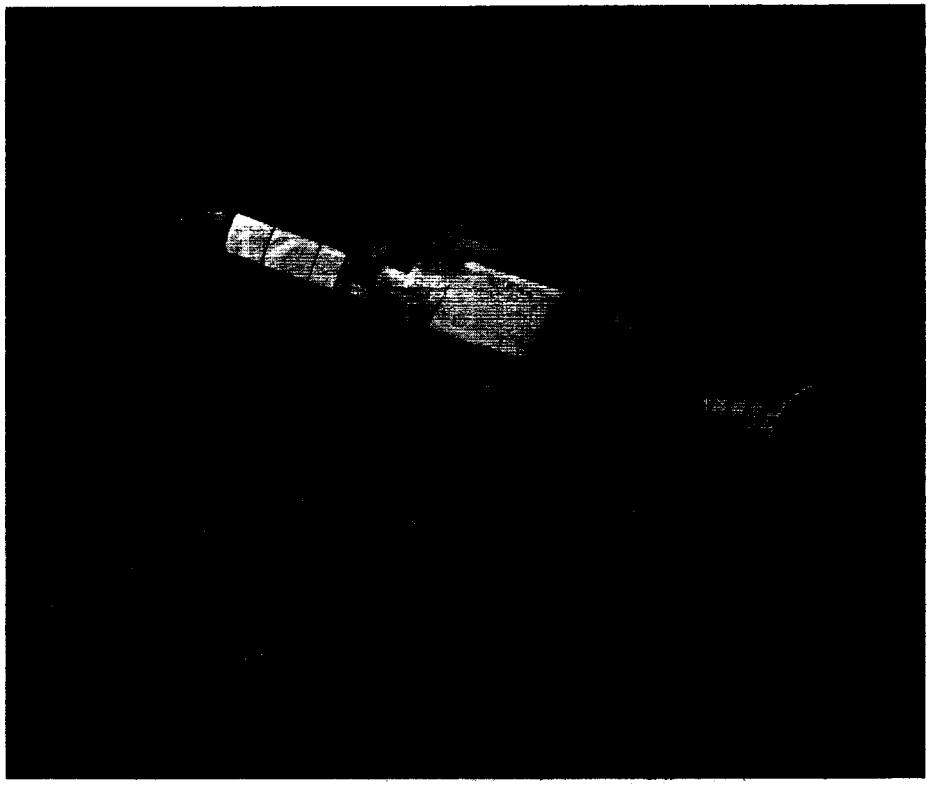
CONTRACT NAS8-29674

GRUMMAN



STORABLE SPACE TUG SYSTEMS STUDY
Data Dump

Volume 2–Summary, Program Option 2

(NASA-CR-179090) STORABLE SPACE TUG SYSTEMS DATA DUMP. VOLUME 2: SUMMARY, PROGRAM OPTION 2 (Grumman Aerospace Corp.) 118 p Avail: NTIS

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RPT NO. 300 RP-73-005

STORABLE SPACE TUG SYSTEMS STUDY
Data Dump

Volume 2–Summary, Program Option 2

19 September 1973

CONTRACT NAS8-29674

RPT NO. 300 RP-73-005

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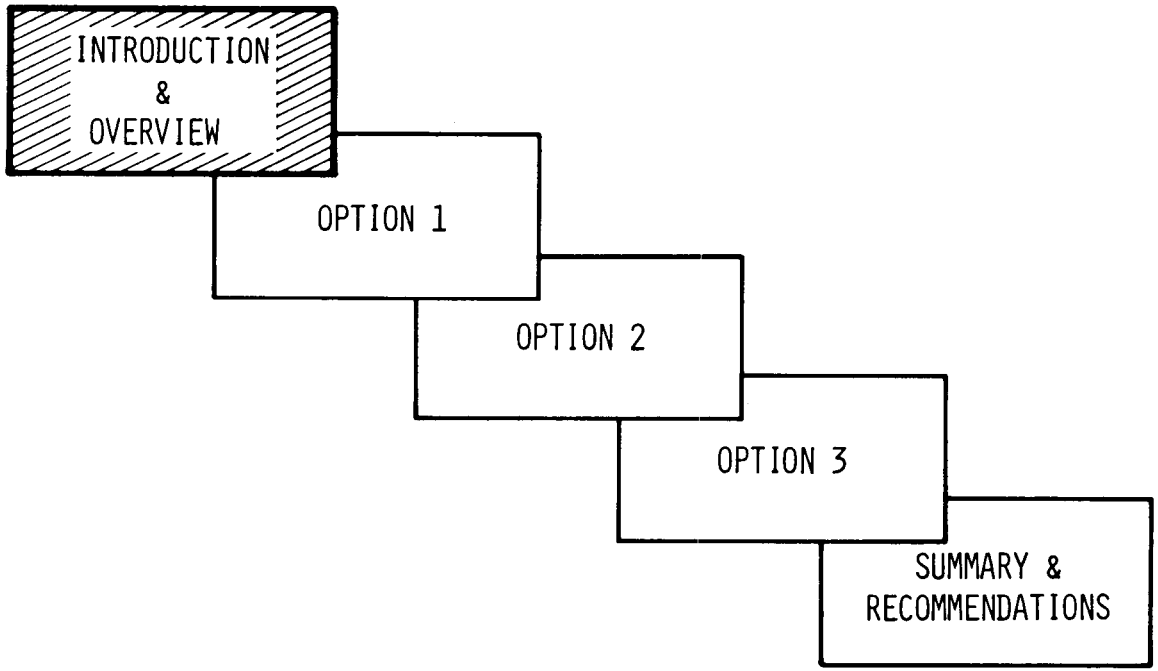
STORABLE TUG DATA REVIEW



I-10
II-12
III-41

DATA DUMP MATRIX

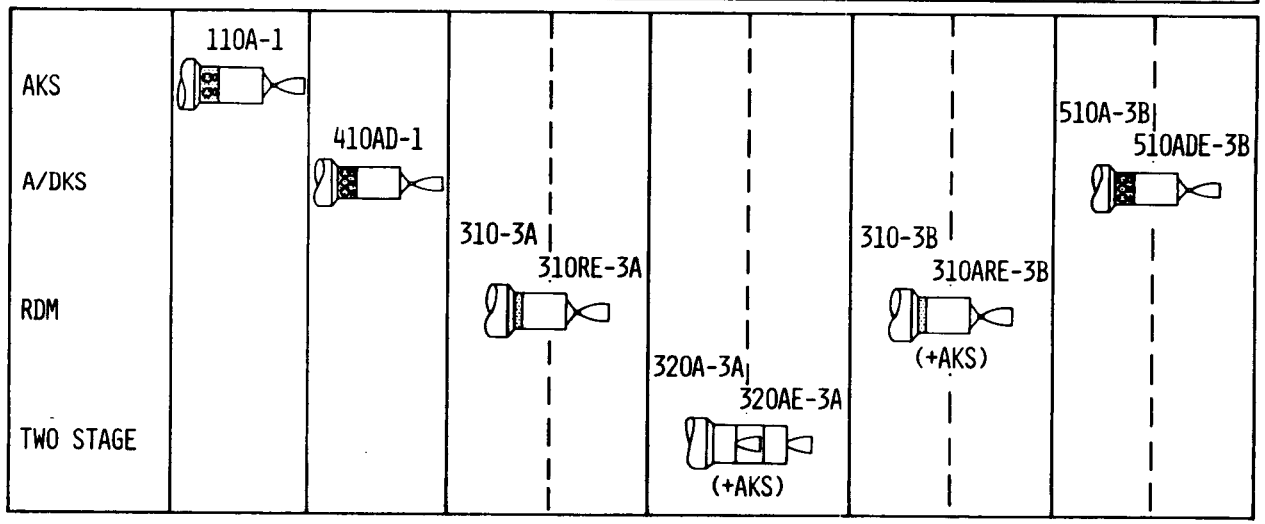
This chart identifies the concepts Grumman developed for the September Data Dumps.

The essential features of the program options are listed under each option heading and then a small sketch of the candidate concepts are placed under the appropriate option heading. For example, within Program Option 1, Grumman studied concept 110A-1 which is seen to be a single stage tug with an apogee kick stage module.

The concepts are identified by a two-part numbering system. The first part of the number provides traceability to the July Concept Selection meeting design which was used as the starting point in developing the configuration. The dash number simply specifies the Program Option within which the concept has been developed.

DATA DUMP MATRIX

OPTION	1	2	3A				3B			
IOC	DEC '79	DEC '83	DEC '79	DEC '83	DEC '79	DEC '83	DEC '79	DEC '83	DEC '79	DEC '83
GEOSYNCH DEPLOY, LB	3500									
GEOSYNCH RETRV, LB	0	3500	0	2200	0	2200	0	3500	0	3500
COST EMPHASIS	MIN DDT&E	LOW DDT&E - LOW TOTAL COST								



SENSITIVITY STUDIES	• DELAY IOC 2 YR	• ADV IOC 2 YR • DKS VS RDM • SERVICE MISS.	• DELAY IOC 2 YR

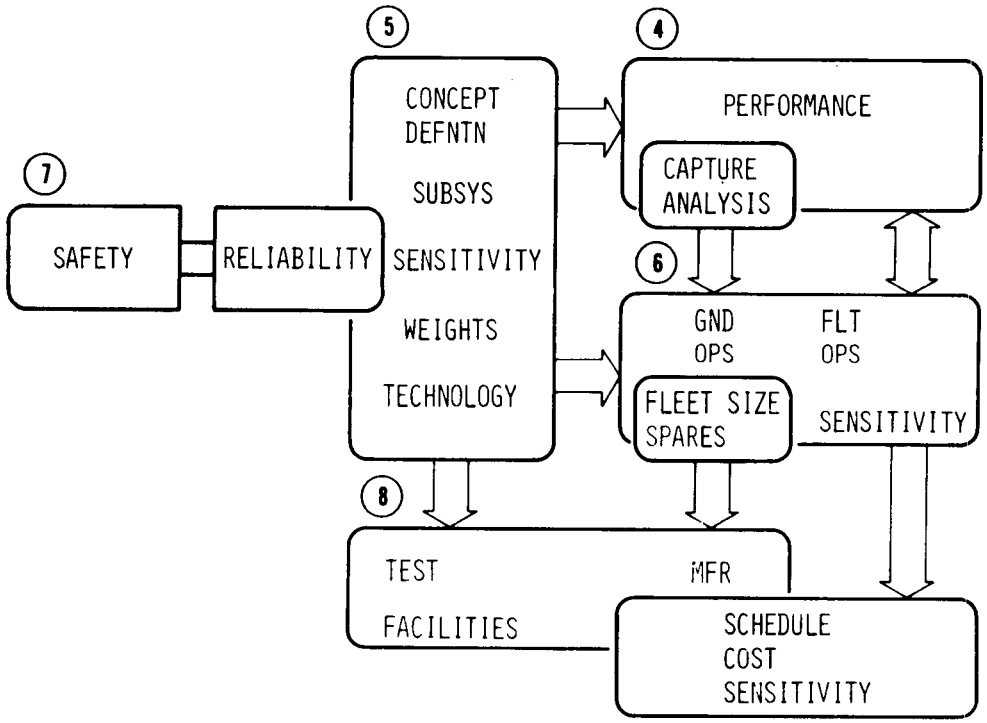
I-19, II-21, III-59

DATA DUMP VOLUME GENERATION

We have carefully followed NASA's detailed Data Dumps outline in preparing the Data Dump Volumes.

Volumes 1, 2 and 3 are extracts from the information of Volumes 4 - 8 and summarize the three program options.

DATA DUMP VOLUME GENERATION



VOLUME	EDITOR
4 MISSION ACCOMP	B. SIDOR LR5-1491
5 SYSTEMS	C. J. GOODWIN LR5-2453 M. H. DANDRIDGE LR5-1494
6 OPS - GND	R. GENDIELLIEE LR5-1631
OPS - FLT	A. NATHAN LR5-1486
7 SAFETY (INCL REL)	H. WOLF LR5-1492 B. FRUMKIN LR5-1492
8 PROGRAMMATICS	R. McCAFFREY LR5-1487

I-18

VEHICLE CHARACTERISTICS SUMMARY

This is a brief overview of the physical characteristics of the vehicles. Each concept meets or exceeds its performance requirements.

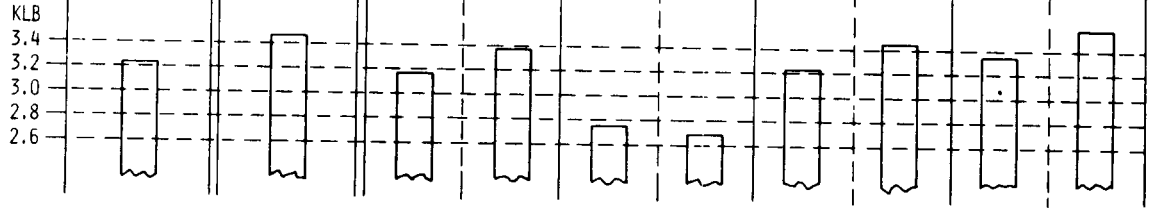
Tug lengths are short. As will be seen later in the inboard arrangement drawings, extra payload length beyond the 25 ft. requirement can be accommodated. For example, concept 110A-1 can deploy a payload 30.5 ft. long. When operated with an apogee kick stage, the payload can be 25.5 ft. long. Only the two-stage concept, using both stages, requires a two-position nozzle to keep length down.

In no case is it necessary to use a higher flexibility engine than Class 1. The Shuttle OME 7.5K lb. thrust engine is ample for Option 1.

VEHICLE CHARACTERISTICS SUMMARY

OPTION	1	2	3A				4A			
GEOSYNCH RETRIEVE CAP (LB)	—	3500	—	2200	—	2200	—	3500	—	3500
TUG DESIGNATION	110A-1	410AD-2	310-3A	310RE-3A	320A-3A	320AE-3A	310-3B	310ARE-3B	510A-3B	510ADE-3B
TUG LENGTH, FT	27.92	24.75	24.75		17.06 EACH		24.75		25.0	
BODY DIA, FT	9.92	10.0	10.0		8.16		10.0		10.0	
MAIN PROP. CAPACITY, KLB	56.9	59.5	59.5		32 EACH		59.5		59.5	
MAIN ENGINE										
- OME F=7.5K ISP=	327.2	—	—		—		—		327.2	
- CL. 1 F=12K ISP=	—	338	338		—		338		—	
- CL. 1 (RET.NOZ.) F=12K ISP=	—	—	—		338		—		—	
SUBSYS TECH										
- LOW COST		—	—		—		—			
- LOW WT	—								—	
AUTONOMY LEVEL	IIIA	IIB	IIIA	IIB	IIIA		IIIA	IIB	IIIA	IIB

FIXED WT
NASA MISSIONS SHOWN,
ADD SECURE COMM
FOR DOD MISSIONS



I-8, II-10, III-39

SYSTEMS SUMMARY & TECHNOLOGY

The next two charts summarize the subsystems which are part of each concept. Arrows are used within the Option 3 concepts to show evolutionary changes.

Asterisks have been placed by subsystems to point out SR&T needs. The details of these programs and schedules are developed in Volume 8. These are small programs. The total SR&T funding requirements, excluding engines, are less than $4M.

SUBSYSTEMS SUMMARY & TECHNOLOGY

	OPT 1	OPT 2	OPT 3A		OPT 3B	
	110A-1	410AD-2	310-3A 310RE-3A	320A-3A 320AE-3A	310-3B 310ARE-3B	510A-3B 510ADE-3B
OME 7.5K ENGINE	X					X
*CLASS I ENGINE		X	X		X	
*CLASS I ENGINE - 2 POS. NOZZLE				X		
*PFR HELIUM TANK	X	X	X	X	X	X
*SPACE STORABLE SRM		X				X
16 APS THRUSTERS	X		X →	X →	X →	X →
24 APS THRUSTERS		X	X	X	X	X
NESTED DOME TANKS		X	X	X	X	X
SEPARATE TANKS	X					
TITANIUM GORES		X	X	X	X	
*SPUN-FORM ALUM	X					X
*GRAPHITE COMPOSITE SHELL		X	X	X	X	
STIFFENED ALUM SHELL						X
ALUM HONEYCOMB SHELL	X					

*REQ SUPPORTING RESEARCH & TECHNOLOGY

I-7, II-9, III-38, IX-2

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SUBSYSTEMS SUMMARY & TECHNOLOGY

	OPT 1	OPT 2	OPT 3A		OPT 3B	
	110A-1	410AD-2	310-3A 310RE-3A	320A-3A 320AE-3A	310-3B 310ARE-3B	510A-3B 510ADE-3B
CAROUSEL IMU	X		X	X	X	X
*MICRON IMU		X	X	X	X	X
*LASER RADAR		X	- X	- X	- X	- X
621B & DOPPLER RCVRS		X	- X		- X	- X
48K WORD CDC 469 COMPUTER	X		X	X	X	X
65K WORD CDC 469 COMPUTER		X	X		X	X
DFS COMM	X		X	X	X	X
DFS + CSS COMM		X	X	X	X	X
TV		X	- X	- X	- X	- X
PRIME BATTERY	X					
MOD FUEL CELL		X	X		X	X
*ADV FUEL CELL				X		
CRYOGENIC H_2/O_2 STORAGE		X	X	X	X	X

*REQ SUPPORTING RESEARCH & TECHNOLOGY

I-6, II-8, III-37, IX-1

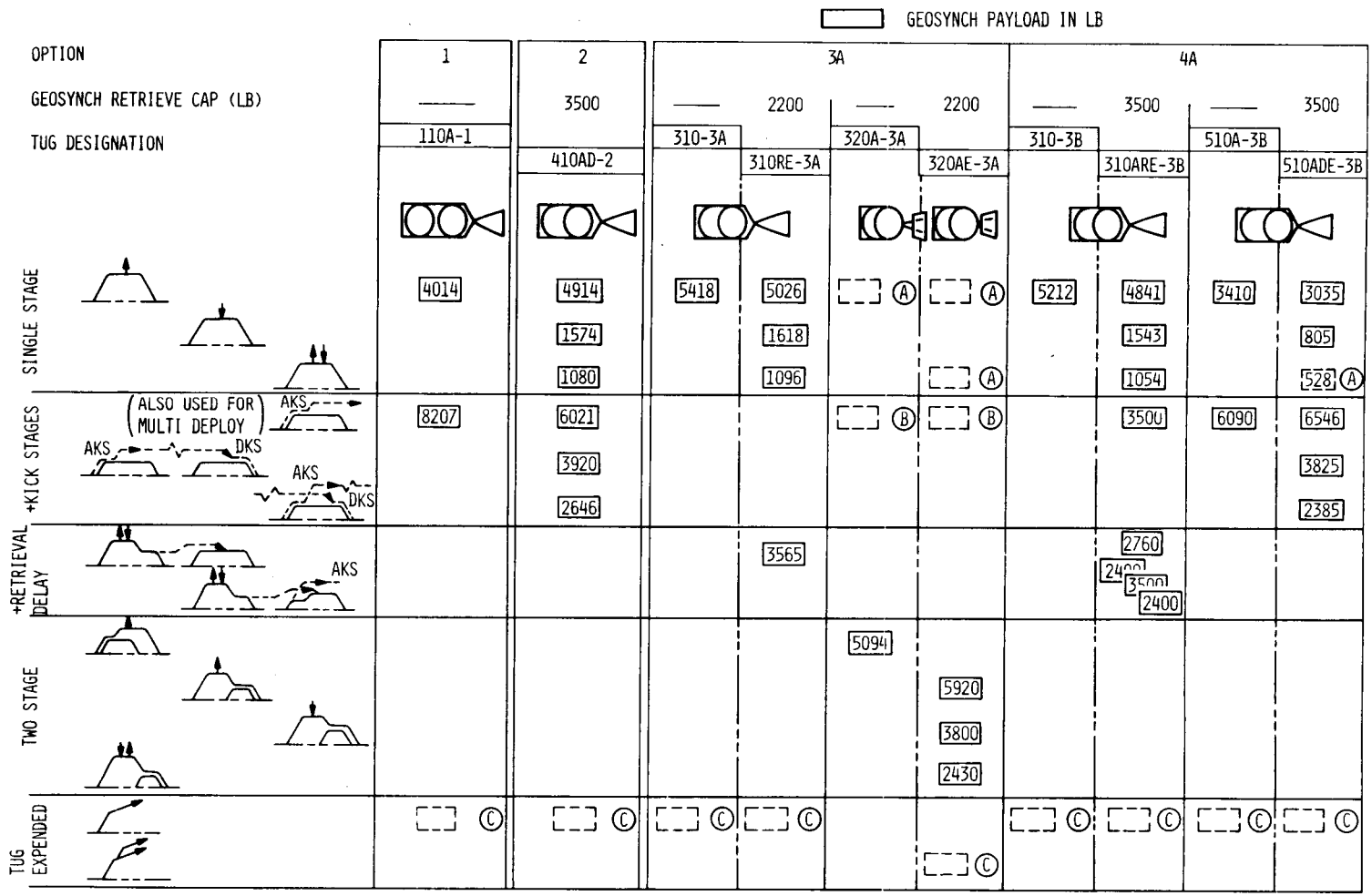
PERFORMANCE SUMMARY

This is a sumary of the performance capability of each Tug concept, grouped by flight mode. Each concept meets or exceeds all performance requirements.

A characteristic of the modular concepts is that they have very wide flexibility in the way they can be operated.

Although they incur increased flight operational cost, the more complex modes represent a powerful technique for increasing Tug performance.

PERFORMANCE SUMMARY



NOTES - (A) USED FOR LOW ENERGY ORBITS (B) USED FOR PLANETARY (P.L. 1920 & 23) (C) USED FOR EXTREME FAR PLANETARY (P.L. 22 & 24)

I-9, II-11, III-40

PROGRAMMATIC/COST CHARACTERISTICS SUMMARY

This highlights key cost features for each of the concepts.

DDT&E for Option 1 is $191M. Since an apogee kick stage is not required to meet the 3500 lb payload deployment requirement, this module has been deferred in the program until it is phased into planetary flight and multiple deployment operations. While the AKS really is optional, we have included it in the program to minimize total program cost.

There is no significant difference between the initial DDT&E of the two 3B evolutionary concepts and, in fact, total DDT&E is only $25M higher for the configuration evolving to Retrieval Delay Module usage as compared to that using apogee and deorbit kick stages. Tug program cost is $50M lower for the RDM program, but this comparison reverses when shuttle flight costs are included. Due to the lower number of shuttle flights of the 510A-3B/510ADE-3B, its program cost is $25M lower.

The two stage configuration has the lowest number of shuttle flights within Option 3. This depresses the total program cost below the other concepts in spite of its high DDT&E and Tug program cost.

PROGRAMMATIC/COST CHARACTERISTICS SUMMARY

OPTION	1	2	3A		3B	
GEOSYNCH RETRIEVE CAP (LB)	——	3500	—— 2200	—— 2200	—— 3500	—— 3500
● TUG DESIGNATION	110A-1	410AD-2	310-3A/310RE-3A	320A-3A/320AE-3A	310-3B/310ARE-3B	510A-3B/510ADE-3B
● PROGRAMMATICS						
IOC	DEC'79	DEC'83	DEC'79/DEC'83	DEC'79/DEC'83	DEC'79/DEC'83	DEC'79/DEC'83
SHUTTLE FLIGHTS	218	245	355	301	365	336
PAYLOAD DELIV - KLB	705	931	1142	1142	1206	1206
TUG FLEET - MAIN STAGE	11	10	23	13L+11U	16	14
AUX STAGE	14A	14A, 72D	4R	9A	34A, 4R	32A, 95D
● COST - $M						
TOTAL PROG (T+S△)	2820	3362	4586	4075	4694	4424
TOTAL PROG (T)	531	789	858	914	861	906
DDT&E - INITIAL/TOTAL	191/220	350	255/329	333/370	255/346	254/318
COST/FLT NASA REUSE T	.96	1.15	.97	1.17	1.05	1.19
EXPEDN T	8.26	11.52	9.37	17.7	9.45	9.19
EXPEND A	2.16	2.40	–	2.42	2.10	2.44
DOD REUSE T	1.03	1.21	1.04	1.26	1.04	1.17
EXPEND A	2.23	–	–	–	2.09	–
PEAK YEAR FUNDING (YR)	71/81(79)	151(82)	85(78)	107(78)	88(78)	97(78)
FIRST UNIT - MAIN STAGE	9.4	13.1	10.7/13.1	10.2/12.7	10.7/13.1	10.2/12.2
AUX STAGE	1.4	A D 1.4 2.4	RDM 1.6	AKS 1.6	RDM AKS 1.6 1.5	AKS DKS 1.6 2.4
TUG PAYLOAD DELIV COST $/LB	277	222	240	258	242	257

III-103

SENSITIVITY STUDIES VS. APPLICABLE CONCEPTS

This chart lists the 15 sensitivity studies that were performed and their relationship to the 6 Space Tug concepts that were considered.

