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DEVELOPMENT AND FLIGHT TEST OF A REAL-TIME ENERGY MANAGEMENT DISPLAY

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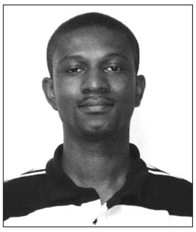

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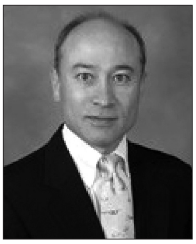

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Abstract. A real-time energy management display is developed and evaluated, and the feasibility and utility of the display in providing real-time guidance and information on an aircraft's energy state is investigated. Flight simulations were conducted with the UTSI's Aviation Systems research flight simulator to validate the display and to evaluate its utility for flying along constant specific excess power (P_S) contours and for directly obtaining P_S contours from level acceleration flight test. This study considers the energy state of the aircraft from the point of view of the relation that exists between specific excess power, P_S, and the forces in flight. The approach yields as one result a cubic function for the P_S of the aircraft. We then directly solve for velocity, V, as the control parameter for a given P_S as a function of altitude, H. Using LabView software, this technique is used to build a real-time energy management display which provides guidance and real-time information on the aircraft's energy state. Flight simulation results proved the display to be successful in obtaining direct P_S contours from level acceleration flight tests and in providing guidance for flights along constant P_S contours at low airspeeds, although it was difficult to keep the P_S constant.

Keywords: specific excess power, level acceleration, altitude, velocity.

1. Introduction

Several approaches to obtain optimal climbs and investigations on the practical benefits of energy management have been reported in recent and past studies. This paper presents a study on the development and evaluation of a real-time energy management display. A real-time energy management display provides real-time guidance and information on the energy state of an aircraft. This information is useful in providing guidance to pilots when changing from one combination of speed and altitude to another and when determining the flight technique to adopt during such maneuvers (Miele 1955; Breakwell 1977, 1978). The utility of the display is investigated for flying along constant specific excess power contours, flying specific excess power contour equal to zero, and directly obtaining specific excess power contours from level acceleration flight test. The display is also investigated for flying optimal paths.

A method that uses the energy state of the aircraft and focuses on the relation that exists between specific excess power and the forces in flight is presented. Specific excess power is expressed as a cubic function. The velocity, V, in the resulting equation can be solved for directly as the control parameter. Since velocity and altitude can be expressed in terms of kinetic and potential energies respectively (Lan, Roskam 1980), a new technique of describing a combination of velocity and altitude is investigated. The technique is programmed with the aid of LabVIEW software (Johnson *et al.* 2006) to build a real-time energy management display that provides useful information about the energy state of the aircraft as well as in-flight guidance. The approach has been successful in using velocity, V, as the control parameter to give guidance for flying along constant specific excess power contours. The display has been flight tested and evaluated in the UTSI's Aviation Systems flight simulator with an X-30 hypersonic aerospace plane and a Piper Saratoga general aviation aircraft for supersonic and subsonic flights respectively.

2. Background

The practical benefits of energy management have been investigated and demonstrated by (Rutowski 1954; Lush 1948; Miele, Capillari 1959; Bryson *et al.* 1969; Sederstrom *et al.* 1973), and many others. E. Rutowski and K. J. Lush were the first to develop the methods of energy techniques. The technique was then used by other researchers for different applications to the problem of aircraft climb as well as in the development of optimal climb paths. Examples of energy technique applications can be found in the research papers by Miele, Berton, Breakwell, George, and schmidt and Herman (Miele 1955, 1959; Berton 2003; Breakwell 1977, 1978; George 2006; Schmidt, Herman 1998).

Rutowski's study considered the aircraft's performance problem from the point of view of the balance that exists between the potential energy and kinetic energy change of the aircraft, the energy dissipated against drag, and the energy derived from the fuel. The form of the equation he used focused on the use of the aircraft's total energy rather than altitude as a significant independent variable in the climb performance of high-speed aircraft. He then used the method of calculus of variation to verify his solution (Rutowski 1954). K. J. Lush also examined the quickest way to change from one combination of height and speed to another. Using the energy concept, he deduced a geometrical presentation which clarified the choice of technique. His study contributed to the use of approximate solutions by using graphical-analytical methods which were based on the concept of energy heights. The study threw light on total energy, the sum of kinetic and potential energies (Lush 1948). A. Miele's and Jr. J. O. Capillari's research analysed the climbing program of a rocket-powered aircraft with regards to minimum time trajectories. The indirect method of calculus of variation was used to show that, if the centripetal acceleration was neglected in the equation of motion, the totality of extremal arcs are composed of a number of constant path inclination sub-arcs plus one variable path inclination sub-arc (Miele, Capillari 1959). Jr. A. E. Bryson *et al*'s study focused on energy-state approximation in performance optimisation of supersonic aircraft. The study applied the equation of motion to a model for performance prediction where a point mass model for motion in a vertical plane was considered (Bryson *et al.* 1969).

