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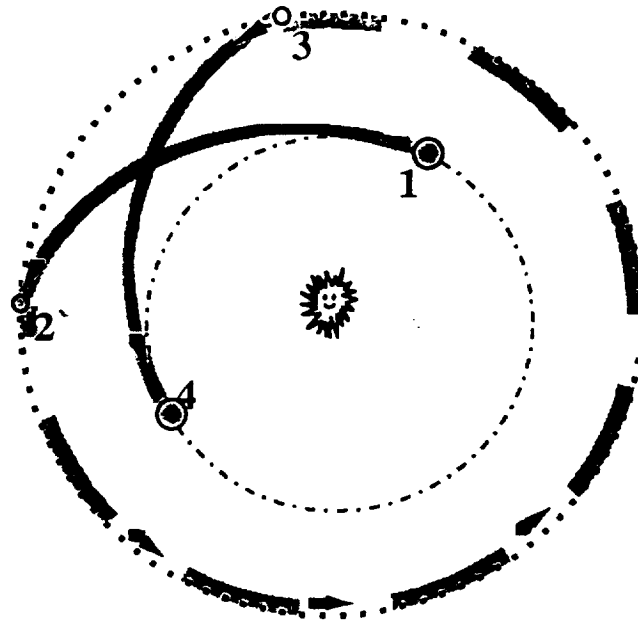
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Summer Faculty Final Presentation:

Mars Mission Design Handbook

2009 – 2024 Opportunities



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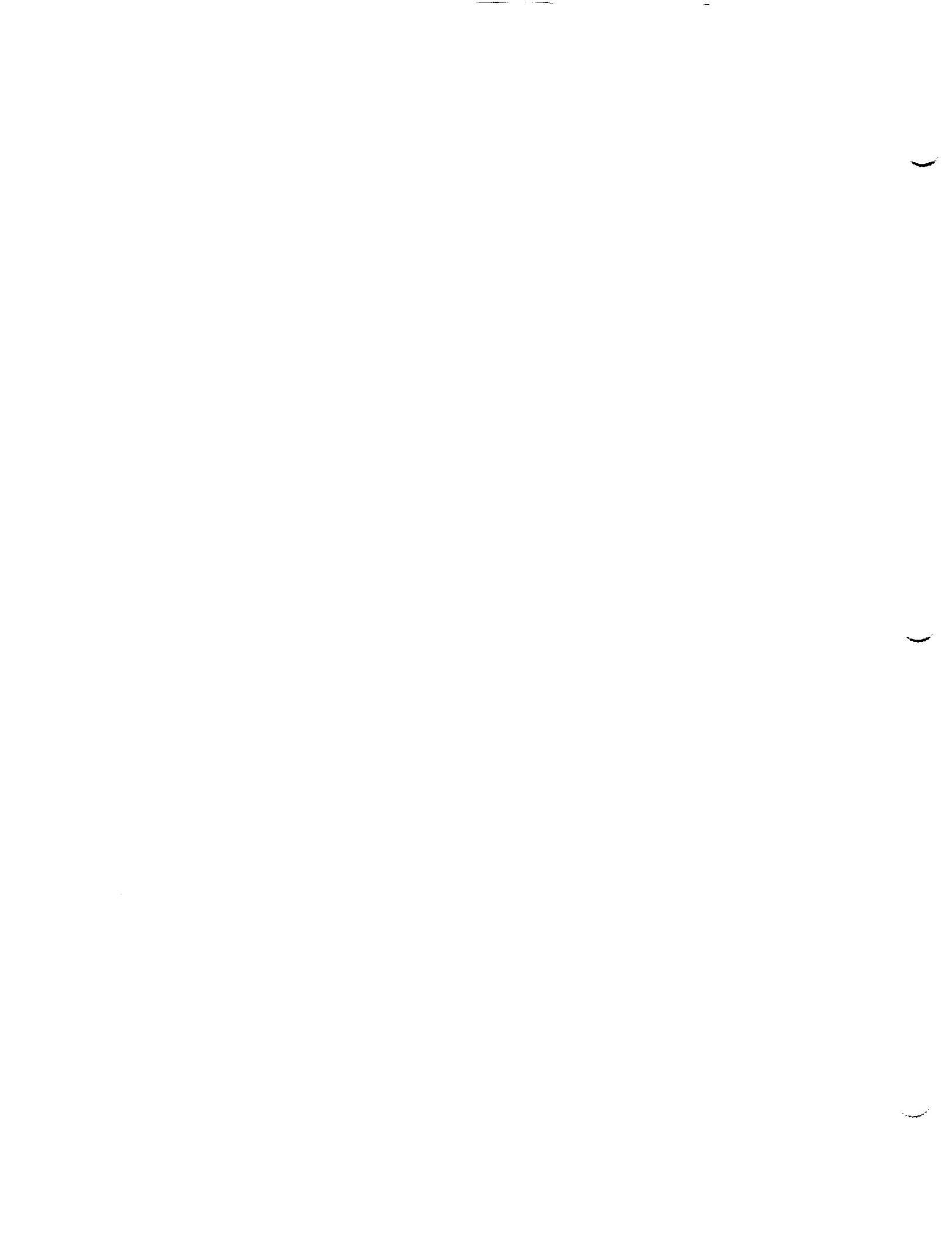
NASA Summer Faculty / PD32

Wednesday

July 30th, 1997

2:30 – 3:20

CR 329



INTRODUCTION/OVERVIEW

Purpose: To provide a mission
design handbook specifically
designed for a Human Mars
mission

2009-2024

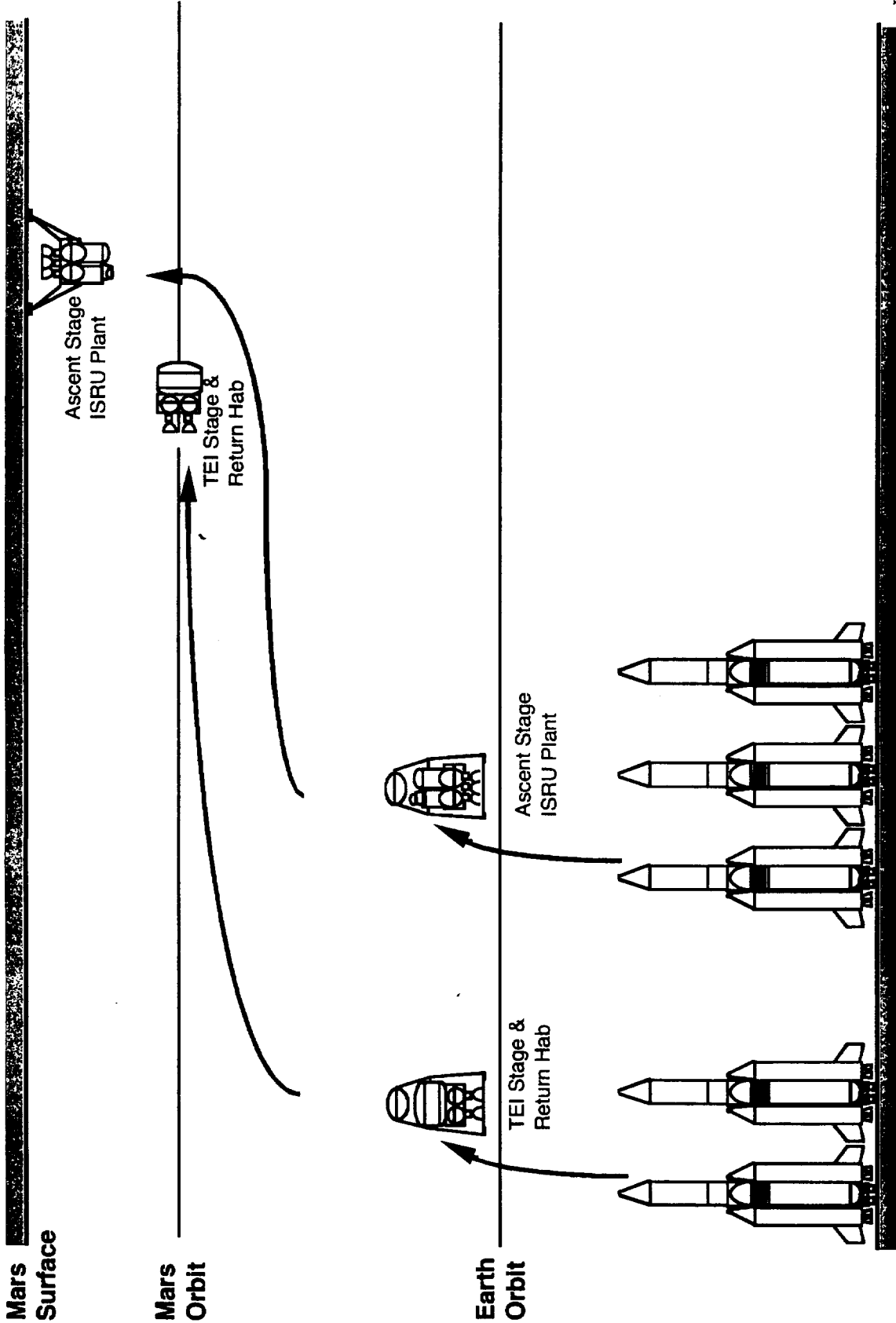
ASSUMPTIONS

- Used general ground-rules for HMM study
- Split mission (2 cargo/1 piloted)
- Earth departure:
 - Launch from LEO (400 km circular)
 - Nuclear thermal propulsion (LH₂)
 - Isp = 931 secs, three 15,000 lb thrust engines
 - 2 perigee burns at departure



