3 |
| | Leave - Mars | 11.0 | 129.5 | 6.8 | 46 |
| | *Orbit Trim | 0.2 | 6.5 | 0 | 2 |
| | Arrive - Mars (No. 2) | 4.6 | 102.8 | 5.7 | 36 |
| 3 | Arrive - Mars (No. 1) | 0.9 | 25.3 | 0 | 8 |
| | *Midcourse | 0.4 | 21.0 | 0 | 7 |
| | Leave - Earth (No. 2) | 6.3 | 242.7 | 11.0 | 85 |
| 1.2 | Retrieval (Per RNS) | 6.7 | 26.4 | 4.0 | 10 |
| | Leave - Earth (No. 1, Per RNS) | 6.7 | 208.5 | 10.0 | 73 |

* $I_{SP}$ = 450 sec

Total Propellant Required = 1,097,800 lb

VJX031 M2BZ

# LAUNCH CONSIDERATIONS FOR MANNED MARS CAPTURE AND LANDING MISSION (1988)

Class 1

- ❑ 4 stages, 1,097,800 lb $LH_2$
- ❑ Each stage weighs 69,245 lb dry
- ❑ Assume ALS 180,000 lb
- ❑ Mission requires 8 ALS launches
  - 4 launches of stage (70,000 lb) + 110,000 lb $LH_2$
  - 4 launches of 174,000 lb $LH_2$ (assume 6000-lb tank)

Class 3

- ❑ 4 stages (1 propulsion, 8 propellant, 1 command and control module)
  - Assume 1,335,000 lb $LH_2$
- ❑ Each stage weighs 85,000 lb dry

Requires:
- 4 launches for propulsion (30,475 lb) plus command and control module (4615 lb)
- 32 launches for propellant module (40,075 lb) (containing 34,000 lb $LH_2$)
- 6 launches 42,000 lb $LH_2$

Total 42 launches (Space Shuttle/Titan IV)

VJY452 M15AA

# NUCLEAR VERSUS CHEMICAL PERFORMANCE COMPARISON (SAME-STAGE TECHNOLOGY)

| Mission (Elliptic Capture Orbits) | OLV Booster | Number of Launches Saturn V | Mission | Payload | OLV/ Booster | Number of Launches Saturn V |
|---|---|---|---|---|---|---|
| Planetary Capture Missions | | | Planetary Flyby Missions-2 | | | |
| 1978 Venus capture | Advanced Chemical<br>Nuclear-restart | 5<br>3 | 1977 triple planet | 220,000 lb | S-IVC<br>Advanced chemical | 4<br>4* |
| 1980 Venus capture | Advanced Chemical<br>Nuclear restart | 5<br>3 | | | Nuclear<br>Nuclear-restart | 2<br>– |
| 1982 Mars capture | Advanced Chemical<br>Nuclear restart | –<br>4 | 1978 dual planet | 200,000 lb | S-IVC<br>Advanced chemical | 3<br>3* |
| | | | | | Nuclear<br>Nuclear-restart | 2<br>– |
| 1978 Mars capture | Advanced Chemical<br>Nuclear restart | 8<br>4 | 1976 dual planet, powered | 200,000 lb | S-IVC<br>Advanced chemical | 3<br>– |
| | | | | | Nuclear<br>Nuclear-restart | 2<br>– |

* Requires two launches for payload

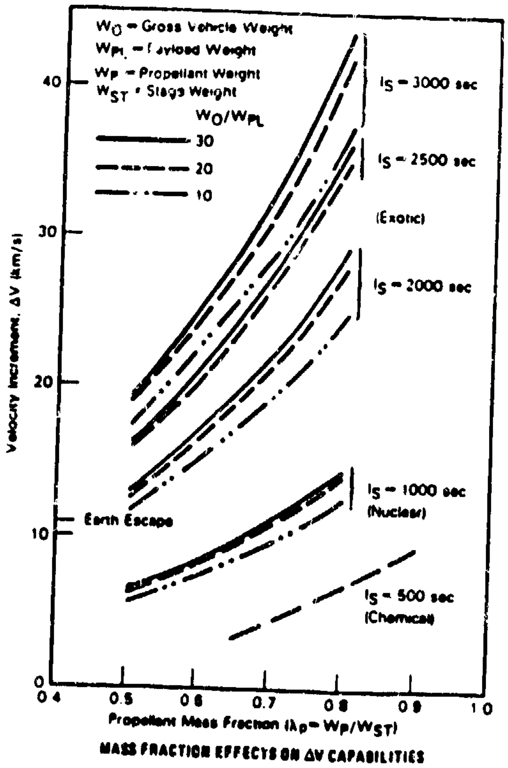
VJY483 M18AA

## VISIONS OF THE FUTURE

- ❒ Deep space travel requires energy and delta velocity (ΔV) in particular
- ❒ Propulsion systems with $I_s$ > 1500 sec are needed