D. C. Sederstrom was the first to apply the energy techniques in the development of an energy display. D. C. Sederstrom (Sederstrom *et al.* 1973) conducted research sponsored by Honeywell on energy management of aircraft systems. The research resulted in the fabrication and flight test of an analog energy/energy rate meter. The program was focused on determining the feasibility and utility of a relatively simple display concept. The display is an instrument panel meter that displays energy rate and energy state of the aircraft and aids energy maneuverability, performance calibration, throttle settings, as well as efficient establishment of steady-state flight conditions. This analog meter does not present the airspeed to fly even though it computes and displays energy and energy rate using on-board measured values and indicates it to the pilot with two different dials. This could give the pilot an extra workload in trying to interpret and collate the dial on a mission. The present study uses a new technique and is programmed with LabVIEW software to display the airspeed to fly and the real-time specific excess power in a digital format which can reduce the pilot's workload on a mission.

3. Methodology

3.1. Direct velocity solution for constant specific excess power paths

The energy state of the aircraft is considered from the point of view of the relation that exists between specific excess power and forces in flight. Specific excess power, P_S, is directly proportional to excess thrust (T-D) and velocity, and inversely proportional to weight. The drag equation is then substituted into the relation and the equation simplified. The approach yields as one result a cubic function for the specific excess power, P_S, of the aircraft. We then directly solve for velocity, V, for the given specific excess power, P_S, as a function of altitude, H, with the assumption that weight, wing reference area, drag coefficient, density, and aircraft thrust are known or calculated for altitude, H.

The solution to the cubic equation yields three roots, and an algorithm is defined to select the highest positive root as the target airspeed. The algorithm ignores negative and imaginary values. The velocity selected is then plotted on an altitude/velocity plot to define a trajectory for a constant specific excess power contour. The technique leads to defining the path of minimum time to change from one combination of speed and altitude to another. Specific excess power, P_S, is defined as the time derivative of specific energy and also as a measure of the engine-airframe's capability to change energy levels: climb, descent, acceleration or deceleration for a given airspeed, altitude, configuration, and power setting. In flight, airspeed (or Mach number) tradeoffs occur quickly enough to be considered instantaneous, and so climbs or dives along the energy level curves take little or no time with no losses (Kimberlin 2003; Lan, Roskam 1980). Use is made of this phenomenon in the approach by flying on a constant specific excess power contour. The technique assumes that weight, drag and thrust are constant for a small transition as the algorithm calculates each step forward. The equation is derived from the basic energy principle which assumes that conservation of mechanical forces permits the exchange of potential energy and kinetic energy in zero time with no losses. The aircraft is considered to be a point mass with the mass located at the center of gravity and conservative forces assumed to be non-dissipative. The approach is possible since energy levels can be defined by two variables, velocity and altitude.

Total energy is the sum of potential energy and kinetic energy. Specific energy, also called energy height, is obtained by dividing through the total energy equation by the aircraft's weight, W or mg. Specific energy is a function of altitude, H, and velocity, V. This is expressed as

$$E_S = f(H, V, g), \tag{1}$$

where E_S is the specific energy (energy height), ft, H, altitude, ft, V, velocity, ft/s, and g, acceleration due to gravity, ft/sec^2, (sea level, 32.174 ft/sec^2). Specific excess power, P_S can be related to forces where specific excess power is a function of thrust and drag as in equation (2).

$$P_S = f(H, V, T, D), \tag{2}$$

where D is the drag, lbf, T, ambient temperature, ^oR or thrust, lbf. Equations (1) and (2) can be further expressed as

$$P_S = \left(\frac{T-D}{W}\right)V = \frac{dH}{dt} + \frac{V}{g}\frac{dV}{dt}, \tag{3}$$

where W is the weight, lb, and P_S , specific excess power, ft/s. From equation (3), (T-D) V= (force) (velocity) = power, and power divided by weight = specific power. In other words, specific excess power, P_S, is directly proportional to excess thrust (T-D) and velocity, V, and inversely proportional to weight, W. Drag is a function of density, velocity, reference area, and drag coefficient and is given by the relation

$$D = \frac{1}{2}\rho V^2 S C_D, \tag{4}$$

where ρ, density, slug/ft^3, S, wing reference area, ft^2, and C_D , drag coefficient. Hence, drag can be substituted in equation (3) and the equation expressed as

$$P_S = \left(\frac{T - (\frac{1}{2}\rho V^2 S C_D}{W}\right)V. \tag{5}$$

Equation (5) may be simplified to equation (6) as

$$\left(\frac{\rho S C_D}{2W}\right)V^3 - \left(\frac{T}{W}\right)V + P_S = 0. \tag{6}$$