Human Mars Mission Architecture

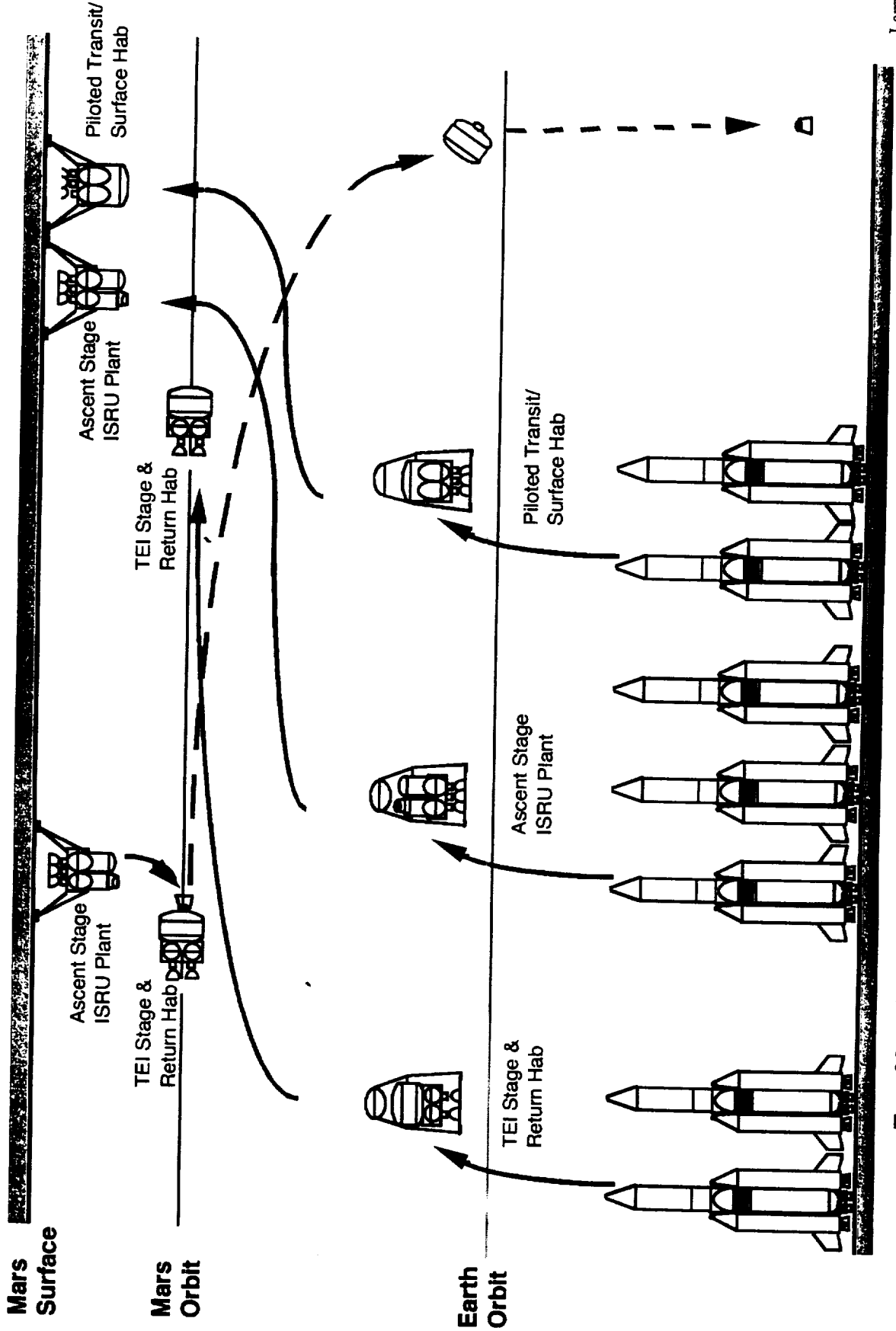
Design Reference Mission: 2011 Opportunity





Human Mars Mission Architecture

Design Reference Mission: 2014 Opportunity



Two 80 mt Launches (Six – Seven 80 mt LV Launches to include backup vehicles)

ASSUMPTIONS

- Mars arrival
 - Aerocapture
 - arrival speed limit 8.7 km/s
 - 250 x 33,793 altitude
- Mars departure (piloted only)
 - Depart from same orbit
 - TEI (Lox/Methane)
 - Isp = 379 secs, two 15,000 lb thrust engines
- Ballistic reentry at Earth (piloted only)
 - Arrival speed limit 14.5 km/s

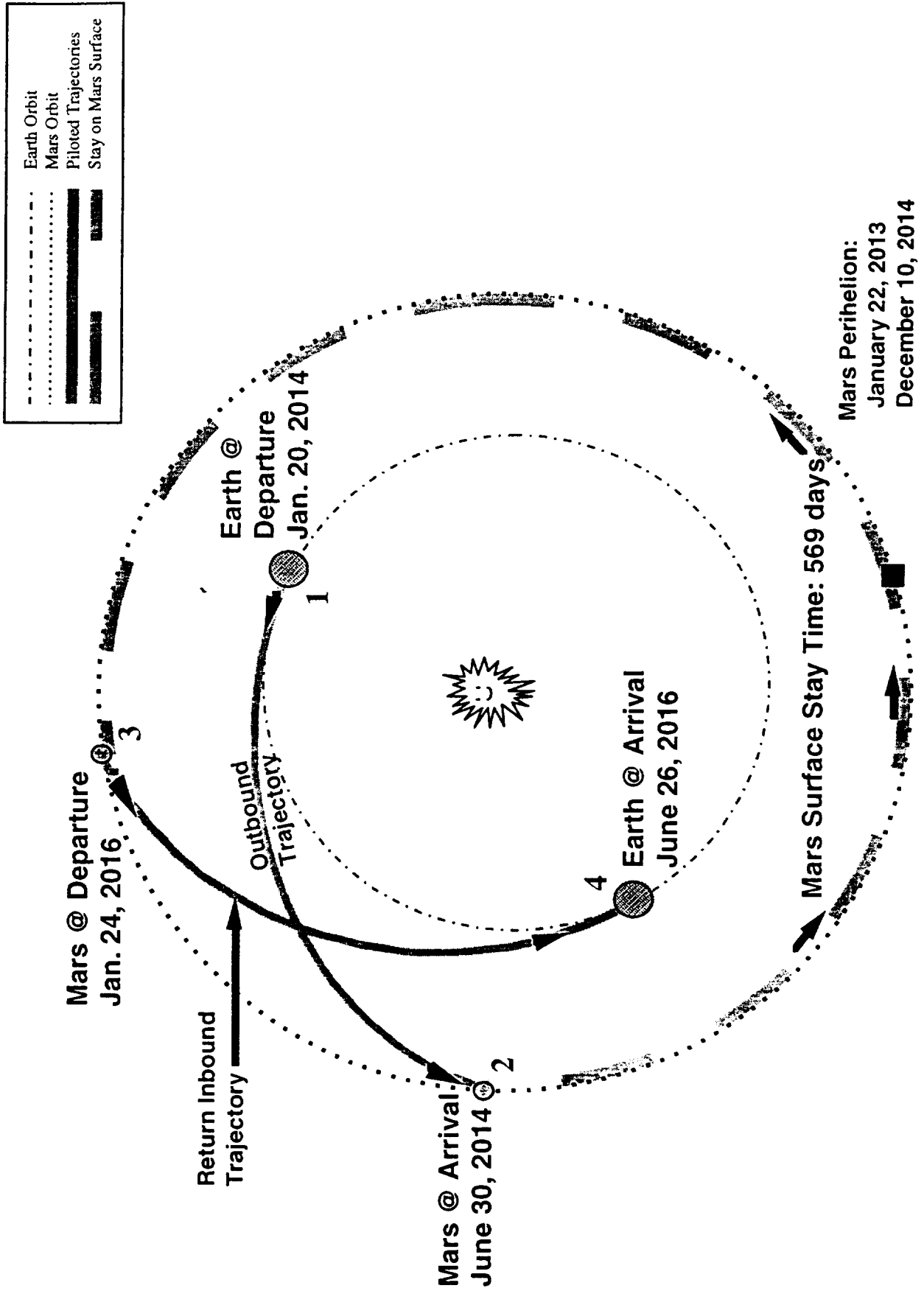
ASSUMPTIONS

- Cargo mission priority is minimum cost (minimum initial mass from LEO)
 - normally Type II
- Piloted missions limited to 180 days TOF each leg
 - normally type I