VJK178

## PROPULSION SYSTEM ΔV CAPABILITIES

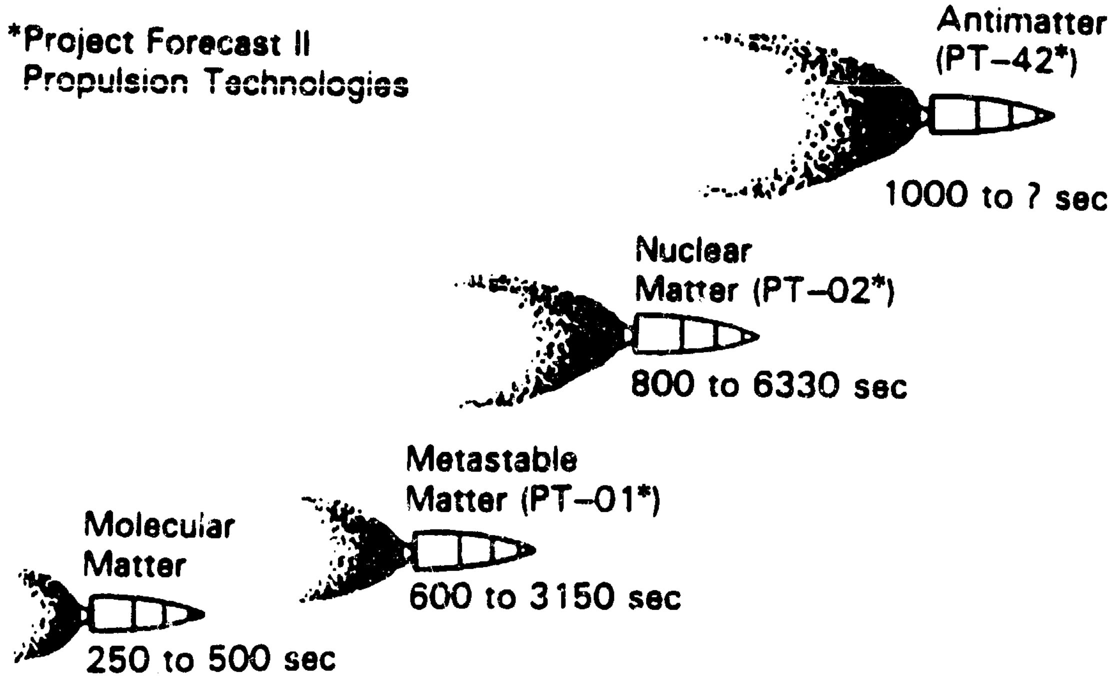



MASS FRACTION EFFECTS ON ΔV CAPABILITIES

- ■ Chemical propulsion can barely achieve earth escape with a single-stage vehicle
- ■ Higher $I_S$ propulsion systems substantially increase payload delivery capabilities
- ■ New exotic propulsion systems need to be developed and made economical to produce, store and use

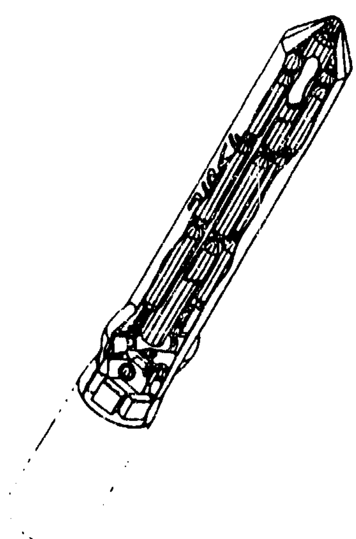
# SPECIFIC IMPULSES OF ROCKET FUELS

*Project Forecast II
Propulsion Technologies




26

MDC H5034C
AIAA 89-2629
MAY 1989



FUSION PROPULSION SYSTEMS

V. E. HALOULAKOS, MCDONNELL DOUGLAS
R. F. BOURQUE, GENERAL ATOMICS

Presented at
AIAA/SAE/ASME/ASEE
25th Joint Propulsion Conference
11-13 July 1989
Monterey, California

