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Delta Improvement Study: Hydrogen Upper Stage

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Several hydrogen engines were compared for use in a new hydrogen stage for the Delta launch vehicle. Optimized trajectory analysis and weight estimates of the stage were included in the analysis. The results indicated that the second stage that uses storable propellants and the solid third stage could both be replaced with a single hydrogen stage. The RL10C engine provided good results.

Introduction

THE Delta commercial launch vehicle has had a long and successful life. It was first launched May 13, 1960 and the mission was unsuccessful. The Echo 1A satellite was carried into orbit on the second Delta mission. Between May 1960 and November 1990, the Delta completed 189 of 201 missions successfully, giving it 94% reliability. The version of the rocket that was considered for upgrade in this study was the Delta II 7925. It first flew on Nov. 26, 1990. The Delta II 7925 consists of three stages and uses nine external solid rocket motors. Propulsion for stage 1 is provided by a liquid core engine burning RP-1 fuel and oxygen. Core stage 2 is a storable liquid core and uses nitrogen tetroxide and A-50 propellants. Stage 3 consists of a solid rocket motor used to insert the payload into geosynchronous transfer orbit (GTO). A payload of 4010 lb can be placed into GTO using the Delta II 7925 with a 9.5-ft payload fairing.[1]

The study reported here is aimed at helping to reduce the use of toxic storable propellants. Special safety steps needed for these chemicals would be eliminated and operations costs would fall as a result. By using a hydrogen and oxygen upper stage, stages 2 and 3 could be eliminated from the Delta II. Figure 1 illustrates this modification. Five engines were examined in the course of this research for use in the hydrogen replacement stage. Included in the research were the following engines: an RL10C, an RL10A-4, an advanced technology low cost (ATLC) engine, an advanced expander cycle engine, and an engine with a simplified injector.

Hydrogen Upper Stage Analysis

The evaluation process involved optimized trajectory calculations using a program called OPGUID. Results from a previous unpublished analysis indicated that the payload estimates quoted by the manufacturer could be obtained within about 100 lb for a 10,000-lb payload. In that analysis, an OPGUID input file simulated the Delta II 7920 carrying its payload into low Earth orbit. The Delta II 7920 is a two-stage version and is capable of low Earth orbit missions only.[1] The analysis used for this research was based on that input file. Insertion into GTO was simulated by the addition of a velocity requirement of 8200 ft/s above a circular orbit of 100 n mile. Burnout weight was provided by the trajectory optimization program.

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Engine characteristics were obtained from the engine designers and are presented in Table 1. The payload weight was determined by subtracting inert weight from the burnout weight. Work done previously (but never published) on a new hydrogen stage was the basis for the inert weight calculation. That work involved the calculation of the weight of about 10 items as a function of propellant weight, mixture ratio, thrust, propellant flow rate, and inert weight. A growth margin of 10% was provided. A margin of 10% was added to the engine weight for new engines. Existing engines received no margin and a margin of 5% was added for derivative engines.

Figure 2 shows burnout and payload weights of an RL10C with 35,000 lb of thrust and an exit diameter of 50 in. From these results, using a propellant weight of 30,000 lb, the inert weight was calculated to be about 6500 lb. The current analysis is based on a design with convex bulkheads and self-supporting tank walls. An alternate approach would be to use a Centaur stage. The difference between the two approaches is largely in the structural design. The Centaur's hydrogen tank has a concave lower bulkhead to provide nesting tanks, and its tank structure requires pressure stabilization.[2] The design for the current analysis should reduce handling and safety difficulties and should result in lower operations costs. On the other hand, if the Centaur design approach is used, the inert weight can be reduced about 2200 lb because the Centaur stage with 30,000 lb of propellant has an inert weight of 4300 lb. All payloads presented in this article could be increased about 2200 lb if the Centaur design approach is selected.

Figures 3 and 4 show the effect on payload of changing the exit diameter and thrust level of the RL10C. From these

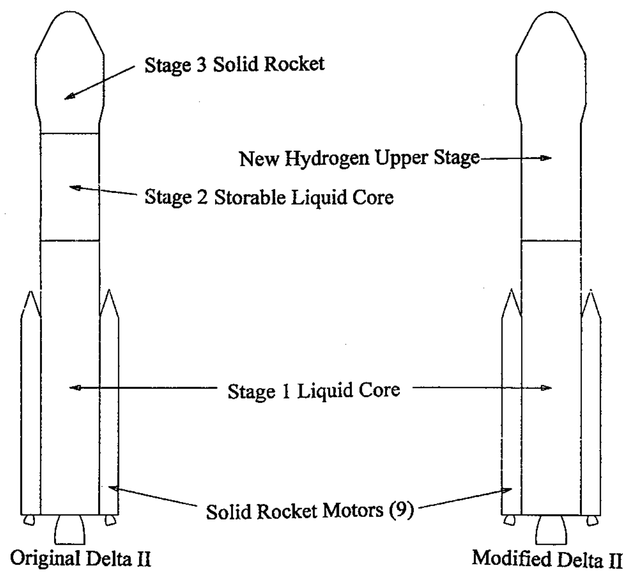

Fig. 1 Delta II improvement (not to scale).

