

# N91-22155

H5830

## 21ST CENTURY PROPULSION

V. E. (Bill) Haloulakos  
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McDonnell Douglas Space Systems Company  
Huntington Beach, California

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

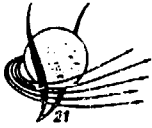
NASA Lewis Research Center, Cleveland, Ohio  
3-4 April 1990



VJY446 M15AA

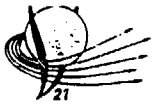
## SPACE TRAVEL IN THE NEXT MILLENIUM?

- 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



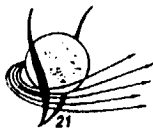
- Ray of hope: The laws of physics are known to have been through many evolutionary and revolutionary changes. In fact, they are in a continuous state of flux**
- Example: For many centuries physics was taught with the atom being exactly what the word means, INDIVISIBLE. Now, of course, atom is just a name and its splitting is history.**

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## **GOALS FOR THE 21ST CENTURY**

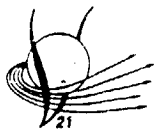
- Expanded space travel and establishment of permanent manned outposts**
- Lunar and Mars outposts represent the most immediate future in space travel and both have history from the very recent past**



VJY4C9 1 M15AA

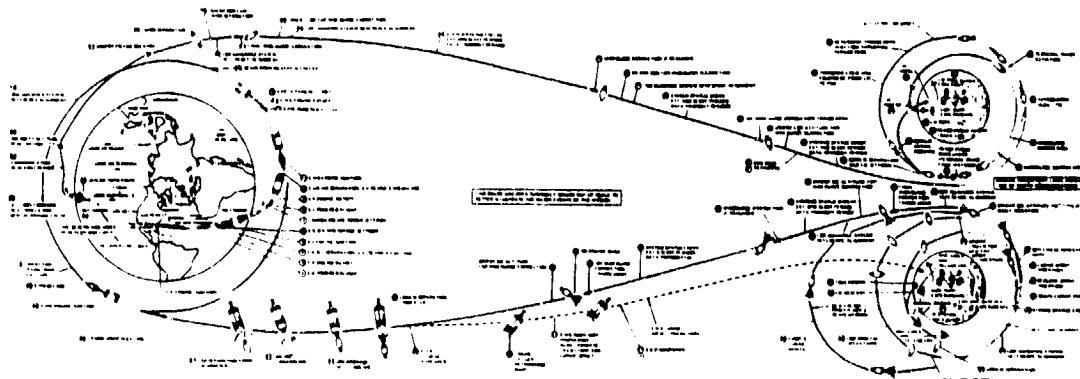
## LUNAR OUTPOSTS

- 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

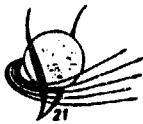


VJY4B0 M15AA

## APOLLO 16 MISSION PROFILE

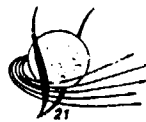


ORIGINAL PAGE IS  
OF POOR QUALITY



## 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<sub>2</sub>/H<sub>2</sub>) with direct nuclear thermal propulsion using the NERVA engine
  
- The following charts summarize the trades and vehicle designs conducted between 1965 and 1973



## 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

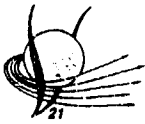
ON TO MARS (REVISITED)

C. BOEHMER

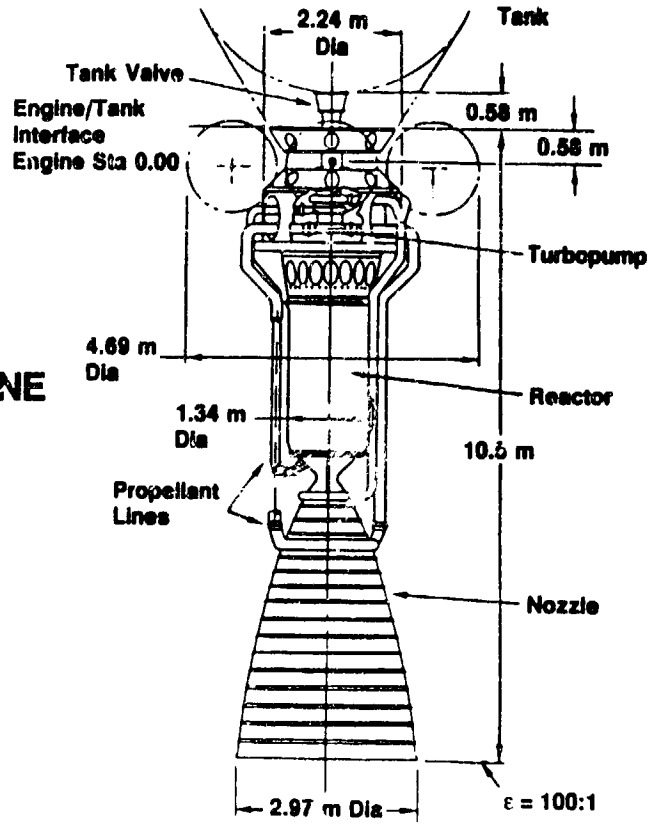
Presented to  
2nd AIAA/JPL International Conference  
on Solar System Exploration  
Pasadena, California  
22-24 August 1989

