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by Robert M. Plencner
Lewis Research Center
Cleveland, Ohio 44135

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16. Abstract

A preliminary investigation was made of using a hydrogen peroxide rocket to obtain "pure" moving source jet noise data. The thermodynamic cycle of the rocket was analysed. It was found that the thermodynamic exhaust properties of the rocket could be made to match those of typical advanced commercial supersonic transport engines. The rocket thruster was then considered in combination with a streamlined ground car for moving source jet noise experiments. When a non-throttlable hydrogen peroxide rocket was used to accelerate the vehicle, propellant masses and/or acceleration distances became too large. However, when a throttlable rocket or an auxiliary system was used to accelerate the vehicle, reasonable propellant masses could be obtained.

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PRELIMINARY STUDY OF A HYDROGEN PEROXIDE ROCKET FOR USE IN MOVING SOURCE JET NOISE TESTS

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Robert M. Plencner

NASA-Lewis Research Center

SUMMARY

A preliminary study was made of a simple hydrogen peroxide rocket as a tool for moving source jet noise experiments.† Thermodynamic analysis of the system showed that jet velocities in the range between 457 m/sec (1500 ft/sec) and 914 m/sec (3000 ft/sec) are obtainable by using appropriate amounts of water injection and nozzle pressure ratios. Over 30 percent of the total mass flow can be injected water before saturation occurs. A good match between the exhaust gas densities of the hydrogen peroxide rocket and typical advanced commercial supersonic transport engines can be obtained using percentages of injected water between 20 to 30 percent and nozzle pressure ratios between 2 and 5.

The adaptability of the system to a streamlined ground car for moving source jet noise experiments was also studied. Analysis of the use of a 1360 kg (3000 lb) testbed

†The author wishes to acknowledge that Dr. Edward Willis of Lewis Research Center suggested this concept.

car showed that propellant masses of less than 453 kg (1000 lb) were required to make a 8047 m (5 s mi) test run at 100 m/sec (330 ft/sec). It was also found that propellant masses and/or acceleration distances became too large when a non-throttlable hydrogen peroxide rocket was used to accelerate the vehicle to cruising speed. Therefore a secondary propulsion system or a throttlable rocket would have to be used to accelerate the vehicle.

INTRODUCTION

The effect of forward velocity on jet noise is one of the several areas of aircraft noises which requires further investigation. It would be advantageous to the development of improved prediction models to obtain "pure" jet noise data over an independently-varied range of flight conditions, engine cycle parameters, flow geometries, installation factors and other variables. This type of comprehensive data is not possible with aircraft-flyover and ground-vehicle tests using aircraft engines because these test methods are inherently limited to the cycle parameters, flowpath and other variables that correspond to available engines and aircraft/engine combinations. In addition, the resulting noise data may be contaminated by internal engine noises. Results from anechoic wind tunnel tests using a heated air jet in the surrounding flow to simulate a moving source are also controversial due to the correction factors which must be applied to the experimental results. Therefore, a simple rocket thruster is considered in order to provide a more flexible jet noise source. The thruster system that is investigated consists of a rocket in which the propulsive energy is generated by the decomposition of hydrogen peroxide. Downstream throttling and water injection are used to obtain the desired exit conditions. A schematic diagram of this system is shown in figure 1. Because the rocket thruster has no inlet and no moving parts, it should be free from contamination by other noise sources and thereby produce an essentially pure jet noise signature. The rocket is adaptable to a mobile testbed, thereby making it possible to easily measure the noise produced by a moving source jet.

ANALYSIS

The propulsion system investigated consists of injection of 100 percent pure hydrogen peroxide into a catalyst bed to accomplish complete decomposition into water vapor and oxygen according to the equation:

$$H_2O_2(l) \longrightarrow H_2O(g) + \tfrac{1}{2}O_2 + 2.89\times10^6 \text{ J/kg } (23.5 \text{ kcal/mole})$$

The products of decomposition are then passed through a throttling orifice after which liquid water is injected and vaporized. The water vapor/oxygen mixture is then expanded through a nozzle to atmospheric pressure. The ideal nozzle jet velocity, U_J, is given by

$$U_J = \sqrt{\frac{2RT_c}{\gamma - 1}\left[1 - \left(\frac{P_e}{P_c}\right)^{\frac{\gamma-1}{\gamma}}\right]}$$

where R is the gas constant, γ is the specific heat ratio, T_c is the nozzle inlet temperature and P_e/P_c is the nozzle pressure ratio. Thus it can be seen that the desired jet velocity may be obtained by varying the amount of water injection which changes the nozzle inlet temperature, by varying the pressure drop through the throttling orifice which changes the nozzle inlet pressure, or by using a combination of these two changes.

The above cycle was analysed by means of a computer code described in reference 1. This program calculates all the thermodynamic data for any amount of water injection and for any pressure ratio. The computer program calculations are based on the following assumptions: one-dimensional form of the continuity, energy, and momentum equations; zero velocity into the combustion chamber; complete decomposition of the hydrogen peroxide; adiabatic decomposition; isentropic expansion; homogeneous mixing; ideal gas law; variable specfic heat; and zero temperature and velocity lags between condensed and gaseous species. The program also includes the effects of phase changes and dissociation.

The adaptibility of the hydrogen peroxide rocket system to a streamlined ground car testbed is investigated. The characteristics of the car that is considered are shown in figure 2. The vehicle is assumed to accelerate to a cruising speed of Mach 0.3 (330 ft/sec) and then run at constant velocity over a distance of 8047 m (5 s mi).

The equation of motion for the streamlined ground car is given by

$$M \frac{dV}{dt} = \dot{m}\, U_J - D - R$$

where M is the instantaneous mass of the car, $\dot{m}$ is the rocket mass flow, V is the velocity of the car, U_J is the exhaust jet velocity, D is the aerodynamic drag and R is the rolling resistance. The integral equations for the time, ta, and distance, Sa, needed to accelerate the car to 100 m/sec (330 ft/sec) are obtained from the equation of motion. They are given as

$$t_a = \int_0^{100} \frac{M_i - \dot{m}\, t}{\dot{m}\, U_J - \frac{1}{2} \rho V^2 S C_D - \mu (M_i - \dot{m}\, t)}\, dV$$

$$S_a = \int_0^{100} \frac{(M_i - \dot{m}\, t)\, V}{\dot{m}\, U_J - \frac{1}{2} \rho V^2 S C_D - \mu (M_i - \dot{m}\, t)}\, dV$$

where M_i is the intial mass of the car, ρ is the atmospheric density, S is the frontal area of the car, C is the coefficient of drag, and μ is the coeficient of friction. The above system of integral equations was solved numerically using a Runge-Kutta scheme.