A check (✔) indicates that specific analyses were performed against the indicated baseline concept to establish the sensitivity results. Applicability (APPLIC.) indicates that, although the sensitivity analyses did not specifically address that baseline concept, the results of the analysis are applicable by similarity.

The results of the sensitivity analysis are generally applicable to most of the concepts with two notable gaps:

(1) Many of the performance trades cannot be applied to the two stage concept (320A/320AE-3A) because of its unique operational modes

(2) Most trades related to payload retrieval or payload support are not applicable to the deploy only Tug concept (110A-1)

The results of these sensitivity studies are discussed on the following three charts. The only sensitivity studies not discussed here are the ground operations sensitivity studies, which are covered under Operations, and the two year IOC delay sensitivity which is discussed under Programmatics.

(Ref. Vol. 5, Book III, Section 5.9)

SENSITIVITY STUDIES VS. APPLICABLE CONCEPTS

CONCEPT

SENSITIVITY	110A-1	410AD-2	310 - 3A/ 310RE-3A	320A- 3A/ 320AE-3A	310- 3B/ 310ARE-3B	510A- 3B/ 510ADE-3B
1. AUTONOMY	✓	✓	APPLIC.		✓	APPLIC.
2. 0.97 RELIABILITY		✓	APPLIC.		APPLIC	APPLIC.
3. 30 DAY SERV. MISS		✓	APPLIC.		APPLIC	
4. DOD COMM. REQM'TS		APPLIC	✓	APPLIC.	APPLIC.	APPLIC.
5. P/L COMMAND, & C/O		APPLIC.	✓	APPLIC.	APPLIC.	APPLIC.
6. ELEC. POWER TO P/L	✓	✓	✓	✓	✓	✓
7. DESIGN LIFE	APPLIC.	APPLIC.	✓	APPLIC.	✓	APPLIC.
8. SPIN-STAB. P/L RET.			✓	APPLIC.	APPLIC.	
9. RENDEZVOUS & DOCK.	✓	APPLIC.	APPLIC.		APPLIC.	APPLIC.
10. NESTED VS. SEP. TANKS	APPLIC.	APPLIC.	✓		APPLIC.	APPLIC.
11. IN-FL PROP. DUMP	✓	APPLIC.	APPLIC.		APPLIC.	APPLIC.
12. MAIN ENGINE SELECT.	✓	✓	✓		✓	✓
13. USE OF RDM		✓				
14. GROUND OPS TRADES	✓	APPLIC.	APPLIC.	APPLIC.	APPLIC.	APPLIC.
15. 2 YEAR IOC DELAY	✓	✓	✓			

SENSITIVITY STUDY RESULTS - SUMMARY

1. Autonomy

The results of our autonomy sensitivity study indicated that:

- o Autonomy level II is best suited for Option 2 and 3
- o Autonomy level IV is an attractive candidate in Option 1 because of low DDT&E. A close second choice is autonomy level II with relatively low DDT&E and close to $40M total program cost savings.

The level I system had degraded performance due to the slow convergence characteristics of the Horizon Scanner Star Tracker system.

The selected level II system requires the use of the 621B NAV SAT which introduces schedule risk and technology issues. It is recommended that the interferometer approach which utilizes undedicated RF sources as landmarks be considered as an option.

The level III system introduces high software development and operating costs for both ground and onboard computer systems.

High ground involvement and costs precludes the use of a level IV system for the more complex Option 2 and 3 programs.

2. Reliability

All but 10 of the 67 lbs of redundancy required on the 410AD-2 Tug to achieve the baseline 0.97 mission success reliability is also required to maintain safety of flight when the Tug is in the vicinity of the orbiter. The Tug without any of the 67 lbs. of redundancy has a 0.98 reliability for a 36 hour deployment mission. Therefore, the safety of flight requirement in the vicinity of the orbiter has a more pronounced effect on hardware redundancy than mission duration.

The sensitivity analysis also indicated that it may be cost effective to design the Tug for a mission success reliability goal greater than 0.98.

3. 30-DAY SERVICING MISSION

The 30 day servicing mission involves servicing of four satellites in geosynchronous orbit. The Tug carries a reusable 500 lb. servicing unit for this purpose. The Tug accomodates the 30 day servicing mission requirement by providing add-on EPS cryogenic tanks and APS propellant tanks. The EPS tanks were sized for 340 kwh for Service Mode I and 451 kwh for Service Mode II. The total usable APS propellant requirement was 1020 lb. The performance capability and cost impact are indicated on the chart.

SENSITIVITY STUDY RESULTS - SUMMARY

SENSITIVITY AREA	RESULTS
1. AUTONOMY	o LEVEL II - MOST ATTRACTIVE FOR OPTIONS 2 AND 3 o LEVEL IV - MOST ATTRACTIVE FOR LOW DDT&E OPTION 1 o LEVEL I - HIGHEST PERFORMANCE PENALTIES o LEVEL III - HI DDT&E AND TOTAL PROGRAM COST
2. 0.97 RELIABILITY	o TUG WEIGHT SAVING (10-67 LB) IS MORE DEPENDENT ON SAFETY CRITICAL ISSUES THAN SHORTER MISSION DURATION o TUG RELIABILITY GOAL > 0.98 MAY BE COST EFFECTIVE
3. 30-DAY SERVICING MISSION	o SERVICE MODE I - TOTAL SRU DEPLOY WEIGHT = 686 LB OR 172 LB/SATELLITE - INCREASES TO 2516 LB OR 629 LB/SATELLITE IF SERVICE UNIT IS LEFT IN MISSION ORBIT - TUG DDT&E COST INCREASE IS $8.4M (SERVICE UNIT ASSUMED GFE)

4. DOD COMMUNICATION REQUIREMENTS

The baseline Tug communication subsystem was designed to accomodate both the NASA requirements (STDN and TDRS compatibility) and the DOD requirements (SGLS compatibility plus secure comm). The Tug performance and cost penalty to accomodate SGLS and secure comm., in addition to meeting the NASA requirements was estimated to be 32 lbs. of communication subsystem hardware and $430K DDT&E cost. The per unit production cost impact was estimated to be $75K. All secure comm. equipment is assumed to be GFE to the Tug program and is not costed.

It was noted that the biggest contributor to the baseline communication subsystem cost was the requirement for TDRS spread spectrum compatibility. This requirement results in a 12 lb. weight penalty and a $7M DDT&E cost impact.

5. PAYLOAD COMMAND CONTROL AND CHECKOUT

The baseline Tug was designed to provide a payload command control and checkout interface. The Tug performance and cost penalty to meet this requirement was estimated to be 53 lb. of subsystem hardware with a $4M DDT&E cost impact. The per unit production cost impact was estimated to be $570K. The TV assembly was assumed to be required for payload monitoring and support only.

6. ELECTRICAL POWER TO PAYLOADS

Providing 300 watts of electrical power to payloads while they are attached to the Tug requires additional primary battery capacity for concept 110A-1 and increased fuel cell reactant storage for the other concepts. The required payloads support times were 11 hours for concept 110A-1, 57 hours for concept 320AE-3A and about 100 hours for all the other concepts. The performance penalty was a reduction in payload delivery capability of 140 lbs. for 110A-1 and less than 40 lbs. for all the other concepts. The DDT&E cost impact was negligible. The total productions cost impact ranged from $400K for 110A-1 to about $1M for 310RE-3A.

7. DESIGN LIFE

The Tug design life study indicated that most Tug hardware is not life limited and a design life of 100 missions is practical. Major areas of concern are the main propulsion tanks, main engine, fuel cell and thermal coatings and MLI.

It was found that the number of Tugs expended (for planetary missions) during the program had a significant effect on the operating life and consequently the optimum design life of a Tug. For example, for the 310/310RE-3A program where 17 Tugs are expended, a difference in Tug design of from 20 to 50 missions only changed the fleet size by one vehicle.

SENSITIVITY STUDY RESULTS - SUMMARY (CONT.)

SENSITIVITY AREA	RESULTS
4. DOD COMM REQUIREMENTS	o ADDING DOD COMM REQUIREMENTS (SGLS PLUS SECURE COMM) TO NASA REQUIREMENTS: - INCREASES TUG WEIGHT BY 32 LB - INCREASES TUG DDT&E COST BY $430K (SECURE COMM EQUIPMENT IS GFE) o PROVIDING TDRS (SPREAD SPECTRUM) COMPATIBILITY IS LARGEST COST DRIVER - INCREASES DDT&E BY $7M
5. PAYLOAD COMMAND CONTROL AND C/O	o WEIGHT INCREASE OF 53 LB o DDT&E COST INCREASE OF $4M
6. ELECTRICAL POWER TO PAYLOADS	o PROVIDING 300W POWER TO PAYLOADS - REDUCES CONCEPT 110A-1 DEPLOY CAPABILITY BY 140 LB - REDUCES OTHER CONCEPTS DEPLOY CAPABILITY BY $<$ 40 LB - NEGLIGIBLE DDT&E IMPACT. TOTAL PRODUCTION COST BETWEEN $0.4-1.1M
7. DESIGN LIFE	o MOST TUG HARDWARE IS NOT LIFE LIMITED o OPTIMUM DESIGN LIFE VERY DEPENDENT ON NO. OF TUGS EXPENDED

8. SPIN-STABILIZED PAYLOAD RETRIEVAL

The objective was to determine the effect if the Tug were required to despin spin-stabilized payloads which are candidates for retrieval. Using TOPSS study results a reusable despin kit was assumed to be carried by the Tug. The only significant impact was the reduction in Tug payload retrieval capability of about 120 lbs.

9. RENDEZVOUS AND DOCKING

The objective was to determine the impact on the Tug of providing retrieval capability. Concept 110A-1 was chosen as the point of departure. It was estimated that 350 lbs of weight must be added to 110A-1 to achieve retrieval capability. The net result is a reduction in Tug deployment capability of over 900 lbs. The DDT&E increase to 110A-1 to provide retrieval capability was estimated to be $54M.

10. NESTED DOME vs. SEPARATE TANK

A comparison between nested dome and separate tank configurations indicated that the separate tanks were heavier by 70 lbs for titanium and 129 lbs for aluminum. A cost comparison for titanium tanks indicated that the separate tank configuration would reduce DDT&E by $1.2M and first unit cost by $90K. The separate tank configuration simplifies manufacturing and inspection and reduces the potential hazard associated with leaks.

11. IN-FLIGHT PROPELLANT DUMP

Providing in-flight propellant dump instead of designing for landing with full tanks results in a reduction in Tug weight of 42 lbs, a reduction in adapter weight of 11 lbs and an orbiter increse of 4 lbs. This results in an equivalent Tug weight reduction of 49 lbs. In-flight propellant dump reduces Tug DDT&E by $400K and increases total Tug production cost by $35K.

12. MAIN ENGINE SELECTION

A sensitivity analysis based on performance and cost indicated that the 8096-B2 engine merits further consideration in all of the concepts considered. The performance improvement of the OME 12 over the OME 7.5 is very small and does not justify the increased DDT&E. The performance improvement of the Class II over the Class I again is not large enought ot justify the delta DDT&E.

13. USE OF RDM

The objective was to determine the program impact of substituting an RDM for the DKS in the direct-developed high performance Option 2 concept. The Tug with RDM reduced DDT&E by $14M and Tug only program cost by about $70M, but resulted in a total program cost increase of over $200M.

SENSITIVITY STUDY RESULTS - SUMMARY (CONT.)

SENSITIVITY AREA	RESULTS
8. SPIN-STABILIZED PAYLOAD RETRIEVAL	o ASSUMED TUG USED GFE DESPIN KIT o TUG PAYLOAD RETRIEVAL CAPABILITY REDUCED BY 120 LB.
9. RENDEZVOUS AND DOCKING	o ADDING RETRIEVAL CAPABILITY TO TUG INCREASES WEIGHT BY 350 LB AND REDUCES DEPLOYMENT CAPABILITY BY > 900 LB o COST OF PROVIDING RETRIEVAL CAPABILITY IS $54M
10. NESTED DOME VS. SEPARATE TANK	o SEPARATE TANK CONFIGURATION: - INCREASES TUG WEIGHT BY 70 LB (T_I) AND 129 LB (A_L) - DECREASES COST: DDT&E BY $1.2M AND PRODUCTION BY $1M - SIMPLIFIES MANUFACTURING AND REDUCES POTENTIAL HAZARDS
11. IN-FLIGHT PROPELLANT DUMP	o RESULTS IN EQUIVALENT TUG WEIGHT REDUCTION OF 49 LB o REDUCES DDT&E COST BY $400K. INCREASES PRODUCTION COST BY $35K.
12. MAIN ENGINE SELECTION	o 8096-B2 ENGINE MERITS FURTHER CONSIDERATION IN ALL OPTIONS o OME 12 AND CLASS II ENGINES ARE NOT COST-EFFECTIVE
13. USE OF RDM	o USE OF A TUG WITH RDM INSTEAD OF DKS IN OPTION 2 - REDUCES DDT&E BY $14M. - INCREASES TOTAL (TUG + SHUTTLE) PROGRAM COST BY OVER $200M.

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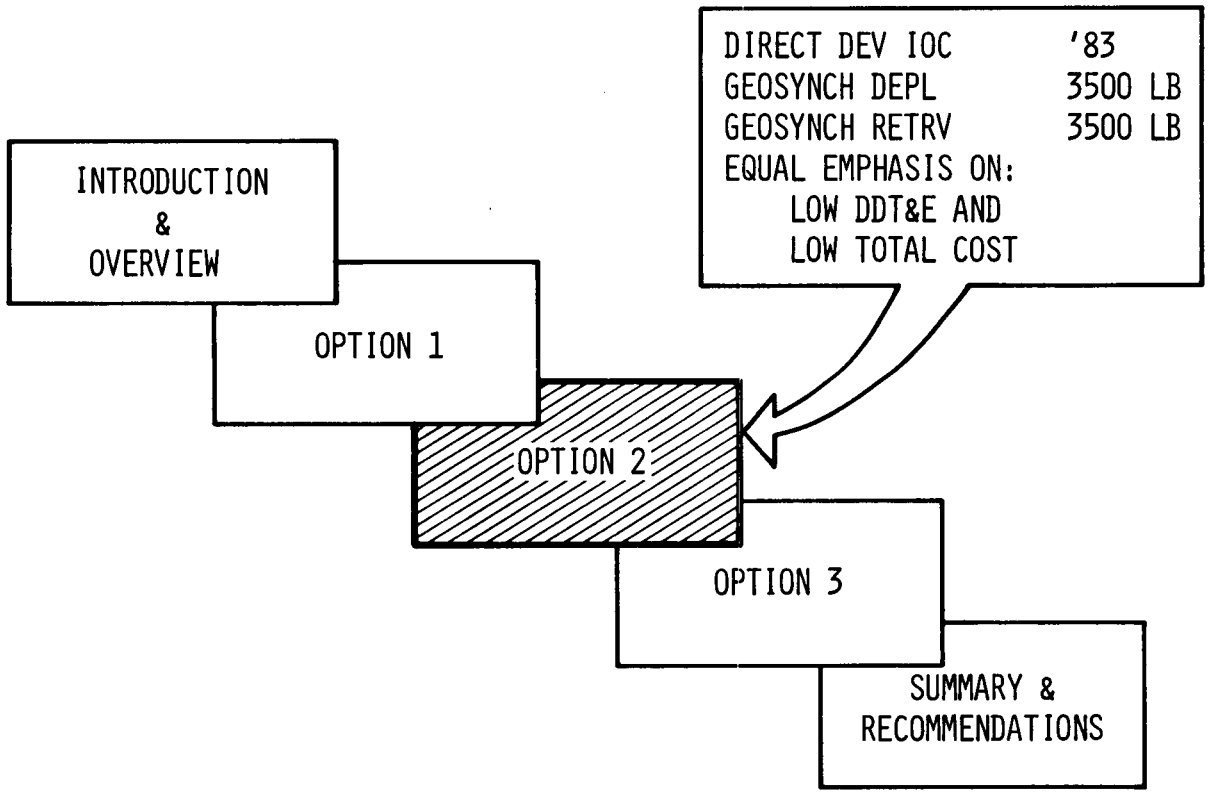
STORABLE TUG DATA REVIEW



I-12
II-14
III-43

OVERVIEW 410AD-2

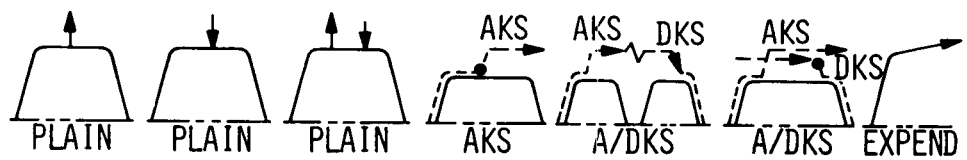
This is a high performing vehicle which uses kick stages to give increased performance. As a basis of comparison with 510ADE-3B, which also uses AKS and A/DKS, this is a higher performing "plain" tug and, therefore, more costly but it uses kick stages less often than does 510. Its performance as a plain tug serves as a realistic basis upon which to evaluate service missions and retrieval delay missions sensitivity studies.

The deployment and retrieval payload capabilities of the tug are shown for candidate flight modes and missions, together with costs and the number of flights and vehicles upon which they were based.

(Ref. Vol. 5, Part I, Opt. 2, Sect. 5.2)

410AD-2 OVERVIEW

- FEATURES
  - SINGLE STAGE TUG WITH AKS OR A/DKS FOR SOME PAYLOADS
  - SOME DKS LAUNCHED BY OTHER MEANS IN 81/83 FOR PL RETRIEVAL FROM '83
  - BASIC TUG PERF KEPT HIGH TO MAKE SERVICE MISSION & RDM SENSITIVITIES REALISTIC
  - MAIN ENGINE - CLASS 1, I_{SP} = 338 SEC — I_{SP} = 338 SECS
  - FIXED WEIGHT = 3411 LB
- FLIGHT MODES



- PERFORMANCE — GEOSYNCH → PLANET →
  - DEPLOY (LB — 4914 — 6021 — 3920 — PL 22 & 24
  - RETRIEVE (LB) — 1574 — (& PL 23) — 3920
  - ROUND TRIP (LB) — 1080 — 2640
- PROGRAMMATICS
  - DDT&E $M350
  - TOTAL PROGRAM $M3362
  - NO. OF FLIGHTS 245
  - NO. OF TUGS 10
  - NO. OF AKS 14
  - NO. OF A/DKS 72

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OPTION 2 410AD-2 PERFORMANCE SUMMARY

Concept 410AD-2 meets the 3500 lb deployment requirement without kick stages, but requires a deorbit kick stage to meet the 3500 lb retrieval requirement.

The delta-V budgets shown on the facing page text accounts for gravity losses resulting from the 12,000 lb thrust engine. A finite burn simulation which utilizes a gravity turn during the early portion of the maneuver and cross product steering during the terminal portion was used to define delta-V's for the transfer and circularization burns. The transfer to geosynchronous altitude was split into two burns. A 2 degree plane change was split between the two outbound transfer maneuvers and the remaining 26.5 degrees performed during the circularization burns.

All performance calculations account for APS, EPS and stop/start consumables. A detailed calculation was made for each concept and flight mode by accounting for attitude maneuvers for prethrust orientations, navigation sightings and IMU alignments. All limit cycle operations, both narrow and wide, were accounted for in the calculations. Midcourse corrections, terminal rendezvous and translations required to null residuals after each main engine burn was taken into account in the evaluation.

(Ref. Vol. 6, Sect. 6.3)

OPTION 2 - 410AD-2 PERFORMANCE SUMMARY

VEHICLE CHARACTERISTICS

W_{BO} = 3411 LBS
ADAPTER WT. = 1510 LBS
W_P- CAPACITY = 59500 LBS

I_{SP} = 338 SEC
THRUST = 12,000 LBS
FPR = 1.7% Δ V

DELTA-V ~ FPS

	CORE			K.S.	
	OUTBOUND	ON-ORBIT	INBOUND		LOSSES
• DEPLOY	13967	0	13885	N/A	84
• DEPLOY + AKS	11948	0	12335	2077	79
• RETRIEVE	13967	30	13885	N/A	84
• RETRIEVE + DKS	11358	30	12175	2684	79
• ROUND TRIP	13967	130	13885	N/A	84
• RND TRP + AKS/DKS	8315	710	9416	5730/5869	80

	CONSUMABLES ~ LBS		GEOSYNCHRONOUS PAYLOAD - LBS
	APS	EPS + LOSSES	
• DEPLOY	281	69	4914
• DEPLOY + AKS	217	48	6021
• RETRIEVE	409	82	1574
• RETRIEVE + DKS	628	72	3920
• ROUND TRIP	449	148	1080
• RND TRP + AKS/DKS	423	96	2640

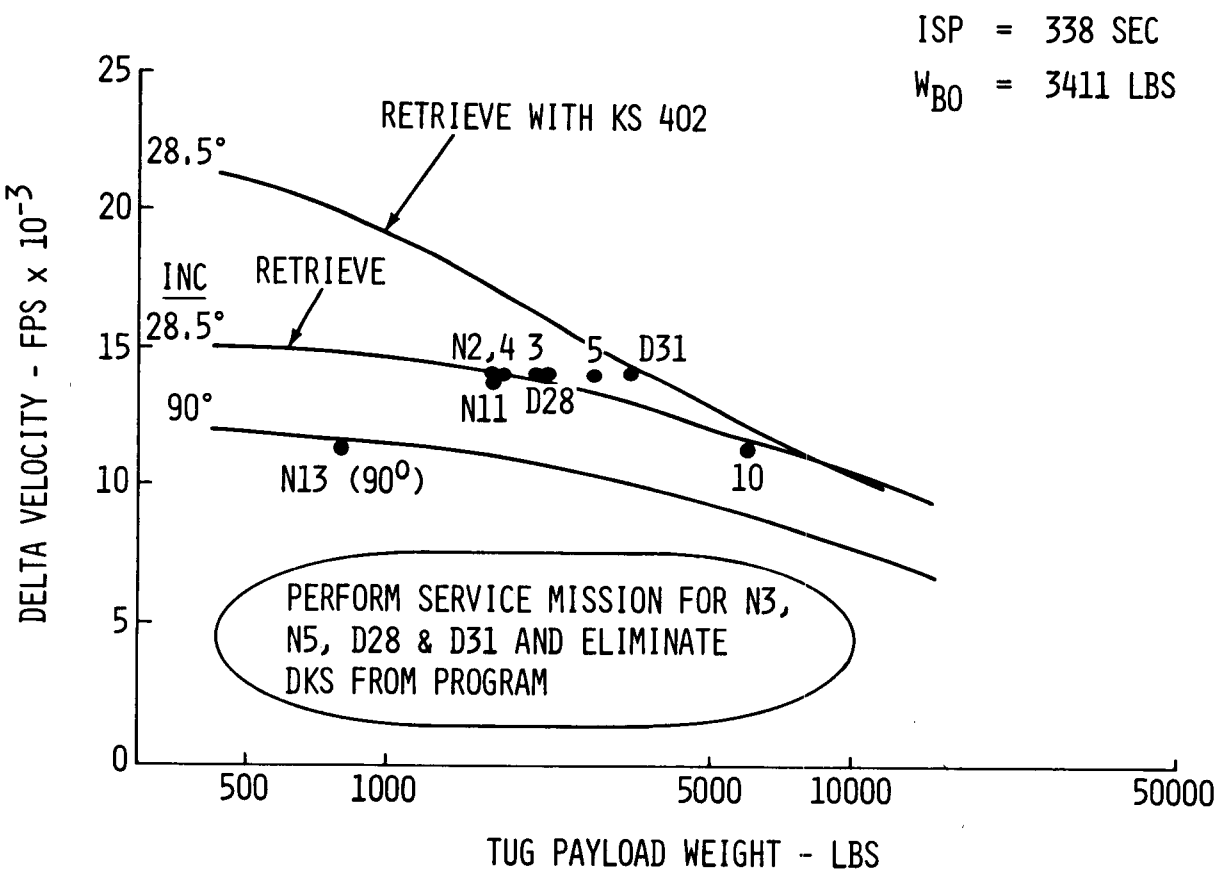
OPTION 2 - 410AD-2 RETRIEVAL PERFORMANCE

NASA missions N3 and N5 require 30 retrieval opportunities or 33% of the total NASA retrieval traffic. These missions need deorbit kick stages for capture. Missions N2 and N4 are slightly above the current capability of 410AD-2 for retrieval without a kick stage. Either a 165 lb inert weight decrease or a 2300 lb. Shuttle performance increase would provide the margin for capturing these payloads with an unaugmented TUG.

