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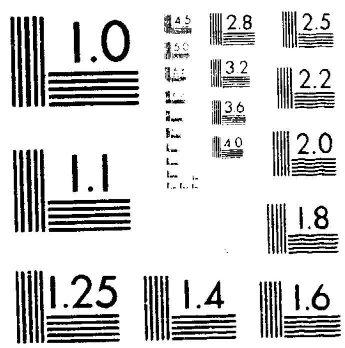

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# EFFECT OF WATER INJECTION AND OFF SCHEDULING OF VARIABLE INLET GUIDE VANES, GAS GENERATOR SPEED, AND POWER TRAIN NOZZLE ANGLE ON THE PERFORMANCE OF AN AUTOMOTIVE GAS TURBINE ENGINE

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**U.S. DEPARTMENT OF ENERGY**
**Conservation and Solar Applications**
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# EFFECT OF WATER INJECTION AND OFF SCHEDULING OF VARIABLE INLET GUIDE VANES, GAS GENERATOR SPEED, AND POWER TURBINE NOZZLE ANGLE ON THE PERFORMANCE OF AN AUTOMOTIVE GAS TURBINE ENGINE

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## SUMMARY

The engine power augmentation, specific fuel consumption, and emissions obtained with water injection downstream of the compressor were investigated over a range of variable inlet guide vane settings, gas generator speeds, and power turbine nozzle settings on the Chrysler/ERDA Baseline Automotive Gas Turbine Engine. The experimental results were used to estimate the potential fuel economy of a vehicle powered by a Chrysler/DOE Upgraded engine augmented with variable geometry and water injection.

Results indicated the amount of power augmentation achieved depends upon the method of utilizing the variable geometry. Power increases of over 20% and SFC reductions of over 5% were obtained with water injection and variable geometry utilization if gas generator speed was varied to keep turbine inlet temperature constant. When gas generator speed was held at 95% of design, the power augmentation was about 16% and SFC reduction was about 4%. The hydrocarbons and carbon monoxide emissions were not influenced by the water injection, but the oxides of nitrogen in the emissions were reduced by as much as 35%.

The results indicate at least a 6% improvement in fuel economy might be achieved over a composite (55% city/45% highway) Driving Cycle using a 75KW (100 HP) engine which could be augmented to 89 KW (120 HP) relative to an 89 KW (120 HP) unaugmented engine. The vehicle powered by the smaller, augmented engine would have the same acceleration characteristics as a vehicle powered by the larger engine.


## INTRODUCTION

The power from an automotive gas turbine engine can be augmented through the use of variable geometry and injection of water downstream of the compressor (and upstream of the regenerator). An experimental investigation was conducted to determine the amount of power augmentation that can be obtained. The Chrysler/ERDA Baseline regenerative automotive gas turbine engine was used for these tests.

A characteristic of the gas turbine engine is to run efficiently over only a narrow speed range at or close to its maximum speed and maximum turbine inlet temperature. This is a severe handicap to its application as an automotive powerplant which must be efficient over a broad range coinciding with the prevalent driving speeds of the automobile. To reduce this handicap, the efficient operating speed range has to be either broadened or shifted downward toward the midspeed range. The approach is to design the engine for less power, to shift this narrow efficient operating range downward. However, this severely limits the driveability (acceleration) of the automobile. This performance limitation can be reduced by augmenting the power of the less powerful engine with:

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(1) variable inlet guide vanes;
(2) with both water injection and variable inlet guide vanes;
(3) with both water injection and increased gas generator speeds; or
(4) with both water injection and variable power turbine nozzle angle.

Tests on aircraft engines in the 1950s and, more recently, tests on the Chrysler/ERDA Baseline gas turbine engine by Chrysler, have demonstrated that a gas turbine engine output power can be efficiently augmented by as much as 10% by injecting water into the engine inlet. This is reported in Reference 1. Unfortunately, the amount of water necessary to provide this amount of power augmentation has led to the erosion of the compressor impeller blades. This was noticed in both the aircraft and automotive tests. The aircraft engine manufacturers overcame this problem by injecting the water interstage or downstream of the compressor. Reference 3 discusses the injection of water interstage on an afterburning engine to solve the problem of compresor casing thermal contraction caused by injecting water upstream of the compressor. It was suggested that to solve the problem of compressor impeller erosion the water be injected downstream of the compressor even though work reported in Reference 4 indicated that water injection rates required for water injection downstream of the compresor are about twice as great as for compressor inlet water injection.

The background, function, purpose, and test results of the use of variable inlet guide vanes to augment the maximum power of the Chrysler/ERDA Baseline Gas Turbine engine are presented in Reference 2. Some of the VIGV tests reported in Reference 2 were also conducted in this investigation to establish a base for comparison to the water injection results.

This investigation was conducted to complement the Chrysler test program reported in references 1 and 2. An engine similar to the one described in reference 1 was modified by installing water spray nozzles downstream of the compressor in the diffuser section. This location is upstream of the regenerator. No other modifications were made to the engine except for the addition of instrumentation needed to determine output power, specific fuel consumption, emissions, and various temperatures and pressures in the engine.

All data were taken at steady-state conditions. The engine was allowed to stabilize for at least ten minutes at each point before data was recorded. The basic gas generator speed investigated was 95% of design. The influence of the variable inlet guide vanes was investigated over the range of -20° to +30° without water injection and from 0 degrees to -30 degrees with water injection. Water was injected at rates that resulted in water/air mass ratios of .0076, .023, and .039. Power turbine nozzle angle could not be measured; however, the same power turbine nozzle setting was insured by always operating the engine at the same dry reference point prior to any water injection. The output shaft speed was held constant (3473 ± 9 RPM) for all data points. Table I lists actual selected engine operating parameters for all the test points.

One of the power augmentation procedures examined in this investigation would require gas generator speeds higher than design. This would tend to reduce the life of the engine as designed but it was investigated to determine its effectiveness. Designers of new engines might be able to utilize it without any significant compromise in durability or rotor inertia.

The author acknowledges the assistance of John L. Klann of the Systems Analysis and Assessment Office at Lewis Research Center for the theoretical prediction of SFC vs HP shown in Figure 15 and for theoretical projections of fuel economy.