The form of equation (6) is a cubic function which can be solved mathematically for the values of V, which are the three roots of the equation. The known variables in equation (6) are density, reference area, lift coefficient, weight, and thrust; hence we can directly solve for velocity, V, for a given constant specific excess power, P_S, as a function of altitude, H. Equation (6) is then solved as a cubic function as is in (Gagnon 2009). The solution to the cubic equations yields three roots. Generally, there can be three possibilities in the solution (Gagnon 2009). The solution can yield three real roots, only one real root and two imaginary roots, or finally three real and equal roots depending on the values of each variable. In the model developed in this study, we are only interested in the first case which yields three real roots. The result for the three real roots is one negative root and two positive roots. The two positive roots consist of one small root (velocity) and one large root (velocity). The solution algorithm presented is defined to select the largest positive root as the desired airspeed. Imaginary values and negative values are neglected since solutions containing these numbers were found not to be reasonable airspeed values.

3.1.1. Analytical calculation

An analytical calculation has been performed to calculate for velocity by substituting known and calculated values for the parameters in the cubic function in equation (6). Mach number, drag coefficient, and thrust values were generated by interpolating in a grid plot of drag coefficient and thrust coefficient versus Mach number (Sutton 1992; Raymer 2006; Kimberlin 2003). Thrust coefficient is interpolated from a plot of thrust coefficient versus Mach number and thrust is calculated from the relation

$$T = C_T q S, \tag{7}$$

where

$$q = \frac{1}{2} M^2 P \lambda, \tag{8}$$

λ is the ratio of specific heat and P is pressure which is calculated from the relation

$$p = p_0 \left(\frac{T}{T_0} \right)^{-(g/aR)}. \tag{9}$$

Density is calculated from the relations

$$\rho = \rho_0 (1 - 6.875 \times 10^{-6} H)^{4.2561} \tag{10}$$

and

$$\rho = \rho_0 \left(\frac{T}{T_0} \right)^{-[(g/aR)+1]}. \tag{11}$$

Equations (10) and (11) represent the density for the troposphere. The weight of the aircraft is calculated from the difference between the initial weight, W_i, and the final weight, W_f, at any time as in equation (12). The solution for the model is simplified in the flow diagram shown in Fig. 8.

$$W = W_i - W_f. \tag{12}$$

3.1.2. Assumption of constant thrust

The assumption that weight, drag and thrust are constant is made in the model defined for a small change in airspeed and altitude. This assumption is possible because the time to travel from one thrust to the other with change in altitude, H, is assumed to be very small. In the display, the airspeed computed is plotted from point to point and increases as the altitude increases. The flight profile on the altitude versus Mach or velocity plot is created by setting the initial conditions and using a computational solver to move forward in time. The time rate of change is the length of the time step. This time value is multiplied by the velocity computed to give the next step ahead, and the subsequent steps forward are computed in the same process to reach the final destination altitude.

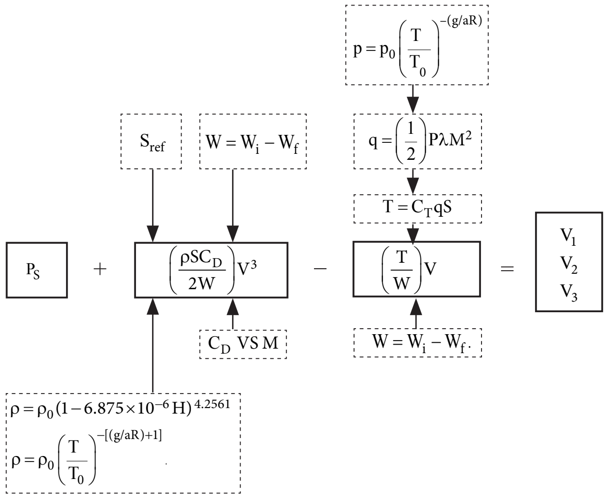

Fig. 1. Constant P_S direct solution flow chart

Fig. 1 shows a diagram of the constant P_S direct solution flow chart.

3.2. Real-time energy management display

The real-time energy management display is programmed with the aid of LabVIEW version 8.5 software (Johnson *et al.* 2006) and installed in the UTSI Aviation Systems engineering flight simulator. The display format is shown in Fig. 2 and Fig. 3. The display has different front views and displays flight parameters depending on which parameters are selected. Fig. 2 shows view 1, which displays density, thrust, weight, drag coefficient, drag, density ratio, the three roots (velocities) computed, desired specific excess power, airspeed, real-time P_S, target airspeed in ft/s and ktas, the plot for altitude versus airspeed, and a stop button. The program algorithm selects the third root on the display as the target airspeed. Fig. 3 shows view 2, which displays Mach number, elapse time, altitude/altimeter, and attitude direction indicator. During a flight test, only the target airspeed and the real-time P_S or the parameters needed may be selected to be displayed. This helps to reduce information clutter and ease pilot workload. The display can also be resized to fit the screen of the computer or flight data recorder being used. The display outputs all the parameters shown on the front panel into a text file that can be used for data analysis. The display is initiated by clicking the play button and stopped by clicking the stop button. The real-time energy management display can be installed on a hand held data acquisition system, any computer in the aircraft, or in any flight simulator for flight test.

