Hypersonic Aerospace Sizing Analysis for the Preliminary Design of Aerospace Vehicles

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Abstract

A REVIEW of the literature indicated that a general weight and sizing analysis for the preliminary design of aerospace vehicles was not available. This paper describes the developed methodology and provides examples to illustrate a new model, the Hypersonic Aerospace Sizing Analysis (HASA). HASA can be used to predict the size and weight of hypersonic single-stage and two-stage-to-orbit vehicles and transports, and is also relevant for supersonic transports. The propulsion systems considered include turbojets, turboramjets, ramjets, scramjets, and liquid-fuel rocket engines.

Contents

The design of single-stage-to-orbit (SSTO) vehicles presents a particular challenge because their performance is highly dependent on their size and weight, propulsion system, and aerodynamics. To assess the tradeoffs between performance and size and weight in mission analysis studies, it is desirable to be able to change vehicle configurations with relative ease. An analytical model that can predict a vehicle's size and weight requirements for various payloads, propellant types, and methods of propulsion, including both air-breathing and rocket-propulsion systems is needed. (See Ref. 1 for a thorough discussion of current methods.)

Several weight-prediction techniques have been developed using statistical correlations for specific vehicles. They include the Space Shuttle Synthesis Program (SSSP), 1970[2]; the Weight Analysis of Advanced Transportation Systems Program (WAATS), 1974[3]; and the Systems Engineering Mass Prediction Program (SEMP), 1979.[4] The limitations of these programs are that SSSP and SEMP were developed explicitly for the Space Shuttle, and the WAATS program can predict the vehicle weight but not the size for both subsonic and supersonic vehicles.

A recent sizing method which also evaluates the relative range of the vehicle was developed by Fetterman[5] in 1985 for subsonic, supersonic, and hypersonic aircraft. A limitation is that the method requires an initial baseline aircraft. As component changes are made, the aircraft size and weight are adjusted accordingly.

A review of the various computer models available for vehicle weight predictions suggested that a new preliminary weight/sizing prediction technique was needed that would cover a broad range of hypersonic vehicle configurations. A weight and sizing model applicable to all types of vehicles did not exist in mid-1986, although several of the models reviewed were adequate for a specific class of vehicles if reliable designs were available to calibrate the model. It became desirable, then, to obtain a model which could 1) predict vehicle size and weight for both single-stage and two-stage-to-orbit vehicles as well as transports, 2) account for different propulsion systems, 3) provide absolute values for vehicle size and weight, and 4) be able to account for changes in technology (i.e., materials and propulsion systems).

HASA is a sizing/weights analysis that determines vehicle length and volume consistent with body, fuel, structural, and payload weights. The vehicle component weights are obtained from statistical equations for the body, wing, tail, thermal protection system, landing gear, thrust structure, engine, fuel tank, hydraulic system, avionics, electrical system, equipment, payload, and propellant. In the full paper, sample size and weight predictions are given for the Space Shuttle Orbiter and other proposed vehicles, including four hypersonic transports (HST), an SSTO vehicle, a two-stage Space Shuttle with booster and Orbiter (TSTO), and a supersonic transport (SST). In addition, sample calculations of the size and weight of each vehicle are presented for various fuel and payload mass fractions. Most important, HASA provides absolute values for the vehicles it sizes.

Vehicle size is obtained by iteratively solving for the vehicle volume, wetted area, length, and equivalent diameter following the approach of Oman.[6] To obtain a good approximation of the total vehicle weight that is consistent with preliminary design, the vehicle is divided into 14 individual components. The weight for each component is obtained from statistical weight equations; each component has a separate weight equation except for payload weight and volume, which are inputs into the analysis. Because of the number of sizing and weight equations involved in this analysis, it is not possible to cover them in a paper of this size. For a full description of the size and weight equations, as well as the methodology, refer to Ref. 7.

A literature search was conducted to obtain a vehicle data base to assess the accuracy of the HASA model. A limited number of hypersonic vehicles were available in the open literature which had a detailed vehicle weight and geometry breakdown. A total of eight hypersonic vehicles and one supersonic vehicle were defined for this study. They include four HSTs, one SSTO, three TSTOs, and the Boeing 2707 SST.

The HASA model was used to predict the size and weight for each of the vehicles described in the full paper; the size and weight predictions for each of these vehicles are compared in Table 1. Generally speaking, the overall model accuracy is within $\pm 4\%$ of the vehicle gross weight and $\pm 8\%$ of the length. The accuracy of the model for vehicle size and gross weight provides reasonable engineering approximations when the model is used to perform sensitivity and growth studies. As a result, it is felt that these predictions are within the accuracy needed for preliminary design purposes. Furthermore, the current model can predict absolute vehicle size and weight without having to be recalibrated for each vehicle (see Ref. 7).