## SYMBOLS

| | |
|---|---|
| CO | Carbon Monoxide |
| $CO_2$ | Carbon Dioxide |
| f/A | Fuel/Air Ratio |
| HC | Hydrocarbon Emissions |
| HP | Power Output |
| ND | Dynamometer Speed |
| NGG | Gas Generator Speed |
| $NO_x$ | Oxides of Nitrogen |
| P | Pressure |
| PPM | Parts Per Million |
| SFC | Specific Fuel Consumption |
| T | Temperature |
| VIGV | Variable Inlet Guide Vanes |
| WAC | Air Mass Flow Rate |
| WFC | Fuel Flow Rate |
| WWC | Water Flow Rate |

Station Notation is shown in Figure 4.

## ENGINE DESCRIPTION

The engine is a low pressure ratio, regenerative, free-power turbine design. It incorporates a single-stage centrifugal compressor with variable inlet guide vanes, a single can-type combustor, an axial turbine stage to drive the compressor, and a free power-turbine with variable nozzle blading. A drawing of the basic engine arrangement is shown in Figure 1. Figure 2 shows the engine installed in the test stand. Additional information on the engine is contained in Reference 1.

Distilled water was used in the tests. There were two supply lines - one for each side of the engine. Each contained a turbine type flow meter, and each supplied water to a furnace-type simplex burner nozzle. A photograph of the engine showing the location of one of the nozzles is shown in Figure 3.

The station notation convention used for the engine is shown in Figure 4. Both total temperature and pressure were measured at stations 1, 2, 6, and 8, and the exhaust duct. In addition, station 4 pressure and station 5 temperature were measured. Also measured were gas generator speed, dynamometer speed, air flow, fuel flow, water flow, and variable inlet guide vane angle. Mechanical difficulties made it impractical to measure the power turbine nozzle angle.

The inlet air temperature was held constant at 30°C (85°F) for all data points by the facility air system. The power turbine speed was controlled by the dynamometer and was held constant at 3473 $\pm$ 9 RPM for all data points. The variable inlet guide vanes were independently controlled, and the water flow was also independently controlled.

In runs in which gas generator speed was set, the engine fuel control automatically adjusted fuel flow to maintain that speed. This is important to keep in mind when rationalizing events during water injection when power is increased by varying inlet guide vanes and/or the power turbine nozzles.

During most of the runs it was necessary to hold the power turbine nozzle angle at a fixed value. To overcome the previously mentioned problem of measuring this angle, the engine was operated at the same dry reference point prior to any series of runs. At this dry reference point the power turbine nozzle position was set by varying the nozzle until $T_8$ was 705°C (1300°F). With engine inlet temperature, burner exit temperature, gas generator speed, and dynamometer speed set at the constant dry reference point conditions; $T_8$ control was a very accurate method of assuring the same position of the power turbine nozzles.

## TEST PROCEDURE

The constant dry reference point nominal values were: VIGV angle = 0; $N_{GG}$ = 95% design (design equals 44,610 RPM); and $T_8$ = 705°C (1300°F); burner exit temperature 942°C (1727°F). The 95 percent of design gas generator speed point was selected as the dry reference data point, to allow speed and temperature excursions beyond the dry reference point with little risk of engine damage. Selected actual engine operating parameters at the dry reference point are shown in Table 1, items 32, 39, 44, 54, 62, 70, and 90.

Starting at the dry reference point, the following tests were conducted to determine the effect on power, SFC, and emissions:

1. Varying the inlet guide vanes with no water injection.
2. Water injection.
3. Varying the inlet guide vanes with water injection.
4. Varying both the inlet guide vanes and the power turbine nozzle with water injection.
5. Varying the gas generator speed with no water injection.
6. Varying both the inlet guide vanes and the gas generator speed with water injection.

<u>Varying the Inlet Guide Vanes (no water injection)</u>. The inlet guide vanes were varied from -20 to +30 degrees with data recorded every five degrees. During the first series of runs burner exit temperature was not controlled and from -20 to 0 degrees the burner exit temperature exceeded the reference value. Additional tests were then made from -30 to 0 degrees VIGV angle settings and the burner exit temperature was maintained constant at the dry reference value by also varying the power turbine nozzle angle. (A positive sign of the inlet guide vane setting indicates the incoming air is directed into the direction of rotation of the compressor rotor. A negative sign indicates the air is directed opposite to the direction of rotation of the compressor rotor).

<u>Water Injection</u>. After data were recorded at the dry reference point water was injected at water/air flow ratios of .0076, .023, and .039. After allowing enough time for burner exit temperature to stabilize, the water injection data point was recorded. No other changes were made to the operating condition of the engine.

<u>Varying the Inlet Guide Vanes with Water Injection</u>. After the first water injection data point was recorded at 0° inlet guide vane setting, the inlet guide vanes were varied 5 degrees at a time, and data points were taken until the burner exit temperature matched the dry reference temperature of 942°C (1727°F). This procedure was repeated for the other two water/air flow ratios.

Varying Both Inlet Guide Vanes and Power Turbine Nozzle With Water Injection. The inlet guide vanes were varied and data were recorded every 5 degrees, while water was injected. Burner exit temperature was held equal to its dry reference value by varying the power turbine nozzle angle. This procedure was repeated for the other two water/air flow ratios.

Varying Gas Generator Speed ($N_{GG}$) No Water Injection. Starting at the dry reference point, the gas generator speed was increased and data was recorded at points corresponding to 96, 97, and 97.6 percent of gas generator speed. No other changes were made to the engine.

Varying Both Inlet Guide Vanes and Gas Generator Speed with Water Injection. The inlet guide vanes were varied and data were recorded every 5 degrees, while water was injected. The burner exit temperature was held equal to its dry reference value by varying the gas generator speed. The power turbine nozzle angle was held constant at the dry reference value. This procedure was repeated for the other two water/air flow ratios.

## RESULTS AND DISCUSSION

Presented in the following sections are the results of the separate and combined effects that VIGV angle, variable power turbine nozzle angle, speed, and water injection had on power output, specific fuel consumption, and emissions. Because of difficulties in measuring the power turbine vane angle, no attempt was made to determine the SFC and power changes that could be obtained by varying only the power turbine nozzle angle. All data points are shown in Table 1.

### Power Output and Specific Fuel Consumption

Varying the Inlet Guide Vanes With No Water Injection. The result that varying the inlet guide vane angle with no water injection had on power output is shown in Figure 5a. If the VIGV angle is the only variable, and if no attempt is made to limit burner exit temperature, the power output continues to rise at almost a steady rate up to a VIGV angle of at least -20 degrees. At -20 degrees there is a 9% increase in power. If the burner exit temperature is limited to the dry reference point value of 942°C (1727°F) for all negative values by varying the power turbine nozzle, the power output will increase by about 2.5% then start to decrease at about -15 degrees VIGV angle.