4. Results and analysis

4.1. Evaluation flight test

Specific excess power values computed from the conventional method in the flight simulator were inputted into the display under the same conditions of thrust, drag,

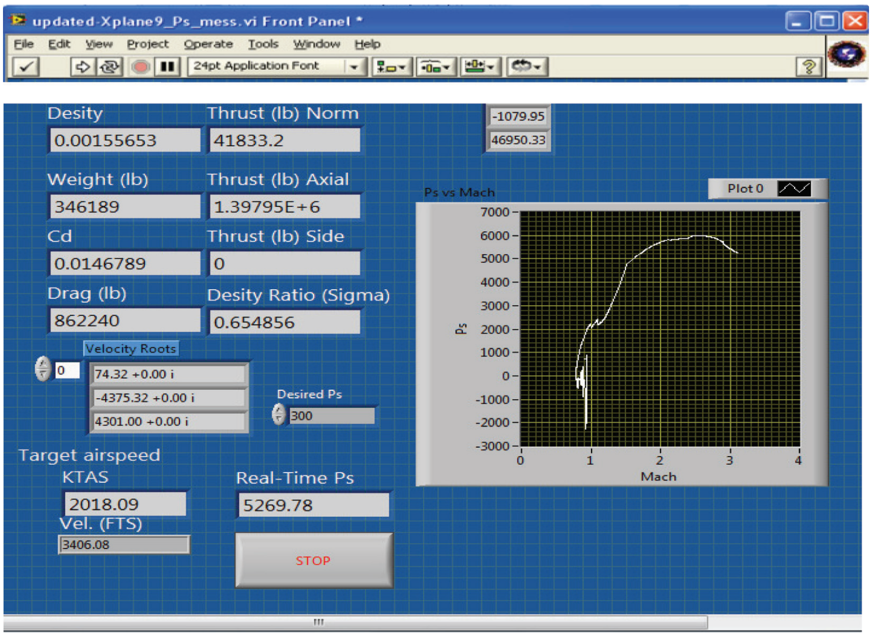

Fig. 2. Real-time energy management display (View 1)

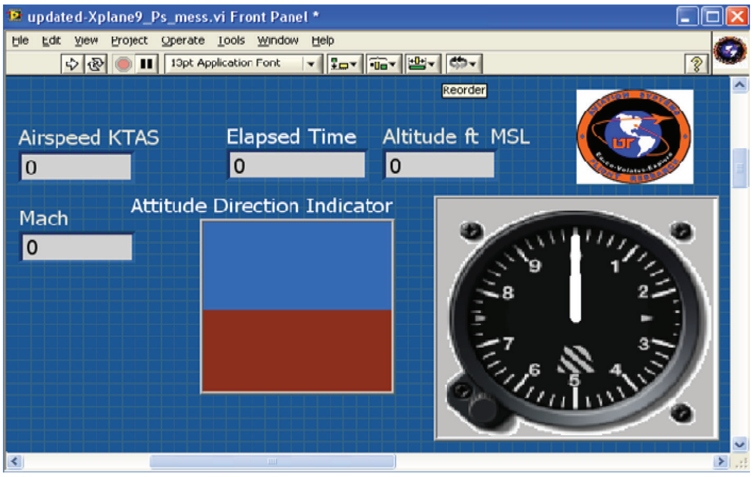

Fig. 3. Real-time energy management display (View 2)

weight and density to verify the accuracy of the airspeed computed by the technique. Aircraft performance analysis in the form of excess power contours were generated with data from a "Piper Saratoga" aircraft and an X-30 aircraft in the University of Tennessee Space Institute's engineering flight simulator using the conventional/classical method and compared for the display's validity and accuracy. The simulator flight test was performed by conducting level acceleration flight tests at different altitudes and the data recorded used to compute the specific excess power for both aircrafts. The simulator test revealed that altitude decreases with P_S; hence the P_S contours on the altitude versus true airspeed and Mach number plots were turned upside down for both aircrafts. This problem was noted for further investigations. The Piper Saratoga's P_S contours generated from the flight simulator were standardised and compared with data taken from an actual flight test with the UTSI Piper Saratoga aircraft at altitudes 4000 ft and 5000 ft, which showed a slight variation. The variation in maximum level flight speed for both flights was 100 ft/s. The variations of the data from the flight simulator when compared with the actual flight test were considered acceptable for the model aircraft used. The data from the flight simulator proved valid for the evaluation since it compared near accurate to the data from the actual flight test.