Assuming that the hydrogen peroxide rocket parameters such as mass flow and jet velocity are held constant, there will still be a net accelerating force acting on the ground car after the vehicle achieves its cruising speed. Therefore, the aerodynamic drag or rolling resistance will have to be increased in order to obtain a zero net accelerating force and allow the vehicle to cruise at a constant velocity. Under these conditions the total propellant mass, M_{P_t}, required for the accelerating and cruising portions of the test run is

$$M_{P_t} = \dot{m}\,(t_a + t_c)$$

where t_c is the time required for the cruising portion of the test.

If the vehicle is accelerated to cruise by means of an auxiliary power unit or if the hydrogen peroxide rocket thrust is throttlable, then it is possible to set the cruise thrust available just equal to the minimum thrust required by the vehicle at the begining of the cruise. Therefore, only a small additional drag would be required to compensate for the change in rolling resistance due to the change in vehicle mass in order to cruise at a constant velocity. The thrust required by the vehicle is

$$T_r = D + P$$

The drag at 100 m/sec (330 ft/sec) at sea level for the assumed car is 2306 newtons (518.4 lb) and the rolling resistance is 267 newtons (60 lb). The thrust available from the rocket is

$$T_a = \dot{m}\,U_j$$

where U_j is the rocket jet velocity. Equating the thrust required and thrust available the mass flow required can be expressed in terms of the exhaust velocity

$$\dot{m} = (2306 + 267)/U_J$$

The time required to run the 8047 m (5 s mi) test at a constant velocity of 100 m/sec (330 ft/sec) is 80 sec. Thus the propellant mass required for only the cruise portion of the test is

$$M_{P_c} = 80(2306 + 267)/U_J$$

The total propellant mass required to accelerate and cruise the vehicle when the H_2O_2 rocket is throttlable is then given by

$$M_{P_t} = \dot{m}\, t_a + M_{P_c}$$

RESULTS

Figure 3 shows the variation of nozzle inlet temperatures with the percent of injected water in the total flow. The maximum nozzle inlet temperature of 1275 K (1836° F) occurs when no water is injected. This temperature is the adiabatic decomposition temperature of pure hydrogen peroxide. The figure also shows that at standard pressure (nozzle pressure ratio equal to one), as much as 36 percent of the flow may be injected water before saturation occurs. It is quite important to avoid saturated flow as this could cause noise reflections off the condensed particles which would destroy the validity of the model.

The jet velocities obtainable for various nozzle pressure ratios and percentages of injected water are shown in figure 4. Typical advanced commercial supersonic transport jet engine exhaust velocities at takeoff are between 457 m/sec (1500 ft/sec) and 914 m/sec (3000 ft/sec). These velocities can be obtained with the hydrogen peroxide rocket system by using pressure ratios between 2 and 5 and percentages of injected water less than 30 percent. The percentage of injected water must be kept below approximately 30 percent to avoid saturation.

The band of typical advanced commercial supersonic transport jet engine exhaust gas densities is shown superimposed on the curves of density versus pressure ratio for the rocket in figure 5. The band of jet engine densities lies within the unsaturated region of the rocket exhaust gasses for pressure ratios between 2 and 5. The figure indicates that between 20 and 30 percent of the mass flow of the rocket must be injected water in order to get the best match in densities between the exhausts of the jet and the rocket.

Mach numbers of the exhaust gasses shown in figure 6 were found to be principally a function of pressure ratio. Typical takeoff nozzle exit Mach numbers for advanced commercial supersonic transport engines range from 1.0 to 1.4. These Mach numbers can be obtained by the hydrogen peroxide rocket using nozzle pressure ratios from 1.9 to

3.0.

Figure 7 shows the total propellant required to accelerate the ground test vehicle to Mach 0.3 and then perform a 8047 m (5 s mi) test run at constant velocity. For a rocket where the thrust is not throttlable, the amount of propellant needed is quite large at low jet velocities and large mass flow rates. Reasonable propellant masses can only be obtained using low mass flow rates. Figure 8 shows that at the low mass flow rates the acceleration distances become large. Therefore, to obtain reasonable propellant masses and acceleration distances over a full range of jet velocities, it would be desirable to use an auxiliary power system or a throttlable hydrogen peroxide rocket to accelerate the vehicle. For a rocket where the thrust can be throttled back at cruise to just equal the thrust required, figure 7 shows that much lower total propellant masses are required as the mass flow is increased. For these cases it may be possible to use the rocket to accelerate the vehicle for all the jet velocities of interest. It should be noted that nozzle size could become a limiting factor as the mass flow is increased.

For the case where an auxiliary power unit is used to accelerate the vehicle, figure 9 shows the propellant needed for only the 8047 m (5 s mi) test run at constant velocity. For a low jet velocity of 457 m/sec (1500 ft/sec) a propellant mass of less than 454 kg (1000 lb) is required.

This amount could reasonably be put into the assumed 1361 kg (3000 lb) vehicle. The cruise propellant mass required drops off significantly as the jet velocity is increased. At a 914 m/sec (3000 ft/sec) jet velocity only 227 kg (500 lb) of propellant is required.

CONCLUDING REMARKS

This brief study has shown that the hydrogen peroxide rocket system has the potential of effectively modeling moving source jet noise. In addition to the conventional nozzle that was considered, adaptation of the system could be made to alternative nozzle configurations of current interest such as the co-annular nozzle or the annular plug nozzle shown in figure 10.

The values assumed for the physical characteristics of the streamlined car (C_D, total mass, rolling resistance etc.) were chosen as typical values and by no means the best obtainable. Moreover, the streamlined car considered for a testbed could be replaced by other vehicles such as a light aircraft or an RPV. It should also be noted that only water was considered for the injected specie. However, more flexibility may be gained by substituting another suitable specie to be injected in place of or in addition to the water.

REFERENCE

1. Gordon, S.; and McBride, B.: Computer Program for Calculation of Complex Chemical Equilibrium Compositions, Rocket Performance, Incident and Reflected Shocks and Chapman-Jouquet Detonations. NASA SP-273, 1971.