McDonnell Douglas Space Systems Company

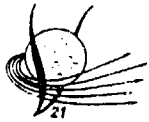
**MCDONNELL DOUGLAS**



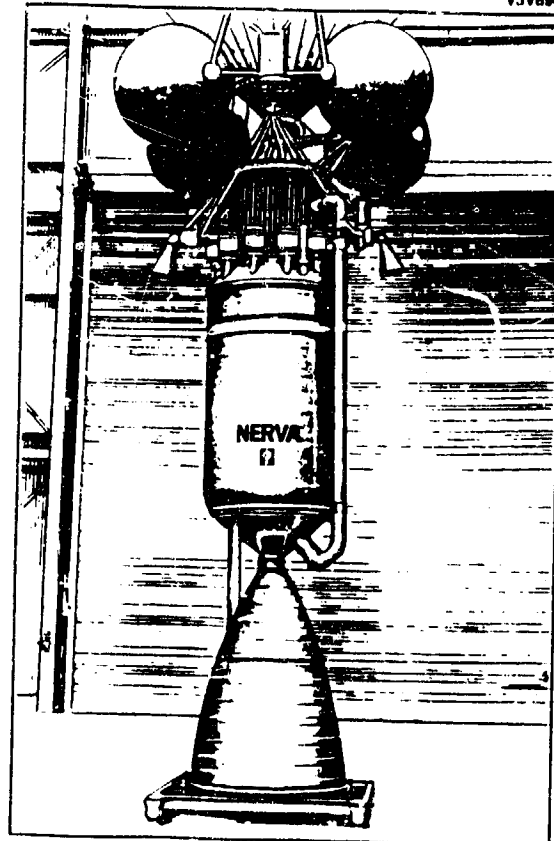
VHV768



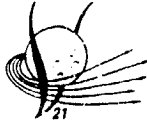
### NERVA FLIGHT ENGINE CONFIGURATION



VJV890



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

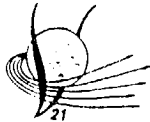


## NUCLEAR ROCKET REACTOR TESTING LASL (LANL)

	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

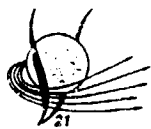
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## NUCLEAR ROCKET REACTOR/ENGINE TESTING WESTINGHOUSE/AEROJET



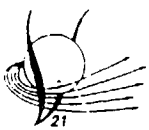
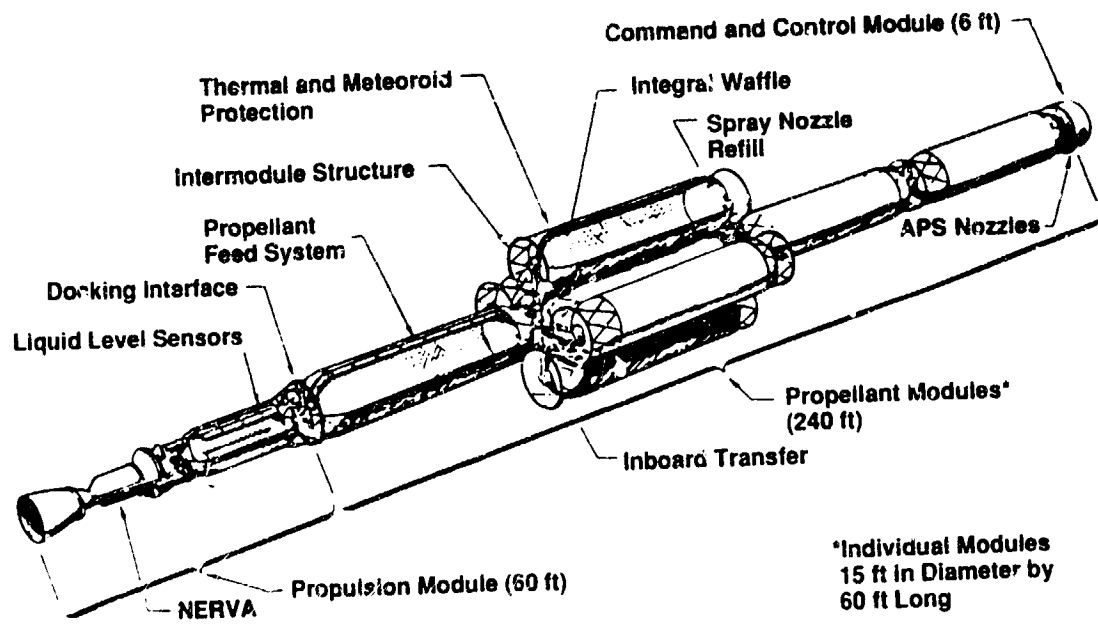
	Date	Power Level (MW)	Run Time (min)
NRX - A2	Sept 1964	1100	5
NRX - A3	April 1965	1100	17
NRX - EST	March 1966	1100	28
NRX - A5	June 1966	1100	30
NRX - A6	Dec 1967	1100	60
XE	Mar 1969	1100	10

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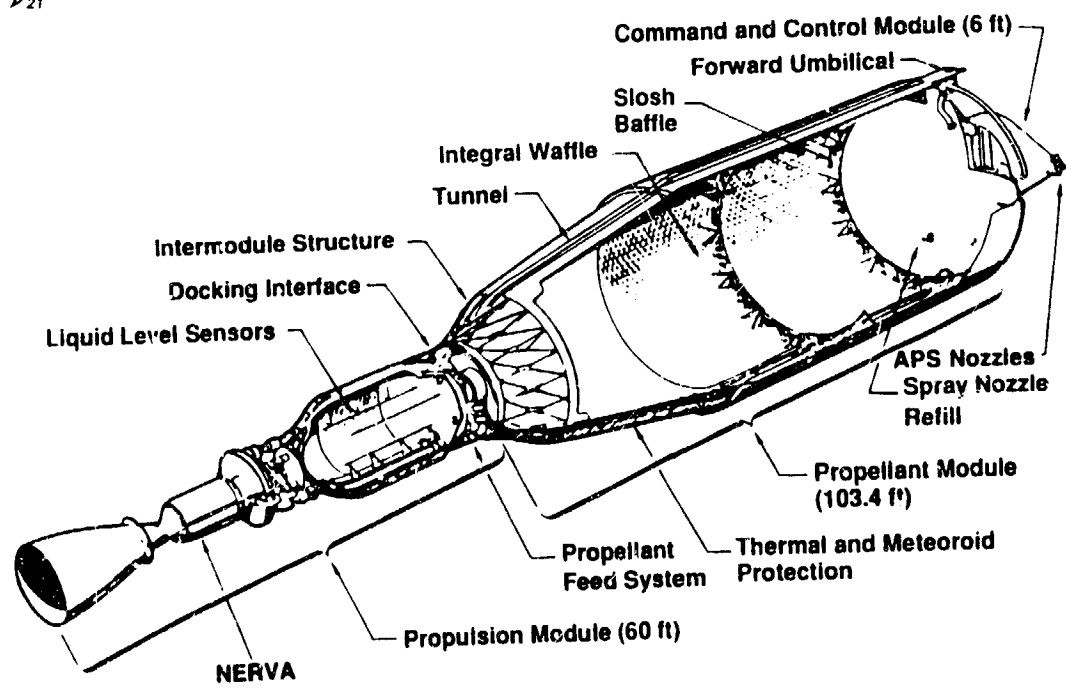
VJV872.1