The display developed was installed in the UTSI's engineering flight simulator, and various flight tests were conducted to evaluate its application. Data output from the flight simulator was linked to the display to provide real-time data (density, thrust, weight, and drag) for the computation.

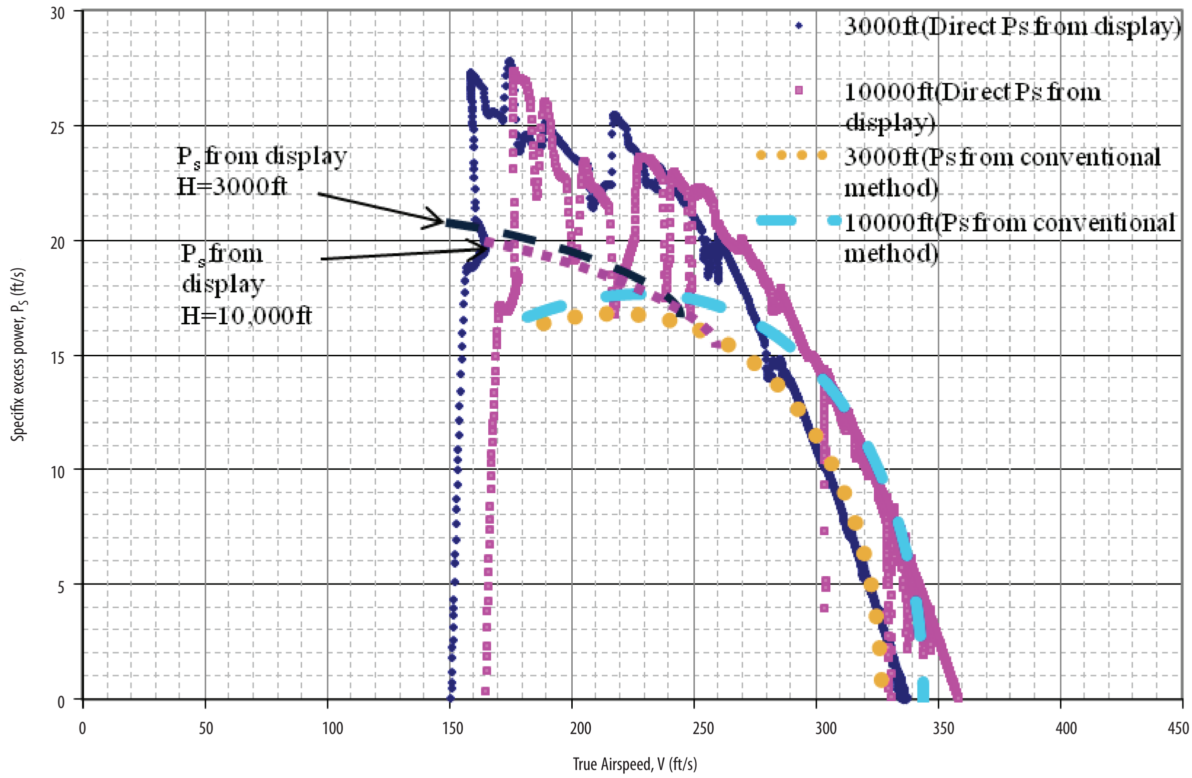

Fig. 4. Specific excess power, P_S (ft/s) versus true airspeed, V (ft/s) for Piper Saratoga (conventional method and direct P_S from display) (engine: Lycoming 300 hp, config.; clean config., GW: 3600lbs. method: level acceleration, maximum power setting, flight conditions: Hpo~2000 ft &10,000 ft, Vo~150-355ft/s

