Design Methodologies for Space Transportation Systems, by Walter E. Hammond

Acknowledgments: It should be emphasized that it is simply impossible for a single person to encompass all of the knowledge and experience required for the conceptualization, design, engineering, fabrication, manufacturing, operations, and maintenance of such a complex undertaking as the manned reusable launch systems of the 21st century. Subsequent to the drafting of this work, a comprehensive publication has been released by NASA that captures much of the information herein. The author was privileged to obtain some early pre-release information from NASA and other authors, to whom the credit is due. NASA/TP-2001-210992, "Launch Vehicle Design Process: Characterization, Technical Integration, and Lessons Learned" is an excellent publication that is available for the asking from:

NASA Center for AeroSpace Information
7121 Standard Drive
Hanover, MD 21076-1320
(301)621 -0390

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

This report is also available online at http://mtrs.msfc.nasa.gov/mtrs/2001/tp210992.pdf

The published report contains information that is updated and corrected from its pre-release version as used in the book.

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James C. Blair	AI Signal Research, Inc.
Robert S. Ryan	AI Signal Research, Inc.
Luke A. Schutzenhofer	AI Signal Research, Inc.

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Paul Schuerer

The following additional persons contributed to Chapter 9, Sections 9.2 and 9.3:

James Atherton
Charles Morris
Gray Settle
Marion Teal

The readership is encouraged to contact the AIAA for additional errors, omissions, or corrections in the above work. An appropriate contact point is:

Heather Brennan
AIAA Publications Development
1801 Alexander Bell Drive, Suite 500
Reston, VA 20191- 4344
703/264-7568 - 703/264-7551 FAX
heatherb@aiaa.org   http://www.aiaa.org

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The following are known errors that have been found in the AIAA *Education Series* Book, *Design Methodologies for Space Transportation Systems*, by Walter E. Hammond, ISBN No. 1-56347-472-7, © 2001 by AIAA.

Page No.	Correction

377 Third paragraph, item 5), rep1ace 3rd through 5th sentences with following:
The airlines, with thousands of flights per day, have developed a "minimum equipment list." This list, despite its name, is detailed compilation of aircraft equipment or systems, with the different faults or malfunctions that can occur. Such anomalies or malfunctions are usually discovered during preflight checkout, although they could occur in flight or during maintenance operations on the ground. The minimum equipment list guides the flight crew as to whether the plane should be grounded or not until the problem is fixed, but the aircraft commander is afforded some discretion in making a final call whether to takeoff, land at the nearest airfield, etc. for safety-of- flight reasons. A similar approach of letting future reusable launch vehicles fly even with known faults or anomalies should be adopted, as space flight becomes more routine and flight systems safer with more redundancy built-in.

387, 407 Cost numbers in Table 8.1 disagree with the numbers in Table 8.5 (taken from a different source). The reader should note that it is impossible to precisely predict launch costs even today (2001). Launch costs and price estimates differ significantly, depending upon many factors: the type of fairing used, the target orbit parameters for a particular mission, the amount and type of launch services and payload conditioning required, fluctuating insurance costs and interest rates, inflation factors and the state of the economy, etc. etc. The following Table represents approximate launch costs as known in Jan. 1999, with a 1.047 inflation factor (see Table 8.9) to convert them to fiscal year 2000.

Estimated launch vehicle costs in FY2000 dollars (revised)

Launch Vehicle	LEO Payload, kg.	Unit cost, FY2000 $M	Cost, $/kg, FY2000	First Flight
Saturn V (S–IC + S-II)	280,000	936	3300	1967
Ariane 40-3	4520	63	13,900	1995
Ariane 42P-3	5600	73	13,090	1994
Ariane 44P-3	6370	84	13,150	1995
Ariane 42L-3	6675	84	12,550	1995
Ariane 44LP-3	7650	94	12,318	1995
Ariane 44L-3	7650	105	13,690	1995
Ariane 5	18,000	157	8725	1996
Ariane 5E/S	22,550	89	3947	2002 (1)
Atlas 2A	7000	89	12,714	1992
Atlas 2AS	8200	100	12,768	1993
Atlas 3A	8200	73	9257	1999
Atlas 3B	9500	78	8541	2000
Atlas 5 400 (2)	12,514	98	7791	2002