DOD missions 28 and 31 constitute 10 retrieval opportunities requiring deorbit kick stages. A 4000 lb increase in Shuttle performance would provide the margin to capture DOD mission 27 (6 retrieval opportunities) without augmentation.

(Ref. Vol. 4, Sect. 4.3.2)

OPTION 2 - 410AD-2 RETRIEVAL PERFORMANCE



OPTION 2 - 410AD-2 FLIGHT SUMMARY

Concept 410AD-2 has the performance capability to return all SRM cases except for the 104 missions in which KS405 is used for roundtrip flights. In this flight mode, a cluster of four apogee kick stages are jettisoned at the mission orbit. This flight mode results in 416 SRM cases left in-orbit as space debris. These cases can be returned with the payload, deorbit kick stages and support subsystems by imposing a roundtrip payload penalty of 250 lbs. All other kick stages configured for earth orbit missions are returned.

There are a total of 148 NASA flights of which 107 are launched from ETR and 33 from WTR. Of the 114 DOD flights, 97 are launched fromETR and 17 from WTR. The NASA requires 74 deorbit kick stages flights while DOD requires 66.

Of the "Additional Payloads" assigned to Option 2 to evaluate the growth potential of the concepts, all missions can be captured with the acception of the N10 and the D126 sortie mission. For deployment and retrieval of N6, 7 and 8, KS405 is used in a 2 flight sequence. All additional planetary missions are within the capability of the 410AD-2, but requires 8 additional expendable TUGS.

(Ref. Vol. 4, Sect. 4.3.2)

FLIGHT SUMMARY OPTION: 2 (410AD-2)

FLIGHT MODE		CALENDAR YEAR											TOTAL
		80	81	82	83	84	85	86	87	88	89	90	
TOTAL FLIGHTS	SHUTTLE					43	35	38	38	33	37	38	262
	TUG												SAME
TUG FLIGHT DISTRIBUTION	DEPLOY					(16)	(7)	(10)	(15)	(8)	(17)	(10)	(83)
	SINGLE P/L - CORE					6	5	5	4	3	6	5	34
	- CORE + KS					6		3	4	1	3	2	19
	- EXPEND TUG					2		1	1		3	1	8
	MULTI P/L - CORE					2	2	1	2	2	5	2	16
	- CORE + KS								4	2			6
	RETRIEVE					(10)	(3)	(8)	(6)	(4)	(3)	(8)	(42)
	CORE ONLY					3		7	4	4		3	21
	CORE + KS					7	3	1	2		3	5	21
	ROUND TRIP					(17)	(24)	(20)	(16)	(21)	(16)	(20)	(134)
	CORE ONLY					8	13	10	6	11	10	8	66
	CORE + KS					9	11	10	10	10	6	12	68
	SORTIE						(1)		(1)		(1)		(3)
MISSION MODEL	(TOTAL)					(64)	(64)	(60)	(63)	(59)	(62)	(62)	(434)
	DEPLOY					37	36	32	40	34	42	34	255
	RETRIEVE					27	27	28	22	25	19	28	176
	SORTIE						1		1		1		3
FLT RATE USED IN COSTING						25	33	38	38	33	37	38	242

A 250 LB RND TRIP P/L REDUCTION WILL ALLOW RETURN OF THESE SRM'S

CONFIGURATION 410AD-1

The 410AD-1 configuration employs separate but nested propellant tanks, sharing a common pressure interface only by virtue of the nested separate domes. They are of titanium alloy, welded gore construction, with the cylindrical portion of sheet-stringer construction.

The remaining outer shell is of composite honeycomb construction, attached to the tank girths by mechanical joints.

The engine thrust structure is a conical section of aluminum stiffened sheet construction also. All main support and intermediate frames are of aluminum alloy construction.

An aluminum meteorite shield, supported by fiberglass standoffs on 6" centers, protects the propellant tank over its cylindrical portion.

Twelve lock latches are located at both ends of the Tug for final securing of payloads to Tug and Tug to support adapter. Twelve conical index fittings at both forward and aft interfaces serve to index and align the mating surfaces and transmit shear and compression loads across the interface.

All subsystem equipments are located in side mounted equipment modules for easy access and serviceability.

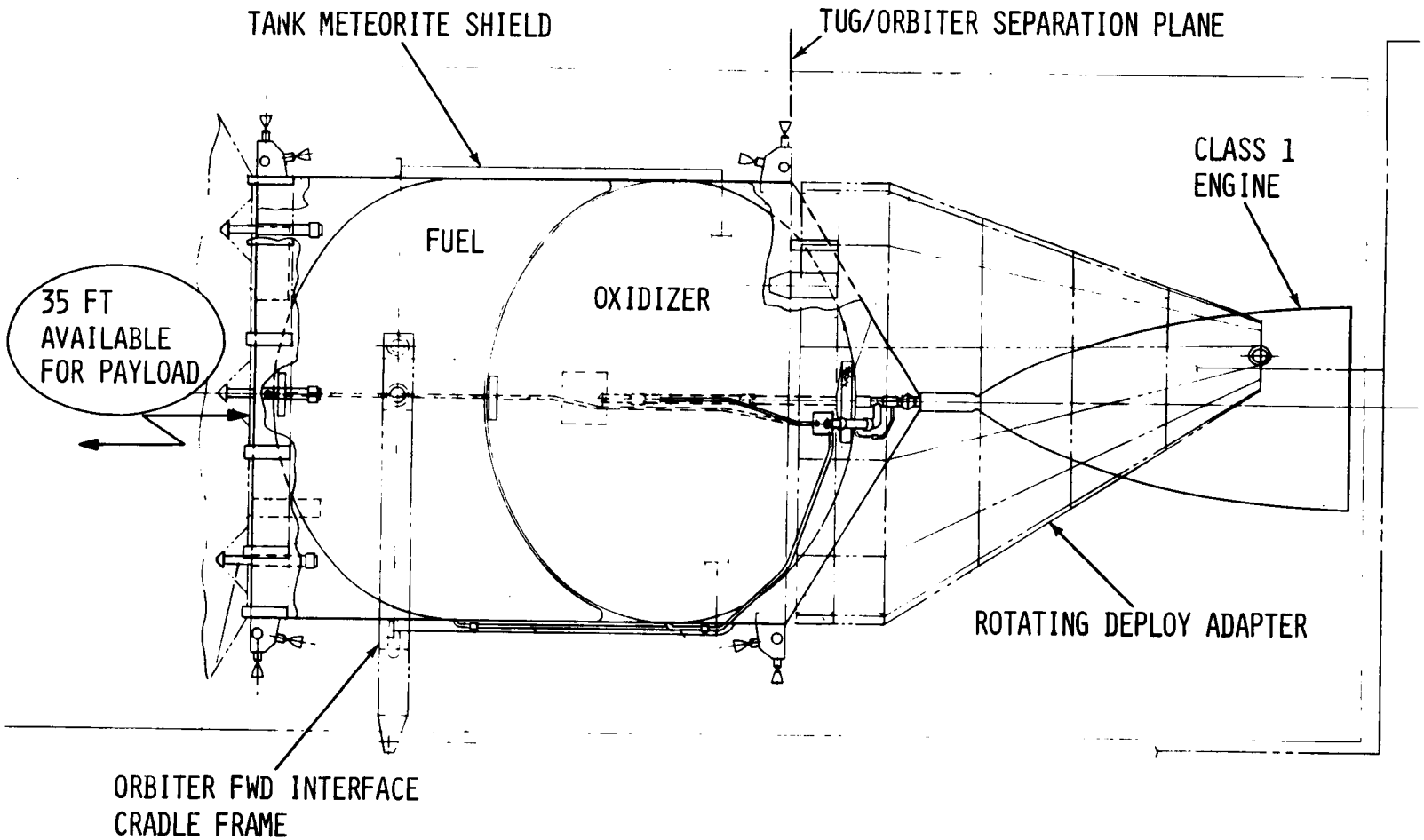
Double goldized mylar blankets with nylon net spacers in conjunction with suitable surface coatings on all exterior surfaces provide the required thermal balance for the spacecraft. In addition aluminum heat pipe radiators mounted on the surface of the equipment modules maintain the thermal balance of the equipment modules.

Four equally spaced probe/drogue type probes are installed at the forward interface for executing retrieval operations.

A complete inboard profile and structural arrangement for this configuration may be found in Volume 5.

(Ref. Vol. 5, Part I, Opt. 2, Sect. 5.2)

INBOARD PROFILE - 410AD-2: SIDE VIEW



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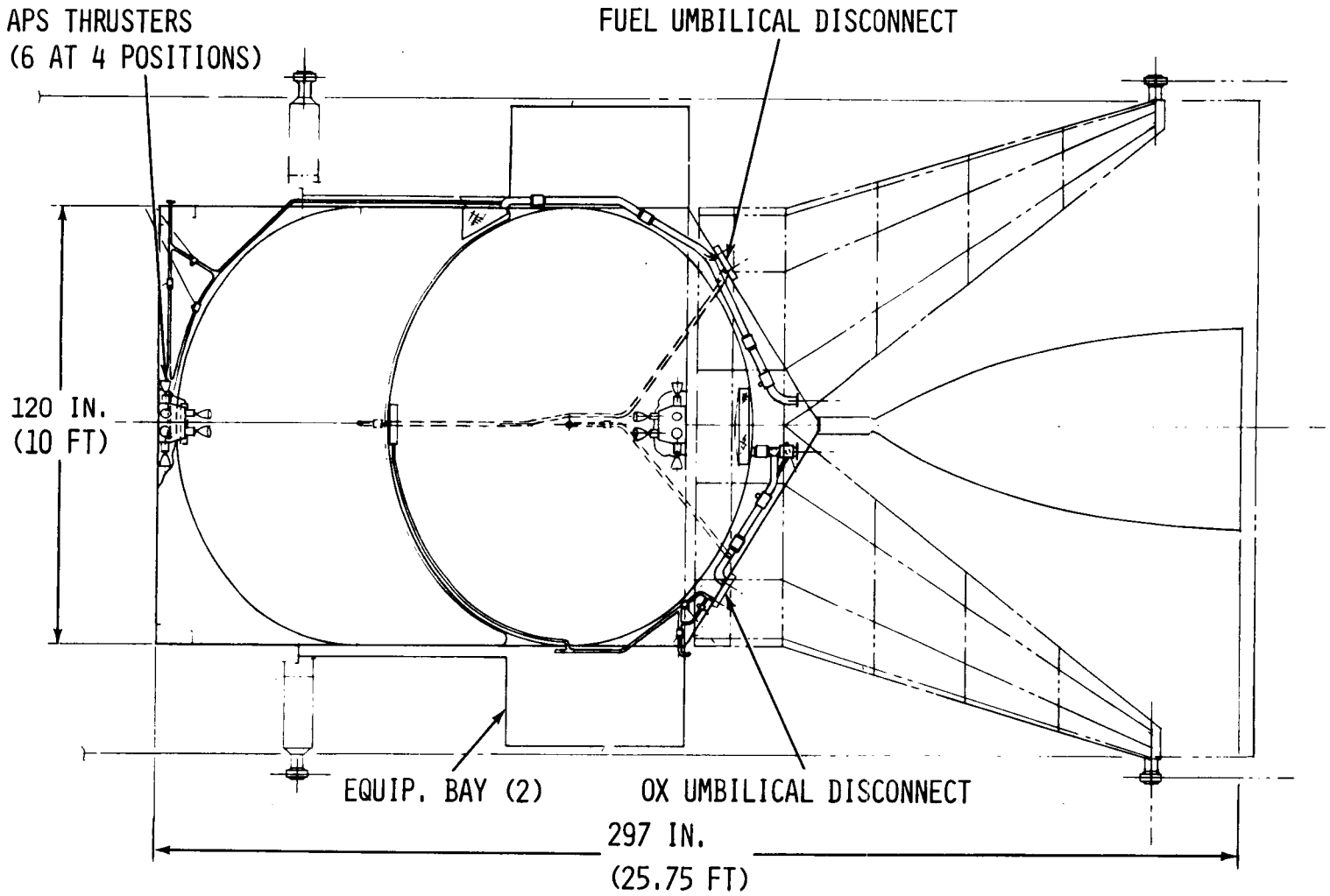
INBOARD PROFILE - 410AD-2: PLAN VIEW



II-31

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CONFIGURATION DESIGN DATA AND WEIGHT SUMMARY
SINGLE STAGE STORABLE TUG 410AD-2

ITEM	FEATURES	WEIGHT-LB
• STRUCTURE		1288
TANKS	NESTED DOME-TI GORES - CAP. = 59500 LB	
FRAMES	ALUMINUM	
OUTER SHELL	COMPOSITE HONEYCOMB	
DOCKING	DEPLOYMENT AND RETRIEVAL MECHANISMS	
• PROPULSION		737
MAIN ENGINE	CLASS I-THRUST = 12000 LB Isp = 338 SECS	
PRESSURIZATION	AMBIENT HELIUM - PRF TANKS-CAP. = 14.2 LB	
ACPS	HYDRAZINE-24 THRUSTERS x 25 LB-CAP. - 450 LB	
• THERMAL CONTROL		89
	MYLAR TANK INSUL. COATINGS, RADIATOR	
• AVIONICS		762
RENDEZVOUS & DOCK	AUTONOMY LEVEL IIB-RETRIEVAL-LASER RADAR + TV	
DATA MANAGEMENT	COMPUTER-65K WORDS - 2 REQ'D	
GUIDANCE AND NAV	2x MICRON IMU - 1x STAR TRACKER	
GUIDANCE UPDATE	SATELLITE AND DOPPLER	
POWER	MODIFIED F/C-CRYO TANKS-CAP. = 90 LB	
	DRY WEIGHT	2876
	DRY WEIGHT & CONTINGENCY	3164
	NON USABLE PROPELLANT	247
	BURNOUT WEIGHT	3411
DEPLOY MISSION	NON IMPULSE EXPENDABLES	48
	ATTITUDE CONTROL PROPELLANT	217
	MAIN PROPELLANT	54900
	PAYLOAD	4914
	TUG AT FIRST IGNITION	63490
	SHUTTLE INTERFACE ITEMS	1510
	TOTAL-SHUTTLE INSTALLED	65000

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MAIN PROPULSION SUBSYSTEM (MPS) - 410AD-2

The 410AD-2 engine is required to start up to 9 times per mission, and must remain on-orbit for up to 117 hours. The planetary missions require that the Tug be turned around and retrofired as soon as possible after the planetary insertion burn. This leads to the minimum restart requirement of 10 minutes.

The capability to drain and depressurize the vehicle in both the horizontal and vertical positions is provided. An in-flight dump system was not included; however, a sensitivity study has been conducted which indicates that it can save vehicle weight and cost due to the reduction in maximum landing weight; incorporation of this capability is desirable.

This vehicle uses nested dome propellant tanks and a pair of prestressed filament reinforced (PFR) helium tanks. In order to meet the 0.97 mission reliability, redundant helium isolation valves and regulators are included.

The engine is the Class I producing a thrust of 12,000 lbs. and an Isp of 338 seconds at a 1.9 mixture ratio. It is a new design based upon current technology. As such, it can provide reasonably high performance at moderate development risk and cost.

The PFR tank is the only subsystem component other than the Class I engine representing any significant development risk. Failure to develop the tank would mean a 48 lb. weight increase should a titanium tank be used as a fall back position.

Fourteen of the sixteen (88%) types of subsystem components are either existing or modifications of existing designs, further reducing subsystem development risk.

(Ref. Vol. 5, Part I, Opt. 2, Sect. 5.2)

410AD-2 MAIN PROPULSION SUBSYSTEM (MPS)

DRIVER REQUIREMENTS

- $20X10^6$ LB-SEC TOTAL IMPULSE
- 9 BURNS/MISSIONS
- 117 HR ON-ORBIT TIME
- 10 MIN MIN RESTART TIME
- 69 HR MAX RESTART TIME
- VERTICAL & HORIZONTAL DRAIN
- MIN 16 PSIA ENG INLET PRESS.
- OFF-LINE SERVICING & CHECKOUT

MPS DEFINITION

- CLASS I ENG
- NESTED DOME TANKS
- PFR He TANKS (3500 PSIA)
- 2 IN. (FUEL), 3 1/4 IN. (OXID) DIA FEEDLINES
- DUAL He ISOL VALVES & REG ASSY
- 23 IN. DIA He BOTTLE

MPS PERFORMANCE

- 12000 LB THRUST
- 338.0 SEC ISP
- 24 PSIA (MAX) MMH TANK PRESS.
- 36 PSIA (MAX) N_2O_4 TANK PRESS.
- 14.2 LB He
- 59,500 LB PROP.
- 1.9 MIXTURE RATIO

DEVELOPMENT RISK & TECHNOLOGY

- PFR TANK

- NEW ENG BASED UPON CURRENT TECHNOLOGY, MODERATE RISK
- 88% OF COMPONENTS EXISTING OR MOD EXISTING DESIGNS

11-27

MAIN PROPULSION SUBSYSTEM (MPS) DESCRIPTION 410AD-2 VEHICLE

This vehicle utilizes the Class I engine to meet performance goals and reduce operational costs through multiple deployment.

The MPS is based upon a design which is almost completely state-of-the-art. The only new design is the helium tanks which are of light weight prestressed filament reinforced (PFR) construction.

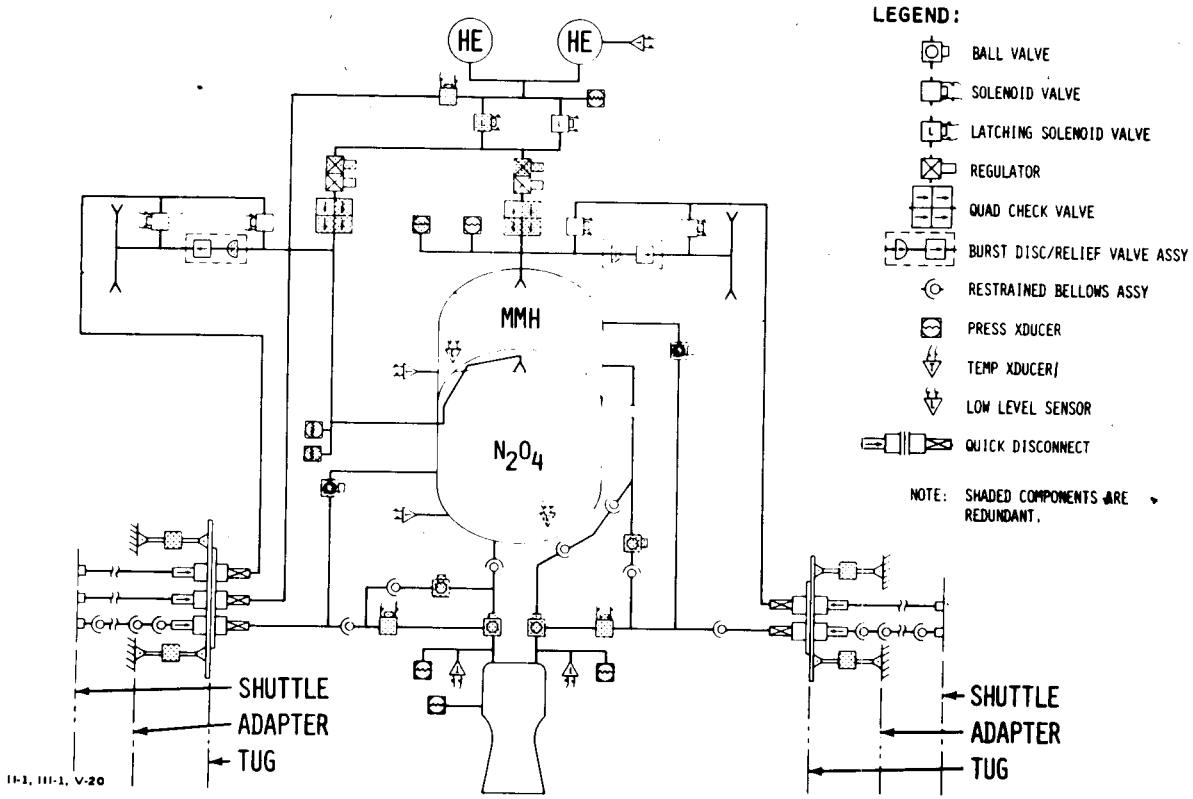
The remainder of the pressurization system is conventional, with pressure control provided by modified OMS regulators and relief valves. The requirement to meet a 0.97 mission reliability dictates the installation of redundant regulators and helium initiating valves. Quad check valves downstream of each regulator prevent the backflow of propellant vapors into the regulators and upstream portions of the helium system. Solenoid valves straddling each relief valve/burst disc assembly allows selective tank depressurization.

Zero g starts are provided for by screen type propellant retention devices located over each tank outlet. These provide sufficient propellant to maintain engine operation until the remainder of the propellant settles. A prevalve is installed upstream of each engine inlet to isolate the propellants from the engine during ground and launch operations and allow engine drain between burns.

Ground drain, in both the horizontal and vertical positions, is provided. The horizontal drain lines lead from the tank equators to the umbilical disconnect panels. Two umbilical disconnect panels are provided on opposite sides of the vehicle. All lines leading to a panel have redundant shutoff capability to meet the MPS fail safe requirement.

(Ref. Vol. 5, Part I, Opt. 2, Sect. 2)

MPS SCHEMATIC - 410AD-2, 310-3A, 310RE-3A, 310-3B, 310ARE-3B, 510A-3B, 510ADE-3B



AUXILIARY PROPULSION SYSTEM - 410AD-2

The fail operational/fail safe requirement demands that the mission be completed after any single failure and shuttle/crew safety be guaranteed after two failures. Sixteen thrusters is the minimum number required to provide attitude control after two thruster failures. Thrust level is driven by the requirement to provide relatively high acceleration in all axes to achieve successful rendezvous on retrieval missions. This requires an increase to twenty four thrusters. The "minimum thrust" requirement is derived from minimum tolerable accelerations which achieve mission completion and is used to establish thruster requirements for the one engine failed case.

Tanks are sized for the guaranteed usable propellant plus 10% contingency. Contingencies include quantity gaging error, trapped propellant and propellant for cross-coupling losses in the event of a thruster failure.

The only component in the system which is not classified as existing or modified existing is the bladder. However the advanced state of elastomeric bladder technology renders it a non-risk item.

(Ref. Vol. 5, Part I, Opt. 2, Sect. 5.2)

410AD-2 AUXILIARY PROPULSION SYSTEM (APS)

DRIVER REQUIREMENTS

- USABLE PROPELLANT = 450 LB
- MIN THRUST PER AXIS = ± 50 LB
- NOMINAL THRUST PER AXIS = ±100 LB
- FAIL-OPERATIONAL/FAIL SAFE DESIGN
- VENT SYS TO 20 PSI AT TUG RETRIEVAL
- VERIFY PROPELLENT QUANT PRE-DOCKING
- NO VENTING IN PAYLOAD BAY

APS DEFINITION

- MONOPROPELLANT HYDRAZINE
- 24 THRUSTERS @ 25 LB THRUST EACH
- 4 PROPELLANT TANKS, LM RCS DESIGN 12.5" D x 34" LONG
- ELASTOMERIC BLADDER PROPELLANT ACQ
- 2 TITANIUM HELIUM TANKS, 12.3" D
- 5/8 IN. LIQ LINES, 1/2 IN. GAS LINES

APS PERFORMANCE

- I_{SP} = 232 STEADY STATE, 170 MIN PULSING
- PRESSURE BUDGET
  - HELIUM TANK = 3900 PSI MAX
  - PROPELLANT TANK = 340 PSI
  - THRUSTER INLET = 325 PSI MIN
  - CHAMBER PRESS. = 140 PSI
- 10% CONTINGENT PROPELLANT REQ

DEVELOPMENT RISK & TECHNOLOGY

- NO TECHNOLOGY ISSUES
- APPROX 90% EXISTING OR MOD EXISTING COMPONENTS

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APS SCHEMATIC - 410AD-2

The Auxiliary Propulsion System is a helium pressurized, monopropellant hydrazine design incorporating state-of-the-art hardware. All components are redundant to the extent that mission completion is possible after any single failure and shuttle/crew safety is guaranteed after any two failures (fail operational/fail safe).