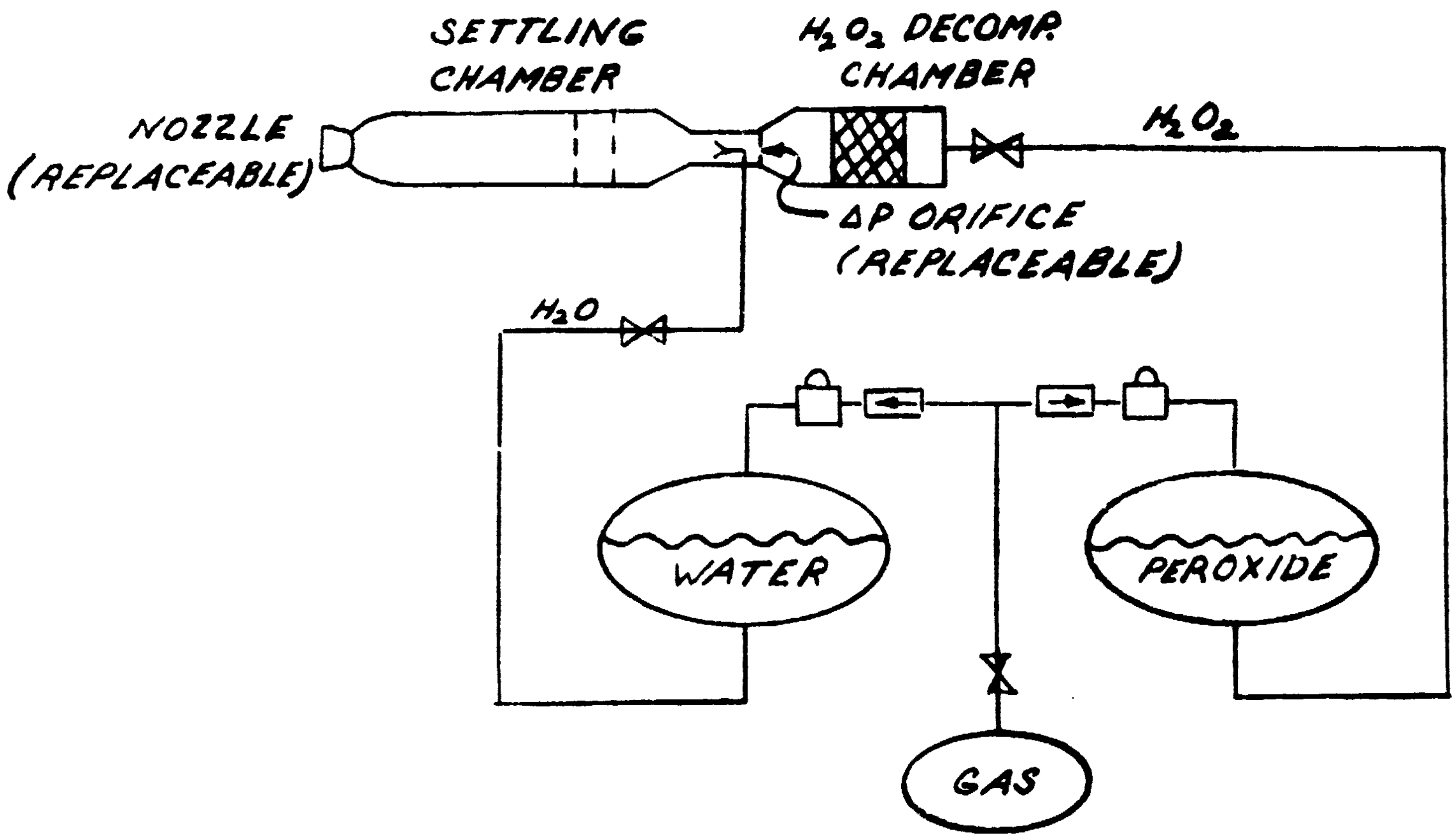
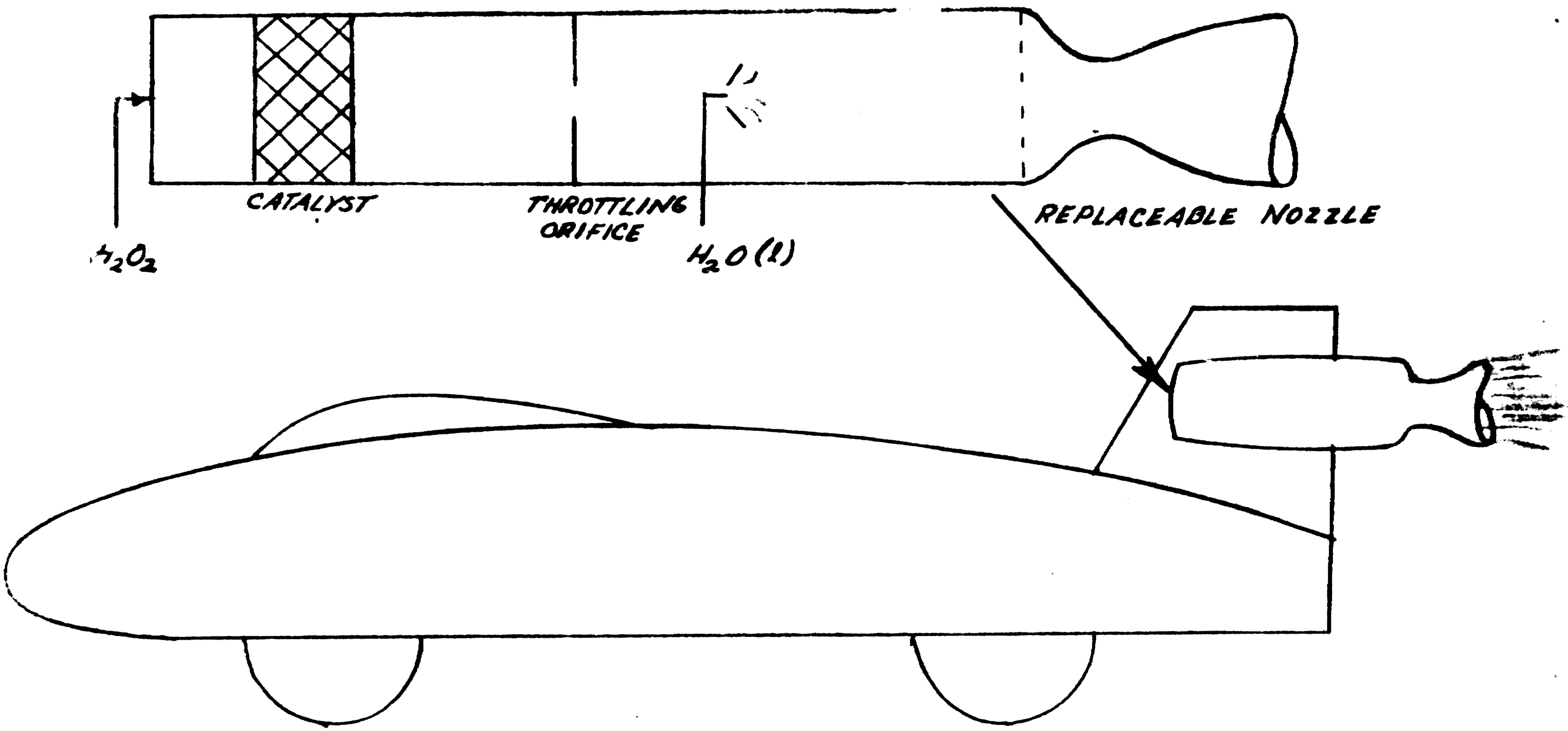