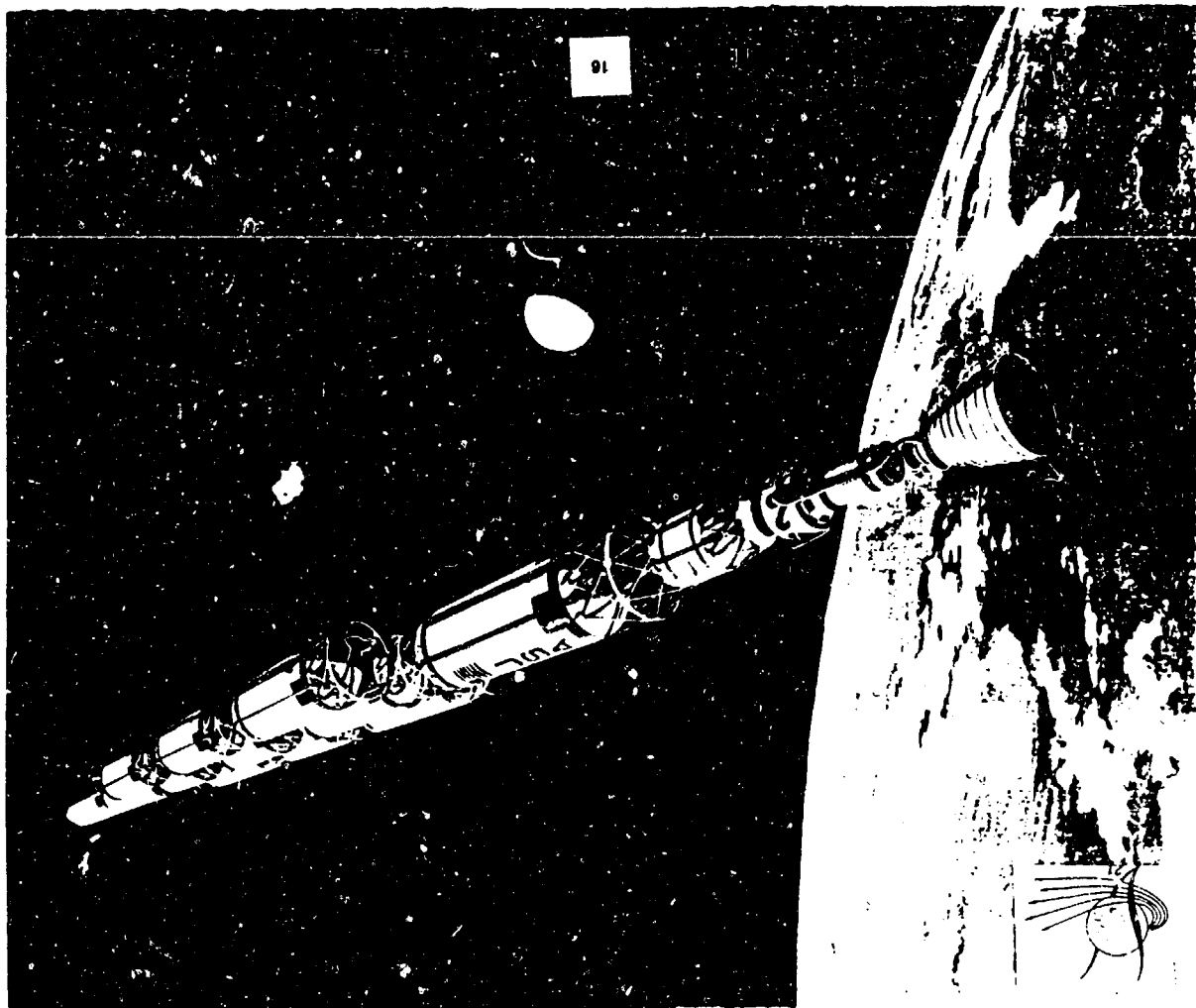
# CLASS 3 MULTI-MODULE RNS



VJV873.1

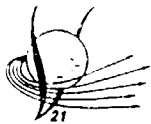
# CLASS 1 SINGLE-MODULE HYBRID RNS





## NUCLEAR STAGE DESIGN/PROGRAM CONSIDERATIONS

VJX042 M1CV



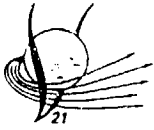
- Structure
- Propulsion
  - Auxiliary
  - Nuclear
- Electrical
  - Power
  - Guidance/Navigation
  - Control
  - Communications
- Thermal Control
- Radiation Protection
  - Configuration
  - Shielding
- Propellant Control
  - Pressurization
  - Chilldown



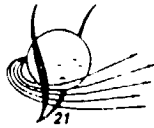
# NUCLEAR STAGE DESIGN/PROGRAM CONSIDERATIONS

(Continued)

