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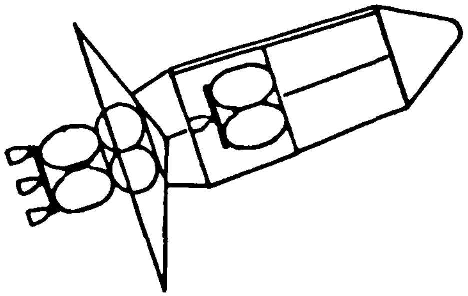
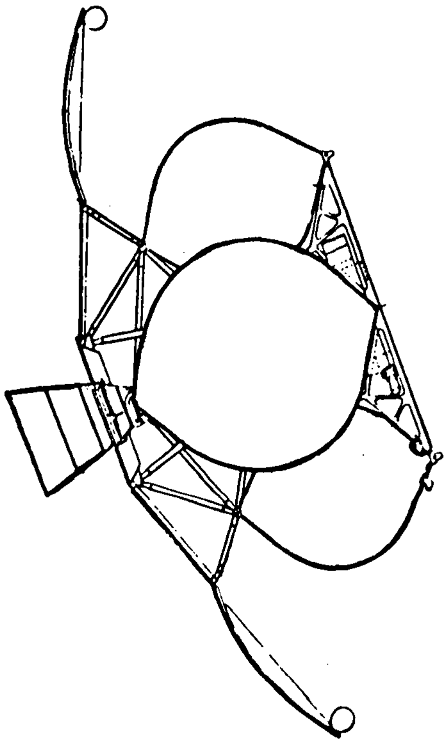
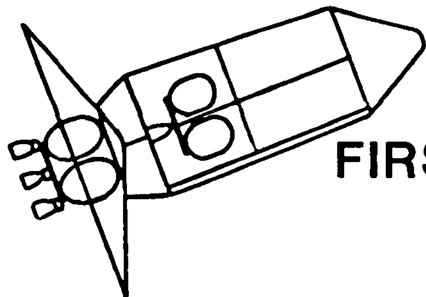


ORBITAL TRANSFER VEHICLE

CONCEPT DEFINITION
AND
SYSTEM ANALYSIS STUDY
NAS8-36108





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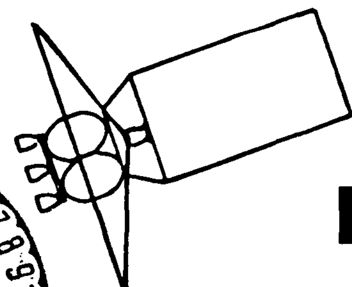

30 OCT 1984

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PROPULSION TRADE STATUS (TASK 2 AND 3)

TRADES	RESULTS
COMBINATION PROPELLANT	FINAL RECOMMENDATION IS LO_2/MMH BEST ALTERNATE TO LO_2/LH_2 AND N_2O_4/MMH BASED DEVELOPMENT AND PROPELLANT WEIGHT
MAIN ENGINE SELECTION (BASED ON REDUNDANCY REQUIREMENTS)	(INTERIM) CRYO RL10-III (7.5K) G.B. 2 EACH (FO) S.B. DELIVERY 2 EACH (FO) S.B. MANNED 2 EACH AND RCS B/U (FO/FS) STORABLE RS-47 (7.5K) G.B. 2 EACH S.B. 3 EACH (NEED 50% THROTTLING)
LH_2 TANK RETRIEVAL (G.B.)	(INTERIM) NON-OPTIMUM MPS BURN AND RCS DUMPING OF RESIDUALS

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The hydrazine reaction control subsystem was selected to minimize mass and DDT&E cost on the ground-based OTVs. The space-based OTVs use integrated systems because of higher total impulse requirements, flexibility, and simplified propellant loading, and the advantage of manned mission back-up. They do represent a significant DDT&E cost, but are estimated to reduce LCC based on the higher I_{sp} and loading simplifications. The GO_2/GH_2 system also supplies a pneumatic pressurant for valve actuation.