The relationship of power output change to burner exit temperature change over the range of variable inlet guide vane angles investigated is shown in Figure 5b.

The specific fuel consumption for the above data points is shown in Figure 5C. Limiting the burner exit temperature results in higher SFC values.

The data points for Figure 5 are 32 to 51 in Table 1.

Water Injection. The injection of water only without allowing the VIGV angle, the power turbine nozzle angle, or the gas generator speed to vary from their dry reference value caused no significant change in power or SFC as shown in figure 6a and 6b. However, it did decrease the burner exit temperature significantly as shown in figure 6c. The data points for figure 6 are 55, 71, and 91.

Varying the Inlet Guide Vanes with Water Injection. For water injection at various water/air flow ratios and inlet guide vane settings, the changes in burner exit temperature from the dry reference value of 942°C (1727°F) and the changes in engine power are shown in Figure 7a. Power increases of up to 13% at the maximum water/air flow ratio (Point 96) were observed. Gas generator speed was maintained at 95% of design.

The effects of water injection alone are noted as points 55, 71, and 91 on figures 7a (these points are shown previously in figure 6). Data points with water injection and with the VIGV angle varied to maintain burner exit temperature equal to the dry reference point value of 942°C (1727°F) are noted as points 58, 75, and 96 on Figures 7a, and 8a. From Figures 7a and 8a, it is apparent that these power increases with water injection are almost the same as those obtained at equal VIGV angle settings without water injection. Further when the points from the highest water/air flow ratio curve from Figure 7a are placed in Figure 8b along with the dry points, it is observed that the power increases are the same for corresponding temperature changes for both the dry and the water injected points.

From Figures 8a and 8b it is concluded that the power increase must be due only to the inlet guide vane angle change. The water injection merely lowered the temperatures, thus making it possible to vary the inlet guide vane angle without exceeding the dry reference point temperature of 942°C (1727,F).

Varying the VIGV angle setting with various water/air flow ratios not only increased power as noted in Figure 8a but effected SFC as shown in Figures 7b, 7c and 7d. The overall trend is to lower SFC values with both increased water injection ratios and increasingly negative VIGV angles. The VIGV angle appears to be the more prominant effect as shown by Figure 7a, 7b, and 7c. When the water injection points 58, 75, and 95 are plotted with the dry VIGV angle points as shown in Figure 8c, it becomes apparent that the changed VIGV angle is responsible for the reduction in SFC (up to 1.5%). The water injection merely allowed the engine to be rematched at a more negative VIGV angle setting which improved both the power and SFC, as noted in Figures 8a and 8C, but without going to the higher burner exit temperatures indicated on Figure 5 b for the more negative values of VIGV without water.

The data points for Figure 7 are 54 to 58, 71 to 75, and 91 to 96. The data points for Figure 8 are 32 to 43, 54, 58, 75, and 91 to 96.

Varying Both the Inlet Guide Vanes and the Power Turbine Nozzle with Water Injection. Shown in Figure 9a are the power changes obtained without water injection and at the three different water/air flow ratios by varying the VIGV angle with the burner exit temperature held to the dry reference point value of 942°C (1727,F) by varying the power turbine nozzle angle. Power increases of up to 16% were observed.

For the above points, the specific fuel consumption as a function of VIGV angle is shown in Figure 9b, which shows a reduction of up to 4.5%.

Varying the Gas Generator Speed Without Water Injection and Without Any Engine Geometry Change. The results that varying the gas generator speed had on power output without water injection or engine geometry change are shown on Figure 10a, and the relationship of power output change to burner exit temperature increase is shown in Figure 10b.

The specific fuel consumption as a function of gas generator speed is shown in Figure 10c.

The data points for Figure 10 are 164 to 167.

Varying Both the Inlet Guide Vanes and the Gas Generator Speed with Water Injection. Shown in Figure 11 are the power change results plotted as a function of VIGV angle for the three different water/air flow ratios investigated. The burner exit temperature was held at the dry reference point value of 942°C (1727°F) by varying the gas generator speed. Power increases up to 23% were observed. Because varying the VIGV angle did not increase the power, the remainder of this section concerns only the results at 0 VIGV angle.

Figure 12a shows that the same amount of power augmentation was obtained with and without water injection by varying gas generator speed. Water injection permitted burner exit temperature to be held constant. In Figure 12b, power change is plotted against the absolute value of the change in burner exit temperature |T5|. This figure shows three sets of data:

1. Water injection only (points 55, 71, 91) (12b only)
2. Power augmentation by varying gas generator speed only.
3. Power augmentation by water injection and varying gas generator speed to hold the burner exit temperature constant (Point 66, 85, 101).

The results show that the power augmentation caused by varying only gas generator speed is at the intersection of the other two sets of data. From figures 12a and b, it is apparent that the power increase results from increasing gas generator speed to rematch the engine to the dry reference burner exit temperature after that temperature was lowered by water injection.

The specific fuel consumption change is shown plotted on Figure 12c along with the dry points of Figure 10c. The results indicate that the rate of improvement in SFC is about the same as obtained by allowing the burner exit temperature and the gas generator speed to increase without water injection.

The power increase and the SFC improvement, therefore, appear to be due only to the gas generator speed increase necessary to rematch the engine to its dry reference burner exit temperature. The water injection by itself did not improve the power output or the SFC.

The limit on the amount of power augmentation possible with water injection was not reached during this investigation. Although it is certain there is a limit on the amount of water that can be effectively injected, no limit was found within the scope of this investigation. However, the slight increase in power between the two highest water flow rates indicates that a limit is being approached on the amount of power augmentation possible from varying the inlet guide vanes with water injection. This is due to the reduced influences of inlet guide vane angles on power augmentation past -20 degrees. Higher water injection rates were not investigated because there was concern about surging the compressor.

## Emissions

The injection of water caused a significant reduction in NOx emissions, about a 35% for the .039 water/air flow ratio. There was also a further reduction in $NO_x$ associated with the reduction in the burner exit temperature of about .7% for each degree centrigrade. The percent reduction was calculated based on the dry reference point taken immediately preceding the water injection points, and is plotted against the reduction in burner exit temperature in Figure 13. Data in Figure 13 includes every water injection test point and are points 26 to 108 in Table 1.