FIGURE 1 SCHEMATIC DIAGRAM OF H_2O/H_2O_2 ROCKET



GROSS WEIGHT – 1360 KG (3000 LB)
CRUISING SPEED – M.3 (330 FT/SEC)
DRAG COEFFICIENT – .2
COEFFICIENT OF FRICTION – .02

FIGURE 2. STREAMLINED GROUND CAR

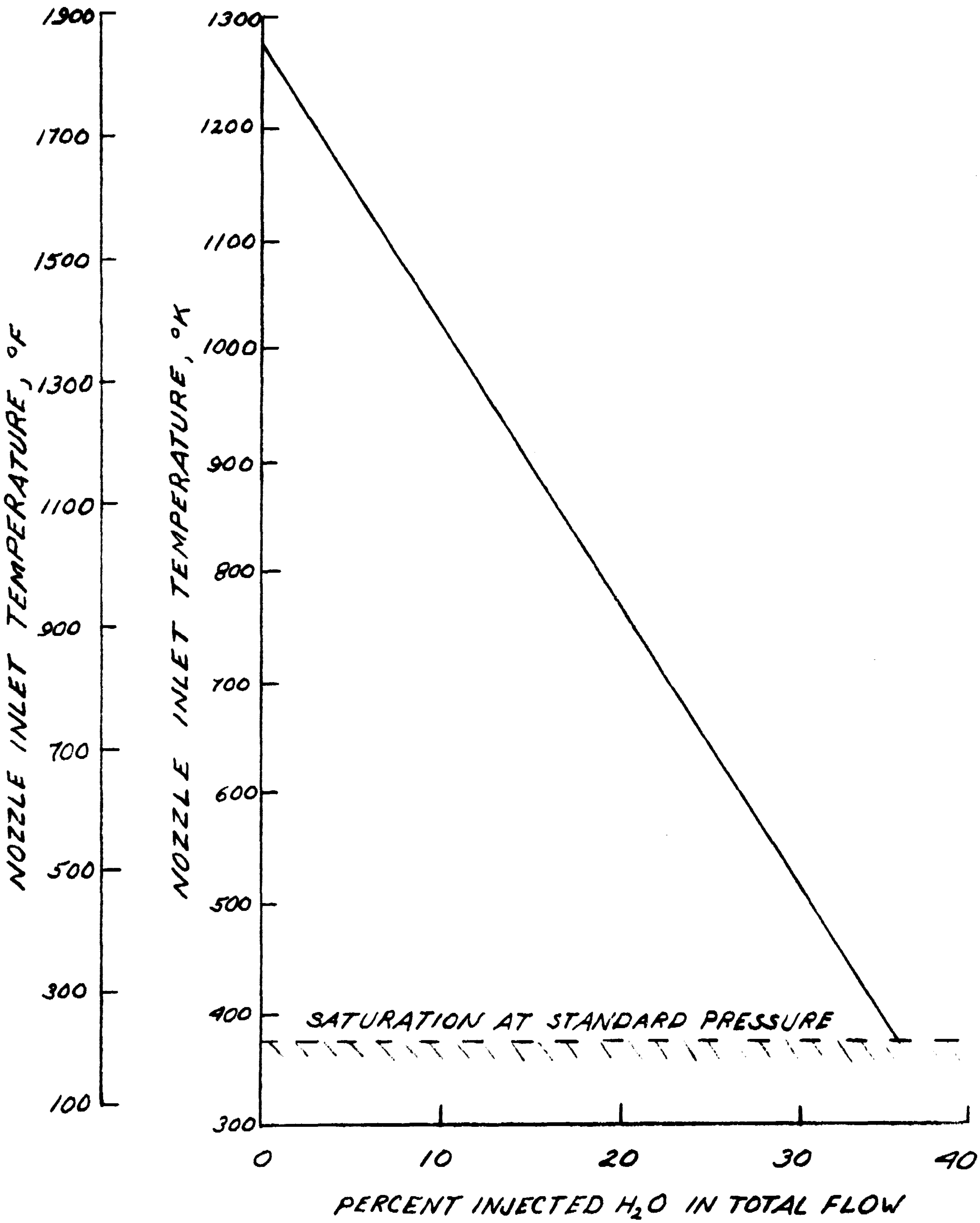