McDonnell Douglas Space Systems Company

MCDONNELL DOUGLAS

# SPACE TRANSFER VEHICLE COMPARATIVE DESIGN DATA

**LEO - GEO - LEO Mission, Mpl = 36,000 kg ; Del V = 9 km/s;**
**Burn Time = 3675s (Constant)**

101041.1 1CX

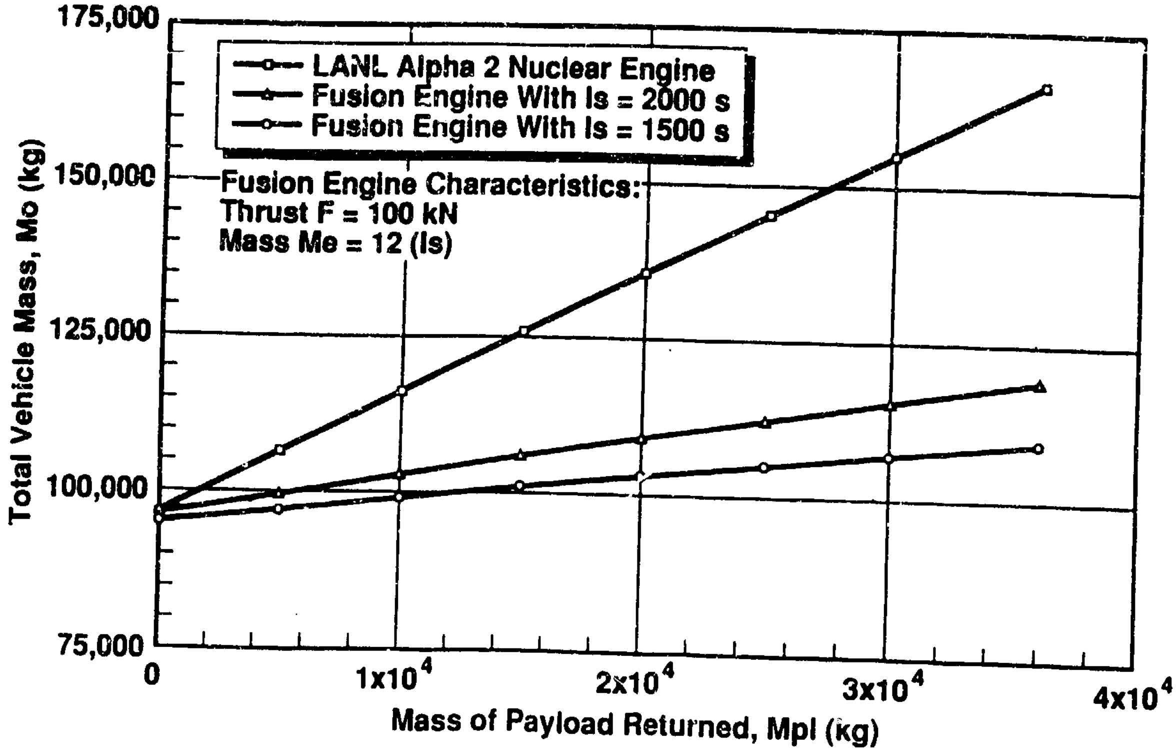
| | | Chemical Cryogenic, 6 RL - 10's | Nuclear, 4 Alpha 2's | Fusion, Me=12 (Is) |
|---|---|---|---|---|
| Rocket Engine | | | | |
| Thrust | (kN) | 400 | 278 | 208 |
| Specific Impulse | (s) | 450 | 860 | 2500 |
| Mass Breakdown | | | | |
| Propellants | (kg) | 333,291 | 134,548 | 34,685 |
| Fuel | ($LH_2$) | 51,275 | | |
| Oxidizer | (LOX) | 282,015 | | |
| Propellant Tank | | | | |
| Total Volume | ($m^3$) | 970 | 1,937 | 499 |
| Mass | (kg) | 8,156 | 10,849 | 2,797 |
| Pressurization | | | | |
| Helium System | (kg) | 1,374 | 1,828 | 471 |
| Engine | (kg) | 792 | 10,270 | 30,000 |
| Miscellaneous | (kg) | 3,411 | 4,538 | 1,170 |
| Total Vehicle Mass | | 383,024 | 198,033 | 105,123 |