A slight reduction in CO and HC was also observed. However, the reduction was small enough to be in the error band of the measuring equipment; therefore, no attempt was made to correlate the changes in these emissions with water injection rate, gas generator speed, or changes in engine geometry.

The emissions data are presented in Table 1.

## Application to the Automobile

To determine the possibilities of the application of power augmentation by water injection to an automobile, the following example was assumed:

1. 1588 kg (3500 pound) automobile.
2. 89 kw (120 HP) engine.
3. 20% augmentation of the max. engine power is possible by some combination of water injection, variable geometry, and gas generator overspeed which will not impair engine life.

The amount of power needed to propel the automobile over either the highway or city driving cycles is about half that needed to provide a desired 0 to 97 km/h (60 MPH) acceleration of the automobile. For example, the 1588 kg (3500 pound) automobile requires 50 kw (67.568 HP) maximum engine power for the urban driving cycle, but requires 89 kw (150 HP) to accelerate from 0 to 97 km/h (60 MPH) in 13 seconds. Figure 14 shows a typical relationship between power per unit weight of the automobile and the time to accelerate from 0-97 km/h (60 MPH). For this example, it has been assumed that 89 kw (120 HP) is needed to provide acceptable acceleration characteristics for the 1588 kg (3500 pound) automobile. If this 89 kw (120 HP) can be provided by an engine nominally designed for 75 kw (100 HP) and augmented by some combination of variable geometry, gas generator overspeed, and water injection to 89 kw (120 HP) then fuel savings can be realized by using the smaller engine which will operate closer to its optimum operating conditions than the larger engine.

In addition, it is expected that vehicle weight will be reduced due to using an augmented 75 kw (100 HP) engine in place of a 89 kw (120 HP) engine. Advanced engines will weigh approximately 1.5 kilograms per kilowatt (2.5 pounds per horsepower) and this is assumed to be the weight that will be saved by using a less powerful engine. Applying this assumption of 1.5 kilograms per kilowatt (2.5 pounds per horsepower) to the example results in a 22 kg (50 pounds) savings due to engine size reduction. Some or all of these savings will be offset by the weight of the water, water tank, and injection system required. Assuming a 2.3 kg (5 pound) water system approximately 20 liters (5.4 gallons) of water could be carried without exceeding the 22 kg (50 pounds) that was saved.

The 55% City/45% Highway FDC composite fuel economy for a 1588 kg (3500 pound) vehicle was generated assuming the SFC vs. HP characteristics for the 75 kW (100 HP) and 89 kW (120 HP) engines shown in Figure 15. The results were 16.7 KM per liter (34.1 MPG) and 15.6 km per liter (31.9 mpg) respectively; a gain of 6 percent for the smaller engine. When the 75 km (100 HP) engine is power augmented by water injection, it takes on the acceleration and driveability characteristics of a 89 kw (120 HP) engine with the fuel economy of a 75 kw (100 HP) engine. Therefore, downsizing the engine to 75 kw (100

HP) results for this example in a fuel economy gain of about 6 percent while meeting the power required for acceleration through augmentation. Since power augmentation was not necessary to execute the 55% City/45% Highway FDC composite driving cycle with the smaller engine, no estimate of water requirements could be made. However, the amount of water required by less conservative driving habits should not be excessive due to the short duration of augmentation demand.

For the purpose of illustration, 89 kw (120 HP) was selected as the minimum power desired for the 1588 kg (3500 pound) automobile, but the example and the trend toward improved fuel economy may be valid for other engine powers and automobile weights.

## CONCLUSION

The power output of an automotive gas turbine engine can be augmented through the separate or combined use of variable geometry gas generator overspeed and injection of water downstream of the compressor (upstream of the regenerator). An experimental investigation using the Chrysler/ERDA Baseline Automotive Gas Turbine Engine was conducted to determine the amount of power augmentation that can be obtained. The base case for all tests was at 95% of design gas generator speed.

Varying only the VIGV angle to -20 degrees produced an increase in power of 9.5% and a decrease in SFC of 1.5%. At the same time however, the burner exit temperature was required to increase.

Varying only the gas generator speed from 95% to 97.6% of design produced an increase in power of 15%, and a decrease in SFC of 4%. At the same time however, the burner exit temperature was required to increase.

Water injection downstream of the compressor resulted in a reduction in burner exit temperature making possible a rematching of the engine back to the original (dry) burner exit temperature. The rematched conditions resulted in an increase in output power and a reduction in SFC without exceeding the base case burner exit temperature. The engine was rematched by the following:

1. Varying the inlet guide vanes;
2. Varying the power turbine nozzle;
3. Increasing the gas generator speed above design;
4. Various combinations of the above.

At a water/air flow ratio of .039 a gas generator speed of 95% of design and a base case burner exit temperature of 942°C (1727°F) the following results were obtained:

1. Varying the inlet guide vanes produced a power augmentation of 13.5% and an SFC reduction of 1.5%.

2. Varying the power turbine nozzle produced a power augmentation of 10%, and an SFC reduction of 3.2%.

3. Varying both VIGV and power turbine nozzle produced a power augmentation of 15.8% and an SFC reduction of 4.5%.

At water/air flow rate of .039 increasing gas generator speed to maintain base case burner exit temperature produced a power augmentation of 23%, and an SFC reduction of 5.2%. Varying the inlet guide vanes provided no additional increase in power.

The above power augmentation was achieved with a 35% reduction in $NO_x$ and without any increase in other pollutants.

When applied to a typical automobile a 6% improvement in fuel economy is predicted over a 55% City/45% Highway FDC composite driving cycle using a 75 kW (100 HP) engine which could be augmented to 89 kW (120 HP) relative to an 89 kW (120 HP) unaugmented engine. The vehicle powered by the smaller, augmented engine would have the same 0-60 mph acceleration characteristics as the vehicle with the larger engine.