FIGURE 3. VARIATION OF TEMPERATURE WITH WATER INJECTION

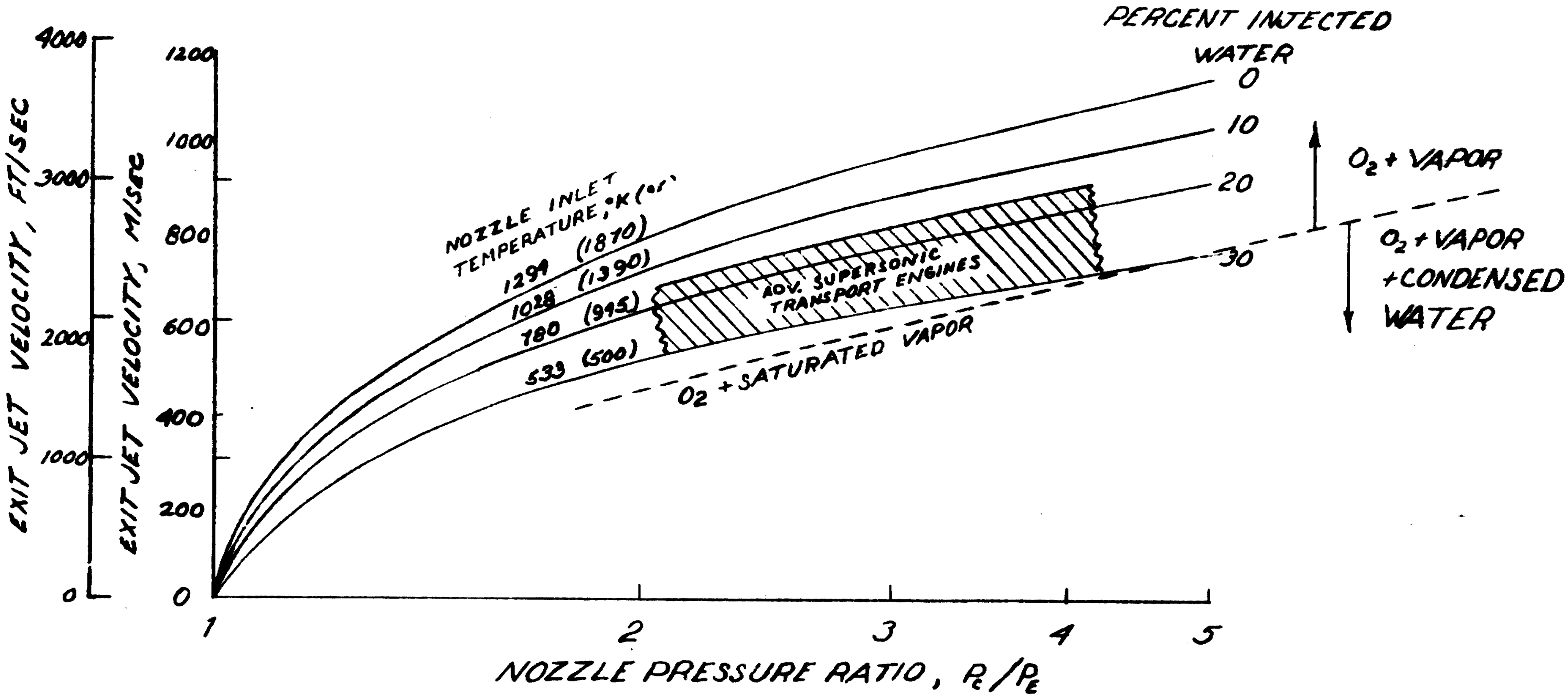


FIGURE 4 - THERMODYNAMIC CYCLE PERFORMANCE OF H_2O/H_2O_2 ROCKET

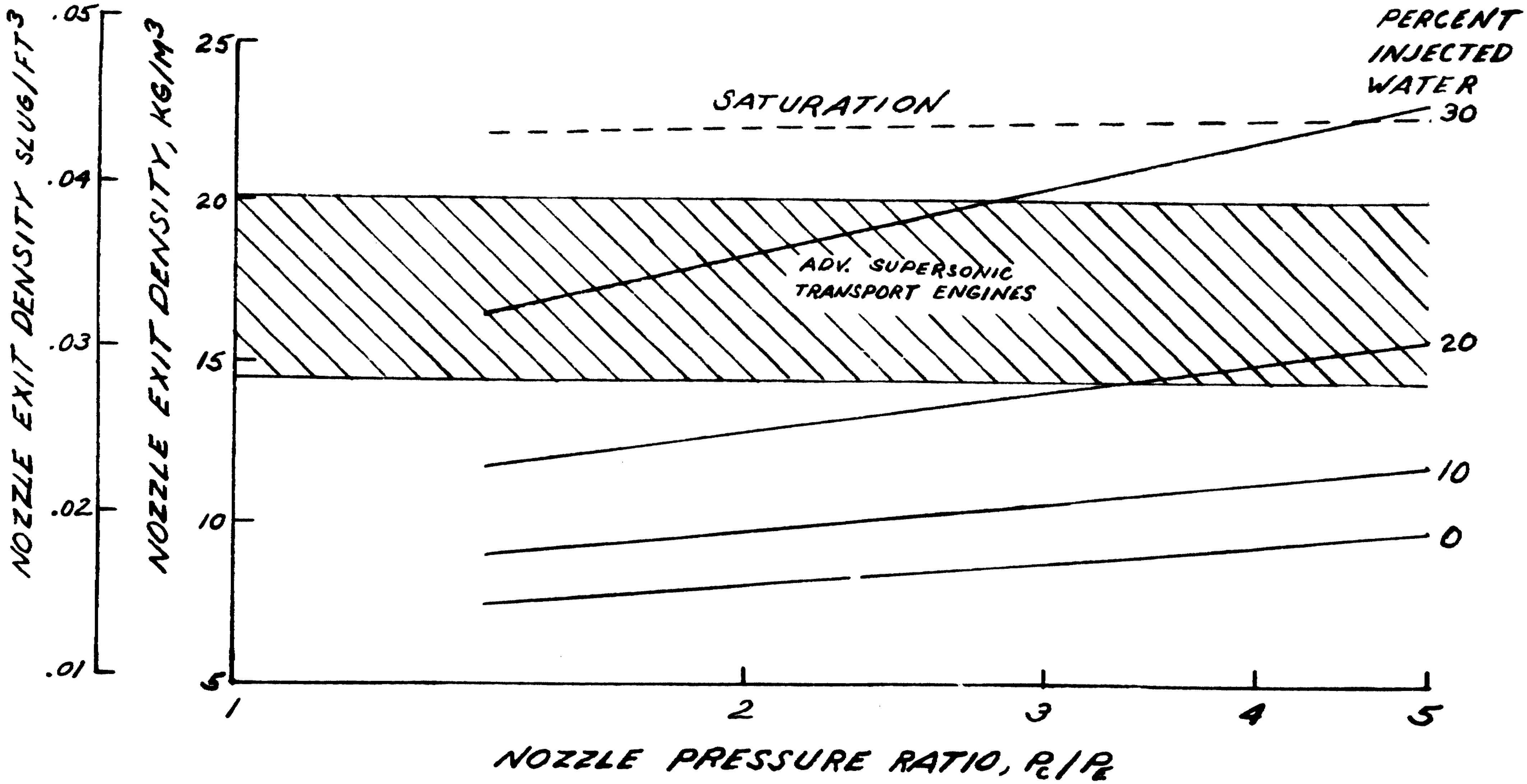