VJX042 M1CV

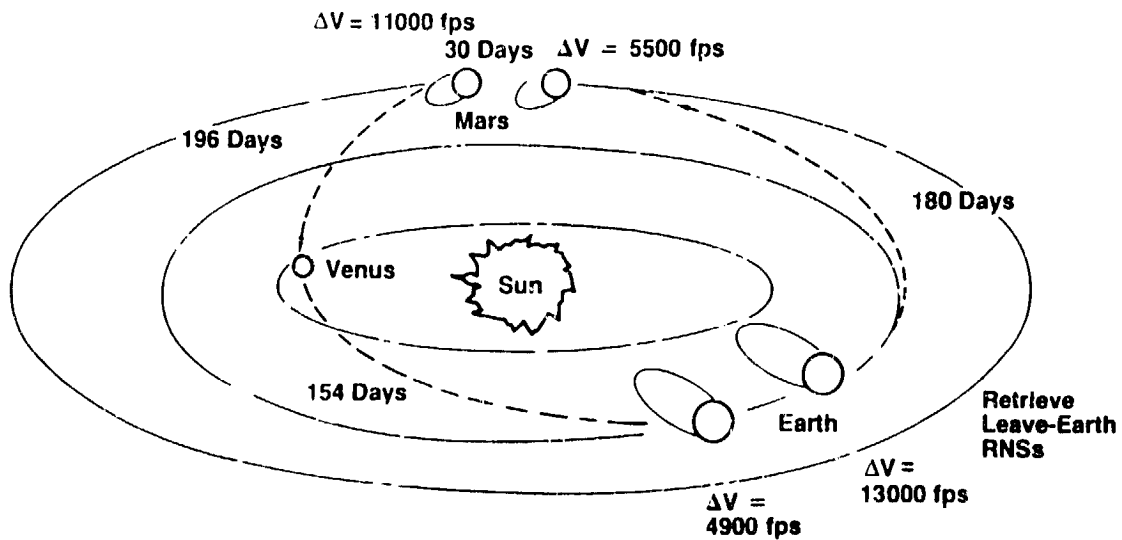


- Weight/Mass Control
- Ground/Orbital Operations
  - Assembly
  - Maintenance
- Safety
- Reliability
- Manufacturing
- Test Plan
  - Component
  - Systems
  - Battleship
- Program Schedule
- Costs



## 1988 MARS LANDING PROFILE

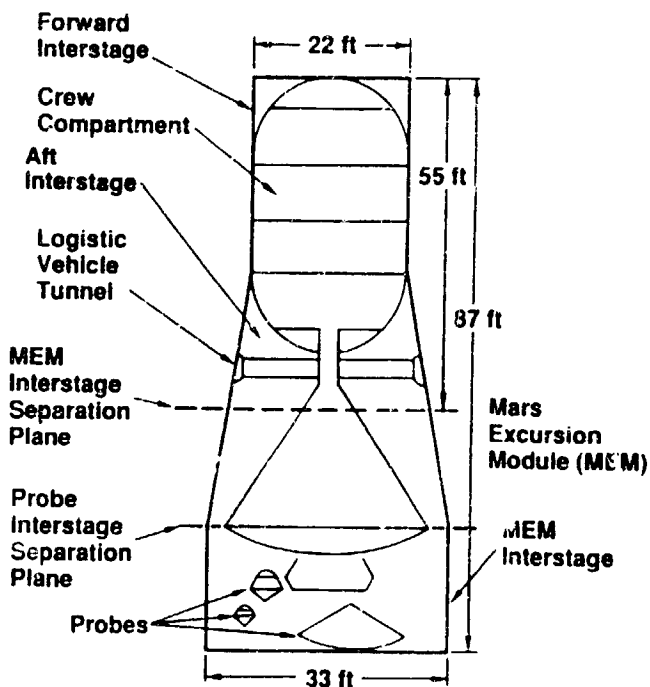
VJV877.1





# MSFC MANNED MARS SPACECRAFT CONCEPT

VJV878.1



	Weight (lb)
Mission Module	82,900
Mars Excursion Module	95,290
Mars Probes	36,000
Venus Probes	4,000
interstages	21,000
<b>Total Spacecraft</b>	<b>239,190</b>



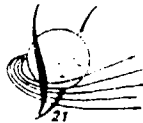
# PROPELLANT REQUIREMENTS - BASELINE MODE

VJV879.1

RNS Number		$\Delta V$ (1000 fps)	$W_p$ (1000 lb)	A'Cool (1000 lb)	$W_p$ (%)
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

\*  $t_{SP} = 450$  sec

Total Propellant Required = 1,097,800 lb



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

VJX031 M2BZ

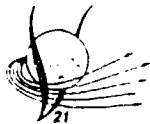
## Class 1

- 4 stages, 1,097,800 lb LH<sub>2</sub>
- 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<sub>2</sub>
  - 4 launches of 174,000 lb LH<sub>2</sub> (assume 6000-lb tank)

## Class 3

- 4 stages (1 propulsion, 8 propellant, 1 command and control module)
  - Assume 1,335,000 lb LH<sub>2</sub>
- 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<sub>2</sub>)
  - 6 launches 42,000 lb LH<sub>2</sub>

Total            42 launches (Space Shuttle/Titan IV)

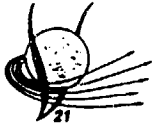


# NUCLEAR VERSUS CHEMICAL PERFORMANCE COMPARISON (SAME-STAGE TECHNOLOGY)

VJY452 M15AA

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	5	1977 triple planet	220,000 lb	S-IVC	4
	Nuclear-restart	3			Advanced chemical	4*
1980 Venus capture	Advanced Chemical	5			Nuclear	2
	Nuclear restart	3			Nuclear-restart	-
1982 Mars capture	Advanced Chemical	-	1978 dual planet	200,000 lb	S-IVC	3
	Nuclear restart	4			Advanced chemical	3*
					Nuclear	2
					Nuclear-restart	-
1978 Mars capture	Advanced Chemical	8	1976 dual planet, powered	200,000 lb	S-IVC	3
	Nuclear restart	4			Advanced chemical	-
					Nuclear	2
					Nuclear-restart	-

