The second of Eq. (10) can be solved for the lift:

$$L = \frac{\lambda_2 \rho S}{4\lambda_1 K} \tag{11}$$

Taking matrix of second partials of H

$$\begin{vmatrix} \frac{\partial^2 H}{\partial T^2} & \frac{\partial^2 H}{\partial T \partial L} \\ \frac{\partial^2 H}{\partial L \partial T} & \frac{\partial^2 H}{\partial L^2} \end{vmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & \frac{2\sigma K}{QS} \end{bmatrix} \tag{12}$$

Thus the problem is singular of degree zero with respect to L and of higher degree with respect to T. Substituting L from Eq. (11) into H and calling new H, H^*

$$H^* = \sigma T + \lambda_1[T - D(E, h, \lambda_1, \lambda_2)]V/M + \lambda_2[L(\lambda_1, \lambda_2, E) - W]/MV \tag{13}$$

where H^* now is only a function of T. Taking first partial $w \cdot r \cdot t$ T

$$(\partial H^*/\partial T) = \sigma + \lambda_1 V/M \tag{14}$$

Taking time derivative

$$\frac{d}{dt}\frac{\partial H^*}{\partial T} = \mathring{\lambda}_1 V/M + \lambda_1 \mathring{V}/M$$
$$= \frac{1}{V}\left[\frac{\lambda_1 V}{M}\left(\frac{\partial D}{\partial V}\right)_h + \lambda_2 \frac{(L-W)}{MV^2} - \lambda_3 \sin\gamma - \lambda_4 \cos\gamma + \lambda_1 gV \sin\gamma\right] \tag{15}$$

Taking time derivative again

$$\frac{d^2 \partial H^*}{dt^2 \partial T} = \frac{1}{V}\left[-\sigma \frac{\partial}{\partial V}\left[\left(\frac{\partial D}{\partial V}\right)_h\right]_h \frac{(T-D)}{M} + \mathring{\lambda}_1\left[-\sigma \frac{\partial}{\partial L}\left(\frac{\partial D}{\partial V}\right)_h + \lambda_2\right]\frac{\partial L}{\partial \lambda_1} + \mathring{\lambda}_2\left[-\sigma \frac{\partial}{\partial L}\left(\frac{\partial D}{\partial V}\right)_h + \lambda_2\right]\frac{\partial L}{\partial \lambda_2}\right] \tag{16}$$

Note that $\lambda_2 = 0$. This follows from the fact that $\lambda_2 = 4\lambda_1 LK/\rho S$, $\lambda_1 = -\sigma V/M$ and assumption (9). Using Eqs. (9-11) the terms in Eq. (16) are

$$\frac{\partial L}{\partial \lambda_1} = \frac{gV}{\sigma} ; \frac{\partial L}{\partial \lambda_2} = \frac{-\rho SV}{4K\sigma M}$$
$$\frac{\partial D}{\partial L}\left(\frac{\partial D}{\partial V}\right)_h = -\frac{4KW}{QSV}; \lambda_2 = -\frac{4\sigma KWM}{\rho SV} \tag{17}$$
$$\mathring{\lambda}_1 = (T - D)\sigma/V$$

$$\left(\frac{\partial^2 D}{\partial V^2}\right)_h = \frac{2QS}{V^2}C_{do} + \frac{4QS}{V}\left(\frac{\partial C_{do}}{\partial V}\right)_h + Q\left(\frac{\partial^2 C_{do}}{\partial V^2}\right)_h + \frac{6KW}{QSV^2}$$

Thus the second time derivative is:

$$\frac{d^2}{dt^2}\left(\frac{\partial H^*}{\partial T}\right) = -\frac{\sigma}{V}\left[\frac{2QSC_{do}}{V^2} + \frac{4QS\partial C_{do}}{V\,\partial V} + \frac{QS\partial^2 C_{do}}{\partial^2 V} + \frac{4KW^2}{QSV^2}\right]\frac{(T-D)}{M} = 0 \tag{18}$$