To illustrate the utility of the HASA model, the relationships of vehicle size and weight to payload and to fuel loadings were investigated. Figures 1 and 2 show the results of changing the payload from 50 to 200% of the design values with fuel fraction held constant. Figure 1 shows the vehicle gross weight

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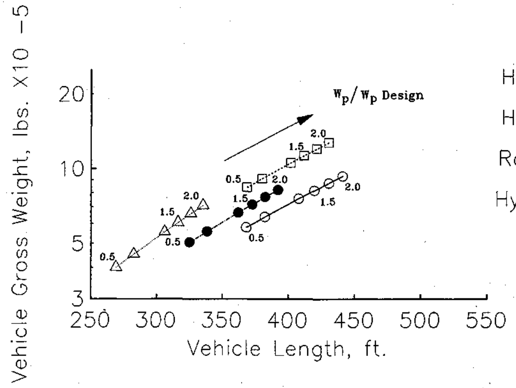

Fig. 1 Effect of payload change on weight vs length.

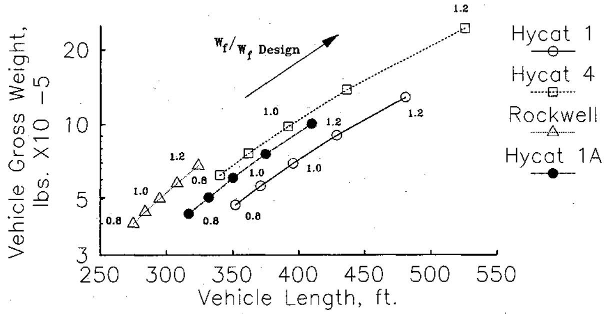

Fig. 3 Effect of fuel loading change on weight vs length.

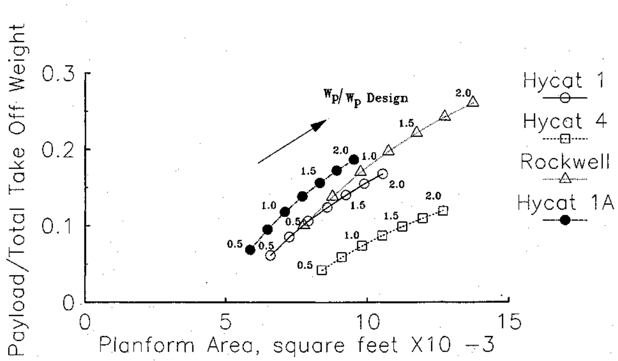

Fig. 2 Effect of payload change on payload fraction vs planform area.

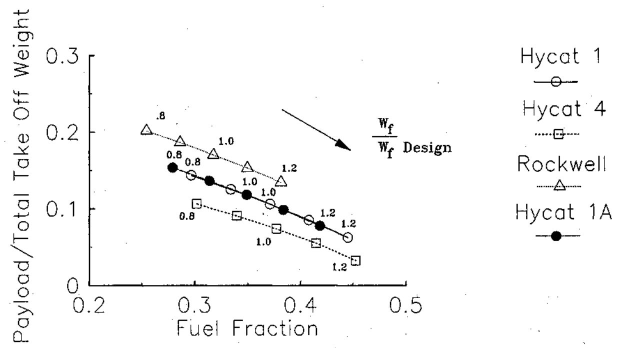

Fig. 4 Effect of fuel loading change on payload fraction vs fuel fraction.

vs vehicle length for four Mach 6 hypersonic transport vehicles. As the payload increases, the vehicle gross weight and size increase. For example, the predicted Rockwell vehicle gross weight increases from 400,000 to 700,000 lb when the payload increases from 50 to 200% of design. (The design payload is 200 passengers.) Figure 2 shows the payload fraction vs planform area for the same vehicles. The payload fraction for the Rockwell vehicle increases from 10 to 26%, and the planform area increases from 7,800 to 14,000 ft^2.

An analysis of the relationship between fuel loading and weight was also conducted using the HASA model because the ability to scale vehicles is central to preliminary design. Figure 3 shows typical results of perturbing the vehicle about its design point by varying the fuel loading from 80 to 120% of the design values. For each of the four vehicles shown, increasing the fuel loading produces a nonlinear increase in vehicle size and weight. This is consistent with the authors' other sensitivity studies[7] showing the effect of fuel loading on vehicle gross weight. Figure 4 illustrates the impact of increasing the fuel loading on payload weight fraction. For example, the payload fraction for the Rockwell vehicle decreases from 0.20 to 0.13 as the fuel fraction increases from 0.25 to 0.38. Increasing the fuel loading of course decreases the payload weight fraction. The sensitivities for each of the aircraft designs is about the same. The differences in absolute level are because of differences in the design payload fraction.

A general vehicle weight and sizing model has been developed for a broad range of vehicles that does not require a detailed vehicle weight breakdown or model recalibration. The HASA model described herein can weigh various classes of hypersonic vehicles, including hypersonic transports, single- and two-stage-to-orbit vehicles, as well as supersonic transports. The weight and sizing methodology of HASA can be used in flight trajectory studies where the flight trajectory, aerodynamics, weight, and propulsion systems vary according to the specified values of vehicle weight, size, and fuel loading for a given mission. The results indicate that HASA is accurate enough, to ±4% of the vehicle gross weight and ±8% of the vehicle length, to be used in preliminary designs. Furthermore, HASA can predict absolute values and trends for hypersonic vehicles without model recalibration. The model also allows for growth studies to be conducted with ease, examples of which are demonstrated herein.

Acknowledgment

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