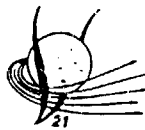
\* Requires two launches for payload



# VISIONS OF THE FUTURE

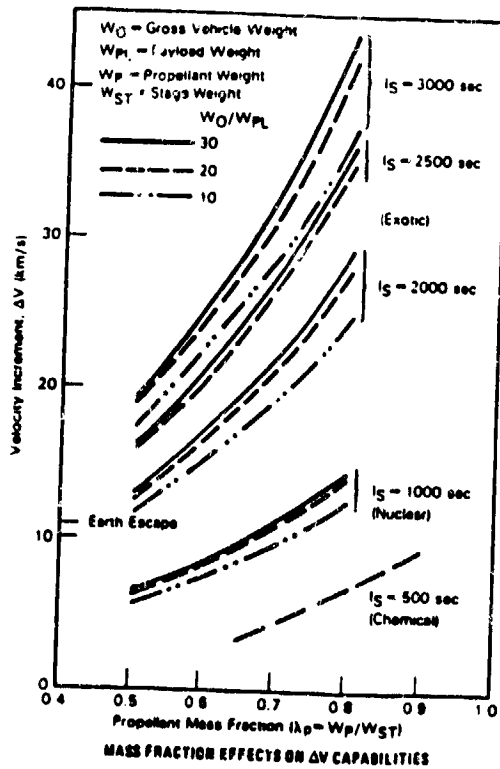
VJY680 M16AA

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

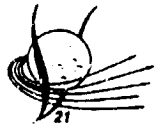


# PROPULSION SYSTEM $\Delta V$ CAPABILITIES

VJK178



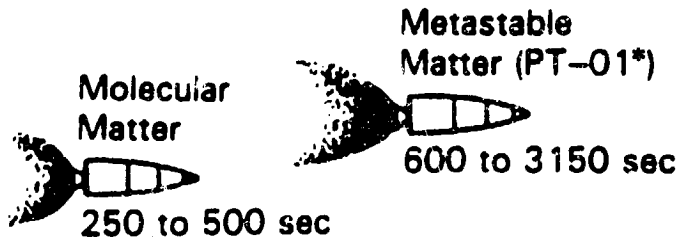
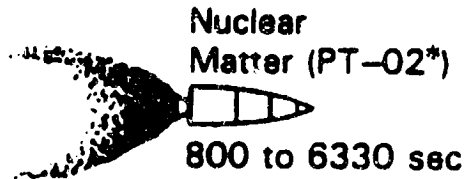
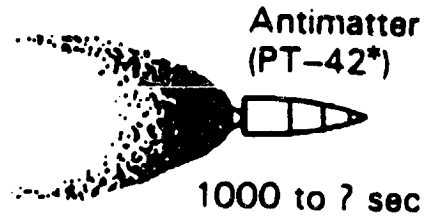
- Chemical propulsion can barely achieve earth escape with a single-stage vehicle
- Higher  $I_s$  propulsion systems substantially increase payload delivery capabilities
- New exotic propulsion systems need to be developed and made economical to produce, store and use



# SPECIFIC IMPULSES OF ROCKET FUELS

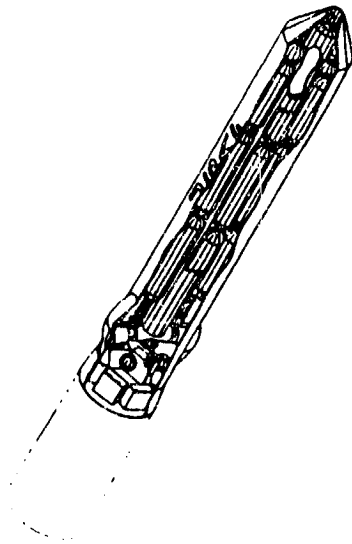
VJN716

**\*Project Forecast II  
Propulsion Technologies**



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MDC H5034C  
AIAA 89-2629  
MAY 1989



**FUSION PROPULSION SYSTEMS**

**V. S. MALOULAKOS, 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)

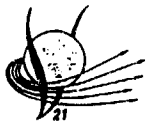
101041.1 1CX



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

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VJY464 M18AA

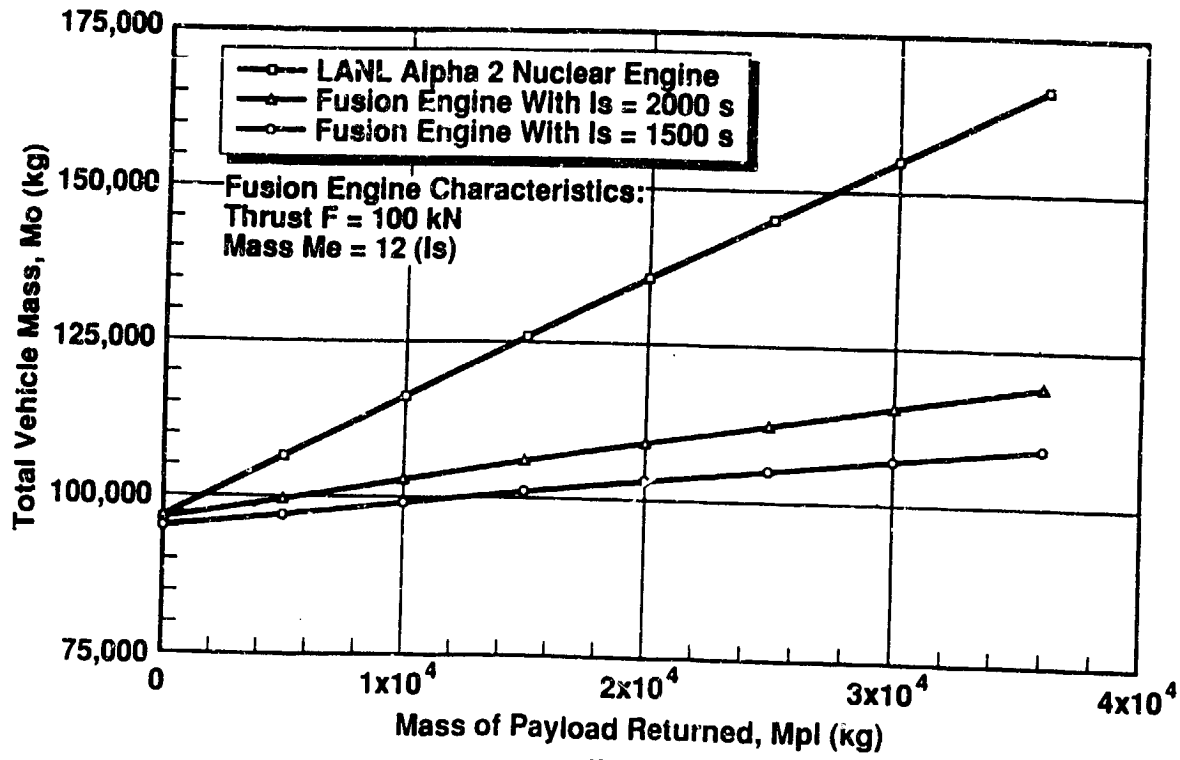


- The initial vehicle mass serves as the key criterion of optimization
- The higher specific impulse of the fusion system results in lower propellant and vehicle mass for the specified mission and payload