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TABLE 1

| RUN | $N_{GG}$ | VIGV (°) | WNC Kg/HR | WAC Kg/Sec | WFC Kg/Sec | f/a | Power Output KW | SFC Kg/Kw-Hr | $P_2/P_1$ | NDC (RPM) |
|---|---|---|---|---|---|---|---|---|---|---|
| 32 | 95.00 | +0.37 | 0.0 | 0.960 | 0.00888 | 0.00926 | 90.223 | 0.354 | 3.702 | 3468.6 |
| 33 | 95.07 | +5.08 | 0.0 | 0.953 | 0.00872 | 0.00916 | 88.132 | 0.356 | 3.678 | 3472.3 |
| 34 | 95.00 | +10.09 | 0.0 | 0.945 | 0.00854 | 0.00904 | 85.543 | 0.360 | 3.635 | 3471.5 |
| 35 | 95.22 | +15.11 | 0.0 | 0.938 | 0.00842 | [illegible] | 84.262 | [illegible] | 3.603 | 3475.6 |
| 36 | [illegible] | +20.12 | 0.0 | 0.926 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 37 | 94.99 | +25.11 | 0.0 | 0.935 | 0.00802 | [illegible] | 77.554 | [illegible] | [illegible] | [illegible] |
| 38 | 95.24 | +30.04 | 0.0 | 0.903 | 0.00785 | 0.00866 | 74.626 | [illegible] | [illegible] | 3476.5 |
| 39 | 94.98 | - 0.10 | 0.0 | 0.960 | [illegible] | 0.00922 | [illegible] | 0.354 | [illegible] | 3471.4 |
| 40 | 95.11 | - 5.13 | 0.0 | 0.969 | 0.00895 | 0.00931 | [illegible] | 0.349 | 3.742 | 3475.9 |
| 41 | 94.96 | - 9.87 | 0.0 | 0.972 | 0.00916 | 0.00943 | 94.211 | 0.350 | 3.766 | [illegible] |
| 42 | 94.87 | -15.14 | 0.0 | 0.978 | [illegible] | 0.00960 | [illegible] | 0.349 | 3.747 | [illegible] |
| 43 | 94.83 | -20.14 | 0.0 | 0.980 | [illegible] | 0.00974 | [illegible] | 0.344 | [illegible] | 3470.3 |
| 44 | 94.37 | +0.16 | 0.0 | 0.970 | 0.00877 | 0.00911 | [illegible] | 0.351 | [illegible] | 3470.3 |
| 45 | 94.85 | -5.11 | 0.0 | 0.963 | [illegible] | 0.00929 | 90.893 | 0.354 | 3.716 | 3471.1 |
| 46 | 94.80 | -10.14 | 0.0 | 0.975 | 0.00907 | 0.00931 | 91.917 | 0.355 | 3.741 | 3468.8 |
| 47 | 94.87 | -15.16 | 0.0 | 0.984 | 0.00919 | 0.00935 | 92.346 | 0.358 | 3.771 | 3470.8 |
| 48 | [illegible] | -20.15 | 0.0 | 0.991 | 0.00925 | 0.00935 | 91.233 | 0.365 | 3.806 | [illegible] |
| 49 | 94.87 | -20.13 | 0.0 | 0.991 | 0.00929 | 0.00930 | 92.347 | 0.362 | 3.811 | 3471.0 |
| 50 | 95.22 | -25.14 | 0.0 | 0.996 | 0.00931 | 0.00931 | [illegible] | 0.374 | 3.826 | 3478.7 |
| 51 | 94.80 | -30.15 | 0.0 | 0.992 | 0.00918 | 0.00930 | 84.372 | 0.392 | 3.779 | 3469.9 |
| 54 | 95.10 | -0.69 | 0.0 | 0.964 | 0.00892 | 0.00924 | 90.591 | 0.354 | 3.739 | 3470.7 |
| 55 | 95.06 | -0.63 | 26.3 | 0.961 | 0.00888 | 0.00923 | 89.333 | 0.356 | 3.729 | 3468.7 |
| 56 | 94.99 | -5.07 | [illegible] | 0.966 | 0.00900 | 0.00931 | 91.632 | 0.354 | 3.753 | 3472.0 |
| 57 | 94.92 | -10.13 | [illegible] | 0.973 | 0.00919 | 0.00944 | 94.121 | 0.352 | 3.786 | 3469.7 |
| 58 | 95.03 | -11.96 | 26.3 | 0.975 | 0.00925 | 0.00947 | 94.772 | 0.351 | 3.809 | 3468.2 |
| 59 | 94.32 | -9.98 | 26.3 | 0.970 | 0.00918 | 0.00945 | 94.651 | 0.343 | 3.735 | 3471.3 |
| 60 | 94.99 | -5.03 | 26.4 | 0.961 | 0.00909 | 0.00946 | 93.397 | 0.350 | 3.752 | 3469.3 |
| 61 | 95.12 | -0.04 | 26.5 | 0.956 | 0.00897 | 0.00934 | 92.967 | 0.347 | 3.712 | 3476.4 |
| 62 | 94.96 | -0.03 | 0.0 | 0.961 | 0.00885 | 0.00920 | 89.449 | 0.356 | 3.709 | 3471.4 |
| 63 | 95.02 | -12.15 | 26.4 | 0.975 | 0.00928 | 0.00951 | 95.527 | 0.350 | 3.802 | 3469.8 |
| 64 | 95.06 | -9.95 | 26.5 | 0.972 | 0.00922 | 0.00948 | 95.515 | 0.348 | 3.789 | 3474.9 |
| 65 | [illegible] | -4.90 | 26.5 | 0.972 | 0.00919 | 0.00945 | 95.368 | 0.347 | 3.791 | 3470.2 |
| 66 | 95.88 | -0.18 | 26.5 | 0.972 | 0.00920 | 0.00945 | 94.819 | 0.349 | 3.784 | 3470.6 |
| 69 | 94.34 | -0.66 | 0.0 | 0.961 | 0.00886 | 0.00920 | 89.236 | 0.358 | 3.717 | 3476.6 |
| 70 | 95.04 | -0.62 | 0.0 | 0.962 | 0.00869 | 0.00920 | 90.302 | 0.355 | 3.729 | 3481.0 |
| 71 | 95.04 | -0.69 | 81.0 | 0.955 | 0.00869 | 0.00930 | 90.601 | 0.353 | 3.736 | 3478.1 |