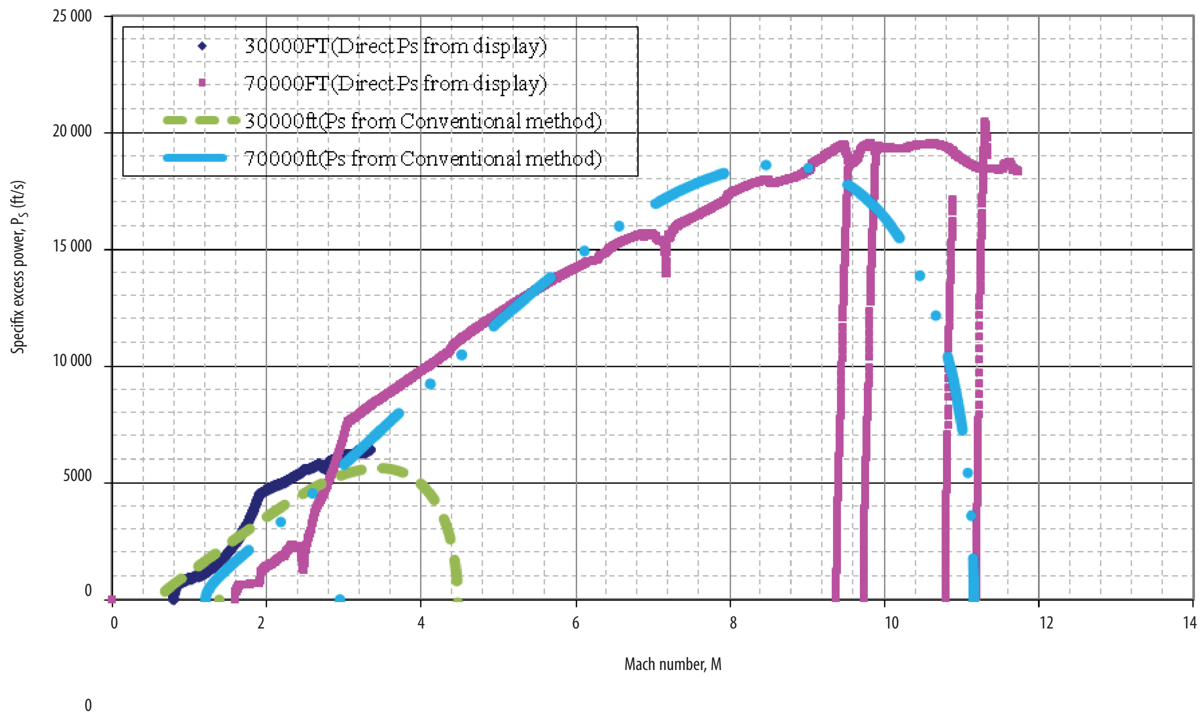

Fig. 5. Specific excess power, P_S (ft/s) versus Mach number, M for X-30 aircraft (conventional method and direct P_S from display). (Engine: rocket, config.; clean config. Maximum power setting, W: 550,000 lbs. Method: level acceleration, flight conditions: Hpo ~10,000 ft -80,000 ft, Mach~0.7–16

4.2. Direct specific excess power contours from level acceleration flight test

Aircraft performance analyses were performed by conducting level acceleration flight tests at different altitudes for both the "Piper Saratoga" and the X-30. The direct specific excess power values computed by the display were then plotted versus their respective airspeeds and Mach numbers for the piper Saratoga and the X-30 respectively. Both plots are representative of figures of the plots generated by the conventional method at the same altitudes. Fig. 4 and Fig. 5 depict the comparison plots for the "Piper Saratoga" (3000 ft and 10,000 ft) and the X-30 (30,000 ft and 70,000 ft) respectively. The cause of the irregularities and scattered points below the curves are due to elevator inputs to maintain level flight. This caused a resultant disturbance of the flight path and hence the real-time P_S computed. A smooth curve as shown by the dotted lines in Figs 4 and 5 can be drawn through the data to represent the maximums of the curves. The test revealed that when the airplane is pitched down, thrust starts reducing; hence the P_S computed starts reducing through zero to negative values. The display returns to normal P_S values once the aircraft is leveled. The use of the display to generate direct P_S has succeeded.

4.3. Flying constant specific excess power contours and optimal flights

Flight tests were conducted in the flight simulator with both the "Piper Saratoga" and the X-30 to investigate the feasibility and the utility of the display for flying along constant specific excess lines. The test revealed that, as the airspeed increases, it becomes difficult to hold the P_S constant, and also once the aircraft deviates from the path, it is difficult to get back on the constant track. However, with constant practice and more experience in flying aircraft, flight on a constant P_S can be achieved. The display has proved more effective for flying constant P_S in the X-30 than in the "Piper Saratoga" since the "Piper Saratoga" does not have much excess thrust.

A simulated flight test was also conducted to investigate the feasibility of using the display to generate data for optimal trajectories for the X-30 with the aim of traversing from one specific excess power contour to the other to gain altitude and with no energy losses. Fig. 6 depicts the plot of specific excess power versus Mach number for this technique from altitudes 5000 ft to 70,000 ft. The use of the display in flying an optimal flight