29

VJY484 M15AA

- The initial vehicle mass serves as the key criterion of optimization
- The higher specific impulse of the fusion system results in lower propellant and vehicle mass for the specified mission and payload

## FISSION AND FUSION ROTV COMPARISON
**TOTAL VEHICLE MASS vs. RETURNED PAYLOAD FROM GEO**
**Assumes Each Vehicle Has Delivered a 36, -kg Payload to GEO**




30

## MDC-GA FUSION SPACE TRANSFER VEHICLE SIZING DATA

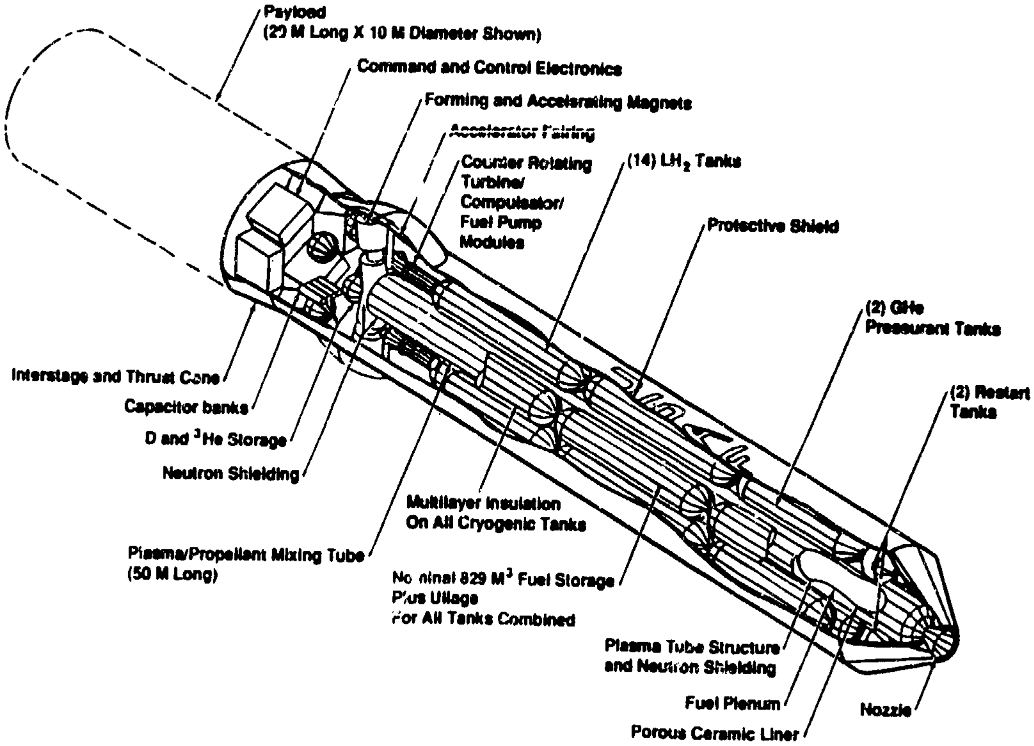
101038 1CX

**Missi n:** Transfer 36,000 kg to Geosynchronous Orbit (GEO)
Return Vehicle Empty and with Original Payload
**Engine:** GA Fusion Engine
Is = 1500 s, Thrust = 100 kN, Mass = 12 (Is)

| Mass Breakdown | | LEO-GEO Empty Return | LEO-GEO Return Payload |
|---|---|---|---|
| Propellant | (kg) | 27,910 | 57,597 |
| Propellant tank | | | |
| Total volume | ($m^3$) | 402 | 829 |
| Mass | (kg) | 2,251 | 4,644 |
| Pressurization | (kg) | 379 | 783 |
| Engine | (kg) | 18,000 | 18,000 |
| Miscellaneous | (kg) | 941 | 1,942 |
| Total Vehicle Mass | (kg) | 98,070 | 118,967 |