| 72 | 95.33 | -5.05 | 80.7 | 0.961 | 0.00914 | 0.00951 | 92.739 | 0.355 | 3.759 | 3473.5 |
| 73 | 95.36 | -10.02 | 80.7 | 0.969 | 0.00927 | 0.00957 | 95.095 | 0.351 | 3.800 | 3475.3 |
| 74 | 95.00 | -15.12 | 80.6 | 0.973 | 0.00947 | 0.00971 | 97.137 | 0.351 | 3.835 | 3472.5 |
| 75 | 94.95 | -19.98 | 80.5 | 0.974 | 0.00967 | 0.00993 | 99.525 | 0.350 | 3.857 | 3473.8 |
| 76 | 95.07 | -15.02 | 80.5 | 0.970 | 0.00961 | 0.00989 | 100.196 | 0.345 | 3.842 | 3477.7 |
| 77 | 94.94 | -10.02 | 80.4 | 0.959 | 0.00951 | 0.00991 | 99.286 | 0.345 | 3.904 | 3474.4 |
| 78 | 95.10 | -5.01 | 80.6 | 0.950 | 0.00935 | 0.00982 | 97.976 | 0.343 | 3.771 | 3478.2 |
| 79 | 95.07 | +0.24 | 80.7 | 0.946 | 0.00924 | 0.00975 | 95.973 | 0.347 | 3.742 | 3476.5 |
| 80 | 95.02 | +0.26 | 80.6 | 0.940 | 0.00925 | 0.00992 | 97.147 | 0.343 | 3.742 | 3476.9 |
| 81 | 95.05 | -19.97 | 80.4 | 0.976 | 0.00955 | 0.00976 | 94.454 | 0.346 | 3.862 | 3479.4 |
| 82 | 95.95 | -14.96 | 80.2 | 0.987 | 0.00977 | 0.00989 | 101.905 | 0.345 | 3.909 | 3475.5 |
| 83 | 96.56 | -9.98 | 80.2 | 0.999 | 0.00982 | 0.00949 | 103.373 | 0.342 | 3.923 | 3479.3 |
| 84 | 96.99 | -5.06 | 80.2 | 0.991 | 0.00935 | [illegible] | 102.407 | [illegible] | 3.916 | 3475.9 |
| 85 | 97.58 | +0.07 | 80.1 | 0.992 | 0.00987 | 0.00994 | 102.321 | [illegible] | [illegible] | 3477.1 |
| 86 | 95.08 | +0.04 | [illegible] | 0.956 | 0.00911 | 0.00951 | 89.414 | 0.367 | 3.723 | 3482.0 |
| 87 | 95.06 | +0.02 | 0.0 | 0.963 | 0.00893 | 0.00926 | 88.747 | 0.362 | 3.711 | 3476.6 |
| 90 | 94.95 | +1.05 | 0.0 | 0.960 | 0.00891 | [illegible] | [illegible] | 0.355 | 3.722 | 3471.7 |
| 91 | 94.93 | +0.84 | 135.3 | 0.948 | 0.00867 | 0.00933 | 90.847 | 0.351 | 3.728 | 3466.8 |
| 92 | 94.61 | -4.98 | 136.5 | 0.952 | 0.00914 | 0.00958 | 91.853 | 0.356 | 3.733 | 3466.5 |
| 93 | 94.90 | -9.91 | 135.5 | 0.960 | 0.00933 | 0.00969 | 95.277 | 0.352 | 3.796 | 3466.8 |
| 94 | 94.94 | -15.16 | 135.5 | 0.968 | 0.00955 | 0.00982 | 97.932 | 0.351 | 3.843 | 3470.9 |
| 95 | 94.94 | -20.05 | 135.1 | 0.970 | 0.00974 | 0.01001 | 100.705 | 0.348 | 3.870 | 3466.1 |
| 96 | 95.02 | -25.21 | 135.0 | 0.966 | 0.00988 | 0.01021 | 102.191 | 0.349 | [illegible] | 3465.9 |
| 97 | 95.95 | -19.87 | 134.8 | 0.986 | 0.01007 | 0.01019 | 106.471 | 0.340 | 3.951 | 3466.0 |
| 98 | 96.72 | -15.02 | 134.7 | 0.996 | 0.01021 | 0.01022 | 108.766 | 0.333 | [illegible] | 3468.7 |
| 99 | 97.26 | -9.87 | 134.8 | 0.994 | 0.01025 | 0.01027 | 107.729 | 0.343 | [illegible] | 3469.7 |
| 100 | 97.61 | -5.17 | 134.7 | 0.997 | 0.01030 | 0.01031 | 108.479 | 0.342 | 3.995 | 3468.4 |
| 101 | 98.49 | -0.30 | 134.7 | 1.001 | 0.01034 | 0.01027 | 110.832 | 0.336 | 4.022 | 3477.4 |
| 102 | 94.90 | -0.07 | 136.4 | 0.932 | 0.00954 | 0.01021 | 98.975 | 0.347 | 3.743 | 3468.1 |
| 103 | 94.51 | -5.07 | 136.3 | 0.938 | 0.00957 | 0.01019 | 100.759 | 0.342 | 3.765 | 3465.2 |
| 104 | 95.15 | -10.06 | 136.1 | 0.951 | 0.00969 | 0.01017 | 103.106 | 0.338 | 3.826 | 3468.4 |
| 105 | 95.17 | -15.32 | 136.3 | 0.962 | 0.00982 | 0.01016 | 104.264 | 0.339 | 3.865 | 3467.3 |
| 106 | 94.75 | -19.96 | 136.0 | 0.962 | 0.00990 | 0.01029 | 102.983 | 0.346 | 3.851 | 3463.7 |
| 107 | 95.00 | -19.98 | 136.1 | 0.965 | 0.00990 | 0.01025 | 103.802 | 0.343 | [illegible] | 3469.2 |
| 164 | 94.97 | -0.13 | 0.0 | 0.959 | 0.00908 | 0.00947 | 90.025 | 0.363 | 3.705 | 3476.2 |
| 165 | 96.03 | -0.12 | 0.0 | 0.975 | 0.00950 | 0.00975 | 95.562 | 0.358 | 3.794 | 3477.8 |
| 166 | 97.06 | -0.13 | 0.0 | 0.991 | 0.00987 | [illegible] | 100.953 | 0.352 | 3.890 | 3477.6 |
| 167 | 97.60 | -0.10 | 0.0 | 0.999 | 0.01005 | [illegible] | 103.945 | 0.348 | 3.916 | 3479.4 |