FIGURE 5. DENSITY AT NOZZLE EXIT

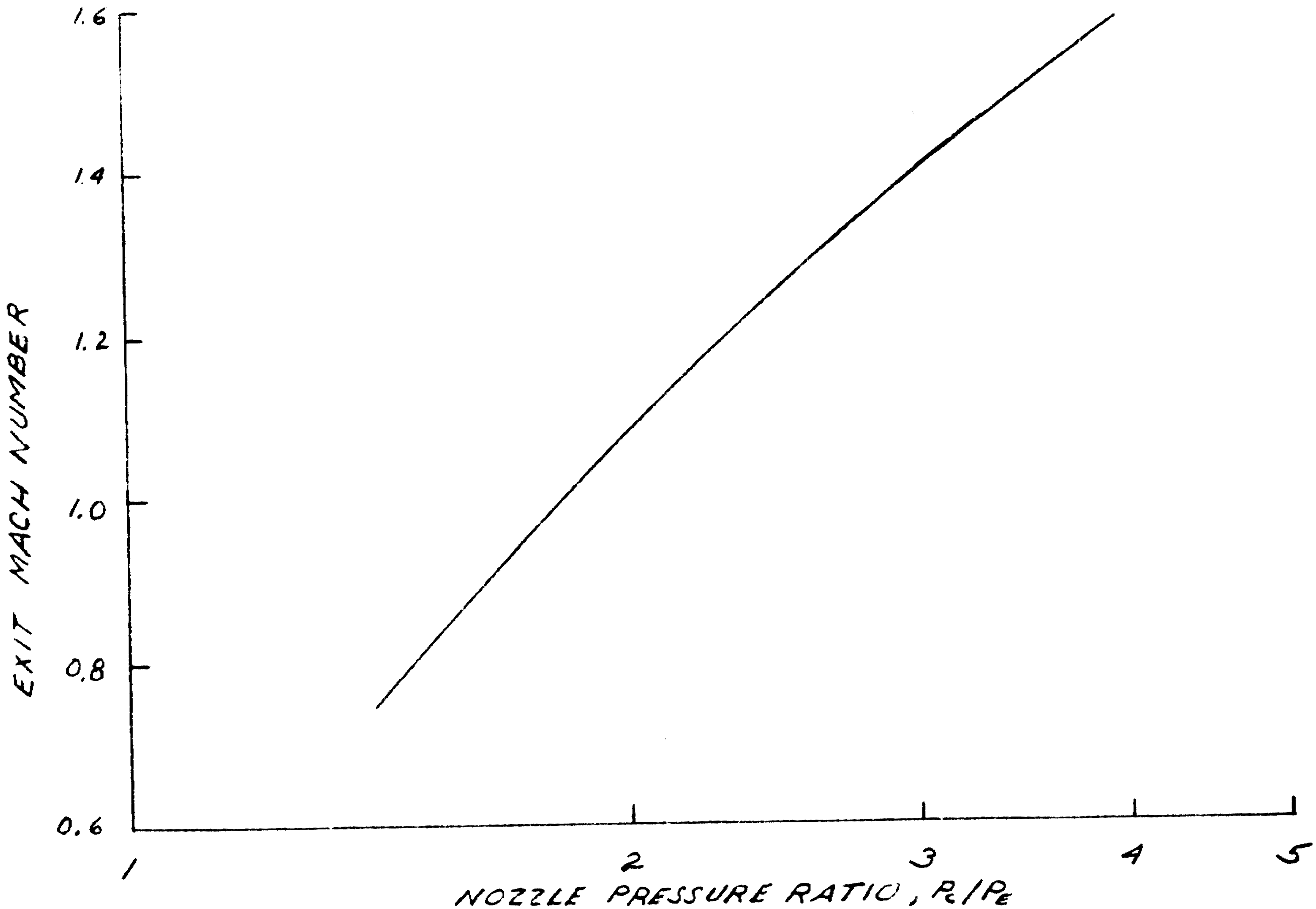


FIGURE 6. MACH NUMBER AT NOZZLE EXIT

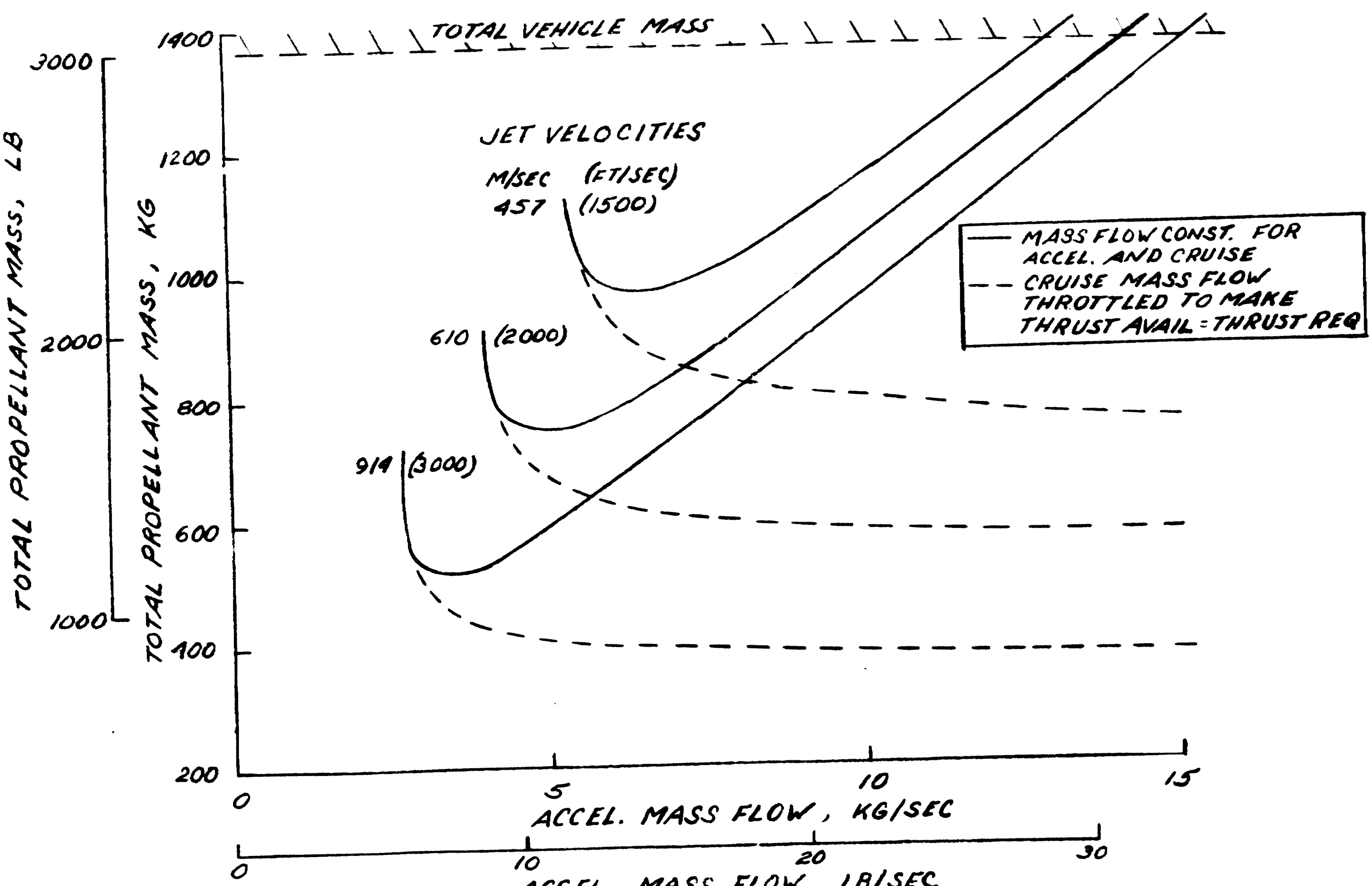


FIGURE 7. TOTAL PROPELLANT REQUIRED FOR ACCELERATION TO MACH 0.3 AND CRUISE 8047 M. (5 S. MI.)