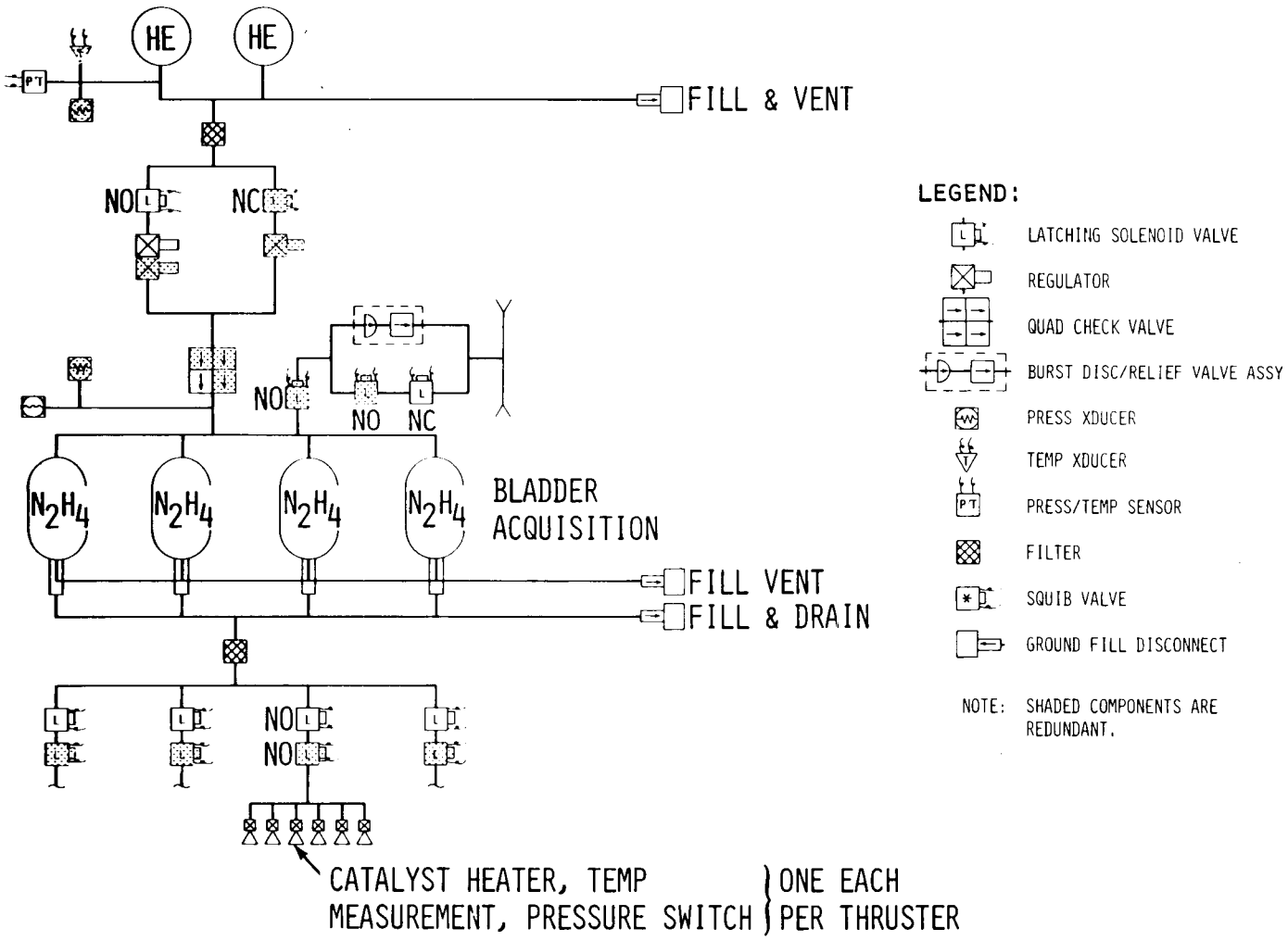
Helium is stored in off-the-shelf, spherical titanium vessels. The helium latching solenoid valve and regulator package, modified LM components, provide pressure regulation to approximately 350 psi. A downstream quad check valve, another LM type design, protects the regulators/solenoid valves against contamination by propellant vapors which may diffuse through the propellant tank bladders. The propellant tanks are modified LM Reaction Control System tanks. They are equipped with fully reusable elastomeric (EPT-10) bladders for propellant acquisition.

The solenoid valve upstream of the relief and vent valve package protects against a failure of the relief valve to reseat or of both vent valves to close after vent, conditions which create a potential tank implosion situation during reentry. Series redundant thruster isolation valves, normally open during Tug operation, are closed in the event of an open thruster failure. Each set of valves isolate one of four groups of thrusters. Four manifolds is the minimum number possible which retains the fail op/fail safe criteria. That is, two groups of thrusters can be isolated and vehicle attitude controlled in all axes.

The thrusters are the 25 lb. thrust, 232 sec. Isp Hamilton Standard model REA 19-3, which was developed for use as the shuttle vernier engine when it incorporated a monopropellant reaction control system. Each thruster is equipped with a catalyst heater to maintain it at 150°F for life considerations.

(Ref. Vol. 1, Part I, Opt. 2, Sect. 5.2)

APS SCHEMATIC - 310RE-3A, 310ARE-3B, 410AD-2, 510ADE-3B



II-2, III-3, V-16

ASTRIONICS SUBSYSTEMS - 410AD-2

The 410AD-2 is a single stage full capability Tug that uses apogee kick stages and deorbit kick stages to deploy and retrieve heavy payloads. The reliability requirements are met with a redundant IMU. For Orbiter crew safety (when the Tug is within 20 miles of the Orbiter) the following additional equipment has been included: computer, APS control electronics, 2 DFS receivers and 1 emergency battery. 94 KW-Hrs of electrical energy is provided by 1 modified shuttle fuel cell stack and cryogenically stored reactants. This energy supplies all Tug vehicle equipment and payload power requirements.

The Tug is required to communicate with the Orbiter, ground and the payload. This requirement is satisfied by a Dedicated Frequency Station (DFS) and a Channel Selectable Station (CSS). The DFS and CSS are designed to be compatible with the NASA (STDN) and Air Force (SGLS) tracking networks as well as the projected NASA Telemetry and Data Relay Satellite System (TDRSS).

A high percentage of the Data Management and Electrical Power Subsystem is modified existing equipment. No new technology is required for these subsystems nor for communications, although new S-Band communications equipment is required since it must be compatible with TDRSS (spread spectrum) and CC1R interference requirements. New technology is required for the GN&C computer and laser radar.

(Ref. Vol. 5, Part I, Option 2, Section 5.2)

410AD-2 ASTRIONICS SUBSYSTEMS - AUTONOMY LEVEL IIB

GUIDANCE, NAVIGATION & CONTROL

- ADVANCED IMU
- STAR TRACKER
- LASER RENDEZVOUS RADAR
- 621B SATELLITE RCVR
- ONE-WAY DOPPLER RCVR
- RISK - AVAILABILITY OF 621B SYS
- NEW EQUIP. REQ
- NEW TECHNOLOGY
  - IMU
  - LASER RADAR

COMMUNICATIONS

- TUG/PAYLOAD, TUG/GND, TUG/ORBITER, TV COMM
- DEDICATED FREQ STA (DFS)
- CHANNEL SELECTABLE STA (CSS)
- STDN/SGLS/TDRSS COMPATIBLE
- S-BAND SYS - INTERNALLY REDUNDANT
- NEW EQUIP. REQ
- NO NEW TECHNOLOGY REQ

DATA MANAGEMENT

- 65K WORD CDC 469 COMPUTER
- ODETICS DDS 3000 TAPE RECORDER
- FLEXIBLE SIGNAL INTERFACE
- 90% MOD EQUIP.
- NO NEW TECHNOLOGY

RETRIEVAL DRIVES GN&C TECHNOLOGY & EQUIPMENT

ELECTRICAL POWER

- MOD SHUTTLE FUEL CELL STACK (2.5KW AT 28VDC)
- CYROGENICALLY STORED REACTANTS (1-O_2 TANK & 1-H_2 TANK) CAPACITY = 94KW-HR
- 10 AMP-HR EMERGENCY BAT. FOR SAFETY
- 70% MOD EXISTING EQUIP.
- NO NEW TECHNOLOGY

II-6

ASTRIONICS SCHEMATIC - 410AD-2

The Data Management Subsystem (DMS) with its Flexible Signal Interface (FSI) is the pivot around which all other astrionic systems revolve. The remaining astrionic systems feed data or commands to the DMS or take commands and information from it. The Communication Subystem in these configurations consists of a Dedicated Frequency Station (for communication between Tug and Orbiter or between Tug and ground) and a Channel Selectable Station (for communication between Tug and payloads or Tug and Orbiter). The incoming information and commands move through the diplexers, redundant receivers and baseband processors to the DOD secure communication units. The secure comm. is used for DOD payloads only. From the output of the Comm. Subsystem the information flows to the Flexible Signal Interface Controller (FSI) and then into the computer. Telemetry signals flow from the instrumentation sensors through Data Acquisition Control Units (DACU) to the FSI and then out through the Comm. system.

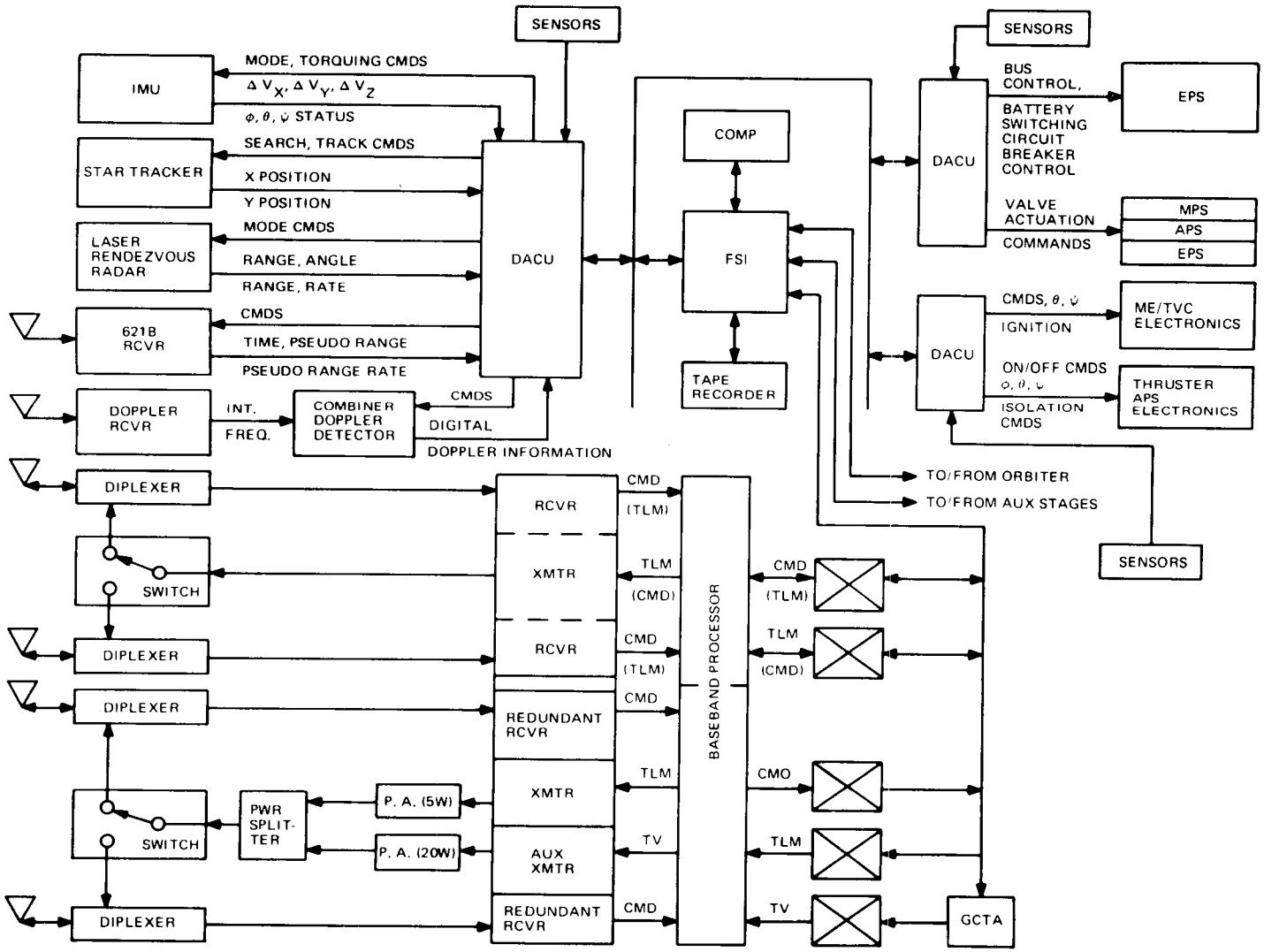
The television camera is a ground controlled unit and its commands flow through the communication subsystems to the DMS system for processing then out to control the camera. The TV information flows back to the ground via the comm. subsystem. The guidance navigation and control information that is measured by the IMU, Star Tracker, Laser Radar, 621B Satellite Receiver and Doppler Receiver flows through a DACU to the FSI and then to the computer for processing. The control outputs from the computer go to the MPS, EPS and APS Subsystems as well as to the ME/TVC and APS electronic units. These are the outputs that activate and control the electrical power systems and thrusting systems of the vehicle.

Status information flows from auxiliary stages to the computer and commands flow from the computer to the auxiliary stages and hardwires.

The information to and from the orbiter is also sent over hardwires when the Tug is in the orbiter payload bay.

(Ref. Vol. 5, Part I, Opt. 2, Sect. 5.2)

ASTRIONICS SCHEMATIC



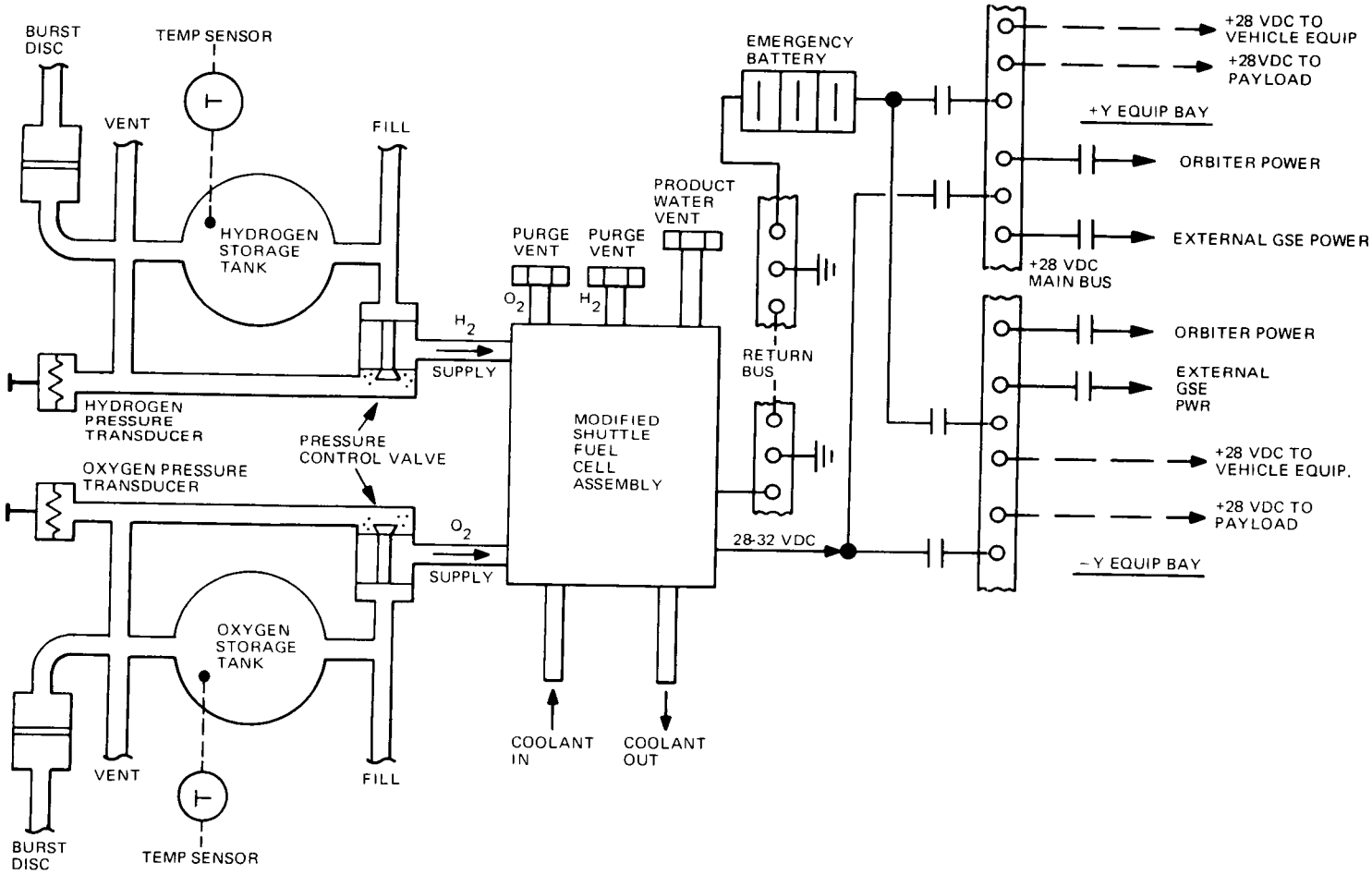
V-1A

ELECTRICAL POWER SUBSYSTEM SCHEMATIC 410AD-2

The prime power source is a modified fuel cell providing up to 2.5 KW at 28 VDC. The hydrogen and oxygen fuel cell reactants are stored in single cryogenic dewars above the supercritical point and supply high pressure gases to the reactant pressure control valves. The fuel cell nominally operates at 60 PSIA and 180°F. The fuel cell oxygen and hydrogen purge plus product water vents are routed overboard. The coolant loop pump is provided within the fuel cell assembly. The fuel cell feeds both equipment bay buses and is backed up by a 10 amp-hr secondary silver zinc battery. This emergency battery powers essential equipment during Orbiter/Tug deployment and retrieval operations and provides for Orbiter crew safety.

The distribution section is a combination two-wire and structure ground (return bus) system. Solid state power controllers are used for applications requiring 5 amps or less and electromechanical remote control circuit breakers are used for 20 amps or larger applications. The orbiter supplies power for critical Tug equipments (e.g. I M U) from earth launch through Tug deployment. GSE power is required for ground checkout. The Tug supplies payload power when separated from the Orbiter.

(Ref. Vol. 5, Part I, Opt. 2, Sect. 5.2)



V-2

Electrical Power Subsystem for { **410AD-2**; **310-3A → 310RE-3A**; **310A-3B → 310ARE-3B**; **510A-3B → 510ADE-3B** }

THERMAL CONTROL 410AD-2

The Tug Thermal Control is driven by the wide latitude in missions, the requirement for no preferred orientation, the limited propellant heat sink when the low altitude polar missions are flown, and by the complement of high power density avionics chosen for a particular configuration.

The MLI blanket required to keep propellants above 40°F for certain missions is carried on all missions. It consists of double goldized mylar with nylon net spacers, lying between the tank and micrometoroid shield along the cylindrical section and directly over both end domes.

An Alzak coating over the outside of the vehicle keeps tank temperatures below 90°F. Silver backed teflon on the saddle bage and heat pipe radiators minimize incident environmental heat absorption and allow a high degree of heat rejection from the avionics.

A base heat shield protects the thrust structure for the main engine nozzle radiation. Electrical heaters on ME and APS assures that unacceptable cold temperatures, 40°F and 150°F respectively, are never reached.

The majority of avionics are mounted on aluminum plates located in the saddle bags and maintained at acceptable temperatures, 30°F to 120°F, through appropriate radiation couplings and electrical strip heaters. The modified fuel cell is on an active pumped heat transport loop which interfaces with a variable conductance heat pipe radiator (VCHP). The high power density TV Power Amplifier is on its own VCHP header/simple heat pipe radiator. The VCHP feature offers its own inherent controls, thereby reducing the need for complex bypass valving with automatic control.

(Ref. Vol. 5, Part I, Opt. 2, Sect. 5.2)

410AD-2 THERMAL CONTROL (T/C)

410AD-2 THERMAL CONTROL (T/C)

DRIVER REQUIREMENTS

- NO PREFERRED ORIENTATION
- LOW ALT POLAR MISSION
- MISSION DURATION = 5 DAYS
- ME NOZZLE RADIATION-COOLED
- MOD FUEL CELL ACTIVELY COOLED
- AUGMENTED COOLING FOR TV PWR AMP

T/C DEFINITION

- 500 FT^2 GOLDIZED MYLAR MLI
- AL BASE HEAT SHIELD
- SILVER BACKED TEFLON & ALZAK COATINGS
- MOST AVIONICS PASSIVE/COOLED
- 17 FT^2 VCHP/RADIATOR FOR FUEL CELL
- 4 FT^2 VCHP/RADIATOR FOR TV PWR AMP
- APS & ME ELECT. HEATERS
- HEATERS FOR AVIONICS PALLETS

T/C PERFORMANCE

- 70^oF VEHICLE FROM LAUNCH TO DEPLOY
- PROPELLANTS - 40^oF TO 90^oF
- AVIONICS - 30^oF TO 120^oF
- BASE SHIELD - 600^oF, THRUST STR - 250^oF
- STRUCT 130^oF MAX ON ENTRY
- FUEL CELL RADIATOR REJECTS 2000 BTU/HR

DVT RISK & TECH

- VCHP REQ ADDITIONAL PERFORMANCE DATA
- UNCERTAINITY IN LIFE/REUSABILITY OF COATINGS & INSULATION

II-23

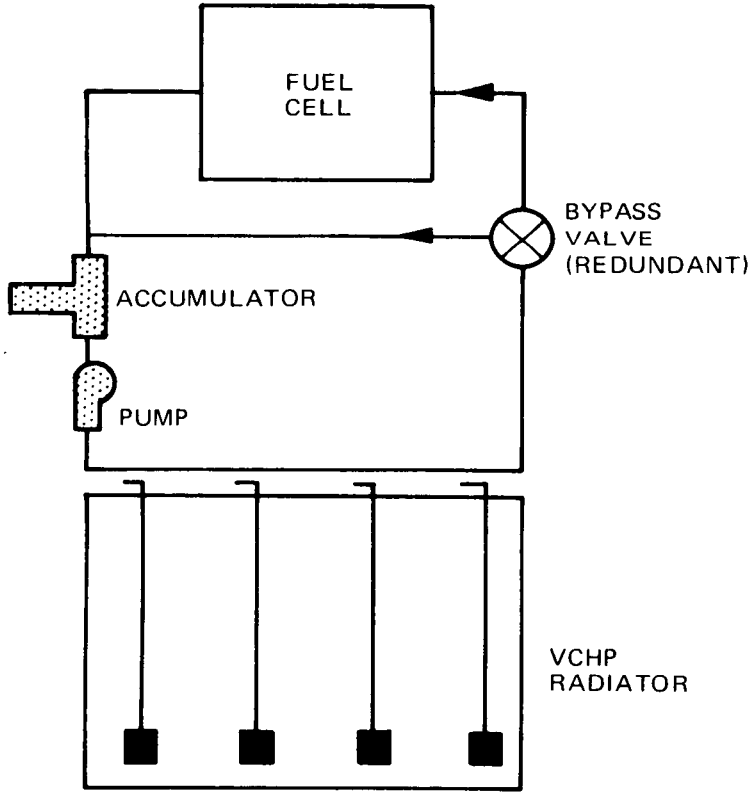
THERMAL CONTROL SCHEMATIC - 41OAD-2

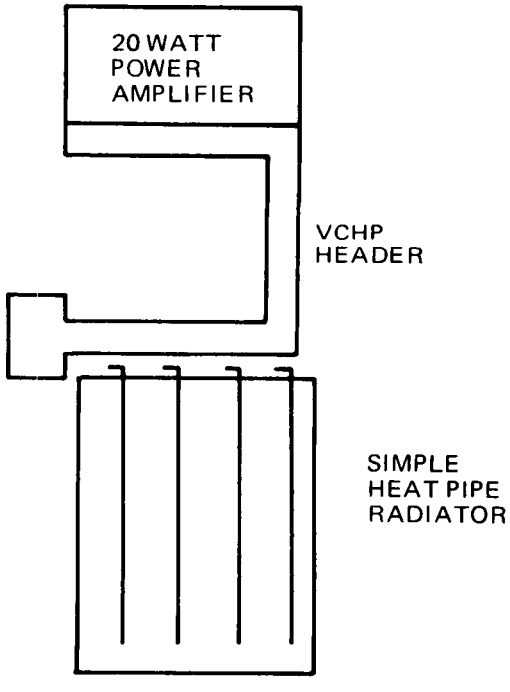
The fuel cell requires active cooling to maintain acceptable temperatures. The pumped loop fuel cell heat transport circuit has redundant by-pass valves with automatic temperature controllers to monitor the flow rate of coolant through the fuel cell as the load changes. The Micron IMU of the evolved configurations does not require active cooling as did the Carousel V IMU Flown on the interim versions.