**TABLE 1**

| $T_2$ °C | $T_5$ °C | $T_6$ °C | $T_8$ °C | $P_2$ kPa | $P_4$ kPa | $P_6$ kPa | $P_8$ kPa | $P_9$ kPa | $NO_x$ PPM | HC PPM | CO PPM | RUN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 204.4 | 941.4 | 791.4 | 703.8 | 374.9 | 375.2 | 183.3 | 109.7 | 103.9 | | 1.8 | 18.1 | 32 |
| 203.3 | 937.7 | 788.7 | 701.1 | 372.5 | 372.9 | 182.3 | 109.6 | 103.9 | [illegible] | 1.7 | 22.1 | 33 |
| 201.8 | 930.7 | 783.0 | 697.2 | 368.2 | 368.7 | 180.9 | 109.4 | 103.9 | 78.4 | 1.9 | 21.5 | 34 |
| 201.2 | 928.8 | 781.6 | 696.3 | 365.4 | 365.9 | 179.9 | 109.3 | 103.8 | 78.1 | 1.9 | 20.9 | 35 |
| 198.8 | 913.9 | 771.8 | 690.3 | 359.0 | 359.6 | 177.7 | 109.1 | 103.8 | 74.8 | 0.6 | 22.7 | 36 |
| 197.6 | 914.1 | 770.0 | 688.7 | 354.0 | 354.5 | 176.0 | 109.0 | 103.7 | 72.9 | 0.5 | 23.2 | 37 |
| 197.2 | 914.2 | 770.4 | 690.4 | 349.6 | 350.2 | 174.5 | 108.8 | 103.7 | 72.9 | 0.2 | 23.9 | 38 |
| 204.6 | 941.3 | 791.1 | 703.6 | 374.6 | 375.5 | 183.3 | 109.7 | 103.9 | 82.7 | 1.0 | 19.9 | 39 |
| 206.8 | 950.7 | [illegible] | 709.7 | 379.0 | 379.9 | 184.8 | 109.9 | 104.0 | 84.8 | 1.6 | 19.6 | 40 |
| 207.4 | 954.9 | 802.3 | 712.6 | 381.4 | 382.3 | 185.3 | 110.0 | 104.0 | 86.4 | 1.6 | 20.1 | 41 |
| 209.3 | 964.0 | [illegible] | 723.1 | 384.5 | 385.4 | 186.5 | 110.2 | 104.0 | 91.9 | 2.4 | 17.2 | 42 |
| 211.3 | 976.3 | 823.4 | 729.5 | 387.1 | 388.0 | 187.1 | 110.3 | 104.0 | [illegible] | 3.0 | 17.3 | 43 |
| 204.7 | 941.7 | 791.4 | 704.1 | 374.5 | 375.6 | [illegible] | 109.8 | 103.9 | 82.2 | 1.4 | 21.2 | 44 |
| 205.2 | 946.0 | 795.4 | 706.7 | 376.6 | 377.7 | [illegible] | 109.8 | 103.9 | 83.4 | 1.4 | 20.6 | 45 |
| 206.8 | 939.2 | 787.1 | 709.5 | 379.7 | 380.8 | 183.6 | 109.9 | 104.0 | 82.8 | 1.4 | 19.8 | 46 |
| 209.1 | 943.8 | [illegible] | 703.3 | 383.9 | 384.9 | 181.9 | 110.0 | 104.0 | 84.2 | 1.4 | 20.4 | 47 |
| 211.0 | 933.9 | 778.3 | 695.3 | 385.4 | 386.6 | 181.8 | 110.1 | 104.1 | 82.3 | 1.4 | 20.7 | 48 |
| 211.5 | 939.9 | 783.7 | 699.5 | 386.0 | 387.2 | 182.5 | 110.1 | 104.1 | 83.0 | 1.4 | 21.5 | 49 |
| 215.7 | 941.0 | 781.4 | 701.0 | 387.5 | 383.8 | [illegible] | 110.2 | 104.1 | 82.4 | 1.4 | 20.2 | 50 |
| 217.1 | 941.8 | [illegible] | 704.1 | 382.7 | 383.9 | 176.0 | 110.2 | 104.0 | 85.6 | 1.4 | 19.5 | 51 |
| 205.2 | 942.1 | 791.6 | 704.3 | 378.6 | 376.4 | 183.0 | 110.0 | 104.0 | 84.1 | 5.0 | 23.4 | 54 |
| 205.0 | 923.8 | 775.6 | 693.0 | 377.6 | 375.9 | [illegible] | 109.8 | 103.9 | 72.4 | 4.7 | 20.5 | 55 |
| 206.1 | 929.2 | 780.0 | 693.7 | 380.1 | 373.4 | [illegible] | 109.9 | 103.9 | 73.7 | 5.0 | 21.9 | 56 |
| 207.6 | 936.6 | 786.2 | 690.1 | 383.4 | 382.9 | 185.2 | 110.0 | 104.0 | 76.2 | 5.0 | 20.6 | 57 |
| 208.6 | 942.2 | 791.0 | 702.7 | 385.7 | 384.5 | 185.9 | 110.2 | 104.0 | 79.6 | 5.0 | 18.5 | 58 |
| 207.6 | 940.8 | 791.4 | 702.3 | 383.4 | 382.3 | [illegible] | 110.0 | 104.0 | 76.5 | 5.1 | 19.4 | 59 |
| 205.8 | 942.2 | [illegible] | 704.5 | 379.9 | 379.0 | 185.5 | 109.9 | 103.9 | 75.6 | 5.2 | 19.7 | 60 |
| 205.6 | 942.5 | 793.9 | 705.1 | 377.9 | 377.4 | 185.3 | 109.9 | 103.9 | 76.5 | 5.1 | 19.6 | 61 |
| 204.6 | 941.1 | 791.0 | 703.9 | 375.6 | 375.1 | 182.9 | 109.9 | 104.0 | 35.3 | 4.7 | 22.0 | 62 |
| 208.8 | 947.8 | 796.4 | 707.6 | 385.1 | 384.7 | 186.6 | 110.1 | 104.0 | 79.0 | 4.4 | 19.4 | 63 |
| 208.2 | 944.0 | 793.2 | 704.8 | 383.7 | 383.6 | 186.1 | 110.1 | 104.0 | 77.1 | 4.3 | 19.2 | 64 |
| 208.3 | 944.2 | 793.2 | 704.3 | 383.9 | 383.8 | 186.2 | 110.1 | 104.0 | 76.4 | 4.4 | 19.3 | 65 |