VJY456 M15AA

## FUSION-PROPELLED REUSABLE ORBIT TRANSFER VEHICLE




32

VJY456.1 M15AA

## MATTER/ANTIMATTER ANNIHILATION

- Problems and promises
  - Production: USAF has priced a production facility at BNL for $10^{15}$ $\bar{p}$/yr at approximately $14 million (1989)
  - Containment: Antiprotons have been stored for long periods at CERN and preliminary designs for transportable storage bottles have been proposed
  - Antimatter use holds great promises for applications in
    - — Medicine: Diagnosis and eradication of tumors
    - — Materials: Location and cure of flaws, processing of composites, etc.
  - This synergism should be explored and pursued

VJY487.1 M15AA

## FAR FUTURE PROPULSION SCHEMES

- Matter/antimatter
  - Antimatter safely stored will deliver its energy, via beam technology, to a flowing propellant. Rates of energy delivery and propellant flowrate to control the level of the thrust to any desired level

- Teleportation *"Beam me up, Scotty"*
  - Matter destructuring (i.e., breakdown into particles), and restructuring to be first perfected on inanimate objects. Transportation to be done by beam technology

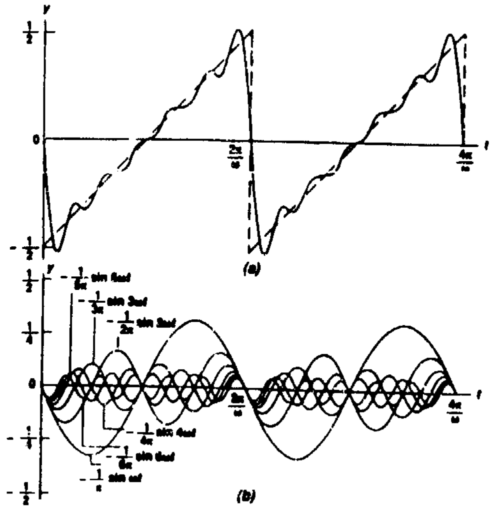
34

VJY488.1 M15AA

## FAR FUTURE PROPULSION SCHEMES (CONT)

- Antigravity
  - Gravity waves will be fully characterized (Why not?)
  - Each celestial body sends out waves whose amplitude and frequency are directly related to its mass and size
  - The net gravity field at any point in space is the result of the gravity wave interference pattern
  - Super sensors and supercomputers analyze this wave pattern and identify its basic components
  - An "antigravity wave generator" will then generate waves of precisely the same amplitude and frequency but of opposite phase. Thus, by causing an exact destructive interference, it will precisely cancel out the gravity field
  - A suitable propulsion system can then accelerate the vehicle to very high velocities with a rather low force and low energy expenditure

# WAVE INTERFERENCE



*(a)* The dashed line is a sawtooth "wave" commonly encountered in electronics. The Fourier series for this function is $y(t) = -\frac{1}{\pi}\sin\omega t - \frac{1}{2\pi}\sin 2\omega t - \frac{1}{3\pi}\sin 2\omega t - \cdots$.

The solid line is the sum of the first six terms of this series and can be seen to the approximate the sawtooth quite closely.

*(b)* Here we show the first six terms of the Fourier series which, when added together, yield the solid curve in *(a)*.



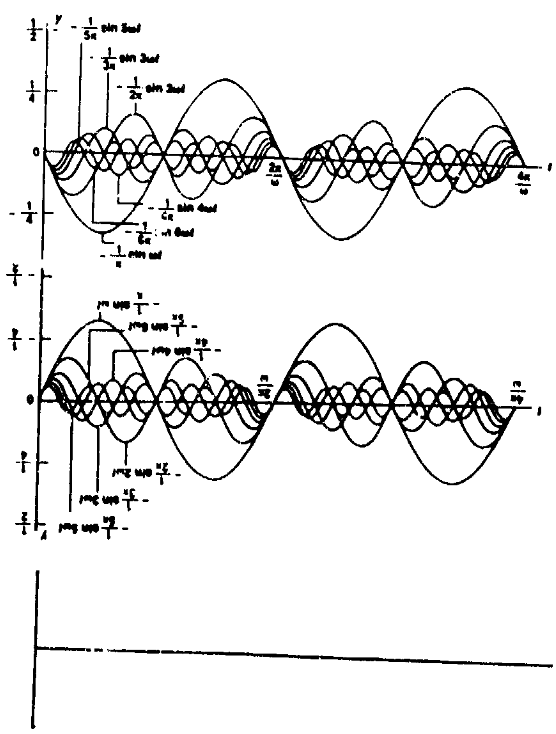


# WAVE DESTRUCTIVE INTERFERENCE

Wave

"Anti-Wave"