The 20 watt Power Amplifier used in conjunction with the TV, is a small solid state unit which dissipates 80 watts in converting 100 watts of DC power to 20 watts of RF power. Because of its infrequent use, less than 2 hours per mission, it is placed on its own loop. A Variable Conductance heat pipe header transports heat to a small, simple heat pipe radiator, providing a self regulating simple heat rejection system.

(Ref. Vol. 5, Part I, Opt. 2, Sect. 5.2)

THERMAL CONTROL SCHEMATIC 310RE-3A,310ARE-3B, 410AD-2,510ADE-3B,320AE-3A





SUBSYSTEM REDUNDANCY ALLOCATION - 410AD-2

Reliability of the 410AD-2 was computed on the basis of both the 168 hour reliability reference mission, and the round trip mission with Apogee/Deorbit Kick Stage (ADKS), of 69 Orbiter hours (45 Tug hours). The deorbit stage was assumed to be in orbit for five years, and to have an active life of three days during deorbit and retrieve operations. Redundancy was selected to meet a combined reliability for the round trip mission (Tug plus ADKS) of 0.97. The reliability of the reference mission of 168 hours (without the ADKS) was calculated to be 0.9751.

To achieve a 0.97 reliability, in conjunction with the 410AD-2 core vehicle, the ADKS was designed to a reliability of 0.9791 by including the following redundancies:

APS	Regulator
DMS	Signal Conditioning/PCM
GN&C	Att. Ref. Unit
GN&C	Prog. Sequencer
GN&C	Star Tracker
GN&C	APS Control Elect
COMM	OMNI Antenna*
COMM	Duplexer*
COMM	Baseband Processor*
COMM	Receivers (8)*

* The communication equipment was assumed to be active during the five year orbital time period.

(Ref. Vol. 5, Part I, Opt. 2, Sect. 5.6)

SUBSYSTEM REDUNDANCY ALLOCATION SUMMARY TABLE -

CONFIGURATION 410AD-2

MEETS 0.97 REL. WITH ADD-ON'S

MISSION - 168 HR. RELIABILITY REFERENCE

SUBSYSTEM	RELIABILITY	REDUNDANCY
• STRUCTURE (INCLUDES INTERFACE SYSTEM)	0.99900	———
PROPULSION		
- MPS	0.99249	He ISO VALVE VENT VALVES
- APS	0.99882	THRUSTER ISO VALVES VENT VALVE
• AVIONICS		
- GN&C	0.99405	APS CONTROL ELECT IMU
- COMM	0.99912	RECEIVERS
- DMS	0.99936	COMPUTER
- THERMAL	0.99871	———
- POWER	0.99328	———
	TOTAL - 0.9751	

APOGEE AND DE-ORBIT KICK STAGES 410AD-2 (SEE 4 SUCCEEDING FIGURES)

Deployment of payloads beyond the capability of the plain tug may be achieved by using solid rocket motors (SRM) as a second stage in the deployment sequence. This stage, the apogee kick stage (AKS), is fired after separation of the payload/AKS from the tug.

If a payload is to be retrieved and an AKS was necessary to deploy it, then a deorbit kick stage (DKS) using SRM is required to place the returning payload in an orbit where the tug can retrieve it.

In Option 2 there are five flight modes requiring the use of kick stages, two modes use AKS only (planetary and multiple deployment) while the remaining three modes use an AKS combined with a DKS (A/DKS) for round trip, deploy for subsequent retrieval and for multiple deployment with subsequent independent retrieval. For each of these modes, the payloads are ballasted to a common weight to minimize the combinations of SRM.

The SRM for the non planetary missions are mounted in various combinations on a common structure, which is a truncated cone of aluminum alloy. Of the six SRM for the round trip mission, four are used for apogee burn and are jettisoned after burn out to minimize the number of de-orbit SRM. The AKS configuration for the planetary mission is the same as the AKS for configuration 320AE-3A (Volume 3) except for the SRM size.

Each AKS has a simple GN&C subsystem which is updated by the tug just prior to their separation. Control during SRM burn comes from vectoring motor thrust. Attitude control prior to payload activation is provided by limit cycle APS. Power comes from an electrical battery.

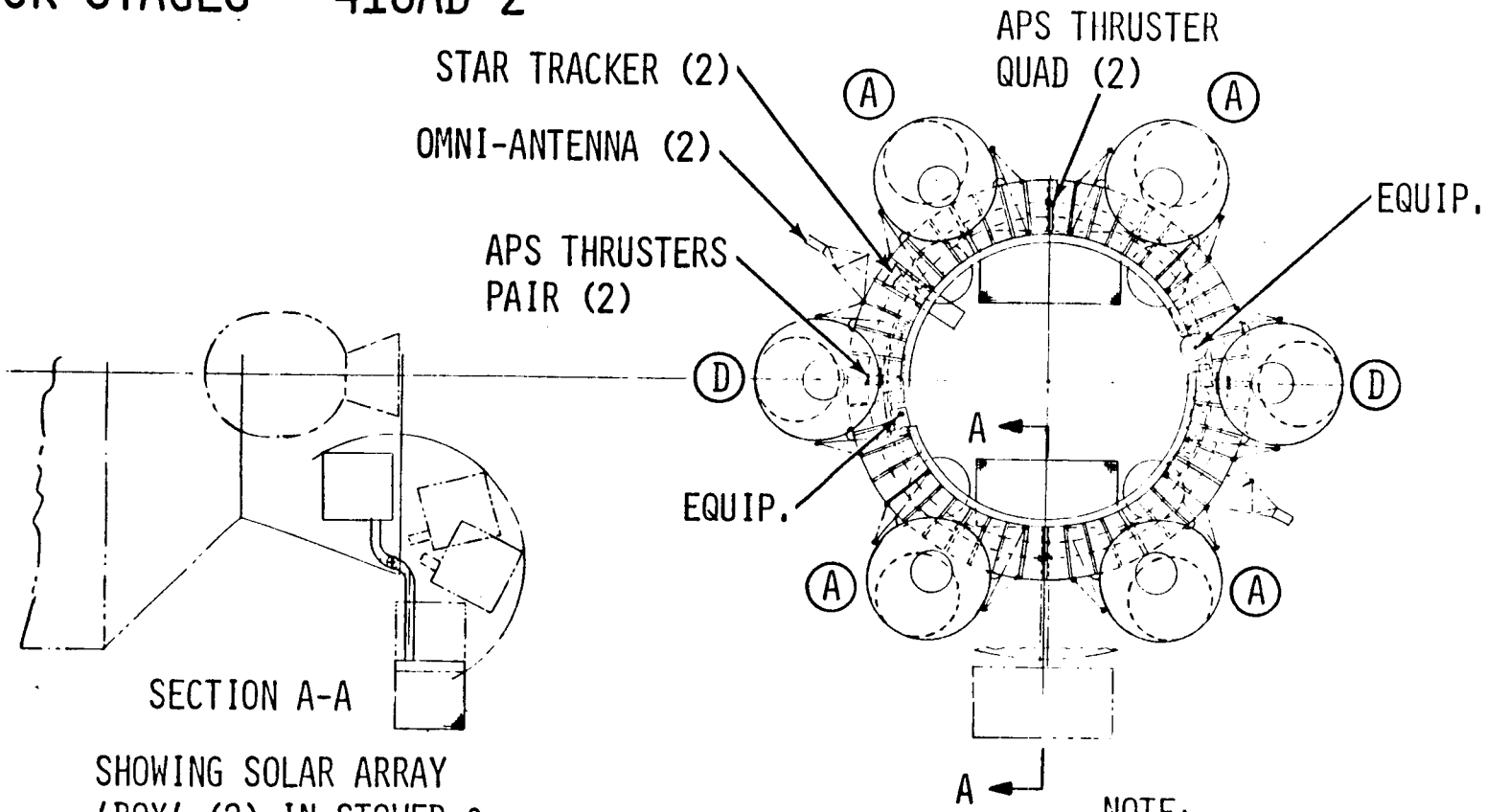
The de-orbit function of an A/DKS requires more sophisticated subsystems than does the AKS. The GN&C subsystem requires, additionally, a star tracker for navigation. Communications requires omni antennas and the electrical power system has an additional battery with solar cell arrays to keep the battery charged during a possible five year mission.

APS thrusters provide roll control during a single SRM de-orbit burn and limit cycle attitude control until the de-orbited payload is retrieved by the tug.

Unless viewing requirements dicate otherwise, all equipment is mounted within the structural shell of the stage.

Ref. Vol. 5, Part I, Opt. 2, Sect. 5.2)

KICK STAGES - 410AD-2

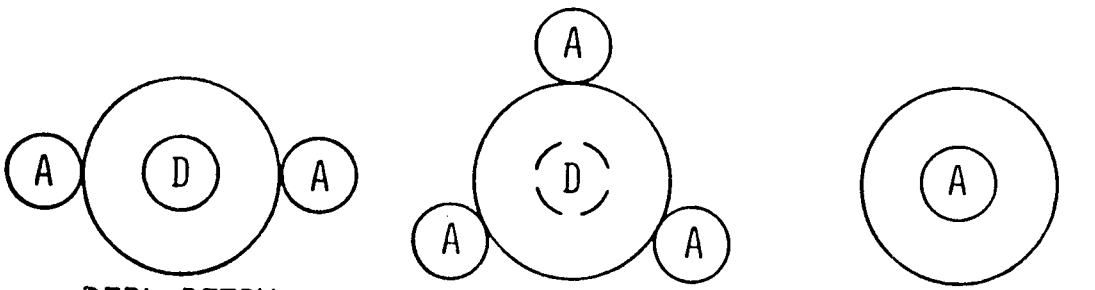


SHOWING SOLAR ARRAY 'BOX' (2) IN STOWED & DEPLOYED POSITIONS

NOTE:
COMMON BASIC AL STRUCT FOR THE NONPLANETARY KICK STAGES

(A) = SRM USED FOR APOGEE BURN

(D) = SRM USED FOR DE-ORBIT BURN



DEPL-RETRV

DOUBLE DEPLOY -SUBSEQUENT RETRV

DOUBLE DEPLOY

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APOGEE/DEORBIT KICK STAGES (A/DKS) CHARACTERISTICS - 410AD-2

		GEOSYNCH				PLANETARY
		ROUND TRIP	DEP / RETRV	MULTI DEP IND RETRV	MULTI DEP	
SRM: APOGEE	WEIGHT EACH	1880 LB	940 LB	1880 LB	1880 LB	1880 LB
	CLUSTER OF	4	2	3	1	9
	3.6 G LIMIT BY BURN =	67 SEC	60 SEC	67 SEC	67 SEC	67 SEC & SERIES BURN
DEORBIT	WEIGHT EACH	1880 LB	1880 LB	1300 LB	———	———
	CLUSTER OF	2	1	1	———	———
	3.6 G LIMIT BY BURN =	67 SEC	67 SEC	62 SEC	———	———
	ϵ	34/1				50/1
	I_{SP}	287 SECS				295 SECS
	λ'	.909				.920
STRUCTURE: AL. FRAMES, SKIN & STRINGERS	WEIGHT	501 LB	441 LB	455 LB	420 LB	449 LB
PROPULSION: SWIVEL NOZZLE TVC GASEOUS N_2 APS	WEIGHT	47 LB	47 LB	47 LB	27 LB	27 LB

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APOGEE/DEORBIT KICK STAGES (A/DKS) CHARACTERISTICS - 410AD-2 (CONTINUED)

		GEOSYNCH				PLANETARY
		ROUND TRIP	DEP/RETRV	MULTI DEP IND RETRV	MULTI DEP	
ASTRIONICS:	WEIGHT	310 LB	310 LB	310 LB	67 LB	67 LB
APOGEE: DIRECTIONAL CONTROL FOR INITIAL STATE VECORT FROM TUG		15 MINS				
APOGEE: BATTERY POWER FOR		30 MINS				
DEORBIT: STATE VECTOR AND DIRECTIONAL CONTROL (STAR TRACKER)		✓				
DEORBIT: BATTERY CHARGED BY SOLAR ARRAYS						
DEORBIT: COMMAND TO INITIATE DEORBIT						
DEORBIT: STAGE STATUS INFORMATION						
RELIABILITY: STAGE APOGEE				.9987		
DEORBIT (CHALLENGE IS 5 YR. IN ORBIT)		.9791				
OVERALL MISSION		.970				
PERFORMANCE: PAYLOAD	WEIGHT	2640LB	3920LB	2770 LB	3500LB	5000LB
STAGE Δ V FPS	APOGEE	5730	2077	6000	3250	10840
	DEORBIT	5869	2684	2320	-	-
COSTS: DDT&E		$65M				

INTERFACES - 410A[illegible]-2

The interfaces consist of all structural and mechanical hardware enabling the Tug to link with Shuttle and to separate from it in flight. It includes those items that will remain in the Shuttle during the flight of the Tug. Included is the operational docking/undocking attachment of the Tug to the shuttle, mechanisms, Propulsion Interconnects, astrionics wiring and umbilicals and the mission specialist station. This text is directed toward the following two figures.

The weights chart identifies and summarizes by subsystem those Orbiter/Tug interface elements which are chargeable against the 65,000 lb Payload. Weights have been established and these elements have been included in the WBS build-up of Tug costs.

The interface schematic divides these items into operational categories rather than by subsystem, starting with signal and service lines (which are part of Tug system) installed in the Orbiter. The schematic identifies the signal or service lines at the interface.

(Ref. Vol. 5, Part I, Opt. 2, Sect. 5.4)

INTERFACE SUBSYSEM WEIGHTS

CONCEPT 410AD-2	WEIGHT (LB)
STRUCTURE	(1090)
• ROTATING ADAPTER	
• FORWARD CRADLE	
MECHANISMS	(96)
• ADAPTER-ROTATION ACTUATOR/BERTHING PROBES & LATCHES	
• CRADLE - BERTHING LATCHES	
• INFLATABLE SUPPORT FOR MAIN ENGINE NOZZLE	
PROPULSION (MAIN)	(47)
• MAIN PROPELLANT FILL & DRAIN LINES AND VENT LINES	
• HIGH PRESSURE GASEOUS He LINES	
• UMBILICAL PANELS	
ASTRIONICS	(131)
• DMS-HARD WIRING	
• GN&C-HARD WIRING	
• COMM. - HARD WIRING + RF.	
• EPS - H_2 & O_2 FILL, VENT DRAIN & PURGE	
• UMBILICAL PANELS	
M.S.S	(146)
• CONTROL & DISPLAY - DATA & COMM. EQUIP.	
• POWER - WIRING - SUPPORT	
TOTAL WITH CONT.	1510

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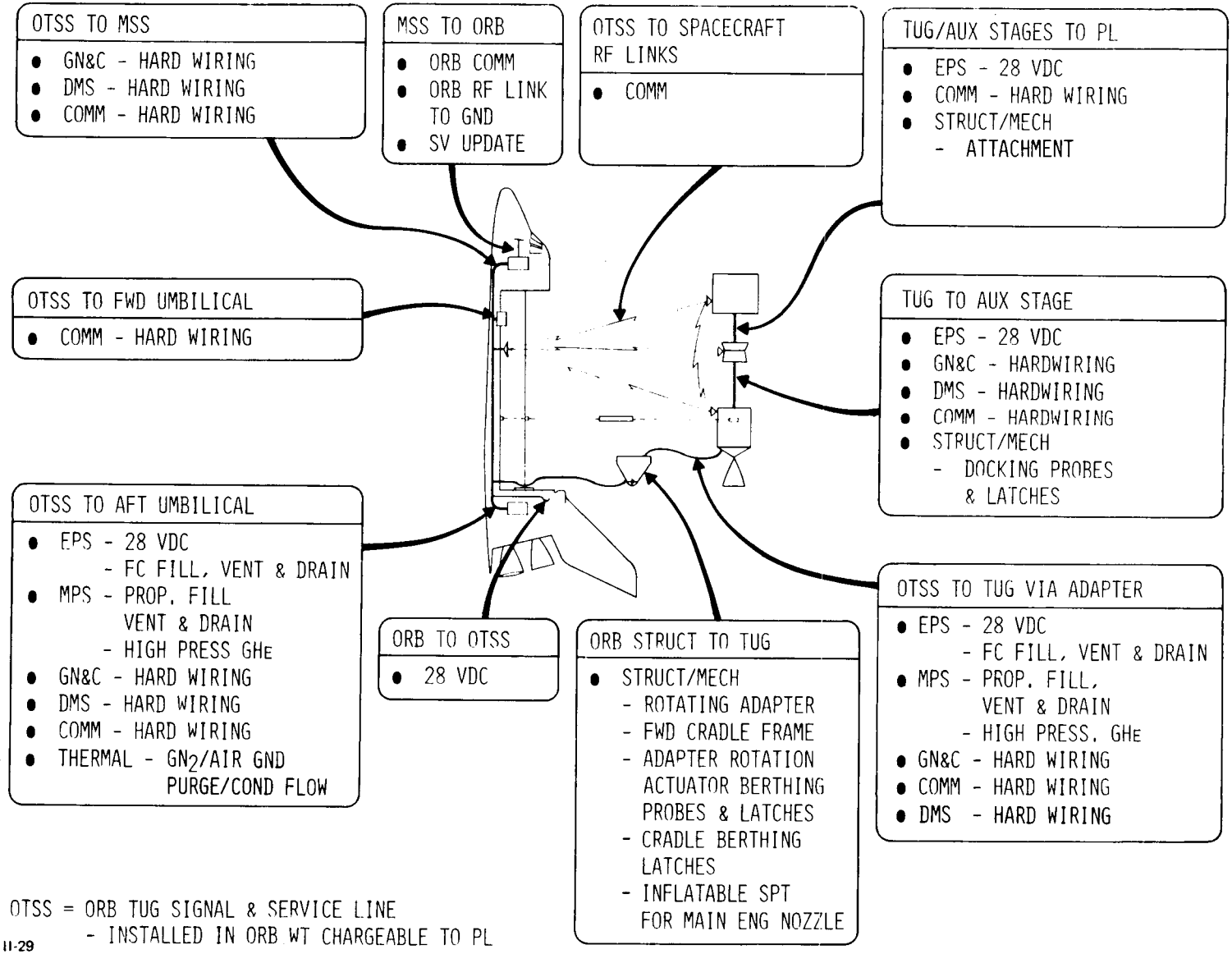
INTERFACE LOCATIONS - SINGLE STAGE TUG 410AD-2



OTSS = ORB TUG SIGNAL & SERVICE LINE
- INSTALLED IN ORB WT CHARGEABLE TO PL

II-29

410AD-2 - MISSION FLOW/COMPLEXITY FACTOR

A methodology has been established to determine the relative complexity of concept flight modes by taking the weighted sum of operations required to perform a mission. All Level I operations (facing page chart) were weighed with the following multipliers:

- 8 for operations involving crew safety
- 4 for operations needed for TUG recovery
- 2 for operations needed for P/L deployment
- 1 for operations needed for P/L recovery

An additional complement of factors were added as follows:

- 8 for critical functions (i.e. docking, staging, etc.)
- 4 for unique trajectory functions (i.e. correct for nodal regression)
- 4 for deficient functions (i.e. P/L loiter C/O)

This approach provides a basis for comparing the operations complexity of the various options and is also used as the scaling factor for determining flight operations cost. Our approach to costing flight operations was to establish a detailed "strawman" cost based on a "Bottoms-Up" estimate of the geosynchronous round trip mission. Our files on LM costs (complexity factor 177) were used to establish this estimate. The costs were then scaled by the complexity factor to establish cost differences between concepts.

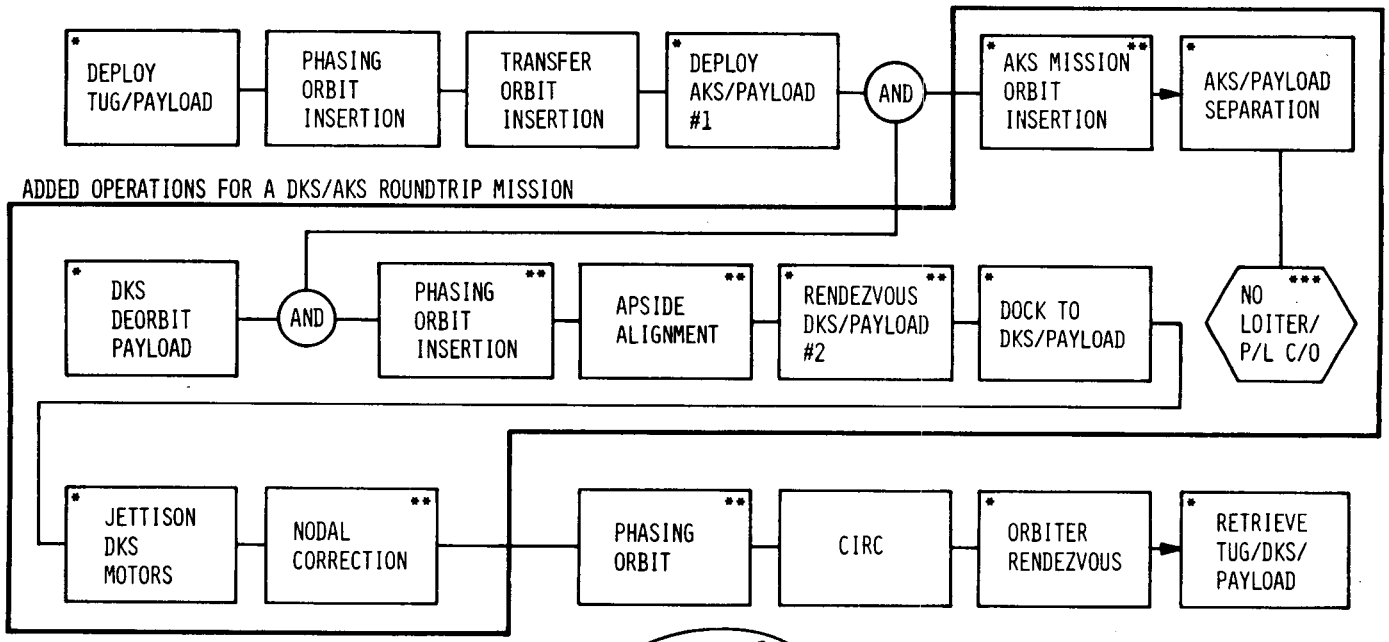
Based on this Cost Estimating Relationship, a 410AD-2 TUG program would have a 104% increase in costs associated with development software, mission planning, documentation, etc. because of those tasks (i.e. AKS staging analysis, guidance requirements, etc.) associated with the add-on stages.

The major 410AD-1 complexity considerations are:

- DKS initialization and alignment
- The D/AKS roundtrip mission imposes a launch window constraint
- The D/AKS roundtrip mission is time critical due to nodal regression

(Ref. Vol. 6, Part I, Para. 6.4.3)

CONCEPT 410AD-2 - COMPLEXITY FACTOR



410AD-2 ROUNDTRIP MISSION IS 104% MORE COMPLEX OPERATIONALLY THAN SIMPLE DEPLOY

COMPLEXITY MULTIPLIERS

● CREW SAFETY	2 x 8
● TUG RECOVERY	6 x 4
● PAYLOAD PLACEMENT	6 x 2
● PAYLOAD RETRIEVAL	11 x 1

*CRITICAL FUNCTIONS	10 x 8
**UNIQUE TRAJECTORY FACTORS	6 x 4
***DEFICIENT FUNCTION	1 x 4
COMPLEXITY FACTOR	171

II-4

OPTION 2 - 410ADE - FLIGHT OPERATIONS COST

Costs for Flight Operations has been split between those funds required prior to IOC and those required after IOC. In establishing these estimates it was assumed that NASA is the contracting agency. If the DOD is the responsible agency the cost estimates presented on the facing page are reversed. Included in these estimates are the manpower for mission planning, flight control, flight evaluation and flight software. The detailed justification for these estimates can be found in Volume 6 "Operations Data Book."