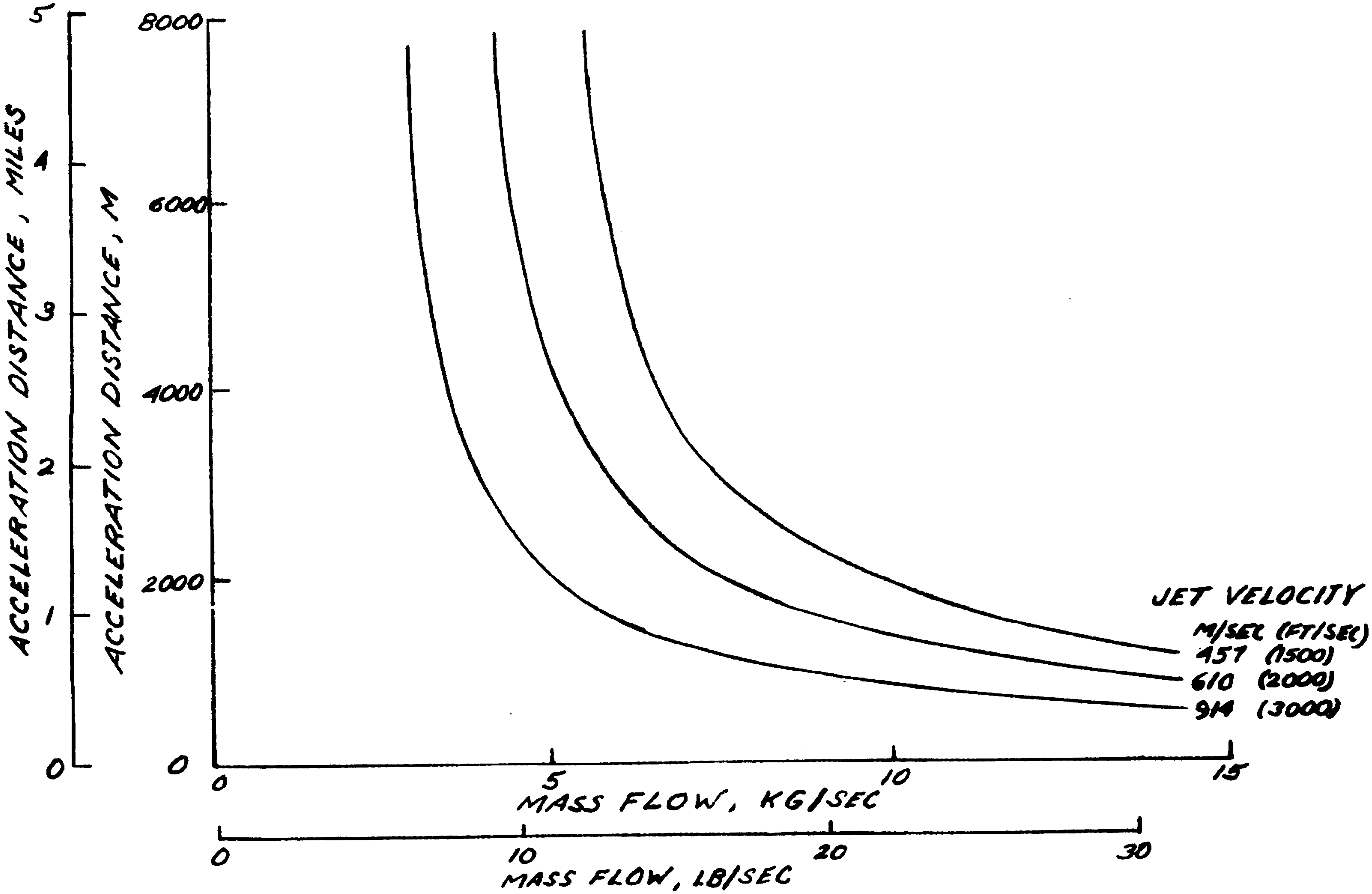


FIGURE 8. DISTANCE REQUIRED FOR ACCELERATION TO MACH 0.3

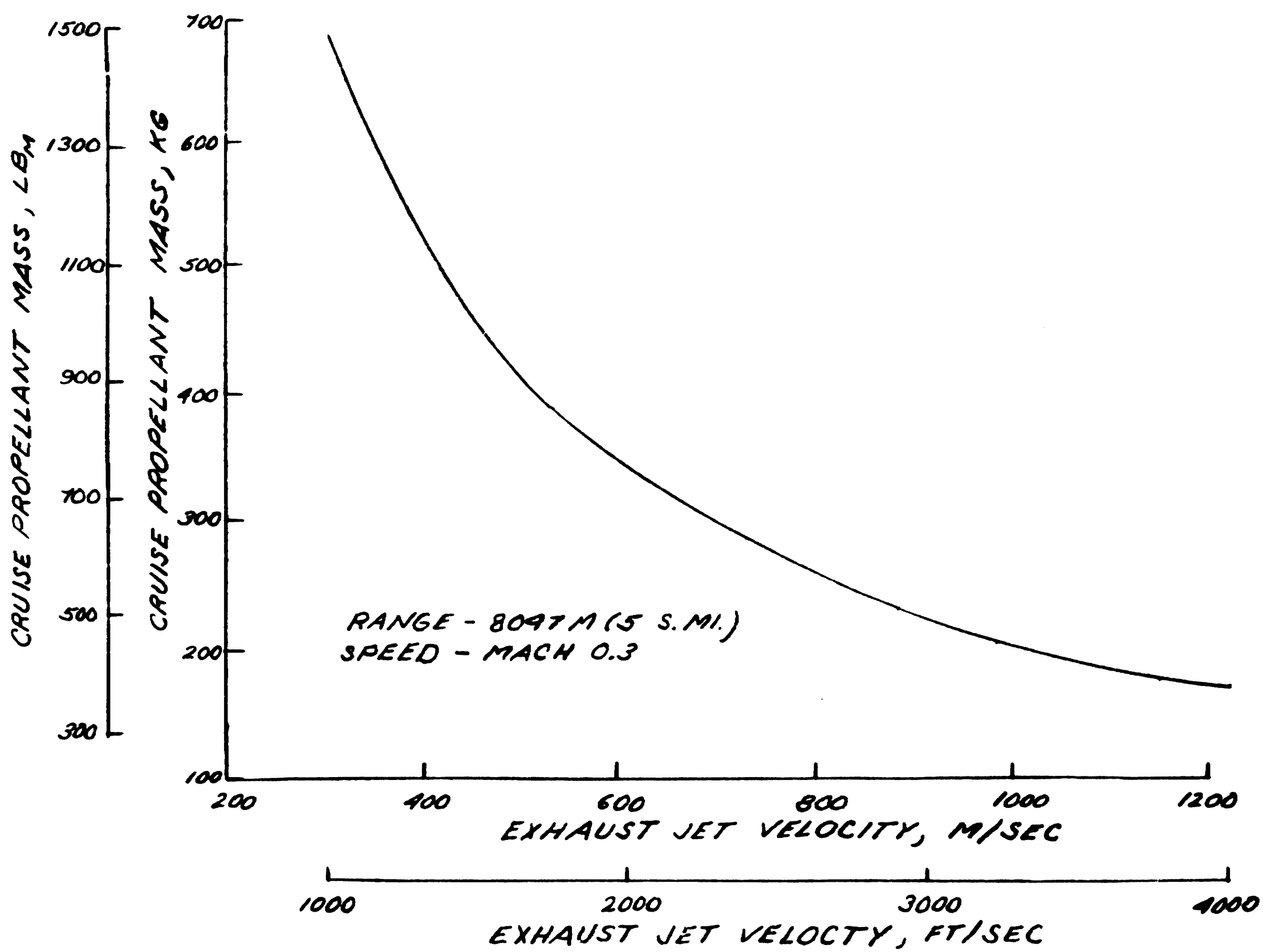
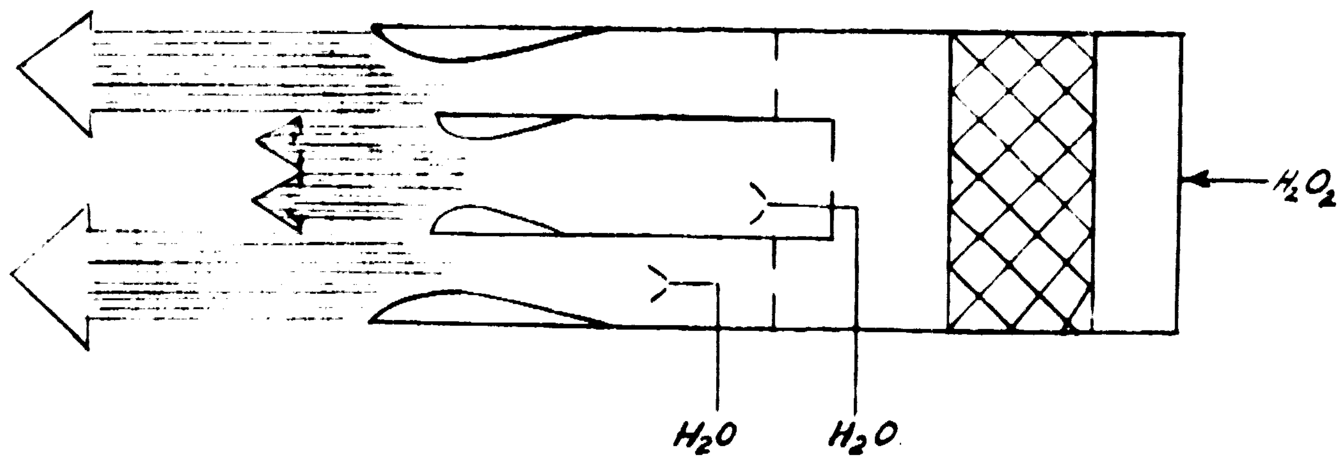