Result: No Wave



VJY481 M18AA

## SCIENCE FICTION?

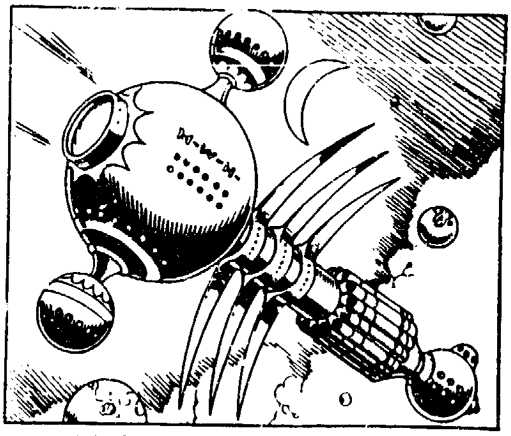
*Yes!*

- Science fiction of one time period is science fact of some later time
- Let us consider the following

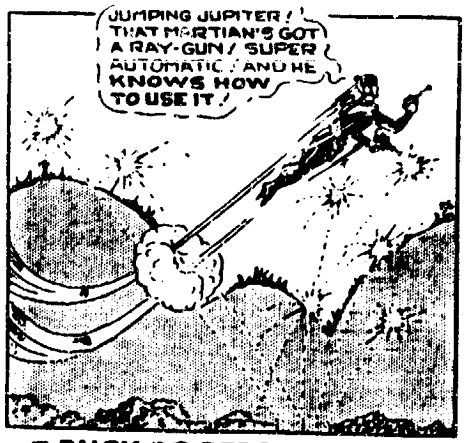
38

## DUCK ROGERS IN THE 25th CENTURY

# SCIENCE FICTION 1934



■ BUCK ROGERS' SPACESHIP



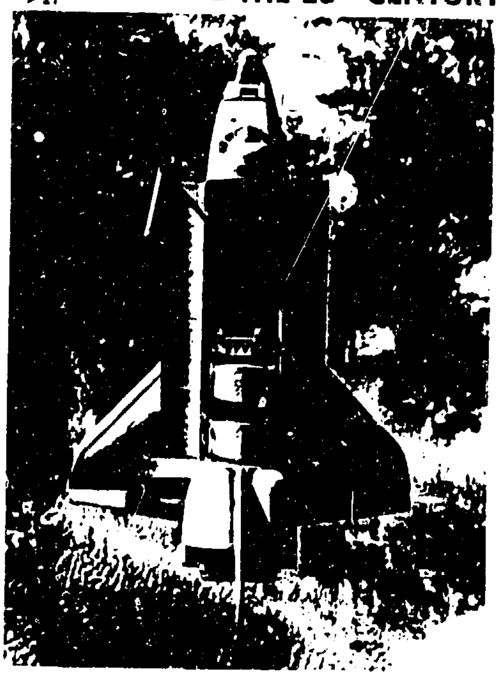

■ BUCK ROGERS WITH HIS FLYING BELT



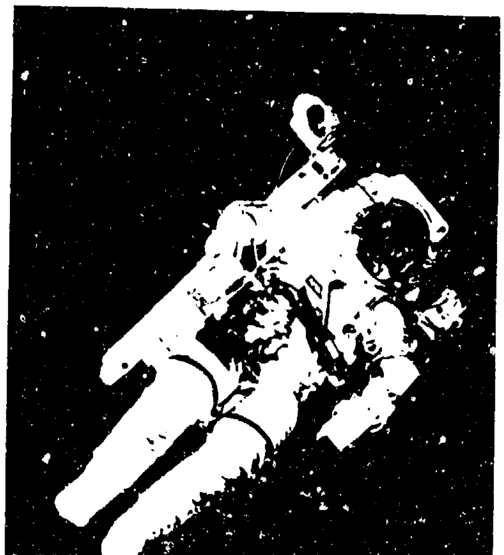
40

# SCIENCE FACT 1934

■ THE 25TH CENTURY ARRIVED IN 50 YRS



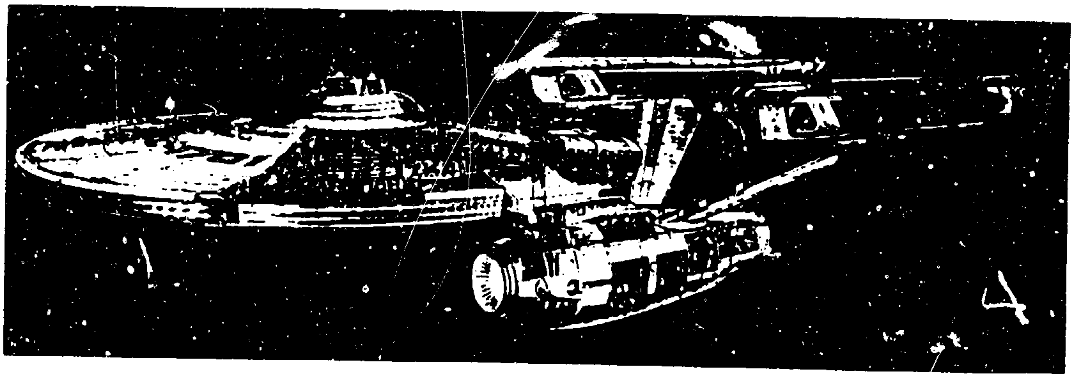
■ ASTRONAUT'S SPACE SHIP



■ NASA ASTRONAUT WITH HIS "FLYING BELT"