The major driver of flight operations non-recurring cost is the development of the software. Estimates are included for the following major computer systems:

- TUG on-board software
- Mission Control Center Real Time Computer Complex
- Vehicle Management and Mission Planning System
- Mission Control Center Simulator

The software costs were established by estimating the word count required to meet the functional requirements of each of the computer systems. Dollar values per word consistent with GAC experience on the F-14, EA2-C and OAO MCC development programs were used for the design phase and programming/verification phase of the development cycle. Word size estimates for the on-board software and real time computer complex were based on the software routines in the LM Guidance Computer which have similar functional requirements to that of the TUG, adjusted to account for the LM software needed for man/machine interfaces. The software estimates for the MCC simulator were based on the requirements for the LM Full Mission Engineering Simulator requirement adjusted to reflect the relative complexity of the vehicles. This software package was assumed to play a threefold role; namely provide simulator capability to the MCC, and to provide the environment to the Astrionics Software development facility and the electronics integration facility. The software estimates for the semi-automated non-real time Vehicle Management and Mission Planning System (VMMPS) requires more in-depth evaluation to determine costs. However, for purposes of at least establishing a cost line element a 30K word system was assumed necessary.

Based on these cost procedures, the total flt. ops DDT&E for the 410ADE is $42M for NASA and $5M for DOD. The average cost per flight is $450K which converts to approximately $275K per payload. Also indicated on the facing page chart is the impact of using Level III autonomy in the 410AD program. A $50M increase in cost results due to the increase in complexity of the ground support software.

(Ref. Vol. 6, Part I, Para. 6.4.4)

410AD-2	
LEVEL II AUTONOMY	

FLIGHT OPERATION COST

	DDT&E		POST IOC		DDT&E		POST IOC	
	LEVEL II	LEVEL III	LEVEL II	LEVEL III	LEVEL II	LEVEL III	LEVEL II	LEVEL III
MISSION PLANNING	10.71	8.77	17.32	14.18	4.09	3.35	13.44	11.01
FLIGHT CONTROL	.86	2.04	15.47	36.69	.42	.99	13.62	32.10
FLIGHT EVALUATION	.54	.54	2.36	2.36	.57	.57	2.22	2.22
FLIGHT SOFTWARE	29.73	36.60	27.85	34.29	-	-	13.55	16.68
TOTAL	41.84	47.95	63.00	87.52	5.08	4.91	42.83	62.68

AVG COST PER FLIGHT

(NASA = 138 FLT/ DOD = 107 FLT)

	NASA, $M		DOD, $M	
MISSION PLANNING	.126		.126	
FLIGHT CONTROL	.112		.127	
FLIGHT EVALUATION	.017		.021	
FLIGHT SOFTWARE	.202		.127	
	.457	.634 (LEVEL III)	.401	.586 (LEVEL III)

LEVEL II AUTONOMY SAVES $50M IN FLT OP COSTS

II-22

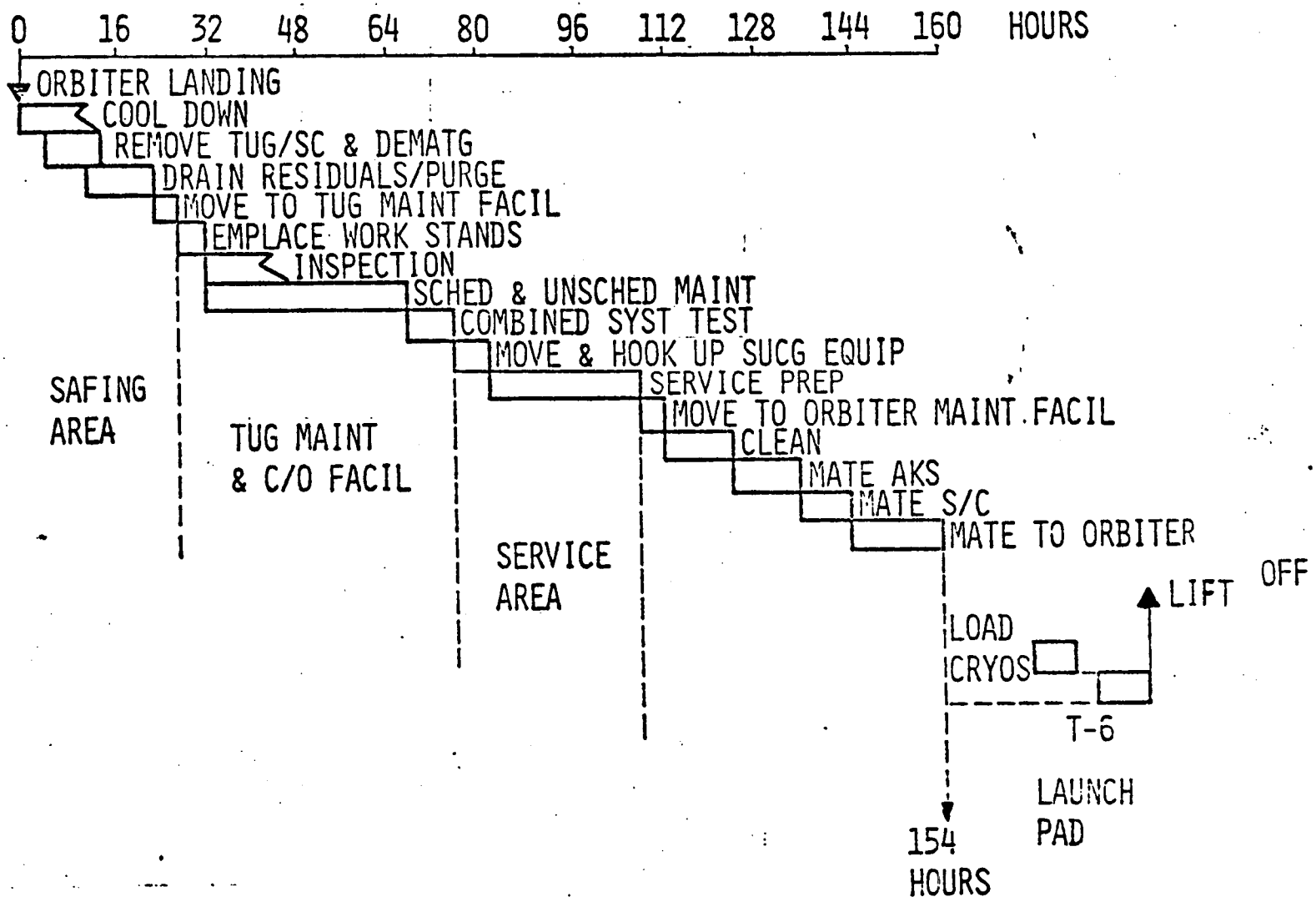
MATURE OPERATIONAL FLOW

The Tug can be turned around at ETR in two weeks using two shift operation. It is expected that WTR will work single shift, requiring four weeks. The mature flow is based on a 90% learning curve flattening out at the 100th flight. This time puts no constraint on the usage based on the current planned buy of Tugs.

It should be noted that our turnaround time stops after mate to the Orbiter and is baselined on mating a fully fueled Tug.

(Ref. Vol. 6, Part II, Sect. 6.15)

MATURE OPERATIONS FLOW

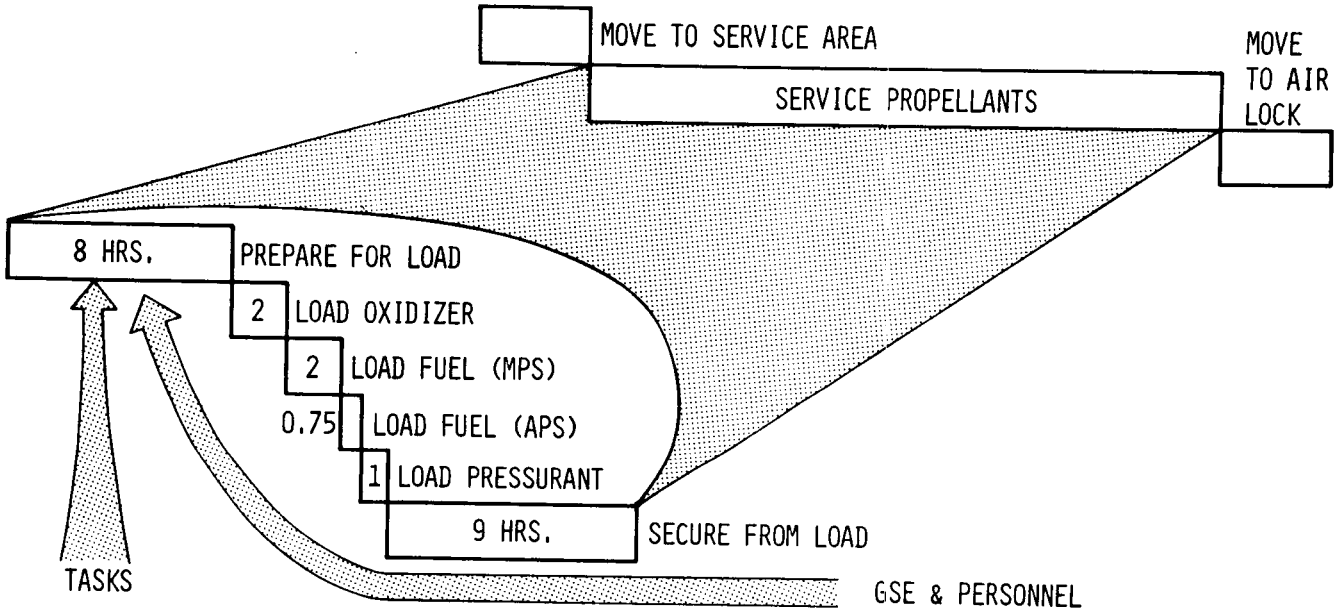


MATURE FLOW BUILDUP

The Mature operational flow was developed by: defining each task identified by functional analysis, identifying the skills required, identifying the GSE requirements and estimating the time to perform each task. The summation of these data is used to create the time lines. This technique lends credibility to the resultant total flow indicating the Tug can be turned around in normal servicing in less than 160 hours.

(Ref. Vol. 6, Part II, Sect. 6.15)

MATURE FLOW BUILDUP



2.1.2 PREP FOR LOAD

- 2.1.2.1 MOVE TO SERVICE AREA
- 2.1.2.2 CONFIGURE TRANSPORTER FOR ROTATION
- 2.1.2.3 ATTACH ROTATING/AGE/GSE TO TUG. VERIFY TBD POUNDS AUX. CRANE CONTROL
- 2.1.2.4 VERIFY FORWARD ATTACH LATCH OPEN
- 2.1.2.5 ROTATE TO VERTICAL
- 2.1.2.6 ROUTE AND ATTACH FUEL AND OXIDIZER SERVICE LINES; ATTACH PRESSURANT LINES

GSE & PERSONNEL

PREP FOR LOAD

AGE/GSE

- HOISTING FIXTURE, TUG ROTATE
- HOSE SET MPS
- HOSE SET APS

PERSONNEL REQUIREMENTS

PROP TECHS	6		
MECH/STRUCT	6	BASE SUPPORT	
SAFETY	5	CRANE OPER	1
QC	5	TOW OPER	1

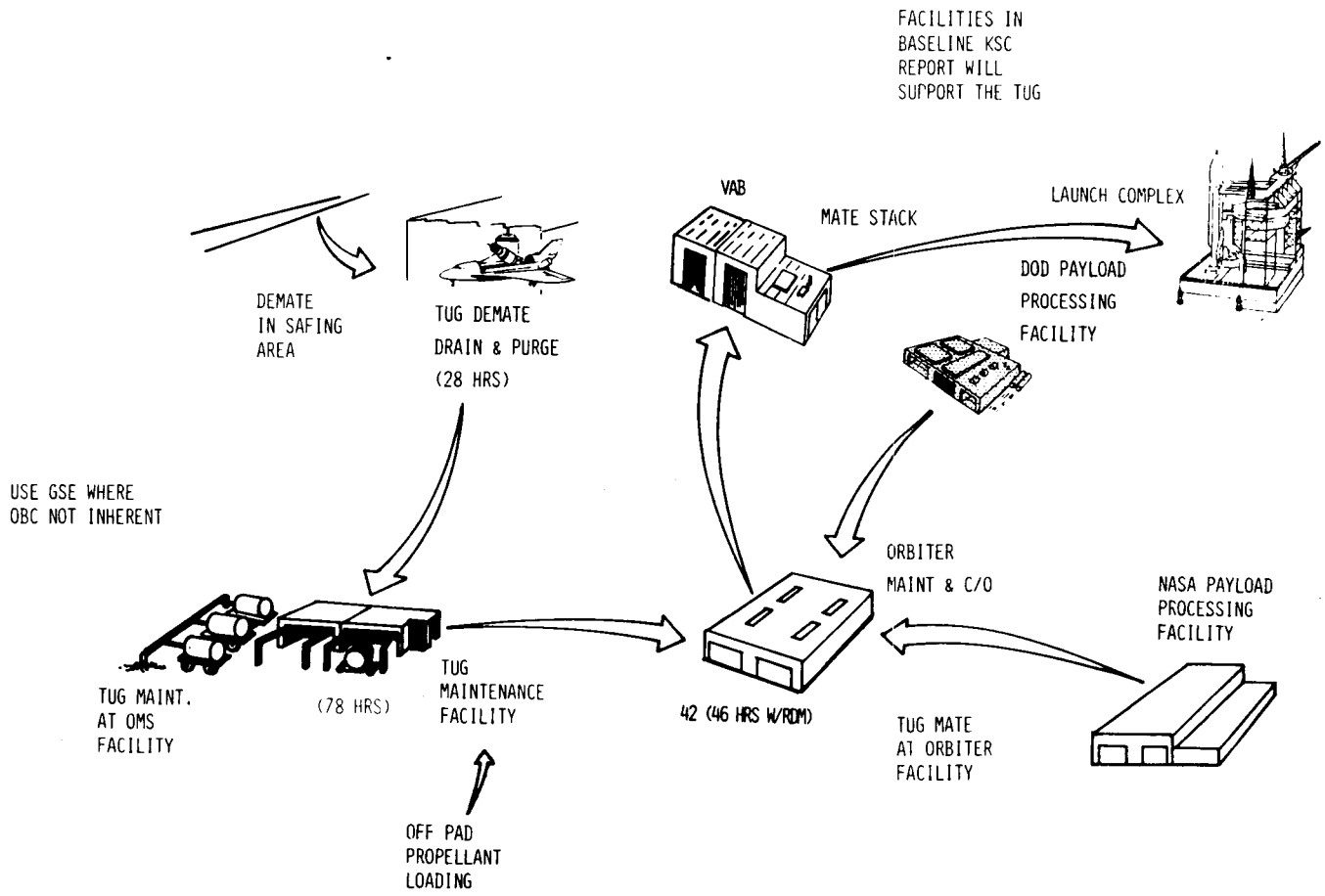
1-36, 11-36, 111-108

TUG LAUNCH SITE PROCESSING FLOW AND FACILITIES

Many trade studies were used in determining the optimum facilities and flow to process the Tug. An advantage of the storable Tug is that many options are open to the operator as to where and when such operations as safeing, mating and servicing are performed. All servicing and mating can be done prior to moving to the pad so the Tug will not be a constraint on launch preperation. This is the approach we chose.

The results of the study show that the Tug can be supported with the baseline facilities in the KSC facilities report. This will keep the facilities cost to a minimum since no new facilities are required.

TUG LAUNCH SITE PROCESSING FLOW FACILITIES



TUG GRND OPS
TURN AROUND LESS
THAN 2 WKS ETR
4 WKS WTR

I-34, II-34, III-107, VI-31, IX-1

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SUMMARY OF SIGNIFICANT TRADES

STORABLE TUG HAS MANY OPTIONS IN MEETING PAYLOAD AND ORBITER

- o ON PAD VS OFF PAD PROPELLANT LOADING
  - REDUCES ON-LINE OPERATIONS BY 6 HOURS
  - ALLOWS COMPLETE VISUAL VIEW AND ACCESS TO TUG DURING LOAD
  - ELIMINATES WETTING TUG/ORB INTERFACE LINES AND RESULTANT CLEANING
  - ELIMINATES SPILLS INTO ORBITER
  - AVOIDS $450,000 STORAGE AND SERVICE FACILITY AT PAD (BASED ON KSC BASELINE OF 19 APRIL 73)

  VERSUS

  - HANDLING LOADED, HEAVIER TUG
  - REQUIRES STRONGER TRANSPORTER TO PREVENT RACKING AND LEAKS
- o HORIZONTAL MATE WITH ORBITER VS. VERTICAL MATE AT PAD
  - EASIER HANDLING
  - NO WEATHER CONSTRAINTS
  - ELIMINATES ADDITIONAL 6 HOUR SERIAL PAD TIME

  VERSUS

  - PAYLOAD LOADED 9 DAYS EARLIER
  - LOADED TUG IN ORBITER 9 MORE DAYS

SUMMARY OF SIGNIFICANT TRADES (CONT'D)

- o OPTIMIZATION OF FACILITIES AND FLOWS
  - TUG MAINTENANCE - VAL. OMS FACIL., OR ORBITER MAINT. FACIL.
    - o OMS FACIL. VENT SYST. & SCRUBBERS SIZED TO HANDLE TUG ALSO
    - o HAZARDOUS FUEL HANDLING AREA ISOLATED AND CONSOLIDATED
  - TUG/SC MATE - TUG MAINT. FACIL. P/L PROC. FACIL., VAR. OR ORB. MAINT. FACIL
    - o ADEQUATE HOOK HEIGHT
    - o CLEAN AREA AVAILABLE
    - o NO ADDITIONAL FLOWTIME TO ORBITER
  - FLOW OPTIMIZATION
    - o USE SERIAL FLOW TILL FLIGHT RATE REQUIRES PARALLEL FLOW AND INCREASED CREW SIZE
    - o USE STAGGERED PARALLEL FLOW FOR 2 STAGE PROCESSING TO OPTIMIZE SKILL UTILIZATION
    - o WTR BASED ON ONE SHIFT, ETR BASED ON TWO SHIFTS

SUMMARY OF SIGNIFICANT TRADES (CONT'D)

- o DEMATE IN SAFING AREA VS TUG MAINTENANCE AREA
  - AVOIDS 6 HOUR ADDITIONAL SERIAL FLOW FOR ORBITER
  - PROVIDES EARLIEST ACCESS TO TUG/SC
  - AVOIDS SIZING TUG MAINTENANCE FACILITY FOR ORBITER
    - $1.08M SAVED
  - ONE HYPERGOLIC HANDLING CREW REMOVES ORBITER OMS & RCS <u>AND</u> TUG
- o GROUND CHECKOUT VS ON BOARD CHECKOUT
  - DECISION TO USE OBC BASED ON FLIGHT OPERATIONS REQUIREMENTS
    - * CRITICAL FUNCTION
    - * CORRECTIVE ACTION CAPABLE
  - NO OBC SPECIFICALLY FOR GROUND TURNAROUND OPERATIONS
    - * VEHICLE WEIGHT VALUED AT $100K/LB.
    - * USE ON BOARD COMPUTER AND INHERENT CAPABILITY ON GROUND AUGMENTED BY GSE
    - * LAUNCH PROCESSING SYSTEM WILL BE AVAILABLE FOR ORBITER

RESIDUAL HAZARDS AND SINGLE FAILURE POINTS: 410AD-2

Those hazards for which design, special procedures and safety or warning devices may not resolve the problem, are considered residual hazards. In addition, where failure of a single hardware element leads to loss of life, vehicle or mission, a single failure point (SFP) is identified. Hazards falling into these categories for this concept are shown in this chart.

Checkout of the fuel cells is accomplished while the Tug is in the P/L bay prior to deployment. The water exhaust will be directed away from the EOS to protect any temperature sensitive coatings.

Although a rationale for acceptance of these situations has been defined, additional study effort is required in the next phase to reduce the hazard to the lowest possible level (controlled category) and/or to eliminate the single failure points.

Additional information on these items is included in Volume VII, Safety and Reliability.

(Ref. Vol. 7 Sections II & VII)

RESIDUAL HAZARDS/SFP : 410AD-2

SATISFACTORY PROGRESS

HAZARDS/SFP	RATIONALE FOR ACCEPTANCE
ABNORMAL LANDING WITH FULL TANKS	ABORT DUMP PREFERRED BY SENSITIVITY STUDY
VENT PROPELLANT FUMES TO PAYLOAD BAY VIA TUG OVERBOARD VENTS (MPS/APS)	EXTREME PAYLOAD BAY TEMPERATURE AND MULTIPLE FAILURES NECESSARY FOR VENTING
JETTISON OF AKS SRM CASES AT PAYLOAD ALTITUDES	CONTACT HAZARD CONSIDERED LOW
VENT FUEL CELL WATER TO PAYLOAD BAY DURING CHECKOUT	VENT DIRECTED AWAY FROM EOS
ABORT LANDING WITH FULL FUEL CELL TANKS	TANKAGE AND SUPPORTS DESIGNED FOR CRASH LOADS
SFP : VALVES FAIL CLOSED (MISSION SUCCESS) - MPS He REGULATOR - ENGINE PREVALVE(S) - APS VENT - APS QUAD ISOLATION - DKS GN_2 SHUTOFF	HIGH RELIABILITY COMPONENTS
LACK OF ADKS CMD OVERRIDE	DETECT UNSTABLE TARGET PRIOR TO DOCKING
SRMS SENSITIVE TO LIQ.PROP. FIRES	IGNIT.SOURCES PRECLUDED IN P/L BAY

SAFETY ASSESSMENT RESULTS: 410AD-2

An assessment of this configuration was performed to determine whether it satisfied the NASA Safety Requirements specified in the Data Package, Space Tug System Studies, April 1973 and those safety requirements derived through analysis. The first column identifies the source of the safety requirement, NASA Data Package or identified hazard. Items in the next column are labeled (R) for requirement unsatisfied, (C) for an operational constraint or (E) for an exception to the NASA or derived safety requirements. The specific items are summarized. In the comments column, the reasons or reactions to the safety assessment items are stated.

Nested tanks are considered acceptable from the standpoint of safety; the safety requirement is that adequate provisions for maintenance of the pressure differential between tanks be incorporated.

The checkmark in the upper right corner signifies a satisfactory safety mark for the configuration for Phase A. The completed Safety Evaluation form for this concept is presented in Volume VII.

(Ref. Vol. 7, Sections II & VII)

410AD-2 SAFETY ASSESSMENT RESULTS

- DATA PACKAGE/ANALYSIS-DERIVED SAFETY REQUIREMENTS USED AS ASSESSMENT TOOL
- ASSESSMENT RESULTS:

REQ'T SOURCE	REQ'T/CONSTRAINT/EXCEPTION	COMMENTS
NASA REQTS	(E) DETECT POTENTIAL TANK FAILURE ON GROUND	FRACTURE MECHANICS PROGRAM USED
	(E) FUEL CELL VAPOR VENTED TO BAY DURING C/O	VENT DIRECTED AWAY FROM EOS
	(R) NESTED TANKS	SEPARATE TANKS PREFERRED
VENTING	(C) NEED FLUID GSE DURING GROUND TRANSPORT	CONTAINS AND NEUTRALIZED VAPORS
RESIDUALS	(R) NO ABORT DUMP	DUMP PREFERRED
	(R) NO MPS DEPLETE	IMPLEMENTATION IS OPEN QUESTION
	(C) "EMPTY" TANKS AT LANDING	SAFEST LANDING CONFIGURATION
COLLISION	(R) (4) SRMs JETTISONED ON ROUND TRIP MISSIONS	68 MISSIONS PLANNED
COMMAND/ CONTROL	(C) WITHIN 30 NM OF EOS: OVER GROUND STATION WHEN TRACKING	SATISFACTORY TO SAFETY

PROGRAMMATICS/COST OVERVIEW 410AD-2

The same depth of programmatics and cost data was developed for 410AD-2, as in 110A-1, and is presented in Volume 8, Part II.

Concept 410AD-2 has a 57 month development cycle and a 71 month production activity for required flight hardware. Peak annual funding ($151M) occurs in FY82. DDT&E and total program costs are $350M and $789M respectively.