Thus, $T = D$ and

$$\frac{\partial}{\partial T}\frac{d^2}{dt^2}\frac{\partial H^*}{\partial T} = -\frac{\sigma}{V}\left[\frac{2QSC_{do}}{V^2} + \frac{4QS}{V}\frac{\partial C_{do}}{\partial V} + \frac{QS\partial^2 C_{do}}{\partial V^2} + \frac{4KW^2}{QSV^2}\right] \leq 0 \tag{19}$$

which satisfies the Generalized Legendre-Clebsch condition, if $C_{do}(M)$ is monotonically increasing $w \cdot r \cdot t$ V at the cruise point, which it is for military aircraft with subsonic cruise points. The cruise velocity and altitude are determined from:

$$\left(\frac{\partial H}{\partial E}\right)_h = -\lambda_1 \frac{V}{M}\frac{\partial}{\partial E}(D)_h + \lambda_4 \frac{\partial V}{\partial E} = 0$$
$$\left(\frac{\partial H}{\partial h}\right)_E = -\lambda_1 \frac{V}{M}\frac{\partial}{\partial h}(D)_E + \lambda_4 \frac{\partial V}{\partial h} = 0 \tag{20}$$
$$H = -\lambda_1 DV/M + \lambda_4 V = 0 = \sigma D + \lambda_4$$

This reduces to:

$$\frac{\partial}{\partial E}\left(\frac{D}{V}\right)_h = 0 ; \frac{\partial}{\partial h}\left(\frac{D}{V}\right)_h = 0 ; \text{ or } \min_{h,V}\left(\frac{D}{V}\right)$$

Comparison with Other Models

The model with lift and thrust as controls thus allows continuous arcs of partial throttles while the energy state equation and the $V - \gamma$ equations do not. The different conclusions are possibly due to the fact that in the energy state and $V - \gamma$ equations $L = W$ is assumed while in the lift-thrust equations lifting arcs ($L \neq W$) are allowed. Thus, in the energy state equation fast changes in altitude can occur without changing the induced drag (drag due to lift) while in the lift-thrust equations large increases in altitude require large lift forces and correspondingly large induced drag forces.

Conclusions

For the minimum fuel-fixed range problem using a dynamical model with lifting trajectories ($L \neq W$), the cruise condition is shown to be a minimizing arc by applying the Maximal Principle including the Generalized Legendre-Clebsch condition for singular arcs. Other dynamical models do not allow a cruise solution but do allow a "chattering" cruise solution.

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Growing Procedural Problems of Washing Mammoth Aircraft

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Introduction

SIZE has always impressed Americans. American industry has augmented the philosophy of the super-size economy into creations of massive earth moving equipment, su-

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pertankers for transporting oil and "new-generation, wide-bodied jet transports." No one can claim that growth has impeded the progress of mankind, but bigness can be accused of producing growing pains and accused of creating profound obstacles to technical and economical realizations. Such has been the case with the introduction of the supersize air transports into military and commercial service.

As of June 1968, when the Lockheed C-5A made its first flight, a new era of logistical maintenance came into being. Procedures for relatively simple processes such as washing of exterior surfaces of airplanes became complex. Many of the procedures formerly used became obsolete and ineffective. Size of the air vehicle, the materials employed in the construction of the vehicle, facilities, support equipment, and the utilization requirements initiated a new look at aircraft washing procedures.

Why is washing so important to an airplane? Unlike a bridge, a building, or even a ground vehicle, the airplane must be made light and strong with minimal fat added to the structural requirements; otherwise, it is sacrificing distance, speed, and payload. These critical structures must be inspected often and thoroughly for any signs of weakness or impending failure. Unless a surface is clean, adequate visual inspection is impossible. Secondly, cleanliness mitigates corrosion. Once pitting corrosion occurs, stress risers and possible cracking are likely. Lastly, washing is done for aesthetics. If an airplane does not have a pleasing appearance, it gives the rationale to a potential passenger that the airplane is poorly maintained and might not be safe. Frequent cleaning has economical advantages too, inasmuch as many soils which deposit on airplane surfaces have deleterious effect on the protective paint finish. Having to repaint an airplane the size of the C-5A can cost an operator well over $50,000 plus the loss in revenue while the airplane is out of service getting repainted.

Problems of Washing

Outdoor Wash Racks

It has been the practice of many air carriers to wash their airplanes at a site where the airplane has an overnight layover in addition to washing the airplanes at the home station. In some cases this task is assigned to a contractor who has an outdoor wash rack facility. For standard-size jets, the wash duration is about two hours and sometimes up to four hours, depending upon the size of the staff, the equipment, and the airplane. When the wide-bodied jet arrived, wash rack facilities were meager and the cleaning schedule more than doubled. Without indoor washing sites, which cost upward from $3 million, the washing crews are obligated to clean outdoors, operating as high as seventy feet in "cherry-pickers" attempting to gain access to heavy accumulations of soils. Not only is mobility difficult in these aerial baskets, but the work is cumbersome, tedious, and sometimes dangerous. Should a breeze be blowing, chemicals being applied by spray will travel several hundred yards and may contact previously cleaned surfaces or other aircraft. Unremoved cleaning compounds on airplane surfaces are not desirable. Some cleaning compounds will attack the ground, laminated glass used for pilot windows. As an example of how expensive these windows are, an individual window on the L-1011 costs up to $16,000. Because cleaning chemicals are selective in their employment, indiscreet application can be hazardous. In one known case, a cleaning solution with an extremely high solvency was directed into actuation mechanisms and caused the mechanisms to corrode and to "freeze-up." The repair was time consuming and expensive.