HMM 2014 Piloted DRM Trajectory

Flight Profile, 161 day Transit Out, 154 day Return



DESIGN REFERENCE MISSION TRAJECTORIES

Primary Cargo Mission Opportunities 2009:

<u>Mission</u>	<u>Launch Date</u>	TMI Velocity		Mars		
		<u>Delta V (m/s)</u>	<u>Losses (m/s)</u>	<u>C₃ (km²/s²)</u>	<u>Arrival Date (days)</u>	<u>TOF (days)</u>
Cargo 1	11/8/11	3673	92	8.95	8/31/12	297
Cargo 2	11/8/11	3695	113	8.95	8/31/12	297

Primary Piloted Mission Opportunities 2014:

<u>Launch Date</u>	TMI Velocity		Mars		<u>TEI Delta V (m/s)</u>	<u>Return Time (days)</u>	<u>Total Duration (days)</u>
	<u>Delta V (m/s)</u>	<u>Losses (m/s)</u>	<u>C₃ (km²/s²)</u>	<u>Arrival Date (days)</u>			
1/20/14	4019	132	15.92	6/30/14	1476	154	888
1/22/14	4018	131	15.92	7/21/14	1476	180	928

Window: 3 days

17 days

TOOLS USED/APPROACH

- Mission Analysis Environment for Heliocentric High Thrust Missions (MAAnE)
 - 1st developed mass models and used to verify
 - Older trajectories
 - JPL “porkchop” plots



Human Mars Mission: Design Reference Mission

DRM "Scrub v3.0" Architecture: 2011 / 2014 Opportunity

-62 days / TMI:

$m_{ab} = 10.6$ mt

$m_{retHab} = 21.6$ mt

TEI Stage (2 RL-10s):
(boil-off: 0.3%/mo ave.)

$m_{dry} = 4.6$ mt

$m_p = 31.3$ mt

24 RCS thrusters

$m_{pyld} = 68.2$ mt

-32 days / TMI:

MLI ETO shielding

$L_{tank} = 20$ m (typ)

TMI Stage:

(boil-off: 1.6%/mo LEO)

$m_{dry} = 22.4$ mt

$m_p = 46.3$ mt

$m_{stage} = 68.7$ mt

3 15 klb_r NTP engines

12 RCS thrusters

2011 TMI Stack 1: 136.9 mt

-92 days / TMI:

$m_{ab} = 16.0$ mt

$m_{serv} = 5.5$ mt

Ascent Stage (2):

$m_{dry} = 2.6$ mt

$m_p = 38.2$ mt

Surface Payload:

$m_{cargo} = 32.5$ mt

(incl. $m_{LH2} = 4.5$ mt)

Descent Stage (4):

$m_{dry} = 4.2$ mt

$m_p = 17.1$ mt

24 RCS thrusters

$m_{pyld} = 77.9$ mt

-2 days / TMI:

TMI Stage:

$m_{dry} = 22.4$ mt

$m_p = 50.6$ mt

$m_{stage} = 73.0$ mt

3 15 klb_r NTP engines

12 RCS thrusters

2011 TMI Stack 2: 150.8 mt

-62 days / TMI:

$m_{ab} = 14.0$ mt

$m_{crew} = 0.5$ mt

Surface Payload:

$m_{transHab} = 19.3$ mt

$m_{misc} = 9.8$ mt

Descent Stage (4):

$m_{dry} = 4.2$ mt

$m_p = 17.3$ mt

24 RCS thrusters

$m_{pyld} = 65.1$ mt

-32 days / TMI:

TMI Stage:

$m_{dry} = 25.6$ mt

$m_p = 51.7$ mt

$m_{stage} = 77.3$ mt

3 15 klb_r NTP engines

12 RCS thrusters

2014 TMI Stack (5): 142.4 mt

Larry Kos

MSFC/PD32

v3. 7/10/97

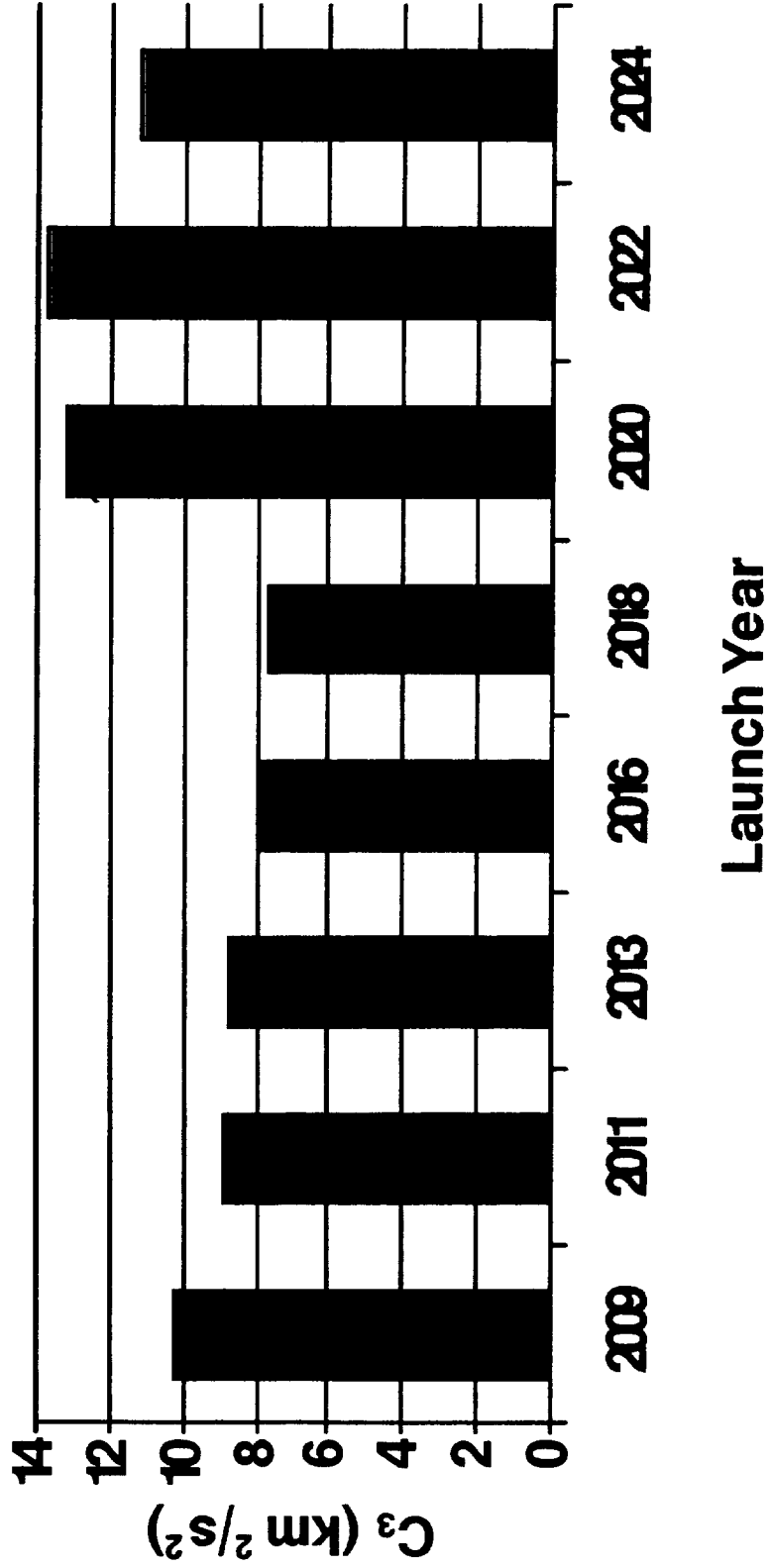
TOOLS USED

- MAnE modeling
 - Inputs
 - Mass models (DRM used)
 - Estimated departure and arrival dates
 - End criteria (net spacecraft delivery mass, TOF, departure or arrival excess speed)
 - Optimization criteria (minimum initial mass, TOF, or total Delta V)