Table 1 Engine data

Engine type	Thrust, lb	Specific impulse, s	Engine weight, lb	Mixture ratio
RL10C				
50-in. exit diameter	35,000	448.0	325	6.0
90-in. exit diameter	35,000	463.4	575	6.0
70-in. exit diameter	35,000	457.3	435	6.0
	30,000	459.7	439	6.0
	25,000	462.3	443	6.0
RL10A-4	20,800	449.0	370	5.5
ATLC	50,000	450.0	800	5.5
Advanced expander	30,000	470.0	710	6.0
Simplified injector				
150 area ratio	30,000	441.0	732	6.0
	40,000	441.0	1026	6.0
	20,000	441.0	473	6.0
100 area ratio	30,000	436.0	586	6.0
200 area ratio	30,000	443.0	915	6.0

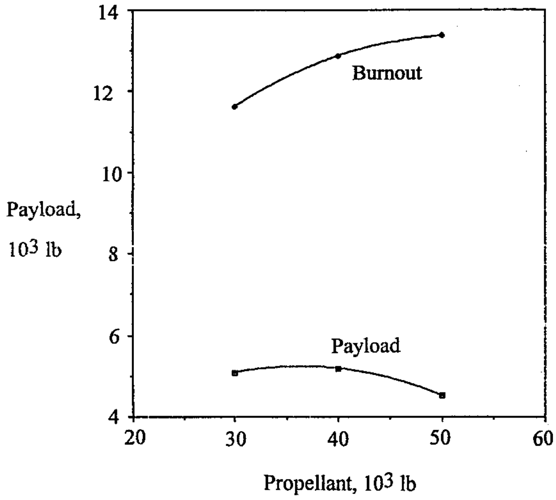

Fig. 2 RL10C, T = 35,000 lb, 50-in. exit.

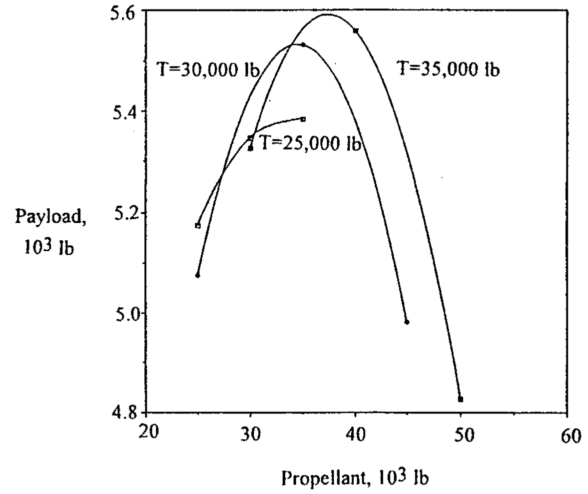

Fig. 4 RL10C, 70-in. exit.

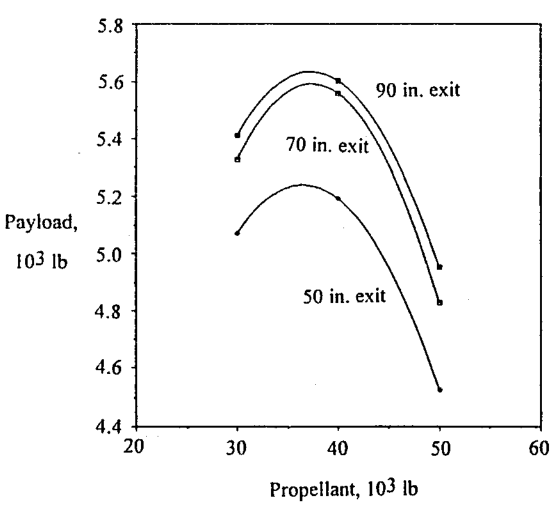

Fig. 3 RL10C, T = 35,000 lb.