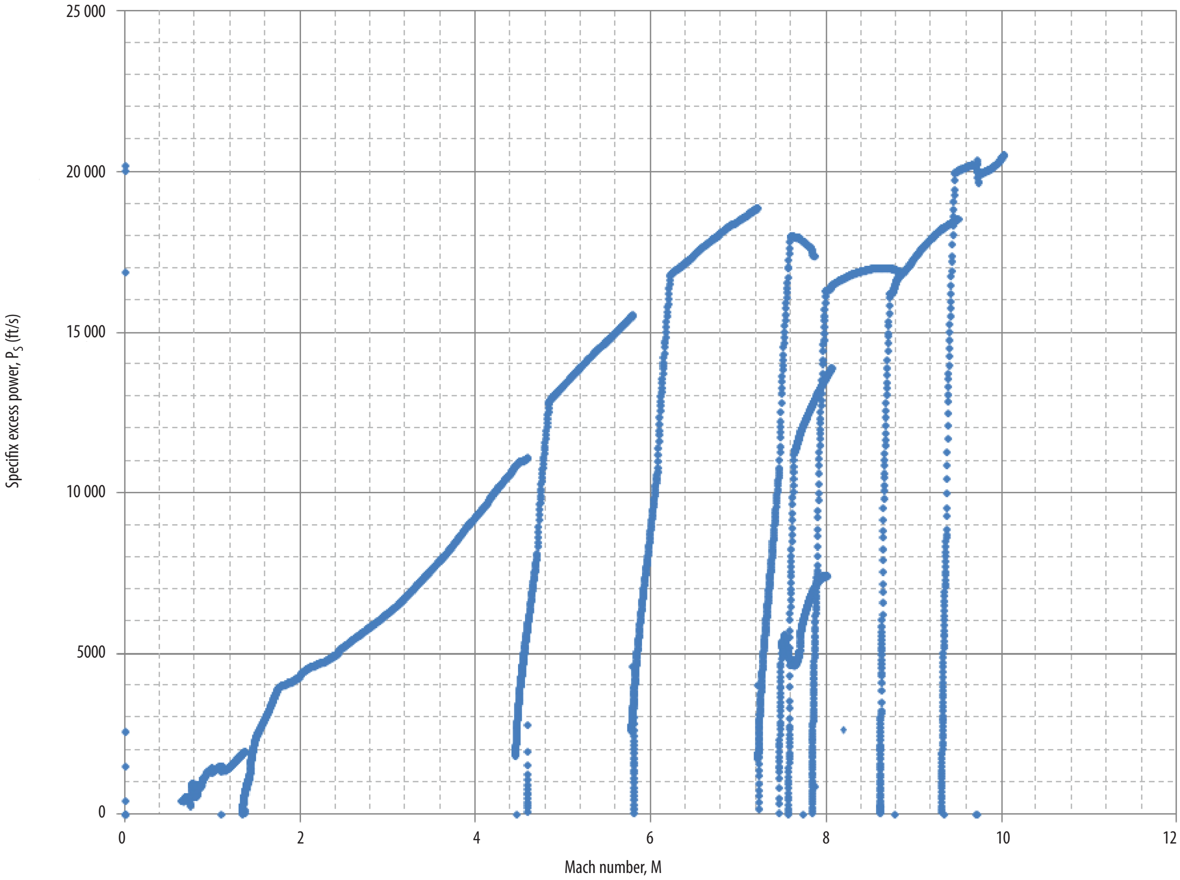

Fig. 6. Specific excess power, Ps (ft/s) versus Mach number, M, for X-30 aircraft. (optimal flight path) (rocket engine, config: clean configuration (max power), weight: 550,000 lbs, flight, conditions: hpo ~ 5000–70,000 ft, Mach~ 0.7–10)

path proved difficult to fly since the pilot had to combine monitoring the target airspeed and specific excess power and also input a next P_S to transition to a higher altitude.

5. Conclusions

A real-time energy management display has been implemented and flight tested in the UTSI Aviation Systems flight simulator. A six-degree-of-freedom model of a high performance plane (X-30) and a low performance general aviation aircraft ("Piper Saratoga") were used in the simulation test. The utility of the real-time energy management display was evaluated for generating direct specific excess power contours from level performance flight test and for achieving flights on constant P_S contours. The display developed has proved to be useful in providing real-time guidance and in providing real-time information on the aircraft's energy state.

The method used in the display's computation relies on the input of the correct initial conditions and parameters specific to the aircraft being used. Flight test results have verified the accuracy of the airspeeds computed by the technique in the present study when compared to that recorded in the flight simulator.

The flight simulation results proved the display to be successful in obtaining direct specific excess power contours from level acceleration flight tests and in providing guidance for flights along constant specific excess power contours at low airspeeds. However flights along zero specific excess power contours and along constant P_S contours at very high speeds were not successful. Flying constant P_S contours with the "Piper Saratoga", which flies at subsonic speed, was not successful either. From the results of the flight test conducted, the use of the display was not successful in flying optimal paths with its current structure. The unsuccessfulness of the display in achieving these purposes was due to the fact that the display's guidance information is provided in a digital format which is very sensitive, and also tracking a number for guidance is nearly impossible. Tracking a computed digital number which is a function of the airplane's attitude and real-time flight conditions is a difficult task and was impossible during the simulation test. A tracking indicator could be a solution to this problem and has been recommended for future studies based on this research.