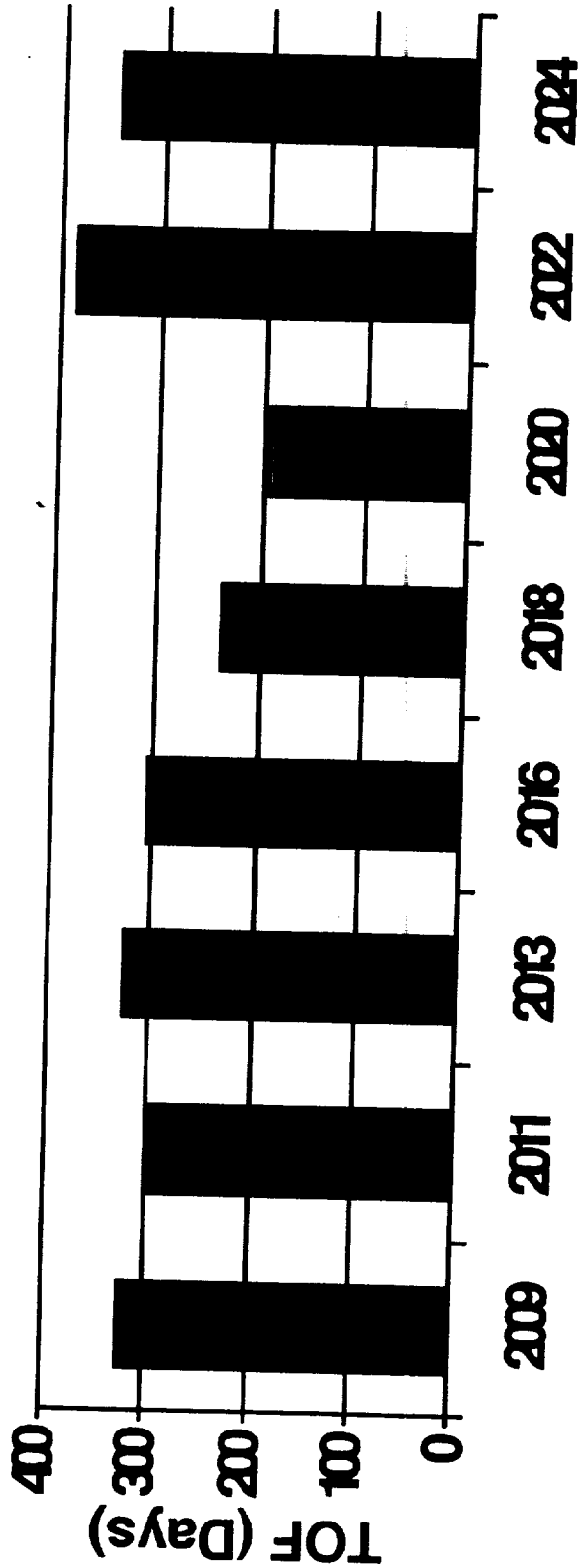
TOOLS USED

- MAnE
 - Output
 - Optimal trajectory along with departure and arrival data
 - Delta Vs
 - Velocity losses
 - Departure and arrival excess speeds