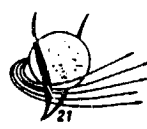


## FISSION AND FUSION ROTV COMPARISON

**TOTAL VEHICLE MASS vs. RETURNED PAYLOAD FROM GEO**  
Assumes Each Vehicle Has Delivered a 36,000 kg Payload to GEO



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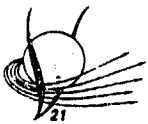


## MDC-GA FUSION SPACE TRANSFER VEHICLE SIZING DATA

101026 1CX

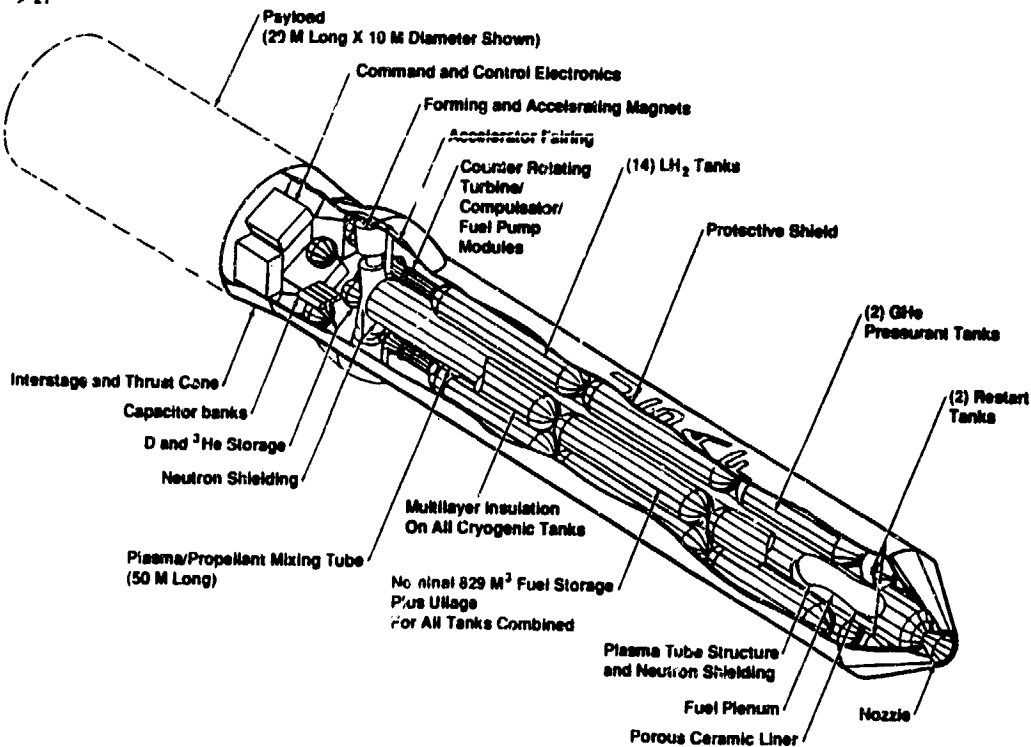
**Mission:** Transfer 36,000 kg to Geosynchronous Orbit (GEO)  
Return Vehicle Empty and with Original Payload  
**Engine:** GA Fusion Engine  
 $I_s = 1500 \text{ s}$ , Thrust = 100 kN, Mass = 12 (Is)

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

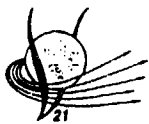


# FUSION-PROPELLED REUSABLE ORBIT TRANSFER VEHICLE

VJY486 M15AA



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# MATTER/ANTIMATTER ANNIHILATION

VJY456.1 M15AA

## □ 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**





## FAR FUTURE PROPULSION SCHEMES

VJY487.1 M15AA

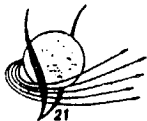
### Matter/antimatter

- 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

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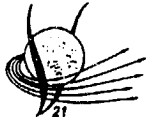


## FAR FUTURE PROPULSION SCHEMES (CONT)

VJY488.1 M15AA

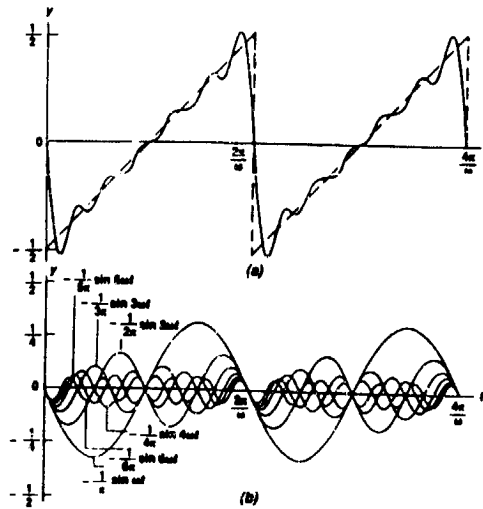
### Antigravity

- 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

VJY489 M15AA

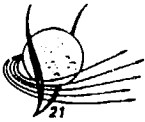


(a) The dashed line is a sawtooth "wave" commonly encountered in electronics. The Fourier series for this function is  $y(t) = -\frac{1}{\pi} \sin \omega t - \frac{1}{2\pi} \sin 2\omega t - \frac{1}{3\pi} \sin 3\omega t - \dots$