Again because of night cleaning schedules out-of-doors, lighting is too often inadequate for the wash crew to see whether surfaces have been rinsed sufficiently of chemical cleaning compounds. This situation is evidenced mostly when the airplane is washed on the ramp by a mobile cleaning unit instead of being moved to the established wash rack. Unfortunately the limitation on the fixed set-up facility for washing necessitates the use of portable cleaning equipment if the fleet is to be afforded any semblance of cleanliness. Night cleaning will continue because the airplanes are usually flying during the day, the peak operational and revenue hours.

Cleaning Materials and Equipment

A major problem in the cleaning of new-generation aircraft is in the cleaning materials themselves. For some reason available compounds which have passed the biodegradability requirements and the nonembrittling tests do not clean satisfactorily at prescribed dilutions. When used at reduced dilution ratios, they often become aggressive to paint, acrylics, and rubber seals. Nonspecification materials which have provided some cleaning advantages are those which include a mild abrasive to assist the chemical in soil removal and yet not attack the paint. It is of significant note that one wash contractor contends, "In my almost forty years of experience in aircraft washing, no appreciable improvement has been made in the cleaning capability of aircraft washing compounds, be they liquid or powder. Many of the modern so-called miracle cleaners on the market today perform no better, if as good, as the original formula for alkaline waterbase cleaner that was developed in 1937. When chromate inhibitors were restricted because of pollution hazards, the modified cleaning compounds that complied with the restrictions were handicapped."

No cleaning compound is currently available which is considered safe on structure and which can be used effectively without the assistance of a piece of agitation equipment such as a brush, abrasive pads or mops. In certain fields of industrial cleaning, high-pressure rinsing is favorable as a mechanical complement to the chemicals; however, high-pressure water is taboo on the modern air transport because of the thin metal, honeycomb panels, and composite structure which make up exterior skins in many areas of the airframe. Automated scrub brushes are out too because of the many delicate appendages; such as antennas, angle of attack vanes, pitots, sensors, vortex generators, static dischargers, etc., on the exterior surfaces.

All-in-all, cleaning continues to be a hand operation in aircraft washing. On the super jets the task is monumental. Imagine, if you can, the responsibility of washing clean the grimy floors of eighteen houses with a living area of 1800 square feet each . . . with a ten-inch wide brush! These dimensions equate to the outside area of a C-5 with the exception of the wheel wells and nacelles. For these surfaces, add another house.

Parochial Attempts Toward Alleviation

What approaches are being taken to alleviate the cleaning problems being confronted on the jumbo jets? One major air line has a progressive cleaning cycle which is a partial answer. Washing for another operator is a function performed while conducting other maintenance, accomplished by limiting the task to dry washing, a process of wipe on, wipe off, using cloths, mops and minimal water. It is a derivative of a process developed by the Navy for carrier-based aircraft. This dry-washing process is employed in combination with the wet-washing process at a large airline base in the South. Gears, flaps, flapwells, wheel wells, and sections of the fuselage belly are wet washed out of doors before the aircraft is hangared. Once in the hangar and the mobile stands are positioned, the aircraft is dry washed or polished. Total lapse time is approximately six hours. This accomplishment is credited to the specialized equipment for gaining easy and rapid access to all areas of the exterior surface.

Several operators are evaluating a barrier coating over the areas of high soil exposure. This coating traps the soils on the surface without permitting them to embed in the paint. At the washing cycle, the barrier coating is released from the airplane surface by a chemical solution which is spray applied. With the release of the barrier coating, the soils are removed, leaving the regular painted surface fairly easy to clean by the conventional cleaning materials and methods. The barrier coating is then reapplied.

Another two operators are reported to be flight testing a clear polyurethane topcoating which is applied over glossy, pigmented paint. Purpose of the test is to determine if the topcoat will prolong gloss retention of the pigmented surface and if it will enhance cleaning time and effort.