Our preliminary engine space maintenance recommendation, based on work with Rocketdyne and Pratt & Whitney, are to modularize the turbo-pump on the cryogenic stage. With a expander cycle engine, it is projected to double the engine's useful life. Storable engines are an open item because they have more active components than the expander cycle. How much the turbo-pump changeout buys in life is not presently defined.

PROPULSION TRADE STATUS (TASK 2 AND 3)

TRADES	RESULTS
REACTION CONTROL SUBSYSTEM	(INTERIM) G.B. N_2H_4 FOR BOTH CRYO AND STORABLE S.B. COMMON FOR BOTH CRYO AND STORABLE
SPACE MAINTENANCE	PRELIMINARY RECOMMENDATION - CHANGE OUT TURBO-PUMP ON CRYOGENIC ENGINES - OPEN ON STORABLES

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MPS CANDIDATE ENGINES

These are the cryogenic (LO_2/LH_2) and storable (N_2O_4/MMH) and LO_2/MMH engine candidates we are considering.

The performance and general description are shown. The engines represent technology levels from existing to current advanced concepts. Our trade studies have and will consider the availability of the engines vs. OTV IOC, cost, and stage impacts of advanced technology compared to existing engines. Our continuing meetings with the various engine contractors will update and modify these characteristics as the program progresses and additional propulsion requirements are derived.

MPS CANDIDATE ENGINES

PROPELLANT	ENGINE	I_{SP} / MR	THRUST 10^3 LB	LIFE, H / NO. STARTS	DEV STATUS	CYCLE	MASS DRY (LB_M)	P_C (PSIA)	ε	NPSH/NPSP FUEL	NPSH/NPSP OXID
LO_2 / LH_2	RL10A-3-3A	446 / 6.0	16.5	1.25 / 20	OPERATIONAL	SINGLE EXPANDER	305	465	61:1	28.6 PSIA	43 PSIA
	RL10A-3-3B	440 / 6.0	15	1.25 / 20	QUAL		305	415	61:1	28.6 PSIA	43 PSIA
	RL10-IIB	460 / 6.0	15	5 / 190	PRODUCT DEVELOPMENT CONTRACT		392	400	205:1	14 FT	7.5 FT
	RL10-IIC	459 / 6.0	15	1.25 / 20			374	400	205:1	28.6 PSIA	43 PSIA
	RL10-III	470 / 6:1	7.5	5 / 190	PROD IMPROVEMENT		400	400	400:1	14 FT	7.5 FT
	RL100	479 / 6.0	15	10 / 300	COMP TECH DEV CONT		427	1500	640:1	15 FT	2 FT
	RL100	474 / 6:1	7.5	10 / 300	STUDY		300	1200	600:1	15 FT	2 FT
	RS44 CORE	463 / 6.0	15	10 / 300	COMPONENT TECHNOLOGY DEVELOPMENT CONTRACT		342	1540	225:1	15 FT	2 FT
	RS44 INCR CAP	481 / 6.0	15	10 / 300			461	1540	625:1	15 FT	2 FT
	RS44 FULL CAP	492 / 6:1	15	20 / 500			407	2052	1175:1	15 FT	2 FT
	AJ23-154	483 / 6.0	3	20 / 500		DUAL EXPANDER	90	2000	1000	0 FT	0 FT
N_2O_4 / MMH	XLR-132	342 / 2.0	3.75	1.0 (CURRENT) / 10		GAS GENERATOR	114	1500	400:1	17 PSIA AT 70 DEG F	37 PSIA AT 70 DEG F
	AJ23-153 TRANSTAR	328 / 1.8	3.75	NA / 15	DEVELOPMENT		128	350	136:1	26 PSIA AT 80 DEG F	57 PSIA AT 80 DEG F
	AJ23-151 PUMP FED OMS	334 / 1.93	6.0	15 / NA	TEST CONTRACT		322	350	154:1	30 PSIA AT 90 DEG F	60 PSIA AT 90 DEG F
	AJ23-156 TRANSTAR III	343 / 2.1	3.75	NA / 16	TECHNOLOGY DEVELOPMENT		104	1430	400:1	28 PSIA AT 80 DEG F	63 PSIA AT 80 DEG F
LO_2 / MMH	ROCKETDYNE DESIGN	367 / 1.4	6.0	—	—		—	1000	400:1	37 PSIA	16.3 PSIA

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LO_2/LH_2 ENGINE TECHNOLOGY ASSESSMENT

This is our assessment of the engine technology available in the OTV time frame.