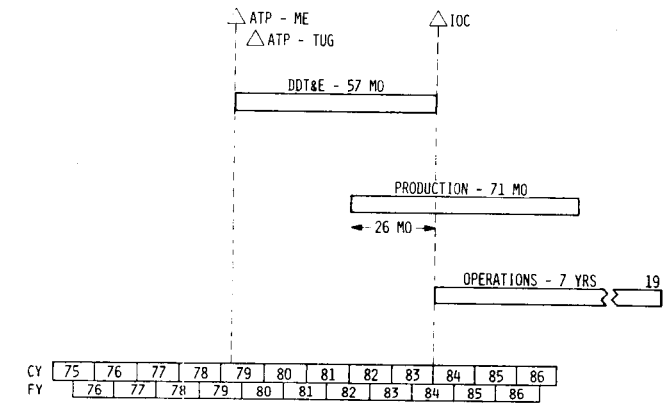
PROGRAMMATICS/COST OVERVIEW - 410AD-2

CHARACTERISTICS

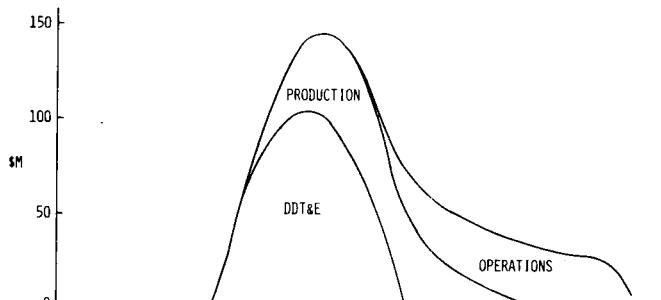
		MAIN STAGE	AUXILIARY STAGE
PHYSICAL:	WEIGHT, LB	3411	864
	LENGTH, IN	297	80
	DIAMETER, IN	120	180
TECHNICAL:	REUSABLE	ONE-STAGE	DKS
	AUXILIARY STAGE		AKS/DKS
	RETRIEVAL	CAPABILITY	
	PROPELLANT CAPACITY, LB	59,500	
	THRUST, LB	12,000	
	ISP, SEC	338	287 & 295
	AUTONOMY LEVEL	11B	
	RELIABILITY	.9751	.9791

WBS #320-00

PROJECT SUMMARY



ANNUAL - PROJECT COSTS



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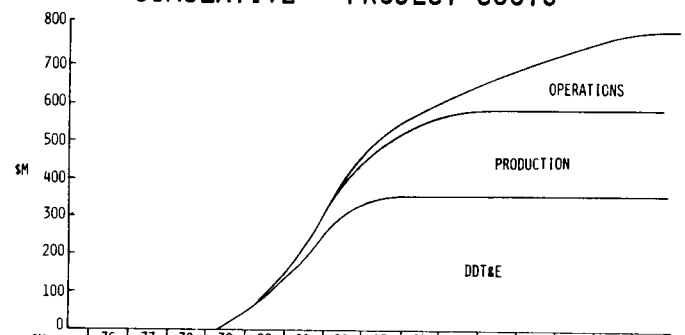
FY	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
DDT&E					47	87	108	80	28							
PROD						13	43	58	51	36	20	9	2			
OPS									16	27	31	31	32	31	27	12
TOTAL					47	100	151	138	95	63	51	40	34	31	27	12

CUMULATIVE - PROJECT COSTS



CY	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	
FY	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91
DDT&E					47	134	242	322	350	350	350	350	350	350	350	350
PROD						13	56	114	165	201	221	230	232	232	232	232
OPS									16	43	74	105	137	168	195	207
TOTAL					47	147	298	436	531	594	645	685	719	750	777	789

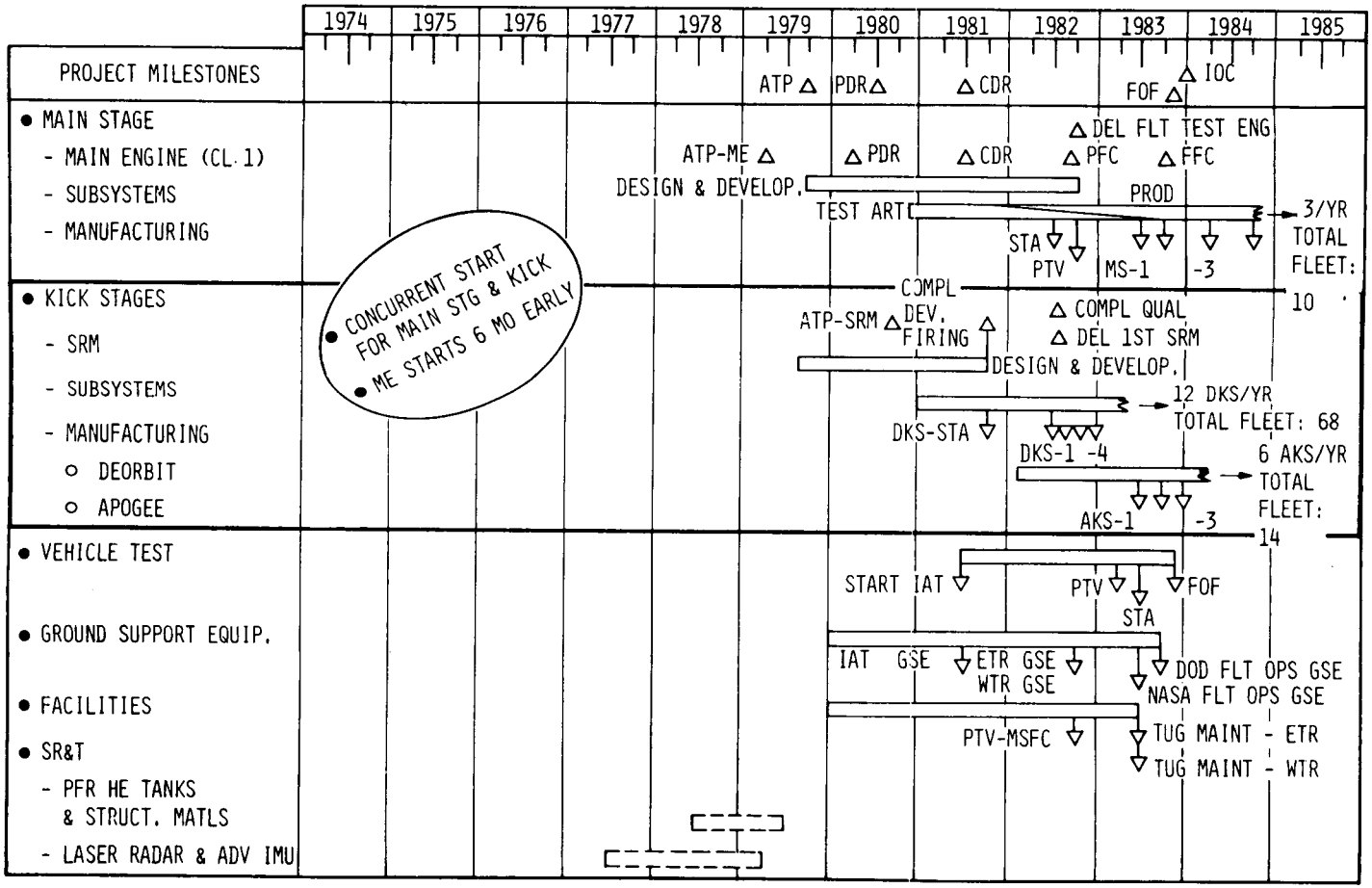
VIII, IX-5, II-37

SUMMARY SCHEDULE - 410AD-2

The primary elements of the 410AD-2 Project Schedule are as described for 110A-1. Authorization to Proceed (ATP) occurs on October 1, 1979 with IOC targeted for January 1, 1984. The design, development and manufacture of the main stage nested dome tanks primarily pace the program. The Class I main engine ATP occurs 6 months before main stage ATP with Final Flight Certification (FFC) occuring two months before main stage first flight. The 410AD-2 main stage major vehicle tests leading to IOC are also as described for 110A-1. Main stage manufacturing begins December 1, 1980 and continues through production of 10 vehicles to support fleet operations. Deorbit Kick Stage (DKS) development begins at the same time as the main stage in order to capture 1986 payload retrieval flights. DKS flights will begin in late 1982 and will be performed with other launch vehicles. Production of Apogee Kick Stages, however, start 13 months after DKS production since AKS operations begin after main stage IOC. DKS vehicle tests start 6 months before the start of main stage vehicle tests and a DKS flight test is planned for September 1, 1982. GSE and Facilities are scheduled to support vehicle test manufacturing ETR/WTR site activation and NASA/DOD Flight Operations Control activations. Both ETR and WTR will be activated to support initial flights in 1983.

(Ref. Vol. 8, Sect. 8.1)

410AD-2 SUMMARY PROJECT SCHEDULE



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410AD-2 GROUND TESTS

Vehicle Test Program

The vehicle test program for 410AD-2 was developed in a similar manner to that described for 110A-1.

Structural Test Articles

The Structural test program for the 410AD-2 Main Stage (MS) is the same as the test program for the 110A-1 MS but is shifted four years later in time. The DKS Structural test article program is basically the same as the MS test program. The AKS structure is the same as the DKS and therefore does not require a separate structural test program.

Propulsion Test Vehicle

The M.S. Propulsion test program for the 410AD-2 configuration is the same as the test program for the 110A-1 except that it is shifted four years later. The DKS propulsion test article program is the same as for the 110A-1 AKS.

(Ref. Vol. 8, Sect. 8.2)

RETRIEVAL CAPABILITY WITH KICK STAGES INCREASE VEH. AVIONICS & FLT TEST BY $16.8M

410AD-2 GROUND TESTS

TEST	TEST ART.	OBJECTIVES	TEST APPROACH
STRUCTURE • MAIN STG (MS) • DEORBIT KICK STAGE (DKS)	• COMPLETE M.S. PRIM. & SEC. STRUCT. INCL. TUG/ORB. & TUG P.L. ADAPTERS • COMPLETE DKS PRIM. & SEC. STRUCT.	• EVAL. DYN., STATIC STRENGTH, SAFE-LIFE & SEPARATION • VERIFY STRUCT./MECH INTERFACES AT LAUNCH SITE	• VIB./ACOUSTIC TESTS • DES. LIMIT STATIC TESTS • STATIC FATIGUE • ULT. STATIC TESTS • SEP. DEMO. • INTERFACE VALIDAT. DEMO. AT KSC.
PROPULSION (MS)	• FLIGHT WT. MAIN STG. STRUCT. • MAIN ENG. SUPPT. S/S LESS ENG. • ENG. SIMUL. UNIT • PTV REFURB. TO FLIGHT OPS.	• DEMO. OPS OF ASSEM. COMPONENTS • DEVELOP C/O & OPS PROCEDURES • VERIFY SERV/HANDLG PROCEDURES • DEMO. SYS. PERF. & CHARACTERISTICS	• COLD FLOW ONLY • REFEREE FLUIDS PHASE - FILL/DRAIN/FLOW TESTS • LIVE PROPELLANTS PHASE - LOAD CONTROL/ ACCURACY - SYS. COMPAT. & DYN. - PERF.SERV./HANDLG. PROCEDURES

Integrated Avionics Tests

The MS Integrated Avionics Test program for the 410AD-2 configuration will be basically the same as for the 110A-1 however, the 410AD-2 IAT facility will include retrieval electronics and Level IIb autonomy hardware. The DKS will be integrated in the same facility as the MS IAT to take advantage of the facility simulation and GSE capability. The DKS will be modified to simulate the AKS for MS-AKS IAT Mission Simulations.

Mockups

The MS mockup for this configuration will be the same as the mockups required for 110A. The DKS will also be mocked up and subsequently modified to serve as AKS mockups.

(Ref. Vol. 8, Sect. 8.2)

410AD-2 GROUND TESTS (CONT'D)

TEST	TEST ARTICLE/FACILITY	OBJECTIVES	APPROACH
INTEGRATED AVIONICS TESTING • INTEG. AVIONICS TEST (IAT) FACILITY - MS - DKS - AKS • AVIONICS SOFTWARE DEVELOPMENT LAB. (ASDL). - MS	• IAT - SHIP SET OF AVIONICS - COMPUTER SIMULATION - SENSOR STIMULUS - FACTORY & LAUNCH GSE • ASDL - COMPUTER FACILITY WITH MATH MODEL SIMULATION OF MS HARDWARE	VERIFY HARDWARE/ SOFTWARE PRIOR TO VEHICLE INSTALLATION & FOF. INCLUDES RETRIEVAL AVIONICS & SOFTWARE	• IAT - SUBSYSTEM INTEG. & END-TO-END FUNCTIONAL VERIFICATION - VERIFY FACTORY C/O PROCED - HARDWARE/SOFTWARE VERIF. - MISSION SIMULATION • ASDL - SOFTWARE DEVELOPMENT
MOCKUPS • MS • DKS • AKS	• WOOD & CARDBOARD MOCKUP OF THE TUG MS, AKS STRUCTURE & DKS INCLUDING EQUIPMENT FOR PDR • WOOD & METAL MOCKUP OF MS, DKS & AKS STRUCT. & EQUIPMENT FOR CDR.	EVALUATE EQUIPMENT ACCESSIBILITY & MAINTAINABILITY. EVALUATE SHUTTLE & PAYLOAD INTERFACE & LINES RUN PRIOR TO FAB OF FINAL HARDWARE	• COMPONENT INSTALLATION • ESTABLISH LINE LENGTHS FOR FINAL HARDWARE FAB • DEMONSTRATE MAINTAINABILITY - ASSESSMENT & DEMOS OF EQUIPMENT CLEARANCES - CONNECTOR & MOUNTING ACCESSIBILITY DEMO - SHUTTLE & PAYLOAD INTERFACE ASSESSMENT

GROUND TEST COST = $25.16M

410AD-2 FLIGHT TESTS

Eight flights are included in the 410AD-2 flight test program. The main stage flight test program is essentially as described for configuration 110A-1. The test sequence is modified slightly to include a retrieval demonstration using a DKS to serve as the retrieval target.

Since the DKS is developed and flown earlier than the main stage, a separate and dedicated flight test is planned to verify the capability of the DKS to function during and after extended exposure to orbital environments. This flight will occur in mid-1982 and could be accomplished as part of a normal Shuttle launch.

(Ref. Vol. 8, Sect. 8.2)

410AD-2 FLIGHT TESTS

TEST ARTICLE	OBJECTIVES	APPROACH
• MAIN STAGE - 1ST PROD. UNIT INCLUDING DFI. • DKS - 1ST PROD. UNIT INCLUDING DFI	• THERMO - VERIFY SYS. THERMAL CONTROL • STRUCT - VERIFY LAUNCH/ORBIT/ ENTRY/LANDING LOADS AND DYNAMICS • PROP - VERIFY MPS/APS • AVIONICS - VERIFY AVIONICS OPS • OPS - EVALUATE TUG/ORB, TUG/KS & TUG/PAYLOAD INTERFACES - EVALUATE SYSTEM PERFORMANCE CAPABILITY - DEMO PAYLOAD DEPLOY & RETRIEVE • DKS - DEMO SYS. PERF. AFTER EXTENDED ON-ORBIT EXPOSURE	• 8 FLT-TEST PROGRAM • FIRST ORBITAL FLIGHT (FOF) COSTED WITHOUT AN OPERATIONAL PAYLOAD - FLOWN WITHIN RETRIEVAL CAPABILITY OF ORB - SEQUENCE INCL: SYS C/O, MPS BURNS, APS C/O, DUMMY PAYLOAD DEPLOY, DEMO RETRIEVE DKS & ORB RETRIEVAL • SUBSQ. FLIGHTS DEPLOY OPERAT. PAYLOADS SELECTED TO DEMO. BUILDUP IN TUG CAPABILITY • ONE DEDICATED FLIGHT TEST OF DKS STAGE IN 1982.

FLIGHT TEST COST = $24.44M

TOTAL VEHICLE TEST = $49.60M

410AD-2 FACILITIES

Grumman's proposed Facility utilization plan was developed using the following ground rules or assumptions:

- Maximum utilization of existing and planned Shuttle facilities.
- Minimize total Facility, GSE and Manpower costs.
- Shuttle Ground Operations Approach - NASA, KSC 4/73
- WTR - No existing facilities available. Shuttle facilities will be the same as ETR.
- Kickstages or RDM's will not operate from WTR.

Facilities Definition Development

- Establish requirements (area, crane and environment) for Manufacturing, Test and Operations' facilities.
- Check availability of existing facilities.
- Schedule construction and activation to coincide with Program Master Schedule need dates.

Costing Procedure

New construction costs were calculated on $/sq.ft. basis. Activation costs are % of construction cost. GSE cost or $/sq.ft. Maintenance costs are based on $/sq. ft./yr.

Differences from Concept 110A-1

- Less Manufacturing space required (410AD-2 is smaller vehicle).
- Concurrent construction and activation of ETR and WTR facilities.
- Higher traffic model requires additional TUG Maintenance Facility at ETR.

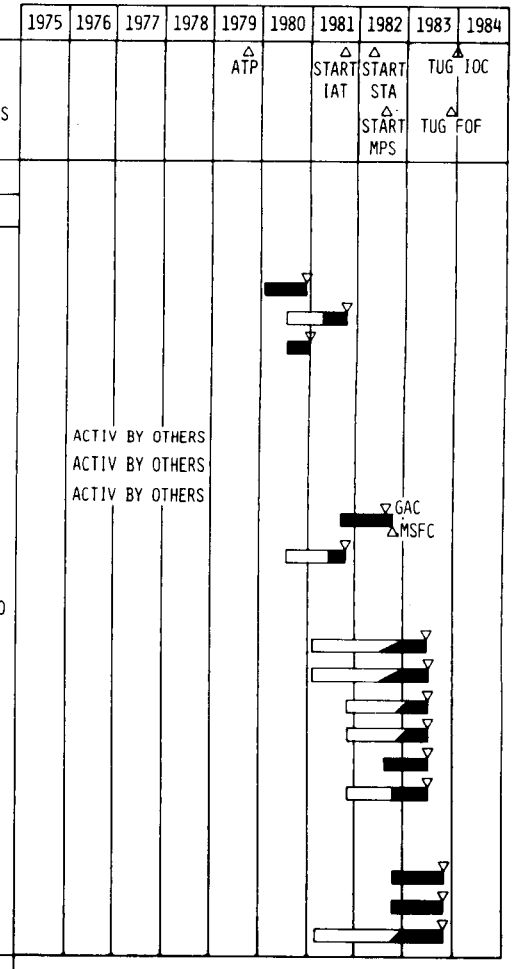
Facilities Requirement Sheets (Ref. Vol. 6, Part 2, Appendix F) and Facilities Plan (Ref. Vol. 8, Part 1, Section 8.3) provide detail requirement, schedule and cost data.

(Ref. Vol. 8, Sect. 8.3)

410AD-2 FACILITIES

CONCURRENT ACTIVATION @ ETR & WTR

FUNCTION	SIZE, SQ FT	EXISTING	MODIFIED/NEW	COST, $M C OF F	COST, $M TOTAL
MANUFACTURING				.055	.520
FAB & ASSY	7,800	GAC-BPA, PLTS 2 & 3			
F/A & C/O	14,200		GAC-BPA, PLT 5		
KICKSTAGE	3,400	GAC-BPA, PLT 5			
TEST				.100	.277
STA	VARIOUS REQMTS	GAC, PLT 5 & WYLE-HUNTS			
THERMAL	-	GAC-BPA, PLT 5			
IAT	1,300	JSC - SHUTTLE ASDL & IATL			
PROPULSION	700	GAC-BPA,HPTF&MSFC-TST ST			
TANK QUAL & ACCEPT	700	GAC-BPA, HPTF			
MAINT & REFURB ETR/WTR				2.380/2.190	3.346/2.860
TUG MAINT FAC	12,00/6,000		EXT ON ORBITER OMS FAC		
PROP SYS SERV FAC	6,000		EXT ON ORBITER OMS FAC		
TUG CLEANING FAC	3,000		EXT ON ORBITER MCO FAC		
KICKSTAGE SRM FAC	2,800/-		EXT ON SHUTTLE SRM FAC		
SUPPORT/WHSE FAC	AS REQD/-	SHUTTLE SHARED @ ETR			
OFFICE	5,000/4,000	EXISTING @ ETR	NEW FAC @ WTR		
ETR/WTR LAUNCH				.413/.494	.535/.616
LAUNCH PAD	-	SHUTTLE FAC-TUG GSE			
SAFING AREA	-	SHUTTLE FAC-TUG GSE			
MISSION CONTROL CENTER	7,500		MOD SPACE @ JSC & SUNNYDALE, CALIF.		
			TOTALS	5.632	8.154



II-3

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410AD-2 MANUFACTURING FLOW

The manufacturing flow and sequence of assembly of the main stage and kick stages is depicted. The flow diagram shows program milestones, engineering drawing release requirements, tool design and fabrication, operation sheet preparation, work order release and the manufacturing and assembly sequence for the major test articles (STA, PTV) and the first flight article.

The direct development option delivers the first spacecraft for a December 1983 IOC. Tooling for the main propellant tanks is the long lead manufacturing item. This configuration uses the nested tank design with gored titanium construction and the 19 month flow from start of tank assembly through delivery is longer than the 110A-1 option because of the increased time for forming and welding the gore sections and because additional time is required for assembly and test of the tanks.

The assembly sequence includes (1) joining the nested tanks by mechanically mating with the aft skirt, (2) adding the forward skirt and (3) systems installation, checkout and acceptance test.

(Ref. Vol. 8, Sect. 8.4)

410AD-2 SPECIAL PROGRAMMATICS

The facing chart summarizes the salient features defined for implementing and managing Program 410AD-2 and indicates specific areas for government participation.

The main factors derived from our analysis of 410AD-2 include: defining the initial flight build up based on initial ground crew launch capability; timing DKS development for concurrent start to capture 1986 retrievals; performing early DKS flights with other launch vehicles; advancing Main Engine go ahead 6 months before the main stage to avoid a critical path; refurbishing the propulsion test article for operational use; and defining a fall back position for every identified risk.

Specific areas for government participation include: establishing Tug/Shuttle interface requirements before Orbiter design freeze; providing payload interface design requirements and mission model data; initiating required activities for Support Research and Technology; providing GFE systems and components (e.g., main engines, and DOD secure comm); supporting propulsion system testing and development and supporting integrated avionics hardware testing and related software development; providing required facilities and performing vehicle ground operations, flight operations and logistic support operations.

(Ref. Vol. 8, Sect. 8.5)

410AD-2 SPECIAL PROGRAMMATICS

- PROGRAM IMPLEMENTATION AND MANAGEMENT
  - FLIGHT BUILD-UP SET BY ETR GROUND CREW LAUNCH CAPABILITY
  - DKS TIMED FOR CONCURRENT START TO CAPTURE 86 RETRIEVALS
  - EARLY DKS FLIGHTS PERFORMED WITH OTHER LAUNCH VEHICLES
  - MAIN ENGINE ATP ADVANCED 6 MONTHS TO AVOID CRITICAL PATH
  - PROPULSION ARTICLE REFURBED FOR FLIGHT
  - FALL BACK POSITION SHOWN FOR EVERY IDENTIFIED RISK

- AREAS FOR GOVERNMENT PARTICIPATION
  - FIRM TUG/SHUTTLE INTERFACES BEFORE ORBITER PDR
  - PROVIDE PAYLOAD INTERFACE DESIGN REQUIREMENTS & MISSION MODEL DATA
  - INITIATE REQUIRED SR&T
  - SUPPORT SYSTEM TEST - AVIONICS HARDWARE/SOFTWARE, PROPULSION
  - PROVIDE GFE SYSTEMS & COMPONENTS, FACILITIES & LOGISTIC SUPPORT
  - PERFORM VEHICLE GROUND AND FLIGHT OPERATIONS

FLIGHT OPERATIONS BUILDUP 410AD-2

The methodology used to establish the 410AD-2 flight buildup is also keyed to achieving all flights defined by the 100% payload capture analysis after the second year of operations. As in 110A-1, the primary factors considered include: NASA defined Shuttle/Tug launch constraints, initial ETR ground crew launch capabilities, and flight mode buildup. In option 2 however, the Shuttle/Tug launch constraints do not apply.

Initial ground crew launch capability is based on a 90% learning factor applied to the minimum ETR ground crew required to support 29 flights in the third year. As a consequence only 20 ETR flights can be achieved in 1984 and 27 in 1985. The minimum WTR ground crew can accomplish all flights planned at WTR.

During the flight buildup period we recommend similar to 110A-1, that flight crew experience be developed by starting with the simplest flight mode and then progressively introducing the more complex flight modes required for 1986.

Our recommended flight buildup for 410AD-2, including 25 flights in 1984 and 33 flights in 1985, encompasses 245 total flights through 1990 or 17 less than 100% payload capture traffic.