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

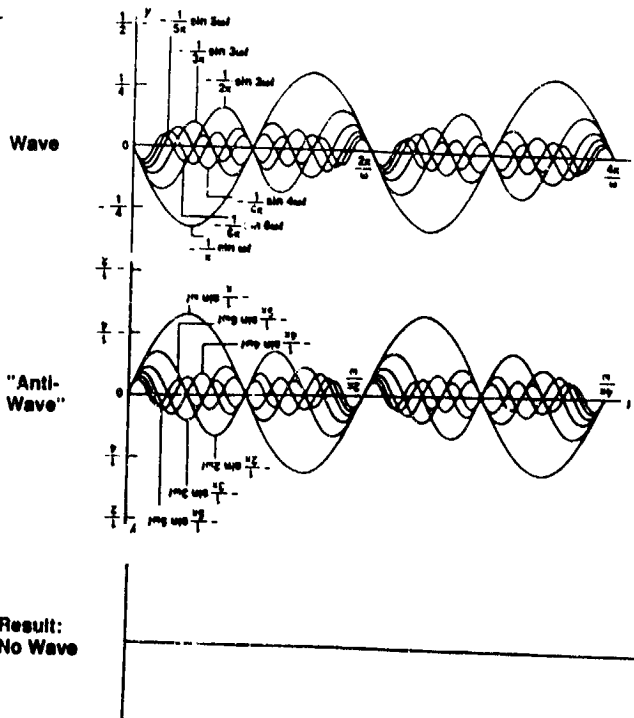
(b) Here we show the first six terms of the Fourier series which, when added together, yield the solid curve in (a).

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# WAVE DESTRUCTIVE INTERFERENCE

VJY480 M15AA





## SCIENCE FICTION?

*Yes!*

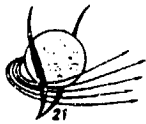
- Science fiction of one time period is science fact of some later time
- Let us consider the following

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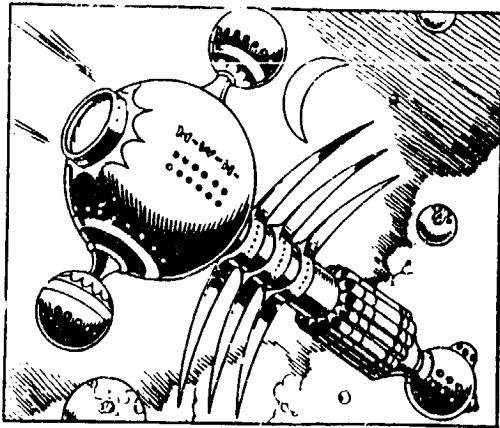


## DUCK ROGERS IN THE 25th CENTURY

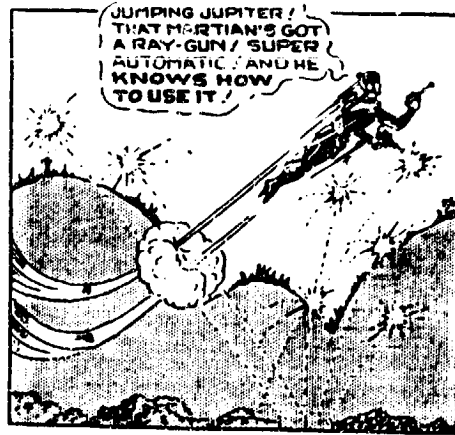




# SCIENCE FICTION 1934



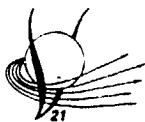
■ BUCK ROGERS' SPACESHIP



■ BUCK ROGERS WITH HIS FLYING BELT

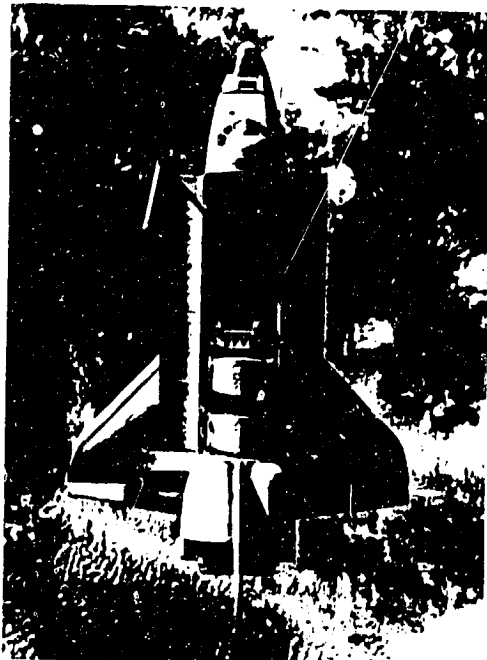
ORIGINAL PAGE IS OF POOR QUALITY

40

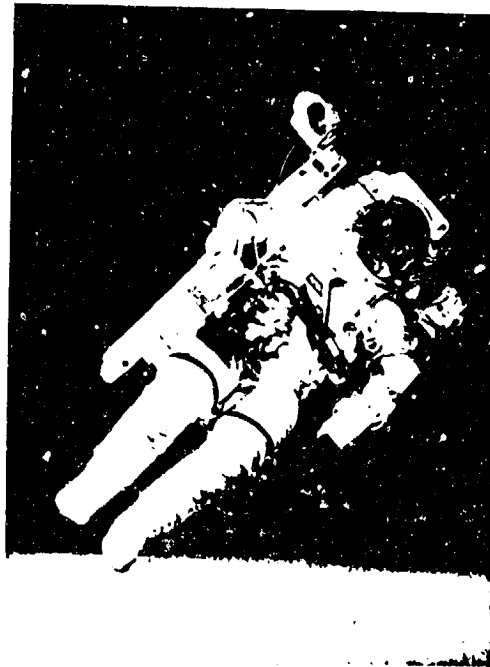


# SCIENCE FACT 1984

■ THE 25<sup>TH</sup> CENTURY ARRIVED IN 50 YRS



■ ASTRONAUT'S SPACE SHIP

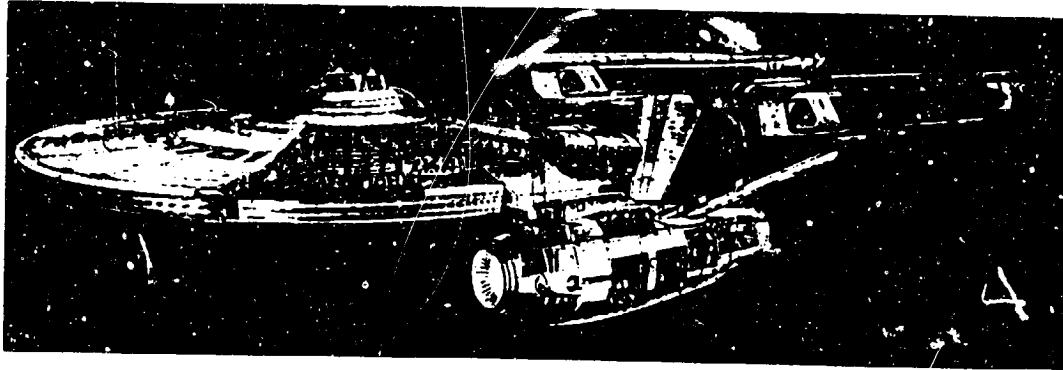


■ NASA ASTRONAUT WITH HIS "FLYING BELT"