Cryogenic engine technology now exists in the RL10 and its derivatives. They are low chamber pressure, gear driven expander cycle engines. The derivatives allow for tank head idle (THI), pump head idle (PHI), and GOX pressurization and low NPSH. The current RL10-3-3A/B for Shuttle and Atlas Centaur require dump conditioning and helium pressurization for start-up, thus they are not included. Intermediate term would provide the RS-44 core and the RL100 because of its cycle commonality with the RL10. Long-term advancements are expected to boost chamber pressure to 2000 psi with the use of hydraulic low pressure pumps and/or dual expander cycles. Current technology contract efforts at NASA/LeRC could make this technology available in the 1988 timeframe if the higher performance is recommended by this study.

LO 2 /LH 2 ENGINE TECHNOLOGY ASSESSMENT

TECHNOLOGY LEVEL	FLIGHT ENGINE AVAILABILITY	ENGINE CANDIDATE
NEAR TERM 1985	1991	RL-10 III Pc=400 PSIA ϵ=400:1 I_{SP}=470 RS-44 Pc=1540 PSIA ϵ=225:1 I_{SP}=463 RL-10 IIB Pc=400 PSIA ϵ=205:1 I_{SP}=460
INTERMEDIATE TERM 1988	1993	RS-44 ADVANCED CORE Pc-1540 PSIA ϵ=625:1 I_{SP}=481 RL-100 Pc=1500 PSIA, ϵ=640:1 I_{SP}=479
LONG TERM 1990-1992	1997	RS-44 FULL CAPABILITY Pc=2000 PSIA ϵ=1175:1 I_{SP} =492 AJ23-154 Pc=2000 PSIA ϵ=1000:1 I_{SP}=483

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N_2O_4/MMH ENGINE TECHNOLOGY ASSESSMENT

Present storable engine technology is the Aerojet transtar engine as it is being developed for Ford Aerospace. Possible OMS improvements are also projected by Aerojet. Chamber pressure is low and limited by fuel cooling and thrust.

Intermediate term storable engines are the expendable XLR-132 under study at AFRPL. This engine uses oxidizer cooling allowing higher chamber pressure, lower mass, and higher specific impulse. Life is not available with the current design, but is also to be studied by AFRPL in 1985-1986. Component testing is underway with a breadboard engine to be tested in 1986. Long-term technology is a reusable XLR-132. The I_{sp}'s shown are for the current 3750 lb_f storable engines except for the OMS derivative engine which is a 6000 lb engine.

N 2 O 4 /MMH ENGINE TECHNOLOGY ASSESSMENT

TECHNOLOGY LEVEL	FLIGHT ENGINE AVAILABILITY	ENGINE CANDIDATE
NEAR TERM 1985	1987 TO 1988	AJ-23-151 PUMP FED OMS Pc=350 PSIA ϵ=136:1 I_{SP}=334 AJ-23-153 TRANSTAR I Pc=350 PSIA ϵ=136:1 I_{SP}=328
INTERMEDIATE TERM 1987	1992	XLR-132 Pc=1500 PSIA ϵ= 400:1 I_{SP}=342 EXPENDABLE
LONG TERM 1991	1995	XLR-132 Pc=1500 PSIA ϵ=400:1 I_{SP}=342 REUSABLE

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The performance of the advanced cryogenic engines is tabulated below. These data were generated from manufacturers parametric data and reverified with them for use in our coarse screening studies. Since it was used for coarse screening of multiple engine and thrust level, the best performance at a constant expansion ratio was used. Length impacts to the stage and optimum expansion was not considered at this stage of the study. Variations in the specific impulse are mainly due to chamber pressure. Rocketdyne and Pratt & Whitney decrease chamber pressure with thrust. Aerojet shows relatively high Pc at low thrust, obtainable through the dual expander cycle. Engine mass is also dependant on manufacture and engine cycle. Pratt & Whitney's gear driven turbo-pump design favors larger engines. Aerojet's dual expander is shown to be lighter at lower thrust even at higher area ratios, again attributed to higher chamber pressure. Rocketdyne is slightly lighter considering the high expansion ratio, because of higher chamber pressure. However, the thrust per weight decreases with thrust because of chamber pressure reduction.