Cargo mission Departure Energies

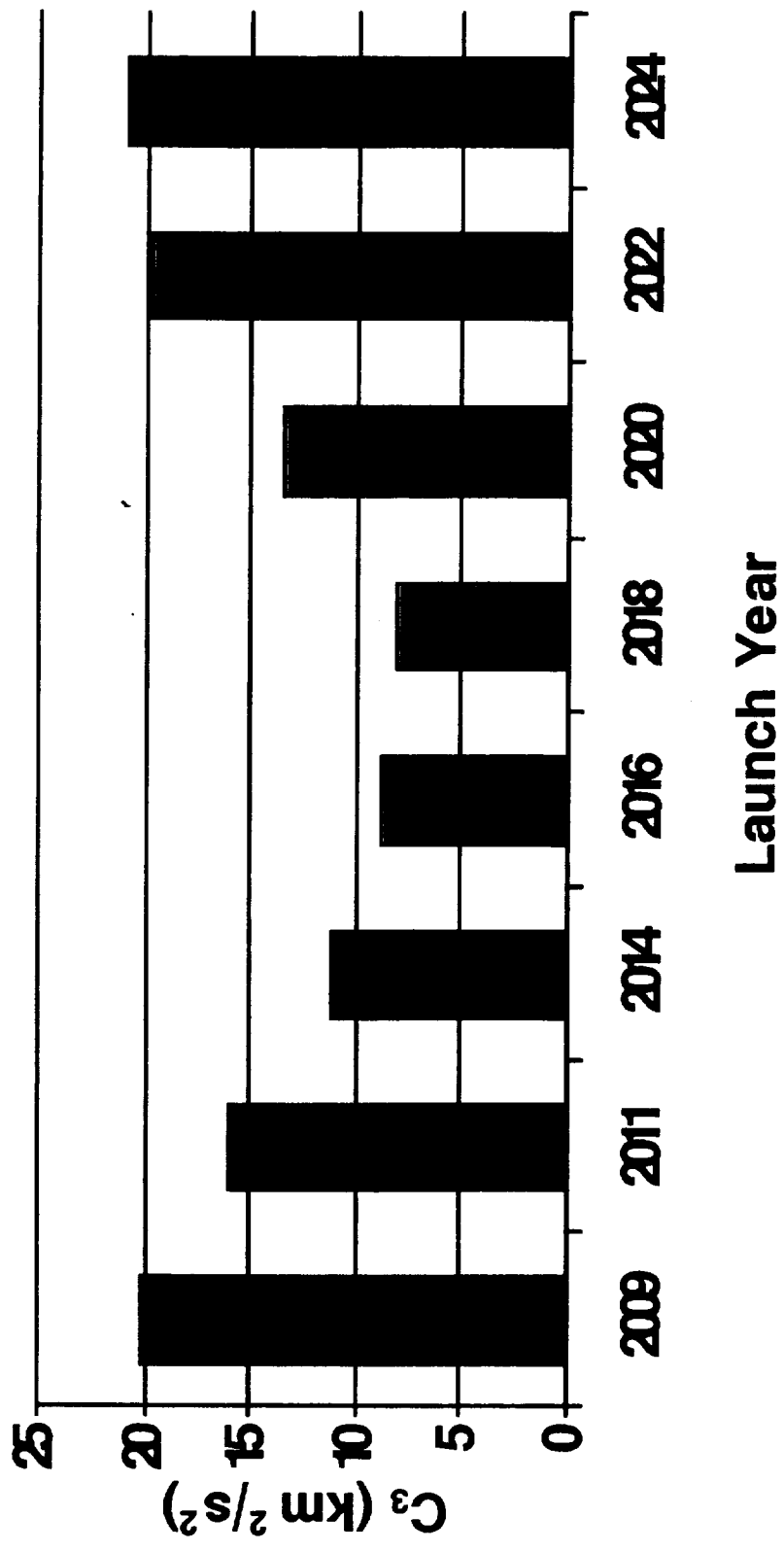


Cargo mission Durations



Launch Year

Piloted Optimal Mission Departure Energies



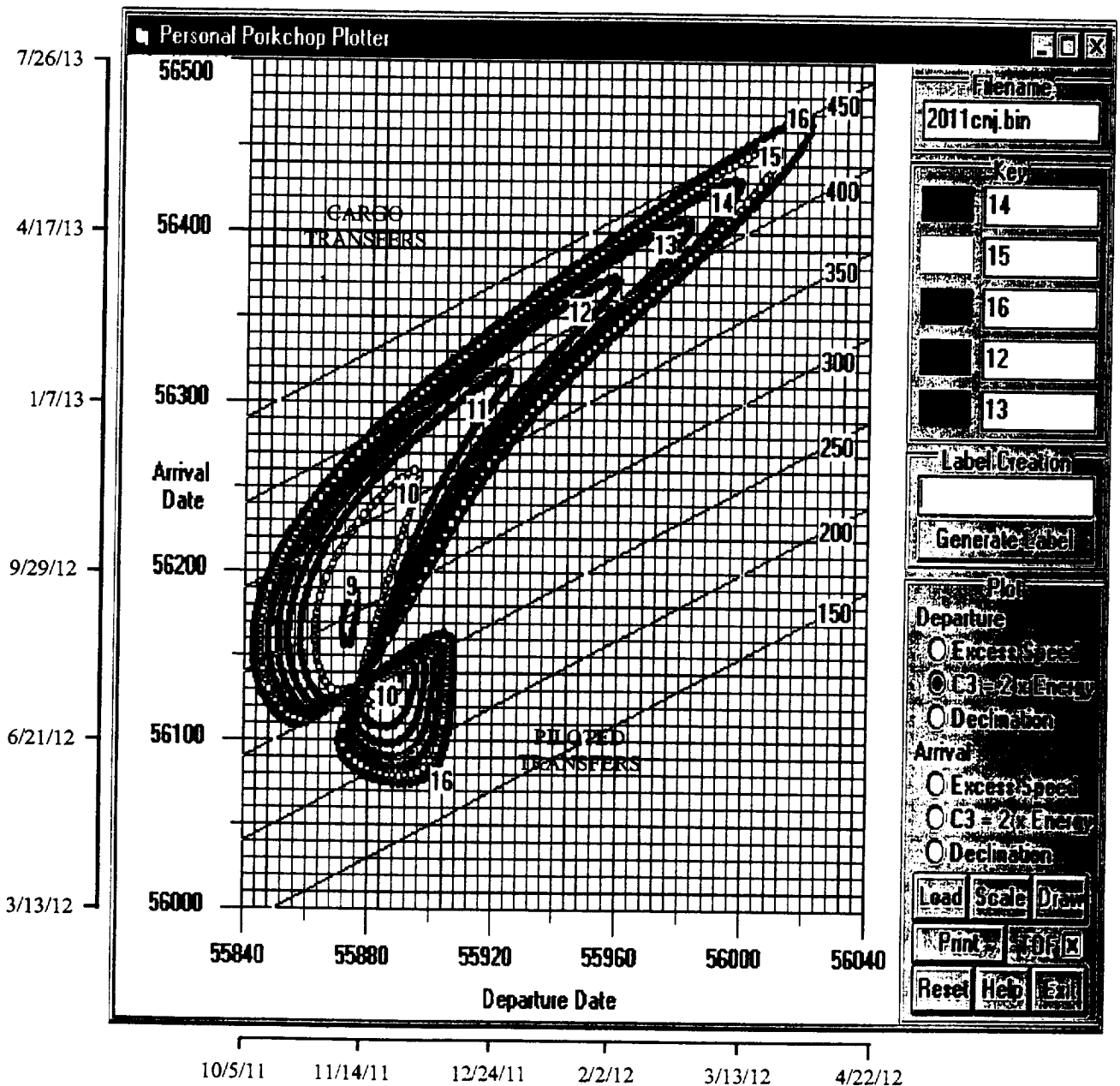
TOOLS USED/APPROACH

- Began developing baseline trajectories
 - Developed “porkchop” plots showing C_3 s and other parameters for each opportunity
 - Used plots to determine starting areas for optimization of trajectories
- Cargo missions: Minimum initial mass in LEO
- Piloted missions:
 - Minimum initial mass for 180 day TOF
 - Minimum in-flight time at 2011 C_3 s