Estimated launch vehicle costs in FY2000 dollars (revised) continued

Launch Vehicle	LEO Payload, kg.	Unit cost, FY2000 $M	Cost, $/kg, FY2000	First Flight
Atlas 5 500 (2)	20,520	98	4751	2002
Delta 2/7320	2680	35	13,674	1998
Delta 2/7325	2865 (1)	40	14,617	2000
Delta 2/7420	3000	38	13,088	1998
Delta 2/7920	4835	48	10,286	1995
Delta 2/7925	5100 (1)	53	10,778	1990
Delta 3 (2)	8343	85	10,190	1998
Delta 4 Medium (2)	8119	55	6775	2002
Delta 4 Heavy (2)	22,680	155	6834	2002
H–2 (Japan)	9200	168	19,062	1994
H–2/SSB	10,000	178	18,584	1995
H–2A/202 (2)	12,988	85	6543	2001 (1)
H–2A/2022	10,000	88	9161	2002 (1)
H–2A/2024	11,000	98	9280	2002 (1)
H–2A/212	15,000	113	7853	2003 (1)
H–2A/222	20,000	138	7198	2006 (1)
Long March 2E (2)	8792	50	5788	1990
Long March 3A (2)	7194	50	6951	1994
Long March 3B (2)	13,588	60	4416	1996
Long March 4B (2)	4491	30	6680	1999
Pegasus	355	12	35,392	1990
Pegasus XL	425	14	34,490	1994
Pegasus XL (Star 37)	450 (1)	16	37,227	unknown
Proton K (Russia)	20,900	70	3507	1967
Proton K/DM–2	19,760	83	4371	1982
Proton K/DM–2M	19,760	88	4636	1994
Proton K/DM–5	19,760	88	4636	1997
Proton M	22,000	88	4164	2001 (1)
Proton M/Breeze M	21,000	98	4861	2001 (1)
Titan IVB/Centaur (2)	21,682	400	18,448	1997
Titan IV/401B	20,900	365	18,285	1997
Titan IV/405B	21,680	250	12,073	1997
Space Shuttle (2)	21,256	300	14,114	1981

Launch Vehicle	LEO Payload, kg.	Unit cost, FY2000 $M	Cost, $/kg, FY2000	First Flight
Space Shuttle (OV-102)	14,800	425	30,066	1981
Space Shuttle (OV-103, OV-104, OV-105)	18,700	425	23,795	1984
Taurus (DARPA)	1220	18	15,448	1994
Taurus (Commercial)	1300	22	17,718	1998
Zenit 2 (Ukraine)	13,740	35	2667	1985
Zenit 2/3SL	6500	85	13,692	1999

LEO Low Earth Orbit is 200 km, 51.6 degree inclination launch from Cape Kennedy
Source: *International Space Industry Report*, Vol. 3, No. 2, Jan. 18, 1999
Launchspace Publications, Inc. (see http://www.launchspace.com)
7929 Westpark Drive
McLean, VA 22102

NOTES:
(1) Estimated by author
(2) LEO Low Earth Orbit is ≈ 200 km Equatorial
Data is courtesy of Futron Corporation (see http://www.futron.com)
7315 Wisconsin Avenue, Suite 900W
Bethesda, MD 20814-3202

Known Errors, continued

Page No.	Correction
438	The caption for Fig. 8.3 should read "Process flow diagram for space vehicle performance and trajectories (courtesy, Space Transportation Directorate, NASA Marshall Space Flight Center, AL, 1999). The content of Fig. 8.3 should be replaced with (see next page) Figure 40, "Performance and trajectories design process flow diagram," on p. 72 of NASA/TP-2001-2100992: *Launch Vehicle Design Process*.
450	Replace (Figure 8.10) in the Inertial Navigation box with (Figure 8.7)
497	Replace the contents of Table 9.2 with the contents of Table 9.4 (p. 515). The caption for Table 9.2 is correct.
515	Replace the contents of Table 9.4 with the contents of Table 9.2 (p. 497).
790	EADSIM is Extended Air Defense Simulation, a war–gaming computer program used by the Army. EADSIM serves as a convenient example of F_{RTB} calculations in Appendix B.4.
827	Artwork shown for Fig. D5 belongs on Fig. D6, p. 828.
828	Artwork shown for Fig. D6 belongs on Fig. D5, p. 827.
831	Renumber Fig. D7 (bottom of page) as Fig. D9. The caption for Fig. D9 is correct.
832	Caption shown for Fig. D8 belongs to Fig. D10. The artwork for Fig. D8 is correct.