At the present time there is an uncertainty in the specific impulse obtained from nozzle expansion ratios of 1000:1 and greater. LeRC has added additional effort in the engine technology programs to test high area rates nozzles next year. When these data become available these parametric data will be revised.

MPS PARAMETRIC DATA FOR TRADE STUDIES

CRYOGENIC ENGINES

	PRATT WHITNEY				AEROJET				ROCKETDYNE			
THRUST $X10^{-3}$,LBS	ISP SEC	WT LBS	LENGTH IN.	EXIT DIA IN.	ISP SEC	WT LBS	LENGTH IN.	EXIT DIA IN.	ISP SEC	WT LBS	LENGTH IN.	EXIT DIA IN.
15.0	478.6	376	120	57	484.4	384	170	70	491.5	395	150	74
7.5	476.3	331	102	47	483.5	272	118	50	490.0	240	130	58
5.0	475.8	243	91	40	482.8	160	100	41	489.5	200	120	51
3.75	473.1	210	83	36	482.5	130	90	34	488.7	170	110	46
EXPANSION RATIO	640:1				1000:1				1200:1			
MSFC I_{SP} PREDICTIONS	477.7				484.1				483.8			

DATA WAS DEVELOPED FROM ENGINE CONTRACTOR
PARAMETRIC DATA BY MMA AND REVERIFIED WITH CONTRACTOR

*MSFC PREDICTIONS FOR POINT DESIGNS (15K) (MEMO PD13 [84-84])

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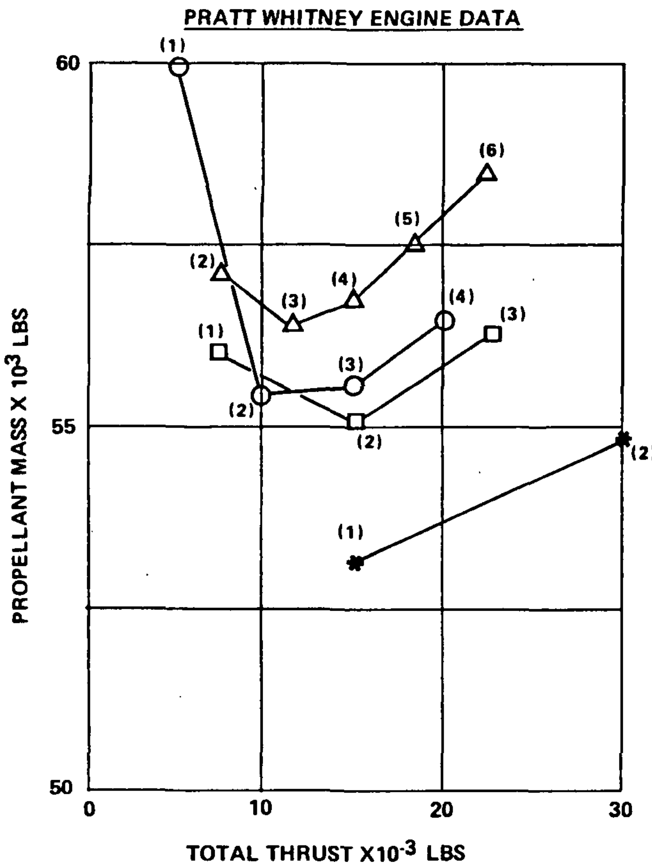
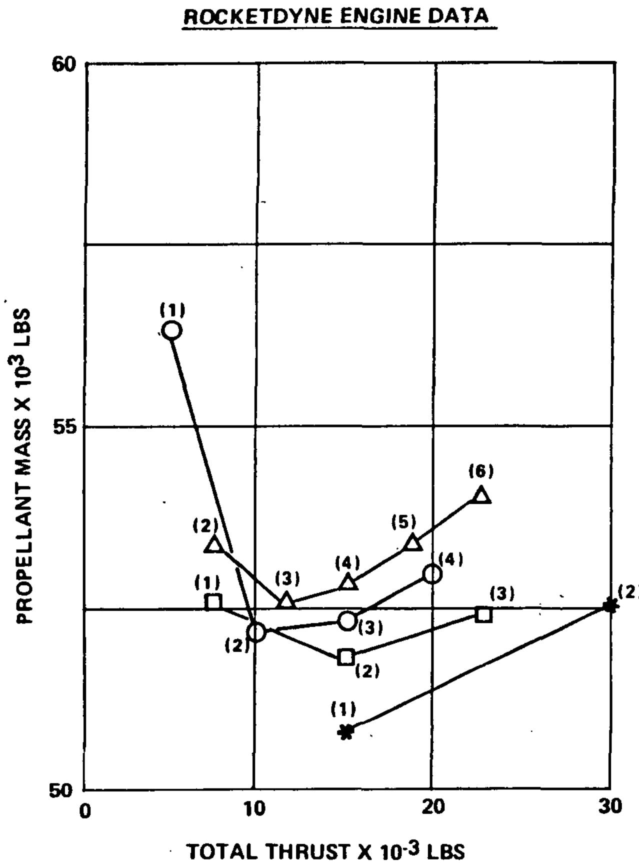
THRUST VS WEIGHT FOR CRYOGENIC 20K DELIVERY MISSION