Earth-Mars Trajectories

2011 Conjunction Class

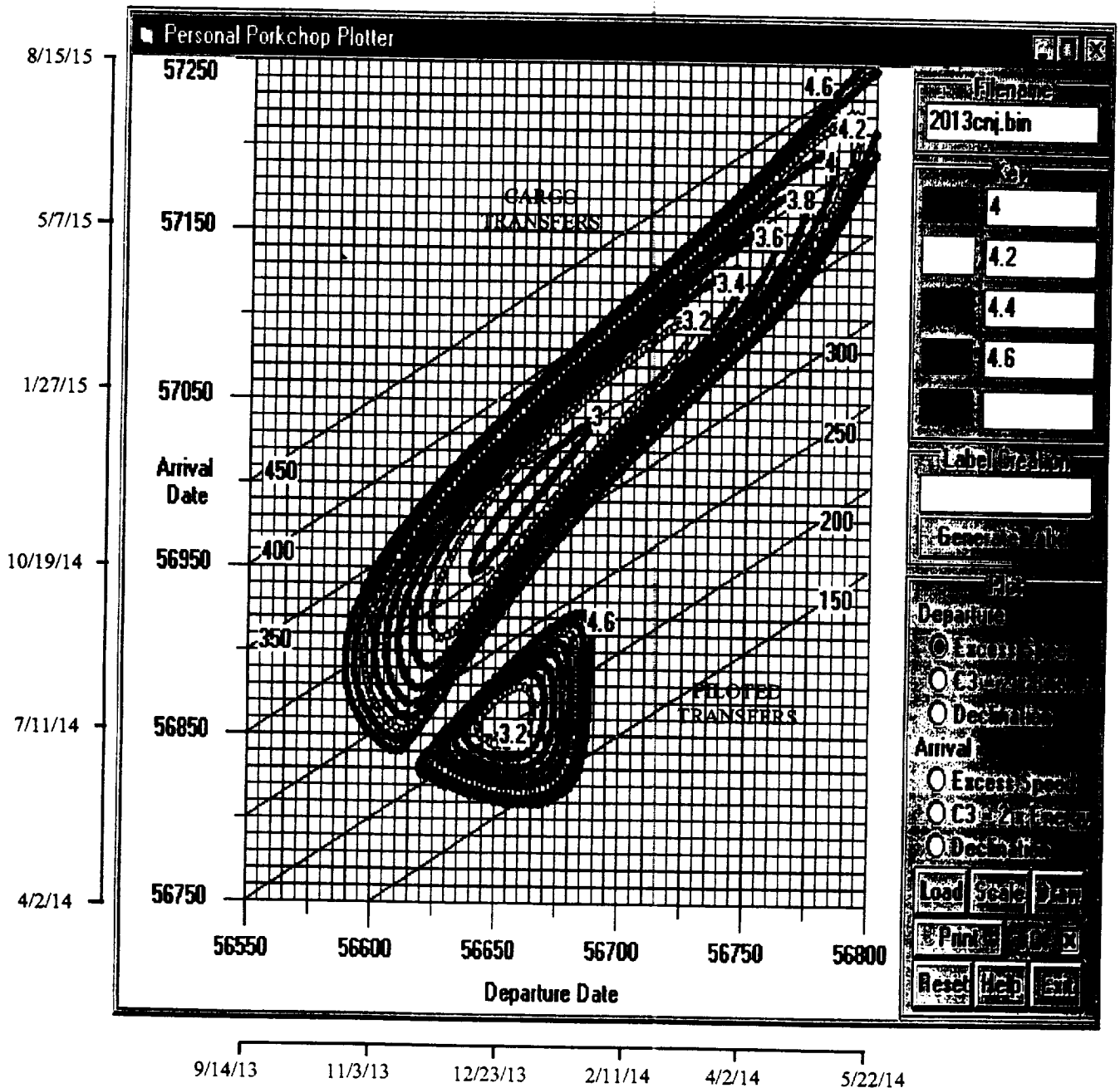
C_3 (Departure Energy) km^2/s^2



Earth-Mars Trajectories

2013/14 Conjunction Class

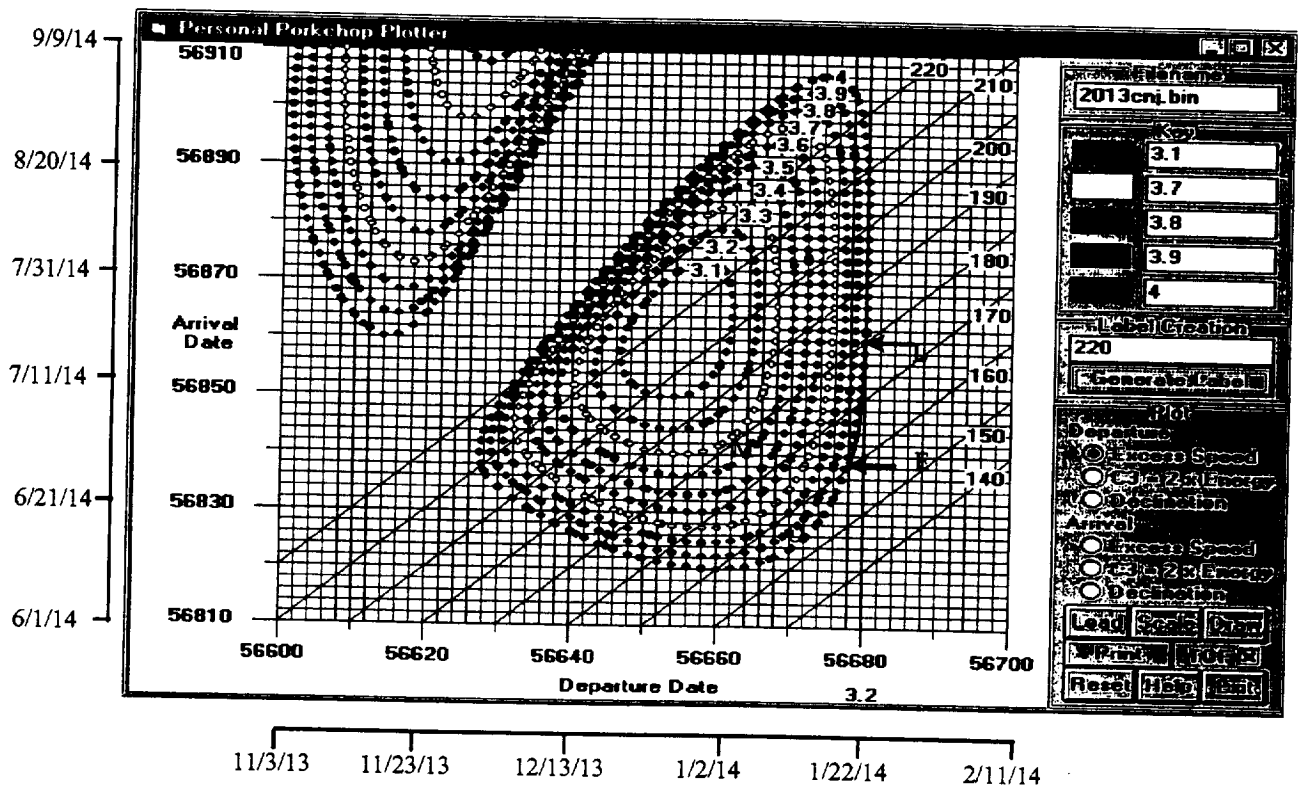
Departure Excess Speed (km/s)



Earth-Mars Trajectories

2013/14 Piloted Missions

Baseline Mission Designed to 2011 Departure Excess Speed



E = Minimum flight time trajectory using 2011 Piloted Mission Departure Excess Speed (3.99 km/s) and while maintaining acceptable Mars entry velocity needed for aerobraking.
Departure: 1/20/14 (56678J) Arrival: 6/30/14 (56839J)

L = Latest possible trajectory to keep flight time limited to 180 days. The acceptable window of opportunity for launch will be along the arc from E to L
Latest Departure: 1/22/14 (56679J) Arrival: 7/21/14 (56859J)

O = Minimum flight time trajectory using 2011 Piloted Mission Departure Excess Speed (3.99 km/s). Mars arrival excess speed = 8.56 km/sec, which exceeds the limit of 7.167 km/sec

M = Minimum departure excess speed and initial mass trajectory for 2014 opportunity for a flight time of 180 days
Departure: 1/4/14 (56662J) Arrival: 7/3/14 (56842)

REDUCED PILOTED MISSION DURATIONS

<u>Year</u>	<u>Mission Duration</u>	<u>Mars Arrival Velocity (km/s)</u>	<u>Earth Arrival Velocity (km/s)</u>	<u>Departure window (days)</u>	<u>Return window (days)</u>
2014	161*	7.17	8.91	3	17
2016	137*	7.17	8.91	8	30
2018	115	6.85	4.38	27	10
2020	151	4.27	5.28	12	1

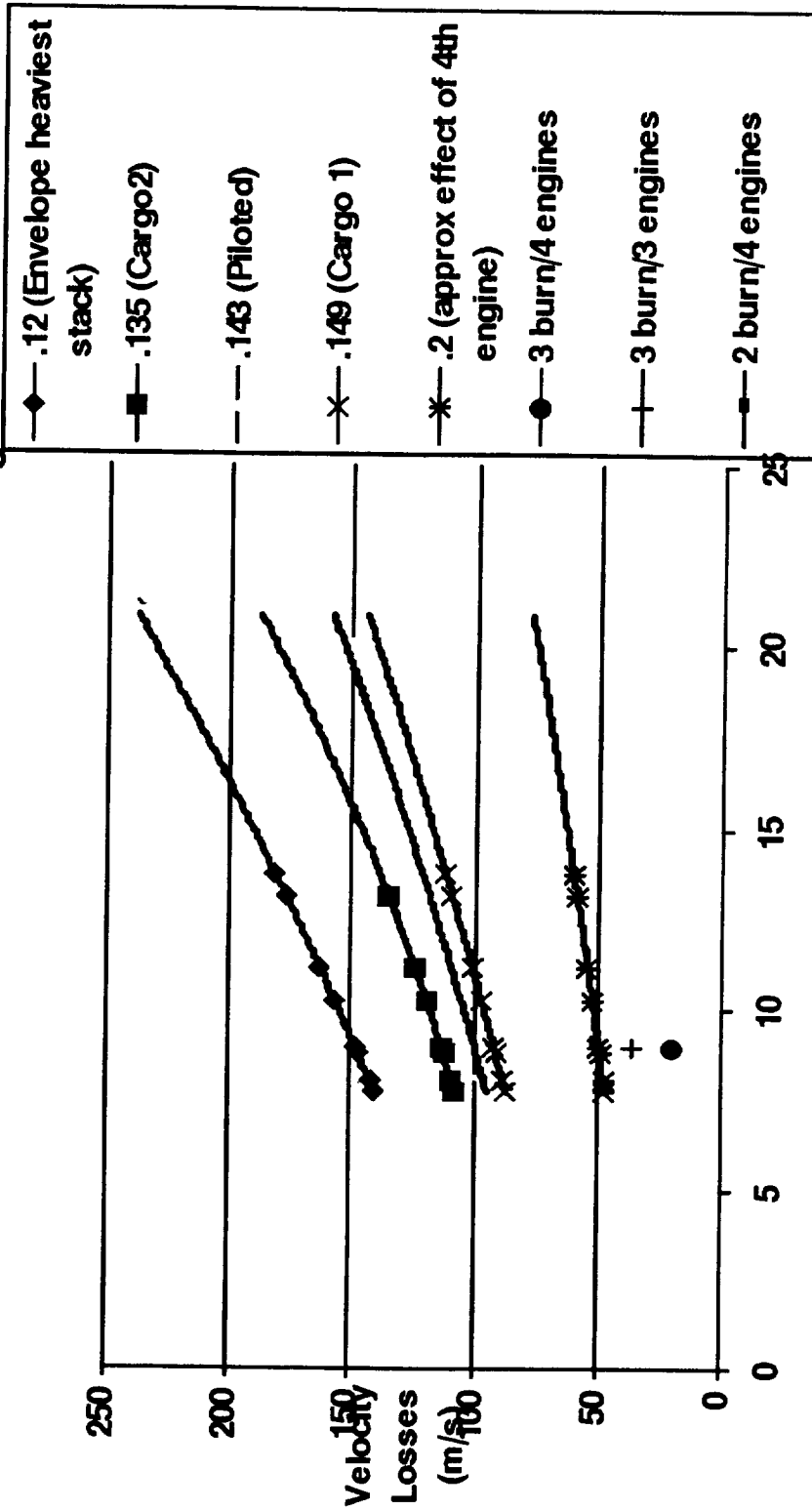
* Arrival excess speed at Mars exceeded at shorter flight times