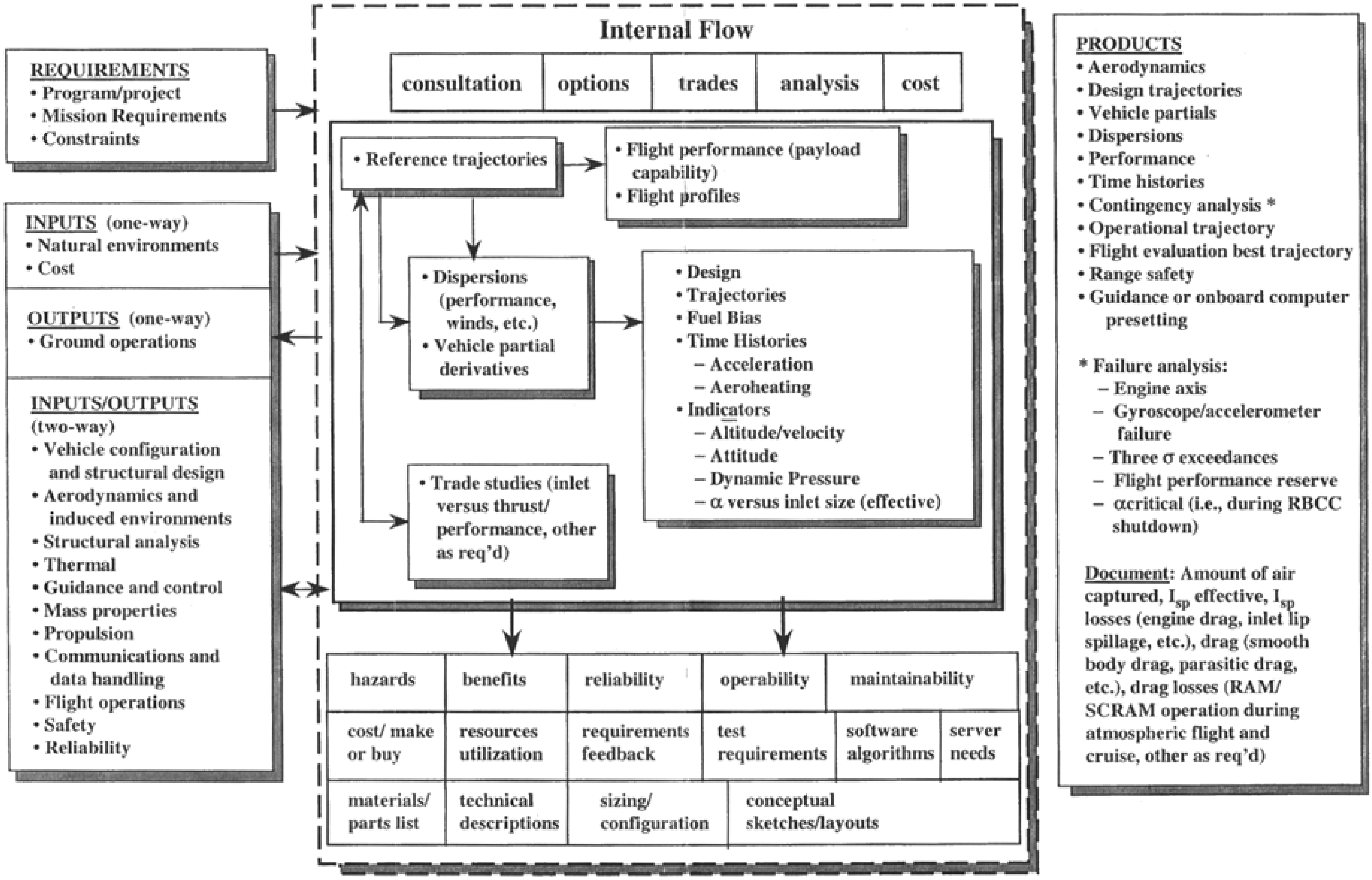

Fig. 8–3 (corrected) Process flow diagram for space vehicle performance and trajectories (courtesy, Space Transportation Directorate, NASA Marshall Space Flight Center, AL., 1999).

Known Errors, continued

Page No.	Correction
832	Second paragraph, first line should begin: “As shown in Fig. D7 and Fig. D9 ...”.
833	Renumber Fig. D9 as Fig. D7. The caption for Fig. D7 is correct.
834	Caption shown for Fig. D10 belongs to Fig. D8. The artwork for Fig. D10 is correct.