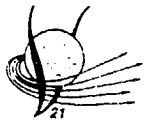
## "STAR TREK" SCIENCE FICTION 1966

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



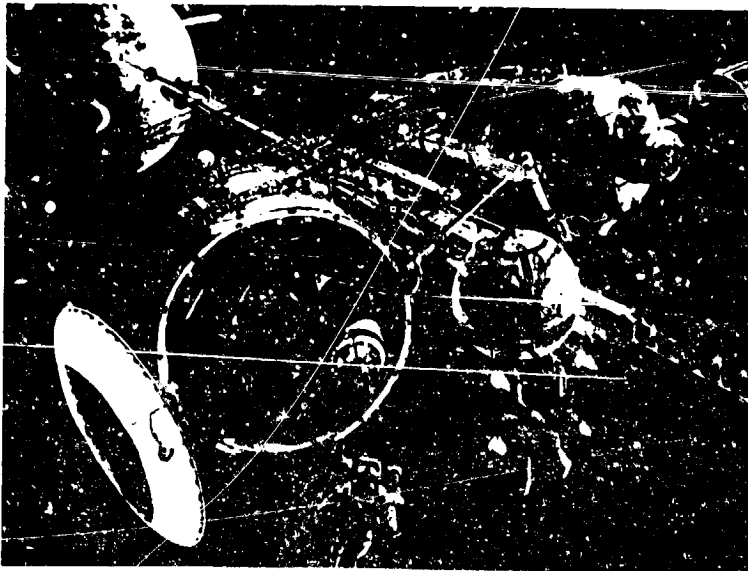
42

ORIGINAL PAGE IS  
OF POOR QUALITY

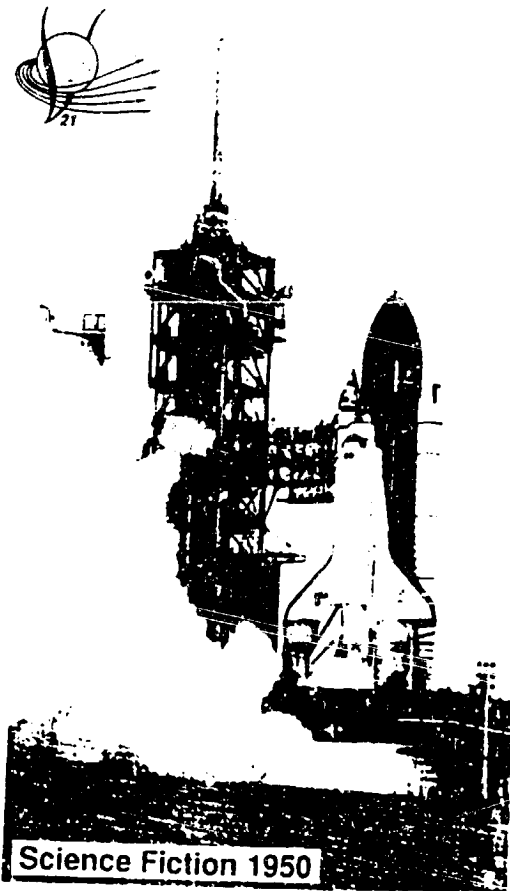


## SCIENCE FACT 2016? (50 YEARS LATER)

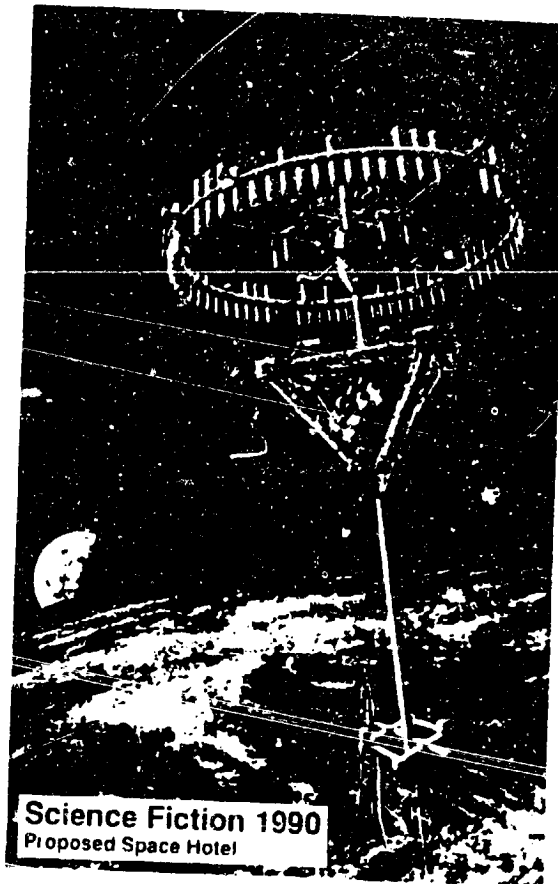
- WILL THE 23<sup>RD</sup> CENTURY HAVE ARRIVED?
- WILL STARSHIP ENTERPRISE AND STARBASE 12 HAVE BECOME REALITIES?



"PIONEERING THE SPACE FRONTIER"



Science Fiction 1950



Science Fiction 1990  
Proposed Space Hotel

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## CAN WE DO IT?

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- 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 railure



- 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!***

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## **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**