In using the display, guidance is ignored when negative and imaginary airspeed values are displayed. This normally occurs when the aircraft is suddenly pitched down, which causes a sudden drop in the airplane's thrust and hence the thrust input to the display. This results in negative and imaginary roots from the computation. However, once the airplane is pitched up, the thrust increases again and positive and non-imaginary roots are displayed.

The display offers a few benefits in flight testing. It eliminates the tedious and time consuming data reduction used in generating specific excess power contours after a level acceleration flight test. Direct P_S can be readily obtained at any altitude after a level acceleration flight. However, since thrust and drag models are not available in actual flight tests, the display would have to be modified to be applicable on an actual flight test. Thrust and drag models would have to be developed to get thrust and drag inputs to the display. The display is a useful research tool and would be useful in flight training and a programme of instruction in energy management.

Although application to flying optimal paths was not fully investigated under different conditions, the display could be modified and its use extended in this application to help aircraft to achieve missions to destination altitudes in a minimum time and with a minimum of energy. The real-time energy management display could be integrated into an airplane's flight planning system and onboard energy and performance management systems for real-time monitoring.

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References

Berton, J. J. 2003. Optimum climb to cruise noise trajectories for the high speed civil transport, *NASA TM-2003-212704*. Cleveland Ohio: Glenn Research Center.

Breakwell, J. V. 1977. Optimal flight-path-angle transitions in minimum-time airplane climbs, *AIAA Journal of Aircraft* 14(8): 782–786. doi:10.2514/3.58853

Breakwell, J. V. 1978. More about flight-path-angle transitions in optimal airplane climbs, *AIAA Journal of Guidance and Control* 1(3): 205–208. doi:10.2514/3.55764

Bryson, Jr. A. E.; Munkund, N. D.; Hoffman, C. W., *et al.* 1969. Energy-state approximation in performance optimization of supersonic aircraft, *Journal of Aircraft* 6: 481–488. doi:10.2514/3.44093

George, B. E. 2006. Dive planning and energy management techniques for negative P_S test points, in *37th Annual International SFTE Symposium*, September.

Gagnon, R. 2009. *Solutions to cubic equations*. 1728 Software Systems [online], [cited 19 July 2011] Available from Internet: <http://www.1728.com/cubic2.htm>.

Johnson, G.; Johnson, G. W.; Jennings, R. 2006. *LabVIEW Graphical Programming*. 4th ed. ISBN 0071451463.

Kimberlin, R. D. 2003. *Flight Test of Fixed-Wing Aircraft*. Tennessee: University of Tennessee. ISBN-10: 1563475642.

Lan, C.-T.; Roskam, J. 1980. *Airplane Aerodynamics and Performance*. Kansas: University of Kansas.

Lush, K. J. 1948. A review of the problem of choosing a climb technique with proposals for a new climb technique for high-performance aircraft, *ARC Technical Report* (2557).

Miele, A. 1955. Optimum flight path of turbojet aircraft, *NACA TM 1389*.

Miele, A. 1959. Minimal maneuvers of high-performance aircraft in a vertical plane, *NASA TN D-155*.

Miele, A.; Capillari, Jr. J. O. 1959. Approximate solutions to optimum climbing trajectory for a rocket-powered aircraft, *NASA TN D-150*.

Raymer, D. P. 2006. *Aircraft Design: A Conceptual Approach.* 4th ed.

Rutowski, E. 1954. *Energy Approach to General Aircraft Maneuverability Problems*. Douglas Aircraft Company Inc.

Schmidt, D. K.; Herman, J. A. 1998. Use of energy-state analysis on a generic air-breathing hypersonic vehicle, *AIAA Journal of Guidance, Control and Dynamics* 21(1): 71–76. doi:10.2514/2.4199

Sederstrom, D. C.; McLane, R. C.; Branch, W. M. 1973. Energy management display, in *4th National SFTE Symposium*, August.

Sutton, G. P. 1992. *Rocket Propulsion Elements, An Introduction to the Engineering of Rockets.* 6th ed.

REALAUS LAIKO ENERGIJOS VALDYMO MONITORIAUS KŪRIMAS IR BANDYMAS SKRYDŽIO METU

I. Atuahene, S. Corda, R. Sawhney

Santrauka. Sukurtas ir įvertintas realaus laiko energijos valdymo monitorius, ištirtos jo galimybės ir panaudojimas informacijai apie energijos būklę teikti. Skrydžio simuliacijos rodo, kad monitorius sėkmingai gauna tiesioginį *PS* kontūrą greitėjančio skrydžio metu ir gali nukreipti skrydžius palei nuolatinį *PS* kontūrą, esant nedideliam greičiui, nors ir sunku išlaikyti nuolatinį *PS*.

Reikšminiai žodžiai: perteklinė galia, horizontalusis pagreitėjimas, aukštis, greitis.