## "STAR TREK"
### SCIENCE FICTION 1966

- 23RD CENTURY STARSHIP ENTERPRISE POWERED BY AN ANTIMATTER REACTION CHAMBER CAN REACH SPEEDS UP TO WARP 8

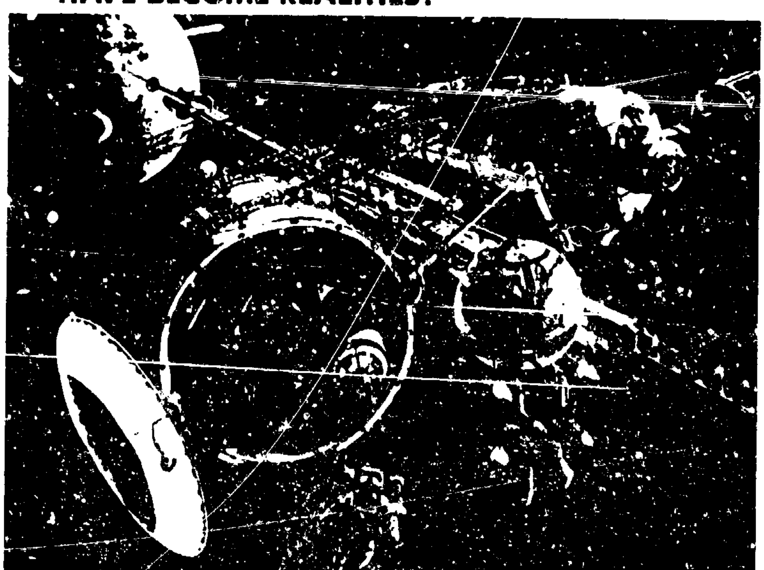




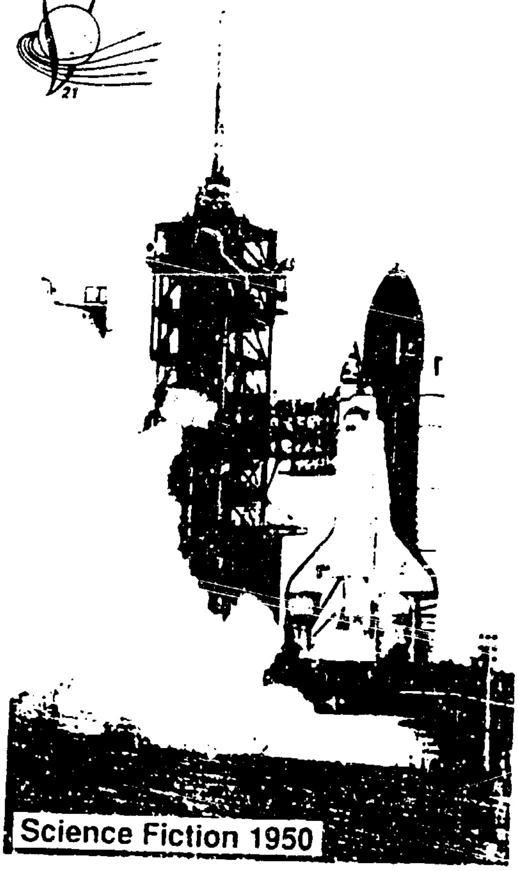
42

## SCIENCE FACT 2016?
### (50 YEARS LATER)

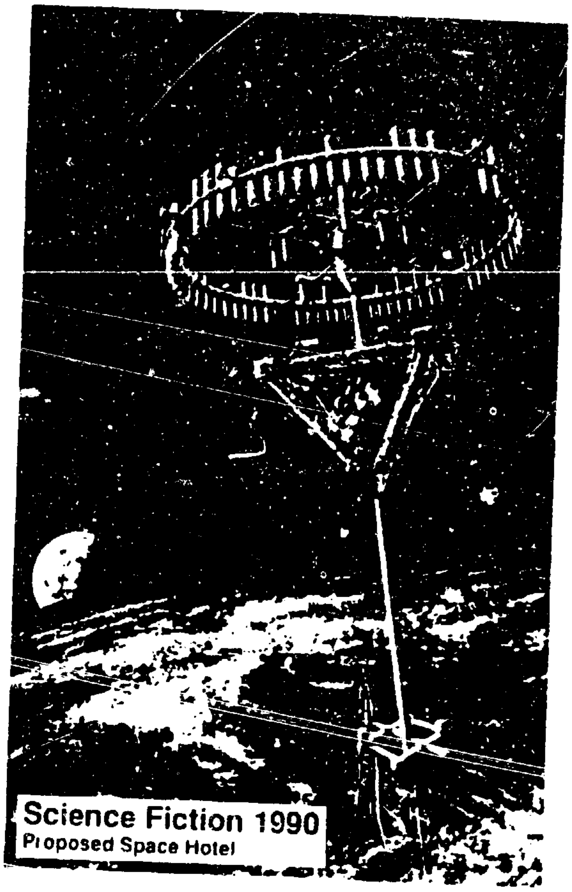
- WILL THE 23RD CENTURY HAVE ARRIVED?
- WILL STARSHIP ENTERPRISE AND STARBASE 12 HAVE BECOME REALITIES?



"PIONEERING THE SPACE FRONTIER"



Science Fiction 1950



Science Fiction 1990
Proposed Space Hotel



44

VJY462 2 M15AA

## CAN WE DO IT?

- Recent history tells us: Yes!
- We went from Sputnik 1 to Apollo 11 in less than 12 years
- From the basic university lab atom splitting experiment (Berlin, Dec 1938) to Hiroshima and Nagasaki (Aug 1945) in 6.5 years
- We need a strong resolve, committment of resources, and dedication
- We should not be afraid of risk and failure

VJY488.1 M16AA

- Some of the greatest advances and discoveries resulted from some apparent "failure" and setback