The OTV propellant mass required for the 20K delivery mission was calculated as a function of number of engines and total thrust as shown on the facing page. The engine contractor's parametric data was used to develop I_{sp} and weight data for 3750, 5000, 7500, and 15,000 lb thrust engines. Results using Pratt & Whitney data and Rocketdyne data are presented since they encompass the range of all engine performance. Aerojet data would fall approximately midway between, thus it was not plotted. The optimum total thrust level is between 10,000 and 15,000 lb for both sets of engine data.

The data indicates that a single 15,000 lb thrust engine has the lowest propellant weight and it would be selected if it were not for redundancy requirements. If two engines are required for redundancy, then the Pratt & Whitney data indicates that two 15,000 lb engines require 374 lb less propellant than for two 7500 lb engines. Using Rocketdyne data, two 15,000 lb engines require 864 more propellant than the two 7,500 lb engine configuration. Thus, we conclude that two 7500-lb engines is the best choice for I_{sp} above 479 seconds.

THRUST VS PROPELLANT WEIGHT FOR CRYO 20K DELIVERY MISSION





SYMBOL	ENGINE THRUST LBS
△	3750
○	5000
□	7500
*	15,000

(1-6) NUMBER OF ENGINES

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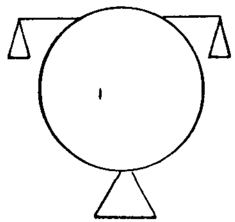
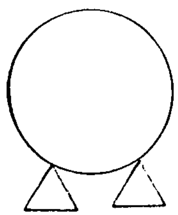
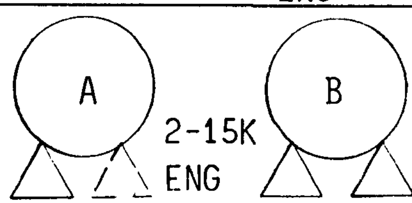
The three options for two failure criteria were traded based on propellant requirements. Cost of propellant is considered to be the largest factor in Life Cycle Cost.

The results for fail safe criteria are shown on the next page. The reference configuration uses a common back-up RCS to meet the fail safe criteria. Net RCS I_{sp} was estimated to be 440 sec resulting from a 460 sec thruster I_{sp} and allowing a 5% loss due to a turbo-pump conditioning system. The conditioning system is a technology that has not been worked since the Shuttle RCS studies of the 70's.