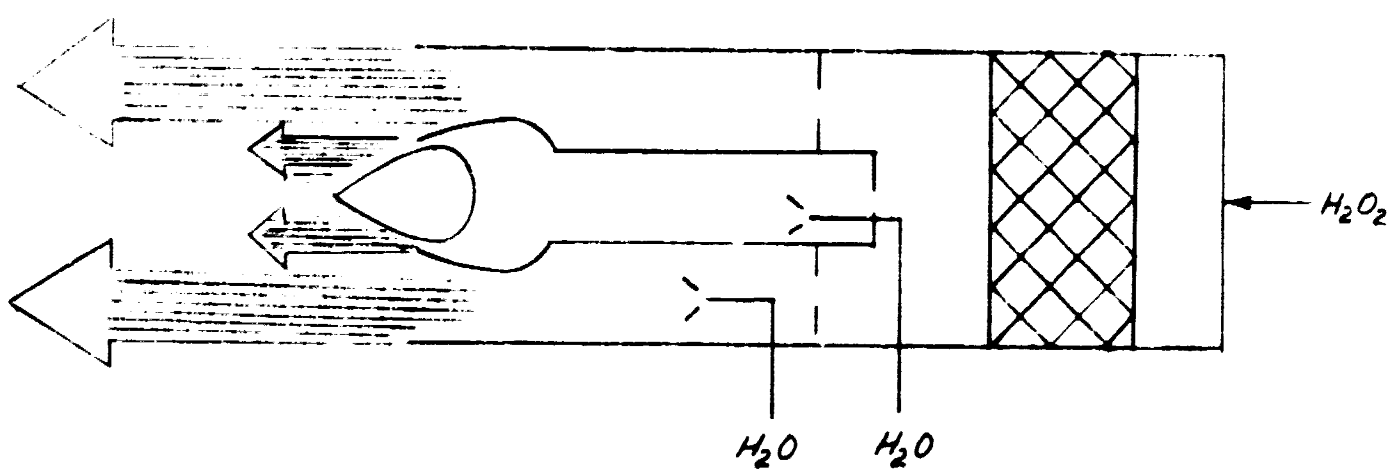


FIGURE 9. PROPELLANT REQUIRED FOR CRUISE ONLY



CO-ANNULAR NOZZLE



ANNULAR PLUG NOZZLE

FIGURE 10. ALTERNATIVE NOZZLE CONFIGURATIONS