Msn	Launch Date	TMI Delta V (m/s)	Vel Losses (m/s)	Mars		Outbd		Mars		Mars		Return		Total		Total Delta Vs (m/s)	
				Arrival Date (m/d/yy)	Flight Time (days)	Stay Time (days)	Dep Date (m/d/yy)	TEI Delta V (m/s)	Return Date (m/d/yy)	Msn	Durn	Return Time (days)	Return Date (m/d/yy)	Msn	Durn		C ₃
Cargo 1	10/14/09	3,737	97	9/6/10	327	---	---	---	---	---	---	---	---	---	---	10.27	3,737
Cargo 2	10/14/09	3,760	120	9/6/10	327	---	---	---	---	---	---	---	---	---	---	10.27	3,760
Piloted	10/30/09	4,219	153	4/28/10	180	536	10/16/11	1,780	180	4/13/12	896	---	---	---	---	20.06	5,999
Cargo 1	11/8/11	3,673	92	8/31/12	297	---	---	---	---	---	---	---	---	---	---	8.95	3,673
Cargo 2	11/8/11	3,695	113	8/31/12	297	---	---	---	---	---	---	---	---	---	---	8.95	3,695
Piloted	12/2/11	4,019	132	5/30/12	180	538	11/19/13	1,476	180	5/18/14	898	---	---	---	---	15.92	5,495
Cargo 1	12/31/13	3,665	91	11/24/14	328	---	---	---	---	---	---	---	---	---	---	8.78	3,665
Cargo 2	12/31/13	3,686	112	11/24/14	328	---	---	---	---	---	---	---	---	---	---	8.78	3,686
Piloted	1/20/14	4,019	132	6/30/14	161	573	1/24/16	1,476	154	6/26/16	888	---	---	---	---	15.92	5,495
Cargo 1	3/21/16	3,627	88	1/20/17	305	---	---	---	---	---	---	---	---	---	---	7.99	3,627
Cargo 2	3/21/16	3,647	109	1/20/17	305	---	---	---	---	---	---	---	---	---	---	7.99	3,647
Piloted	3/14/16	4,019	132	7/29/16	137	630	4/20/18	1,476	130	8/28/18	897	---	---	---	---	15.92	5,495
Cargo 1	5/17/18	3,615	87	1/8/19	236	---	---	---	---	---	---	---	---	---	---	7.74	3,615
Cargo 2	5/17/18	3,635	108	1/8/19	236	---	---	---	---	---	---	---	---	---	---	7.74	3,635
Piloted	5/18/18	4,019	132	9/10/18	115	651	6/22/20	1,314	158	11/27/20	924	---	---	---	---	15.92	5,333
Cargo 1	7/18/20	3,877	109	1/27/21	193	---	---	---	---	---	---	---	---	---	---	13.17	3,877
Cargo 2	7/18/20	3,903	135	1/27/21	193	---	---	---	---	---	---	---	---	---	---	13.17	3,903
Piloted	7/24/20	4,019	132	12/22/20	151	586	7/31/22	1,706	180	1/27/23	917	---	---	---	---	15.92	5,725
Cargo 1	9/14/22	3,906	112	10/2/23	383	---	---	---	---	---	---	---	---	---	---	13.79	3,906
Cargo 2	9/14/22	3,933	138	10/2/23	383	---	---	---	---	---	---	---	---	---	---	13.79	3,933
Piloted	9/10/22	4,198	152	3/9/23	180	543	9/2/24	1,860	180	3/1/25	903	---	---	---	---	19.63	6,058
Cargo 1	10/5/24	3,782	101	9/15/25	345	---	---	---	---	---	---	---	---	---	---	11.19	3,782
Cargo 2	10/5/24	3,805	124	9/15/25	345	---	---	---	---	---	---	---	---	---	---	11.19	3,805
Piloted	10/17/24	4,257	158	4/15/25	180	535	10/2/26	1,841	180	3/31/27	895	---	---	---	---	20.85	6,098

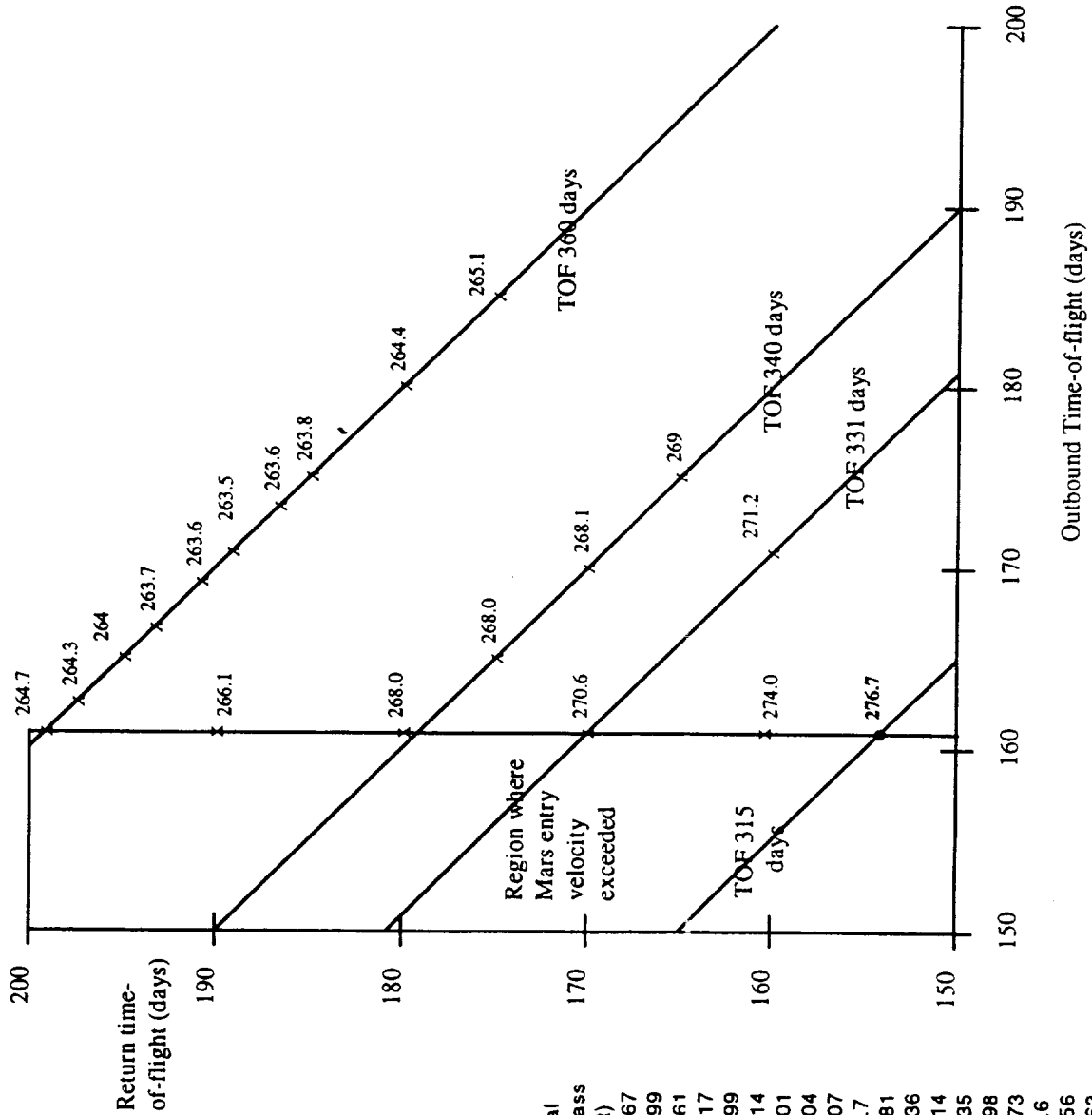
ADDITIONAL STUDIES

- Velocity losses for various Thrust-to-weight ratios
- Piloted total time-of-flight trades
- All chemical configurations (LOx/LH₂)

Velocity Losses at Various Thrust to weight ratios



TIME-OF-FLIGHT TRADES - 2014



PLOT DATA:

TOF Outbnd (days)	TOF Inbnd (days)	Total TOF (days)	Total InitMass (mt)
161	154	315	276.67
161	160	321	273.99
161	170	331	270.61
171	160	331	271.17
165	175	340	267.99
170	170	340	268.14
175	165	340	269.01
161	180	341	268.04
161	190	351	266.07
161	199	360	264.7
175	185	360	263.81
180	180	360	264.36
185	175	360	265.14
163	197	360	264.35
165	195	360	263.98
167	193	360	263.73
169	191	360	263.6
171	189	360	263.56
173	187	360	263.63