The results indicate the 20K manned mission has a severe penalty in carrying RCS margin to accomplish the GEO deorbit (Option 1). Multiple engine at a lower thrust per engine (Option 2)is more optimum to meet the failure tolerance but results in a penalty for unmanned missions over a single, higher performing engine (Option 1). To achieve the unmanned performance but meet the failure tolerance, multiple larger thrust engines were used in Option 3 and the savings in removing one to perform the unmanned mission was determined. The best option was found to be Option 3. However, the amount of structure and feed system mass (SCAR) required to modularize the engine needs to be considered. A preliminary analysis showed that the average sensitivity of propellant to dry weight for the total of unmanned missions is 3.0 lb prop/lb. Using this partial we found that the SCAR mass needed to be less than about 100 lb to break even on propellant.

MAIN ENGINE TRADE STUDY (INTERIM)

FAIL-SAFE

OPTION	DESCRIPTION	MANNED: PROPELLANT 14K RETURN * (LBS)	MANNED: PROP FROM REF (LBS)	UNMANNED: PROPELLANT 20K DEL* (LBS)	UNMANNED: PROP FROM REF (LBS)	COMMENTS
1 (REF)	 RCS (COMMON) 1-15K ENG	70800+5100 =75900	0	50800	0	RECOMMENDED FS
2	 2-7.5K ENG	71600	-4300	51600	+800	
3	 2-15K ENG	A-NOT USED B-71800	A- B-4100	A-50800 OR B-52400	0 (SOME SCAR PENALTY) +1600	BEST OPTION

*ROCKETDYNE ENGINE PERFORMANCE USED

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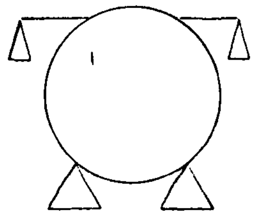
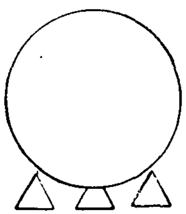
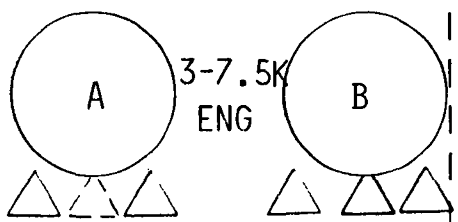
The results for FO/FS are shown on the next page. Again Option 1 used RCS back-up. Option 1 is the best provided the SCAR mass penalty for Option 3 does not exceed 100 lbs. Option 1 requires development of a complex turbo-pump conditioning system where as Option 3 requires additional servicing time to add and maintain the third engine for the manned missions and will also have a scar weight impact.

MAIN ENGINE TRADE STUDY (INTERIM)

FAIL-OP/FAIL-SAFE

		MANNED		UNMANNED		
OPTION	DESCRIPTION	PROPELLANT 14K RETURN* (LBS)	PROP FROM REF (LBS)	PROPELLANT 20K DEL* (LBS)	PROP FROM REF (LBS)	COMMENTS
1 (REF)	 2-7.5K ENG	71600+5000 =76600	0	51600	0	RECOMMENDED FO/FS
2	 3-5K ENG	72400	-4200	52300	+700	
3	 A 3-7.5K ENG B	A-NOT USED B-72100	A- B-4500	A-51600 B-52500	0 (SOME SCAR PENALTY) 900	BEST OPTION

*ROCKETDYNE ENGINE PERFORMANCE USED

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The performance and geometry data for the XCR-132 is shown on the next page. A constant area ratio was used for the coarse screening. This data was used for engine thrust level sensitivity and multiple engine trade studies. Highest performance for storable is found at the higher thrust, with less of an advantage above about 20,000 lb_f. This data is considered applicable to either Rocketdyne or Aerojet engines.

MPS PARAMETRIC DATA FOR TRADE STUDIES

STORABLE ENGINES

	XLR-132				
THRUST $X10^{-3}$ LBS	I_{SP} (SEC)	WEIGHT (LB)	LENGTH (IN.)	EXIT DIAMETER (IN.)
3.75	342.4	114	52	26
5.0	343.1	146	60	30
7.5	344.1	213	74	37
15.0	345.7	426	104	52
20.0	346.1	578	119	59
25.0	346.6	738	133	66
30.0	346.9	905	145	72
	ϵ 400:1			

DATA OBTAINED DIRECTLY FROM ENGINE CONTRACTOR (ROCKETDYNE)

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