(Ref. Vol. 8, Sect. 8.1)

410AD-2 FLIGHT OPERATIONS BUILDUP

INPUTS	CY 84	85	86	87	TOTAL FLTS.
	▽ IOC				
• 100% PAYLOAD CAPTURE - ETR+WTR FLTS	43	35	38	38	262
ETR FLTS	38	27	29	30	
• SHUTTLE/TUG LAUNCH CONSTRAINTS - ETR	NONE				
• INITIAL GROUND CREW LAUNCH CAPABILITY - ETR	20	25	29	30	
• TUG FLIGHT MODE BUILDUP					
SINGLE AND MULTI DEPLOY	ALL	ALL	ALL	ALL	
SINGLE DEPLOY WITH KICK STAGE	ALL	ALL	ALL	ALL	
RETRIEVE	ALL	ALL	ALL	ALL	
ROUND TRIP	ALL	ALL	ALL	ALL	
SORTIE	NONE	ALL	ALL	ALL	
RETRIEVE/ROUND TRIP WITH KICK STAGE	NONE	SOME	ALL	ALL	
SINGLE DEPLOY - EXPEND TUG	NONE	NONE	ALL	ALL	
MULTI DEPLOY WITH KICK STAGE	NONE	NONE	NONE	ALL	
RECOMMENDED FLIGHT BUILDUP ETR+WTR FLIGHTS	25	33	38	38	245
ETR FLIGHTS	20	25	29	30	

BUILDUP RATIONALE

- WTR LAUNCHES CAN BE ACHIEVED
- ETR LAUNCHES CONSTRAINED BY GROUND CREW CAPABILITY PLANNED FOR 1986
- PRE 1984 SHUTTLE/EXISTING STAGE EXPERIENCE ALLOWS MORE 1ST YEAR FLIGHT MODES THAN OPTION 1
- MAXIMIZE GND/FLT CREW LEARNING WITHOUT EXCEEDING DOWN STREAM OPS

PROGRAM SENSITIVITY TO IOC SHIFT - 410AD-2

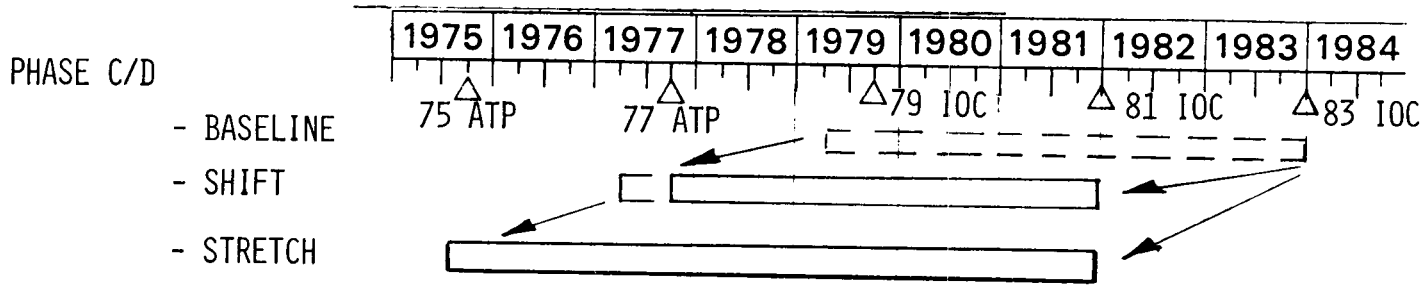
Two programmatic options are available for implementing program 410AD-2 with a 2 year earlier IOC. First the baseline schedule could be shifted 2 years and start at October 77 ATP. The second option uses a schedule stretch out from October 75 ATP to the earlier 81 IOC milestone. Both schedule options assume that the original flight build up is advanced. As in 110A-1, we examined the implications of IOC shift with respect to operations, production and development.

IOC delay results in additional payloads captured (66 deployed and 18 retrieved).

Considering vehicle production two different factors should be addressed. They include schedule implications on manufacturing learning and the availability of existing hardware. For the schedule shift option, manufacturing learning can be more efficiently transferred from test article fabrication to vehicle production than in a stretchout situation. However as in 110A-1 the stretch option allows early contractual arrangements for vendor support of existing hardware.

The impact of advancing IOC on development was also reviewed with respect to schedule, type of contractor support available to NASA/DOD for defining Tug/Shuttle systems and interfaces, vehicle test, facilities SR&T and cost. As noted in 110A-1, for the first two years of stretched schedule, Tug/Shuttle systems and interfaces would be defined by the government with support of a prime contractor. This is an important period for assuring that the two vehicles are compatible as illustrated by the Apollo LM/CSM relationship. The impact on vehicle test and facilities are similar for both schedule options. However, it should be noted that the advanced IMU SR&T requirement would conflict with a similar DOD program. This would require a design change to the Carousel IMU. Assuming that the initial period of schedule stretch is devoted to systems engineering studies we estimate that cost of stretch out will be $14M. Peak funding occurs in 1980 and is $119M for the schedule stretch option.

PROGRAM SENSITIVITY TO IOC SHIFT 410AD-2



	SHIFT	STRETCH
OPERATIONS IMPACT		
ADDL PAYLOADS CAPTURES	66 DEPLOY/18 RETRIEVE	66 DEPLOY/18 RETRIEVE
PRODUCTION IMPACT		
MFG TEST ART/PROD LEARN	BEST	FAIR
EXIST HDWAR AVAIL	IMPROVED	BEST
DEVELOPMENT IMPACT		
SCHEDULE	57 MO	75 MO
SYS & INTERFACE DEFN BY	GOVT + STUDY CONTR	GOVT + PRIME CONTR
VEHICLE TEST	2 YR EARLY	2½ YR EARLY
FACILITIES	2 YR EARLY	ADV AS REQUIRED
SR&T	ADV IMU	ADV IMU
DDT&E	350	364
PAF (YR)	151 (80)	119 (80)

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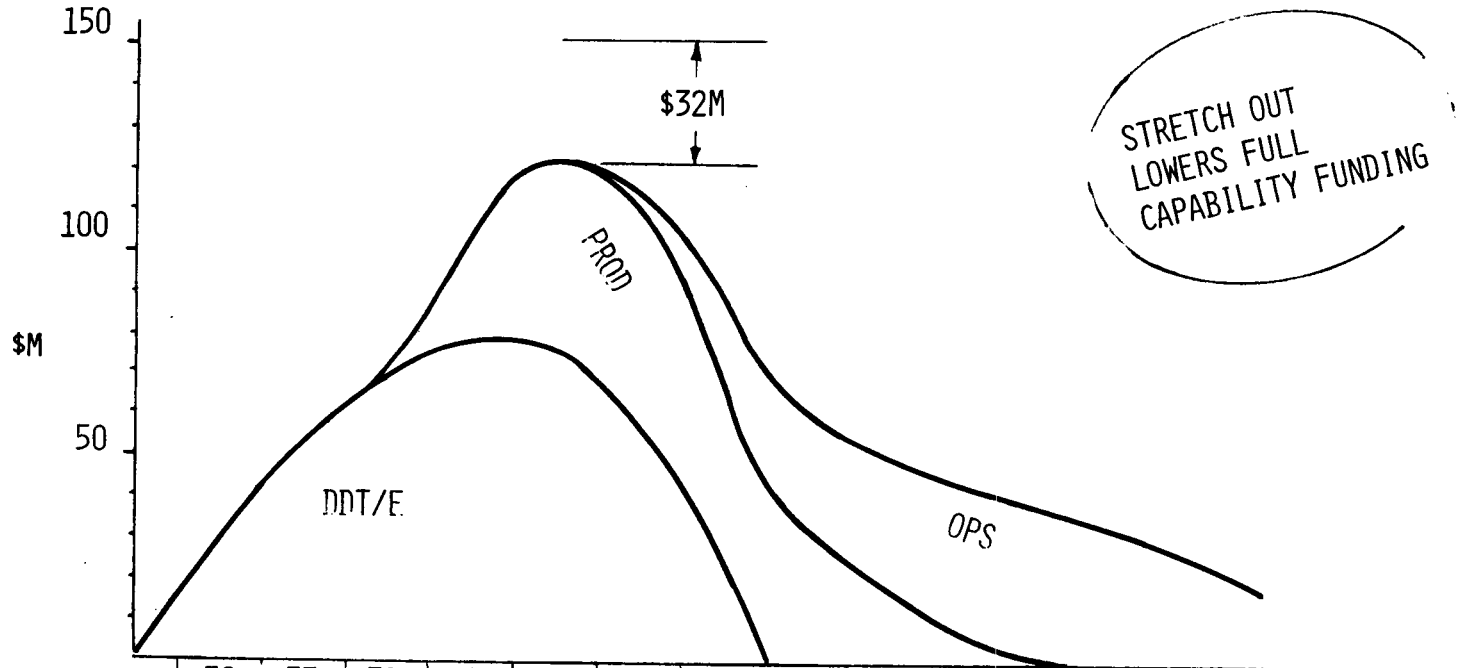
PHASE C/D STRETCH FOR ADVANCED IOC 410AD-2



CY	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	
FY	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	
DDT&E	24	42	57	71	76	58	36									364
PROD				13	43	58	51	36	20	9	2					232
OPS							16	27	31	31	32	31	27	12		207
TOTAL	24	42	57	84	119	116	103	63	51	40	34	31	27	12		793

410AD-2 RISK ASSESSMENT

The technology items and their potential impact are shown on the opposite page. If the prestressed filament reinforced (PFR) helium tank fails to meet its goals, a 6Al4V titanium tank adds 48 lbs to the vehicle. If the advanced (Micron) IMU is unavailable, a Carousel IVB IMU plus a rate gyro unit adds 30 lbs. If the graphite composite shell fails to meet its objectives, an aluminum honeycomb shell adds 38 lbs. The laser radar and space storable SRM are items for which no attractive alternate exists, hence they represent both a schedule and cost risk. If materials compatibility or fracture mechanics data indicate the need to change propellant tank material from titanium to either aluminum or stainless steel, the added weight would be +13 lbs and + 3 lbs respectively. If the heat pipes are replaced by incorporating high heat rejection items on the active loop, there are no weight changes. To recover the weight impact on payload capability due to these possible weight increases, the advanced fuel cell is an open option.

The Class I engine is a new design based on current technology with the exception of the uncertainty in engine life and in the predicted performance with the high expansion ratio nozzles used. It is estimated this engine can miss its performance goals by -3 seconds Isp.

Schedule risk is minimized by the proposed SR&T programs which provide the feasibility of the approach 4 months prior to ATP.

Converting the potential Isp loss and weight increases to a total program cost at a $111K/lb value and adding the potential cost increase items yields a total cost risk of $23.9M for 410AD-2.

(Ref. Vol. 8, Sect. 8.9)

410AD-2 RISK ASSESSMENT

TECHNOLOGY ITEM IMPACT	
• CLASS I ENG	-3 SEC ISP
• PFR TANK	+48 LB
• ADV IMU	+30 LB
• GRAPHITE COMPOSITE	+38 LB
• LASER RADAR	COST/SCHED
• SPACE STORABLE SRM	COST/SCHED
• MATERIALS COMPATIBILITY • FRACTURE MECHANICS	+13 LB
• HEAT PIPES	SCHED

VEHICLE SENSITIVITY (DEPLOY)	PLAIN	WITH AKS
$\frac{\partial P/L}{\partial W \text{ FIXED}}$ (LB/LB)	-3.66	-2.66
$\frac{\partial P/L}{\partial ISP}$ (LB/SEC)	97	93

- TECHNICAL RISK
  - POTENTIAL WT IMPACT: +129 LB
  - POTENTIAL ISP LOSS: -3 SEC

  } ≈ 622 LB OF PAYLOAD (W/AKS)
  - OPEN WEIGHT REDUCTION OPTION: ADV. FUEL CELL
- SCHEDULE RISK
  - PROPOSED SR&T PROGRAMS (COMPL PRIOR TO ATP) PROTECT AGAINST SCHEDULE SLIP
  - AVAILABILITY OF 621 B SATELLITES
- COST RISK
  - POTENTIAL Δ COST $23.9M

MODERATE RISK PROGRAM

II-28

TECHNOLOGY REQUIREMENTS AND DESIRED DATA - 410AD-2

The upper part of the facing chart contains the supporting research and technology (SR&T) items required for 410AD-2; the lower part of the chart contains what we have termed as "desired data". The distinction between the two is that the "desired data" items do not require technology but are considered straightforward engineering development tasks to produce design data prior to Tug program go-ahead (ATP); this will preclude impacting Tug schedules should the data indicate the desirability of an alternative approach.

Excluding the SR&T on the Class I engine, the total SR&T funds requested for 410AD-2 is $1,390K to be expended over an 18 month period culminating 4 months prior to Tug ATP. The advanced (Micron) IMU) is the long lead item (18 months) also excluding the Class I engine.

(Ref. Vol. 8, Sect. 8.10)

410AD-2 TECHNOLOGY REQUIREMENTS & DESIRABLE DATA

	ITEM	SR&T FUNDS, $K	SR&T SCHEDULE, MO	PROPOSED PROGRAM
SR&T	CLASS I ENGINE	TBD	TBD	HIGH ALT TESTS TO OBTAIN PERF DATA ON HIGH ϵ NOZZLE FOR MIXTURE RATIO RANGE
SR&T	LASER RADAR	500	12	FAB & TEST LIGHTWEIGHT, LOW-POWER UNIT USING IMPROVED OPTICS & LIGHTER MIRROR DRIVES
SR&T	PFR HELIUM TANK	125	12	FAB & TEST 3 TANKS UNDER STATIC & DYNAMIC LOADING; ENVIRONMENTAL & COMPATIBILITY TESTS
SR&T	ADVANCED IMU	500	18	DEVELOP SOFTWARE FOR REDUNDANCY MGMT & CALIBRATION OF TWO MULTI-SENSOR TYPE IMU'S
SR&T	GRAPHITE COMPOSITE	15	6	FAB GRAPHITE EPOXY HONEYCOMB SAMPLES & TEST IN VARIOUS PLY DIRECTIONS FOR DESIGN DATA
SR&T	LONG TERM SPACE STORABLE SRM	100	12	PHYSICAL & BALLISTICS PROPERTIES TESTS ON SAMPLES AFTER VACUUM EXPOSURE
DESIRABLE DATA	MATERIALS COMPATIBILITY DATA	25	6	2219-T87, 2219-T81 & 6A14VT1; WITH N_2O_4 & MMH UP TO 130°F
DESIRABLE DATA	FRACTURE MECHANICS DATA	25	6	2219-T87 & 6A14VT1/ K_{IC}, K_{TH} & FLAW GROWTH WITH N_2O_4 & MMH UP TO 130°F
DESIRABLE DATA	HEAT PIPES	100	12	FAB & TEST VARIABLE CONDUCTANCE HEAT PIPE RADIATOR PANEL & HEADER FOR TURN DOWN RATIO & SHUT OFF HEAT FLUX DATA

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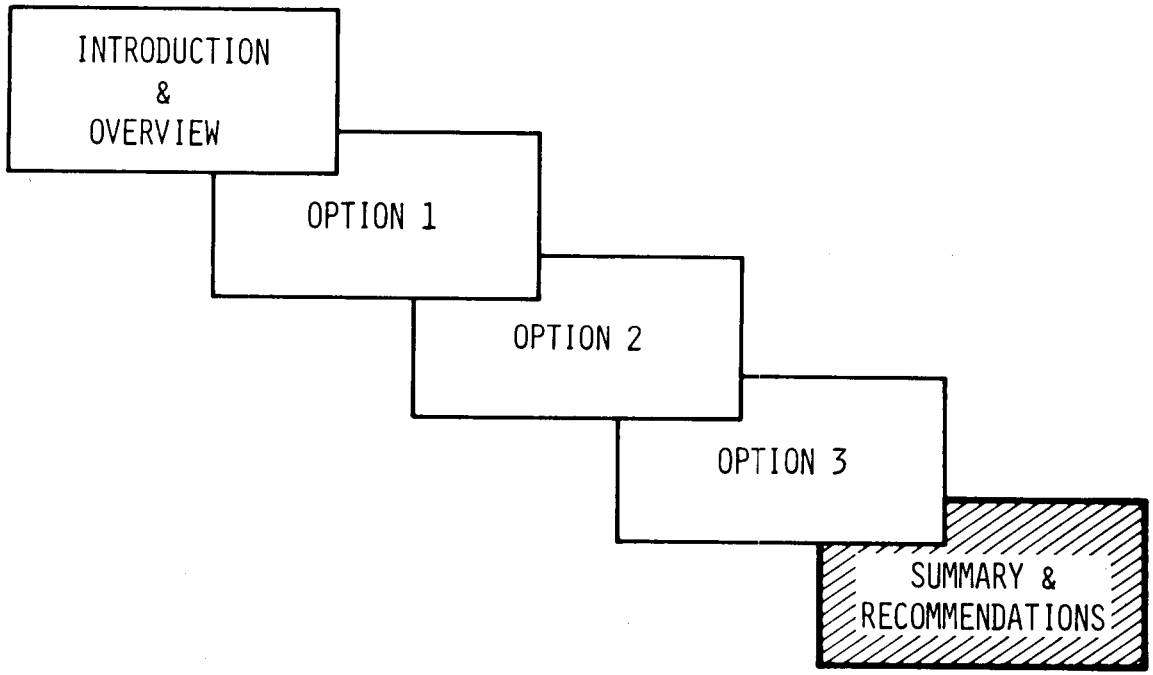
STORABLE TUG DATA REVIEW



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OPTION 1 FINDINGS

DDT&E for this option can be kept below $200M.

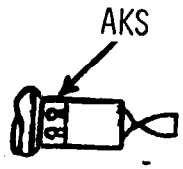
Use of the Shuttle OME 7.5K lb thrust engine in the 110A-1 vehicle results in deployment capability in excess of the 3500 lb geosynchronous requirement without use of an apogee kick stage. We have taken advantage of this feature by deferring the kick stage development until it is desired for planetary missions and multiple payload deployments.

The resulting vehicle is short; it will accommodate payloads up to 30.5 ft. in length. Even with an AKS attached, the payload can be 25.5 ft. long without having to resort to a 2-position engine nozzle.

A maintenance approach has been developed and included in the operating costs which replace subsystems before the equipment failure probability rises significantly. Tanks are operated for 1/4 the life which is demonstrated during development. For costing purposes, this was assumed to be 30 flights after which the tanks are replaced in overhaul and systems verified.

This approach makes it possible to provide all Tug users, including those with planetary missions, a vehicle with reliability in excess of 0.97.

OPTION 1 FINDINGS - 110A-1



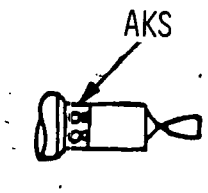
- 3500 LB DEPLOY W/O AKS
  - $191 DDT&E
  - 7.5K OME ENGINE
- PAYLOAD LENGTH TO 32 FT: SEPARATE TANKS
- CHANGE TANKS NOT TUGS
- LOW TECHNOLOGY
- HIGE SCHEDULE CONFIDENCE

OPTION 1 RECOMMENDATIONS

Further work can be done to reduce the initial DDT&E of this program by some avionic subsystems rework, resizing and possibly operational equipment improvements.

It is also recommended that evolutionary options be identified for the minimum DDT&E vehicle to provide deployment growth and limited payload retrieval capabilities. The initial 110-1 vehicle would be unscarred to keep DDT&E below $200M for these evolutionary options so growth, while feasible, would be more expensive than in Option 3.

OPTION 1 RECOMMENDATION - 110A-1



- EXAMINE FURTHER POTENTIAL DDT&E REDUCTIONS

- DEVELOP EVOLUTIONARY PROGRAM
  - LIMITED RETRIEVE PAYLOAD
  - NO INITIAL SCAR

OPTION 2 FINDINGS

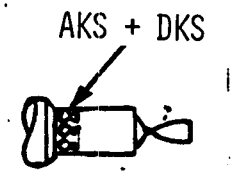
DDT&E is $130M higher than Option 1 due to the greater requirement of this option.

680 lb. of equipment can be delivered for payload servicing of 4 payloads assuming a 500 lb. servicing unit is used for the mission and then returned with the Tug. If the servicing unit is left in orbit, up to 2510 lb. of equipment can be delivered.

A payload servicing approach which requires that all equipment and the servicing unit be returned resulting in only 100 lbs. capability under the present ground rules.

The AKS/DKS is required for 7 payloads (4 NASA and 3 DOD) flying a total of 62 missions or roughly 1/3 of the retrievals. If these 7 payloads could be handled by a servicing mission, it would be possible to eliminate the AKS/DKS from the program, saving development costs, and, more importantly, reducing operational costs.

OPTION 2 FINDINGS - 410AD-2



- DDT&E $130 GREATER THAN OPTION 1
- PAF $70M HIGHER
- PAYLOAD SERVICING CAPABILITY

  680 LB W/O EQUIPMENT RETURN
  2510 LB W/O SERVICE UNIT RETURN
  100 LB WITH EQUIPMENT RETURN

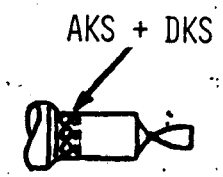
- AKS/DKS NEEDED FOR 7 PAYLOADS
  - SERVICE MISSION COULD ELIMINATE

OPTION 2 RECOMMENDATIONS

A study should be made of the feasibility of eliminating the AKS/DKS requirement by making use of payload service concepts for at least some of the payloads. The study could be performed equally well within this study option or within the framework of Option 3B.

Some further reduction in program costs may be possible by alternate subsystem selection.

OPTION 2 RECOMMENDATIONS - 410AD-2



- EXPLORE ELIMINATION OF AKS/DKS USING SERVICING MISSION
- SEEK FURTHER COST REDUCTIONS

OPTION 3 FINDINGS

The evolutionary performance concept of this option is quite practical. Initial DDT&E can be depressed and still provide a vehicle with a clear path to eventual high performance and payload retrieval.

The choice between candidate within option 3B is not clear. Configuration 310-3B has more expensive low weight subsystems including a Class 7 engine. Its DDT&E is almost the same, however, as 510A with its OME 7.5K lb engine and somewhat heavier but lower cost subsystems because this option also included an apogee kick stage.

With 29 fewer shuttle flights required by the 510A-3B/510ADE-3B concept, it has a total program cost advantage of $255 when compared with the 310-3B/310ARE-3B. The DKS payload impact inherent to 510A-3B/510ADE-3B must be weighed against this total program differential.

If a Retrieval Delay Module is provided in a concept retrieval of some of the heavy payloads, there is no reason to limit retrieving to less than 3500 lb. DDT&E is only $17M higher for 310-3B/310ARE-3B when compared to 310-3A/310RE-3A and this small difference is actually due to an apogee kick stage feature on the 310ARE-3B configuration which is not a disseminating feature.

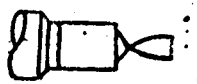
The two stage study has produced some interesting results. 320A-3A/320AE-3A deploys 3500 lb. and retrieves 2200 lb payloads from geosynchronous orbit without the use of solid rocket motor stages.

It has outstanding service mission potential due to its capability to perform in a Retrieval Delay Mode.

Total program cost, $4106M, is lower than the single stage alternatives because of its ability to perform the payload missions with only 301 shuttle flights. While performance is attractive, the concept has high DDT&E and operationally is complex.

OPTION 3 FINDINGS

310-3A/310RE-3



510A-3B/510ADE-3B

320A-3A/320AE-3A

310-3B/310ARE-3B

- EVOLUTIONARY APPROACH FLEXIBLE & COST-EFFECTIVE
- 3B OPTION CHOICE NOT CLEAR
  - INITIAL DDT&E SAME
  - 310 TOTAL PROGRAM COST $254M HIGHER

  BUT AVOIDS DKS PAYLOAD IMPACT
- 2 STAGE CONCEPT
  - 3500 LB DEPLOY/2200 LB RETRIEVE W/O SRM'S
  - OUTSTANDING SERVICE MISSION POTENTIAL
  - HIGHEST INITIAL DDT&E $333M
  - LOWEST TOTAL PROGRAM COST IN OPTION 3
  - COMPLEX OPERATIONALLY
- 3500 LB RETRIEVAL DELAY COST-EFFECTIVE
  - 2200 LBS SAVES ONLY $17M DDT&E

OPTION 3 RECOMMENDATIONS

Concentrate study effort on 3000 lb retrieval. If retrieval requirements fall beyond the single stage capability of about 1800 lb., there is no gain in compromising user retrieval needs below 3500 lb.

The impact of the DKS on the pay loads needs to be established before much more work should be done on this concept.

Evolution to retrieval should be considered in steps. Retrieval could be provided starting with single stage capability and progressing to higher capability using a combination of servicing unit concepts where practical and the Retrieval Delay Module where necessary.

OPTION 3 RECOMMENDATIONS

310-3A/310RE-3A

320-3A/320AE-3A

510A-3B/510ADE-3B

310-3B/310ARE-3B

- FOCUS ON 3500 LB RETRIEVAL (OPTION 3B)
- INVESTIGATE RETRIEVAL EVOLUTION

  "NATURAL" RETRIEVAL ⟶ RETRIEVAL DELAY MODULE
  AND
  SERVICING MODULE

- DETERMINE PAYLOAD IMPACT OF DKS (GOVT. TASK)
  - AFFECTS CHOICE OF 310 Vs. 510