The Military Aircraft Command is planning indoor facilities for complete washing of its C-5A fleet. Outdoor facilities will continue to be used, but hopefully limited to the washing of lower surfaces which are accessible from portable stands and standard length brushes and mops.

Fraternal Approach Toward Alleviation

Procedural problems are surmountable for effective, efficient cleaning of jumbo jets. In time, special equipment will be developed, as will satisfactory cleaning compounds; nevertheless, much of the developments will have to be tailored to specific aircraft configurations, cleaning locations, schedule requirements, and operational spectrum. For resolutions to the procedural problems for washing mammoth aircraft, contributions must be applied willingly from the experiences of aircraft manufacturers, operators, washing contractors, and the specialized chemical compounders. Testing and evaluating of special products and equipment are of interest to all operators; consequently, a mutual organization should have this information for assessing materials and procedures and for recommending improvements. Such an organization is the Air Transport Association, which has an active committee for aircraft cleaning. This committee has both civil and military participation. By the active participation of its members, uniformity of procedures will be promoted so that economy can be shared by all contributors. By collective action of concerned and technically capable people, the procedural problem of washing the jumbo jet will be resolved.

Performance of an Inlet for an Integrated Scramjet Concept

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Introduction

DURING the past decade, the USAF and NASA have funded the development of several small-scale research scramjet engines. These projects have shown that the scramjet is a feasible engine concept; practical levels of thrust have been demonstrated and a substantial technology base has been established.[1] NASA is now conducting a hypersonic (Research and Testing) program[2,3] which is devoted in part to the next logical step in scramjet evolution, the development of engine concepts which will integrate with the airframe. Integration includes the use of the vehicle forebody to precompress the engine airflow before it enters the inlet and the use of the vehicle afterbody for additional expansion of the nozzle exhaust gas. Other principal design criteria are low engine cooling requirements to make part of the heat sink of the hydrogen fuel available for active cooling of the airframe, fixed geometry to reduce weight and system complexity, and minimum external drag. Detailed design studies utilizing advanced basic technology have resulted in the definition of a unique engine concept (Fig. 1 and Ref. 4), which conservative predictions indicate will meet all the above design objectives. Innovative design features of the inlet and combustor coupled with the favorable effects of integration permit high levels of performance over the Mach range from 4 to 10 with relatively low cooling requirements. For instance, at Mach 6 a specific impulse of about 3000 sec is predicted with only 40% of the fuel heat sink required for engine cooling. Experimental investigations are now in progress to substantiate and further develop the design concept; the present Note reports briefly on the measured performance of the inlet at Mach 6.

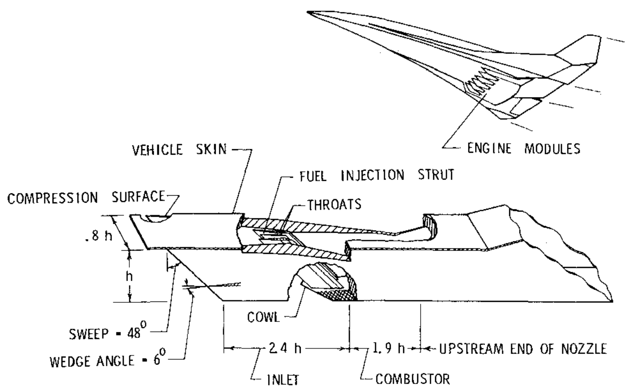

Fig. 1 Inner module of Langley Scramjet Module Concept.[4]

Inlet Design Concept

The cross section of the Langley Scramjet module (Fig. 1) varies from a nearly square capture area to a rectangular inlet throat to a square combustor exit. This type of configuration favors low cooling requirements by reducing the internal wetted area. In addition, a cluster of several such modules mounted on the underside of the vehicle is capable of capturing all the airflow lying between the vehicle surface and the vehicle bow shock at the maximum Mach number, thus producing a maximum thrust. Wall fuel injectors would produce very long mixing lengths for this configuration; therefore, three fuel injection struts have been provided to allow six planes of fuel injection in the stream. This feature not only shortens the combustor but also the inlet since the struts provide a significant part of the inlet flow compression. The leading edges of the sidewalls and all downstream stations are swept at 48° to provide spillage at low Mach numbers for starting with fixed geometry. Spillage occurs through the open window upstream of the cowl leading edge, which is bathed by shocks from the sidewall compression surfaces. The combination of the sweep angle, the sidewall design, and the cowl leading edge location produces near-maximum mass capture ratios as a function of Mach number, and the spilled flow provides a lift increment for the vehicle. The

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