The following typos have been found in the CD–ROM Oversize Figures & Tables folder:

Figure No./Title	Correction to Fig. No./Title
Figure 6.1_Detail.pdf	Figure 6.10_Detail.pdf

Table No./Title	Correction to Table. No./Title
Table 9.1_Function Diagram.pdf	Figure 9.1_Avionics Function Diagram.pdf

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The following cross–references represent a correspondence between this book and NASA TP–2001–210992:

Chapter	Page(s)	Figure or Table No.	NASA TP–2001–210992
1	13	Fig. 1.7, p. 13	Fig. 15, p.33
1	16	Fig. 1.10, p.16	Fig. 18, p.36
1	17	Fig. 1.11, p. 17	Fig. 20,p.37
1	18	Fig. 1.12, p. 18	Fig. 21, p. 39
1	21	Fig. 1.13, p. 21	Fig. 22, p.40;
1	24	Fig. 1.14, p.24	Fig. 8, p. 14
1	26–28	Text	pp. 50-53 (excerpted)
1	30	Fig. 1.16 on CD-ROM (1)	Fig. 96, p. 212
3	122–123	Table 3.2	Table 1, p. 60
4	183	Fig. 4.6	Fig. 35, p.64
4	185	Fig. 4.7	Fig. 36, p.65
4	185	Fig. 4.7_Detail on CD-ROM	Table 2, p. 66
4	186	Fig. 4.8	Fig. 37, p. 67
4	187	Table 4.1	Table 3, p. 68
5	247	Fig. 5.10	Fig. 54, p. 106

Chapter	Page(s)	Figure or Table No.	NASA TP–2001–210992
5	247	Fig. 5.11	Fig. 55, p. 107
5	248	Fig. 5.12	Fig. 56, p. 108
5	249	Table 5.1	Table 14, p. 110
5	247	Fig. 5.11_Detail on CD-ROM	Table 13, p. 109
6	292	Fig. 6.6	Fig. 49, p. 92
6	293	Fig. 6.7*	Table 9, p. 93
6	294	Fig. 6.8	Fig. 50, p. 94
6	295	Fig. 6.9	Fig. 51, p. 94
6	295	Fig. 6.9_Detail on CD-ROM	Table 10, p. 96
6	296	Fig. 6.10	Fig. 52, p. 95
6	296	Fig. 6.10_Detail on CD-ROM (2)	Table 11, p. 97
6	297	Table 6.2	Table 12, p. 98
6	313–315	Text	pp. 132-139 (excerpted)
6	340–344	Text	pp. 140-148 (excerpted)
7	373	Fig. 7.11	Fig. 58, p. 113
7	373	Fig. 7.11_Detail on CD-ROM	Table 15, p. 117
7	374	Fig. 7.12	Fig. 60, p. 115
7	376–377	Table 7.4	Table 16, p. 118
8	438	Fig. 8.3	Fig. 40, p. 72
8	438	Fig. 8.3_Detail on CD-ROM	Table 4, p. 73
8	439	Table 8.1	Table 5, p. 75 (excerpted)
8	440	Fig. 8.4	Fig. 41, p. 74
8	464	Table 8.4	Table 6, p. 79
8	479	Fig. 8.20	Fig. 93, p. 191
8	481	Fig. 8.21a	Fig. 95, p. 194
9	496	Fig. 9.2_Detail on CD-ROM	Fig. 64, p. 125 (excerpted)
9	496	Fig. 9.3_Detail on CD-ROM	Fig. 64, p. 125 (excerpted)
9	497–498	Table 9.2**	Table 18, p. 128
9	499	Fig. 9.4	Fig. 65, p. 127
9	514	Fig. 9.7	Fig. 44, p. 82
9	514	Fig. 9.7_Detail on CD-ROM	Table 7, p. 84
9	515–516	Table 9.4 (2)	Table 8, p. 87 (excerpted)
9	517	Fig. 9.8	Fig. 46, p. 85

NOTES

(1) The oversized Fig. 1.16 in the companion CD–ROM describes the entire N x N matrix of 289 elements (i.e., 17 x 17) that is depicted in Fig. 1.16 of the text. Fig. 6.7 in the text describes a small subset of nine elements (i.e., 3 x 3) of the 289 elements in the 17 x 17 matrix.

(2) As corrected herein.