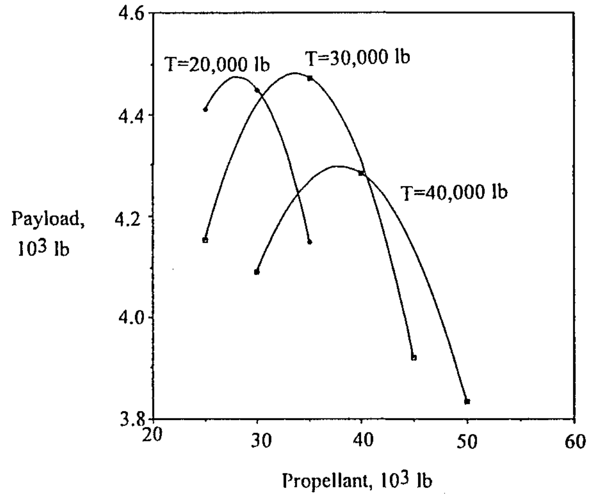

Fig. 5 Simplified injector engine, 150 area ratio.

results it can be seen that the configuration with a thrust of 35,000 lb and a 90-in. exit diameter gives the best payload weight. Figures 5 and 6 show the results of varying area ratio and thrust level of a simplified injector engine. These figures show that a simplified injector engine with an area ratio of 150 and a thrust level of 30,000 lb has the best payload. The best results for these two engines are compared in Fig. 7 to payload levels for the other three engines, which each had only one case available. The RL10A-4 has a thrust of 21,000 lb, which is too low to give a good payload weight. The Advanced Technology Low Cost (ATLC) engine with its relatively low specific impulse of 450 s and relatively high weight of 800 lb has an adequate thrust of 50,000 lb. However, its payload capacity is near that of the RL10A-4 because of the low specific impulse and high engine weight. The possibility of low engine cost may need to be sacrificed in order to obtain

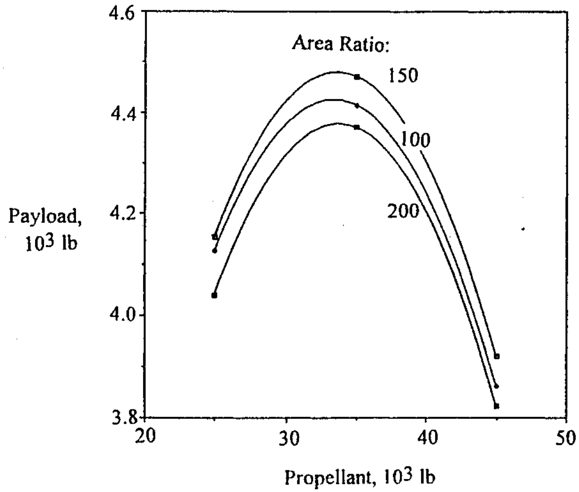

Fig. 6 Simplified injector engine, T = 30,000 lb.

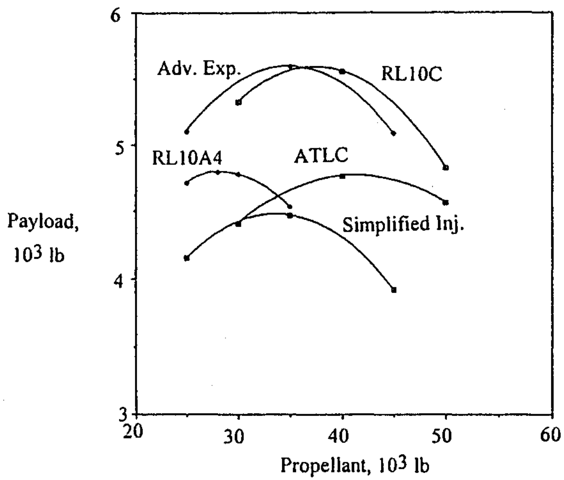

Fig. 7 Engine comparisons.

better payload results. The advanced expander engine data used were for a thrust of 30,000 lb. At the same thrust level, the advanced expander provides a slightly higher payload than the RL10C, but the difference is less than 100 lb. The advanced expander has a higher specific impulse and burnout weight, but the engine weight is higher. An analysis of advanced expander engines at varying chamber pressures could provide an advanced expander engine with an optimum design for this mission and may give a significant advantage over the RL10C. The engine with a simplified injector turned out to have a much lower payload weight than the other engines. Despite its adequate thrust level and specific impulse and probable low cost, its payload weight does not match that of even the RL10A-4.

Conclusions

From the given data and results, it can be concluded that the most likely candidate from among these engines to serve as a replacement upper stage for the Delta II is the RL10C. This engine is a derivative of an existing engine. It will therefore cost less to develop and produce and still provide a comparable payload weight to advanced conceptual engines.

Acknowledgments

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[1]Isakowitz, S. J., "Delta," *International Reference Guide to Space Launch Systems*, AIAA, Washington, DC, 1991, pp. 201–208.

[2]Isakowitz, S. J., "Atlas," *International Reference Guide to Space Launch Systems*, AIAA, Washington, DC, 1991, p. 192.