2014 Tradeoffs/Launch Dates

TOF Outbnd (days) ¹	Dep Date	TMI Prop Reqd (mt)	Earth Minit (mt) ²	Prop Redn (mt) ³	Total TMI Mass (mt) ⁴	TOF Inbnd (days)	Dep Date	Total TOF (days)	TEI Prop Reqd (mt)	Prop Redn (mt) ⁵	Cargo 1 Delivery (mt) ⁶	Cargo 1 Minit (mt)	Total Init Mass (mt) ⁷	Total Delta
161	1/20/14	50.43	141.19	0	76.086	154	1/24/16	315	18.386	0	57.589	135.48	276.672	0
161	1/20/14	50.43	141.19	0	76.086	160	1/20/16	321	16.678	-1.708	55.881	132.8	273.986	-2.686
161	1/20/14	50.43	141.19	0	76.086	170	1/14/16	331	14.421	-3.965	53.624	129.42	270.611	-6.061
171	1/9/14	47.618	138.38	-2.812	73.274	160	1/20/16	331	16.678	-1.708	55.881	132.8	271.174	-5.498
165	1/16/14	49.017	139.78	-1.413	74.673	175	1/11/16	340	13.503	-4.883	52.706	128.21	267.985	-8.687
170	1/10/14	47.796	138.56	-2.634	73.452	170	1/14/16	340	14.421	-3.965	53.624	129.58	268.136	-8.536
175	1/6/14	47.096	137.86	-3.334	72.752	165	1/17/16	340	15.472	-2.914	54.675	131.15	269.008	-7.664
161	1/20/14	50.43	141.19	0	76.086	180	1/7/16	341	12.7	-5.686	51.903	126.85	268.038	-8.634
161	1/20/14	50.43	141.19	0	76.086	190	1/1/16	351	11.382	-7.004	50.585	124.88	266.067	-10.61
161	1/20/14	50.43	141.19	0	76.086	199	12/27/15	360	10.468	-7.918	49.671	123.51	264.7	-11.97
175	1/6/14	47.096	137.86	-3.334	72.752	185	1/4/16	360	11.997	-6.389	51.2	125.96	263.812	-12.86
180	1/4/14	46.596	137.36	-3.834	72.252	180	1/7/16	360	12.7	-5.686	51.903	127.01	264.363	-12.31
185	1/3/14	46.168	136.93	-4.262	71.824	175	1/11/16	360	13.503	-4.883	52.706	128.21	265.136	-11.54
163	1/18/14	49.671	140.43	-0.759	75.327	197	12/28/15	360	10.652	-7.734	49.855	123.92	264.348	-12.32
165	1/16/14	49.017	139.78	-1.413	74.673	195	12/29/15	360	10.846	-7.54	50.049	124.21	263.984	-12.69
167	1/14/14	48.46	139.22	-1.97	74.116	193	12/30/15	360	11.051	-7.335	50.254	124.51	263.734	-12.94
169	1/12/14	47.996	138.76	-2.434	73.652	191	1/1/16	360	11.269	-7.117	50.472	124.84	263.596	-13.08
171	1/9/14	47.618	138.38	-2.812	73.274	189	1/2/16	360	11.498	-6.888	50.701	125.18	263.56	-13.11
173	1/7/14	47.323	138.08	-3.107	72.979	187	1/3/16	360	11.741	-6.645	50.944	125.55	263.628	-13.04

Notes:

- 1) Italicized trajectories have a constraint that the arrival velocity at Mars = 7.167 km/s (otherwise would be greater)
- 2) Minital for piloted outbound = 90.76 mt + TMI propellant required (from MAnE run for baseline trajectory)
- 3) Propellant reduction for Mars outbound = 50.43 - propellant required (from MAnE run for baseline trajectory)
- 4) Total TMI mass = 25.6 mt (dry weight of TMI engine) + propellant required
- 5) Propellant reduction for Earth return flight = 18.386 - propellant required (from MAnE run for baseline trajectory)
- 6) Cargo 1 delivery required = Total payload delivery to Mars (57.589 mt) - propellant reduction
- 7) Total Departure Initial mass in Low Earth orbit = piloted outbound + cargo 1 missions

ALL CHEMICAL PROPULSION

- Chemical TMI Stage (LOx/LH₂)
 - Isp 480 secs, thrust 100,000 lbs, dry mass 18.3mt

	Cargo 1	Cargo 2	Piloted
Mass (mt)	190.47	211.84	196.9
T/W	.238	.214	.230
Aerobrake (mt)	10.6	16	14.04
Delta V (m/s)	3606	3612	3920
Vel losses	24	30	33

LESSONS LEARNED

- Classroom versus application
- Exposure to NASA
- Handbook

2018 Opportunities

Msn	Launch Date	TMI Delta V (m/s)	Vel Losses (m/s)	Mars Arrival		Outbd Flight Time (days)	Mars Stay		TEI Delta V (m/s)	Return Date (m/d/yy)	Return Time (days)	Total		Total Delta Vs (m/s)
				Arrival Date (m/d/yy)	Date (m/d/yy)		Days	Time (days)				Msn	Durn (days)	
Piloted ¹	5/8/18	3,641	97	11/4/18	6/12/20	180	586	1/314	180	12/9/20	180	946	8.11	4,955
Cargo 1	5/17/18	3,615	87	1/8/19	---	236	---	---	---	---	---	---	7.74	3,615
Cargo 2	5/17/18	3,635	108	1/8/19	---	236	---	---	---	---	---	---	7.74	3,635
Piloted	5/18/18	4,019	132	9/10/18	6/22/20	115	651	1,314	158	11/27/20	924	924	15.92	5,333
Piloted ²	6/13/18	4,019	132	12/10/18	7/1/20	180	569	1,476	180	12/28/20	180	929	15.92	5,495

1) Optimal piloted trajectory (minimum initial mass)

2) Latest possible launches designed to 2011 C₃/180 day TOF

10 day Mars-Earth Return Window:
 Depart: 6/22/20
 Arrive: 7/1/20

27 day Earth-Mars Departure Window:
 Depart: 5/18/18
 Arrive: 6/13/18

10 day Mars-Earth Return Window:
 Depart: 6/22/20
 Arrive: 7/1/20

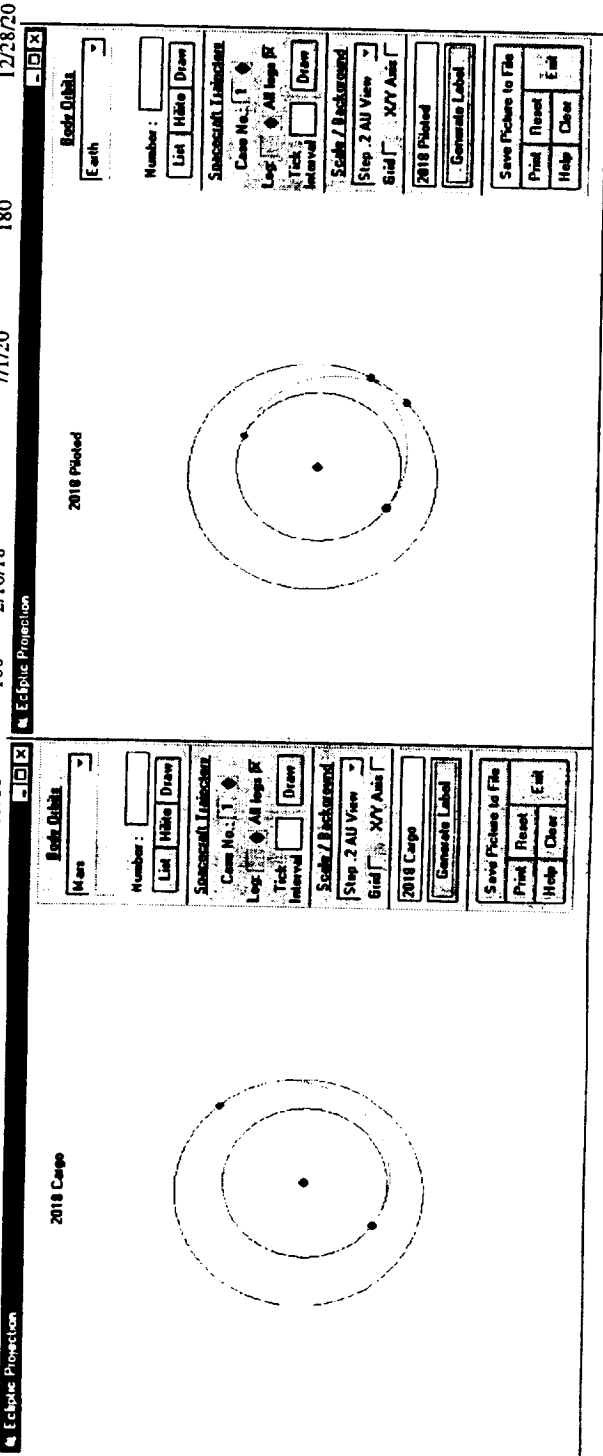


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