**Example:** The negative results of the Michelson-Morley experiment resulted in the Theory of Relativity, $E = MC^2$ etc.

The space exploration initiative, some times called "The Bush Push", will present us with unparalleled challenges and it will undoubtedly lead to even greater developments and discoveries

*Go For It!*

46

VJW206.2 M2CA

## HISTORIC SCIENTIFIC MILESTONES

- 1905: $E = MC^2$
- 1938/39: Uranium Nucleus Split/Einstein writes to FDR
- 1945: Alamogordo – Hiroshima – Nagasaki (40 years later)
  - Notes: – Pressing need (WWII)
    – Manhattan Project, $$$, etc.
- 1955: – Antiproton is discovered
  – Antimatter becomes fact
- 1984: – Trapping and storage of antiprotons achieved
- 1995: ? ? ?
  (40 years later)

SHOULD WE BE DOING SOMETHING?

## FAMOUS PRONOUNCEMENTS

- "Heavier than air flying machines are impossible"
  Lord Kelvin, President, Royal Society, 1895
- "Everything that can be invented has already been invented"
  Charles H. Duell, Director of U.S. Patent Office, 1899
- "There is no likelihood man can ever tap the power of the atom"
  Robert A. Millikan, Nobel Prize in Physics, 1923
- "Who the hell wants to hear actors talk"
  Harry M. Warner, Warner Bros. Pictures, 1927