| 208.2 | 942.1 | 791.2 | 703.1 | 383.2 | 383.2 | 186.1 | 110.1 | 104.0 | 77.3 | 4.3 | 18.5 | 66 |
| 203.6 | 938.2 | 788.3 | 702.5 | 376.4 | 373.6 | 182.5 | 109.9 | 103.9 | 78.0 | 3.0 | 10.6 | 69 |
| 204.5 | 942.0 | 791.9 | 704.7 | 377.6 | 374.8 | 182.9 | 110.0 | 104.0 | 78.5 | 3.1 | 10.5 | 70 |
| 204.2 | 902.1 | 759.2 | 674.1 | 378.3 | 375.8 | 183.6 | 109.6 | 103.9 | 50.4 | 2.9 | 11.3 | 71 |
| 205.4 | 908.3 | 764.4 | 673.3 | 380.7 | 378.4 | 184.4 | 109.6 | 103.9 | 55.3 | 0.6 | 10.6 | 72 |
| 207.1 | 917.8 | 772.4 | 684.3 | 394.8 | 382.5 | 185.9 | 109.7 | 103.9 | 56.6 | 0.6 | 10.3 | 73 |
| 209.0 | 928.5 | 781.6 | 692.7 | 398.3 | 386.1 | 187.1 | 109.9 | 104.0 | 59.0 | 0.5 | 9.1 | 74 |
| 210.9 | 940.9 | 792.4 | 701.9 | 390.6 | 388.4 | 187.9 | 110.0 | 104.0 | 62.8 | 0.5 | 9.2 | 75 |
| 209.3 | 941.2 | 794.1 | 701.0 | 389.1 | 386.9 | 188.7 | 110.0 | 104.0 | 61.4 | 0.5 | 8.7 | 76 |
| 207.1 | 943.9 | 798.6 | 706.8 | 385.2 | 383.2 | 189.2 | 109.9 | 103.9 | 64.2 | 0.5 | 8.9 | 77 |
| 205.8 | 944.1 | 799.9 | 708.4 | 381.9 | 380.0 | 188.8 | 109.7 | 103.9 | 62.1 | 0.1 | 8.5 | 78 |
| 204.7 | 935.7 | 792.4 | 702.5 | 379.0 | 377.1 | 187.8 | 109.7 | 103.9 | 61.2 | 0.3 | 8.8 | 79 |
| 204.2 | 944.8 | 802.1 | 710.0 | 379.0 | 377.2 | 188.8 | 109.6 | 103.8 | 61.3 | 0.3 | 8.2 | 80 |
| 211.5 | 938.9 | 789.8 | 700.0 | 391.1 | 389.4 | 187.9 | 110.1 | 104.0 | 61.1 | 0.3 | 9.7 | 81 |
| 212.7 | 939.4 | 790.4 | 697.6 | 395.7 | 394.1 | 189.5 | 110.3 | 104.1 | 63.1 | 0.3 | 7.4 | 82 |
| 213.1 | 939.7 | 789.3 | 697.1 | 397.2 | 395.3 | 190.2 | 110.3 | 104.1 | 62.3 | 0.3 | 9.3 | 83 |
| 213.2 | 937.9 | 797.4 | 695.6 | 396.6 | 395.1 | 189.9 | 110.3 | 104.1 | 62.7 | 0.3 | 8.8 | 84 |
| 213.7 | 939.9 | 789.0 | 696.7 | 397.6 | 396.0 | 190.2 | 110.4 | 104.1 | 61.6 | 0.3 | 7.9 | 85 |
| 204.8 | 895.2 | 751.8 | 669.7 | 377.0 | 375.7 | 182.8 | 109.6 | 103.9 | 49.6 | 0.3 | 10.4 | 86 |
| 204.0 | 934.3 | 784.7 | 699.1 | 375.3 | 374.5 | 182.0 | 109.9 | 103.9 | 79.0 | 0.3 | 9.5 | 87 |
| 204.3 | 942.4 | 792.5 | 705.4 | 376.9 | 374.4 | 183.1 | 109.7 | 103.9 | 85.7 | 0.9 | 15.8 | 90 |
| 204.1 | 876.7 | 738.5 | 655.1 | 377.6 | 375.4 | 183.9 | 109.1 | 103.9 | 44.4 | 1.3 | 18.0 | 91 |
| 204.5 | 880.3 | 741.7 | 657.4 | 378.6 | 376.6 | 184.2 | 109.1 | 103.8 | 44.3 | 1.2 | 18.5 | 92 |
| 206.8 | 893.4 | 752.8 | 666.1 | 384.4 | 382.4 | 186.2 | 109.3 | 103.9 | 46.6 | 1.0 | 18.6 | 93 |
| 209.4 | 906.1 | 763.4 | 675.3 | 389.2 | 387.3 | 187.9 | 109.4 | 103.9 | 43.8 | 1.0 | 17.3 | 94 |
| 211.4 | 918.6 | 774.2 | 684.5 | 391.9 | 390.1 | 188.3 | 109.6 | 103.9 | 52.9 | 0.9 | 14.9 | 95 |
| 214.7 | 941.8 | 794.8 | 702.7 | 393.8 | 392.0 | 189.1 | 109.8 | 103.9 | 57.3 | 0.9 | 14.1 | 96 |
| 215.2 | 937.0 | 789.2 | 696.0 | 400.3 | 398.5 | 192.0 | 110.0 | 104.0 | 56.6 | 0.9 | 14.2 | 97 |
| 216.3 | 938.8 | 790.1 | 695.5 | 404.1 | 402.4 | 193.7 | 110.2 | 104.1 | 56.5 | 1.0 | 14.5 | 98 |
| 215.9 | 936.8 | 788.5 | 693.1 | 403.6 | 402.1 | 193.4 | 110.1 | 104.1 | 56.1 | 1.1 | 15.5 | 99 |
| 216.6 | 937.6 | 788.7 | 694.4 | 404.6 | 405.0 | 194.0 | 110.2 | 104.1 | 56.9 | 1.0 | 15.6 | 100 |
| 217.8 | 943.8 | 793.9 | 697.0 | 407.3 | 405.8 | 194.9 | 110.3 | 104.1 | 57.9 | 0.9 | 14.9 | 101 |
| 204.4 | 934.8 | 796.5 | 703.2 | 379.1 | 377.7 | 190.6 | 109.2 | 103.8 | 54.0 | 0.9 | 14.2 | 102 |
| 205.1 | 937.1 | 798.1 | 704.1 | 381.3 | 380.0 | 191.2 | 109.3 | 103.9 | 53.5 | 0.8 | 15.8 | 103 |
| 208.0 | 942.7 | 801.3 | 706.8 | 387.4 | 386.2 | 192.4 | 109.5 | 103.8 | 55.8 | 0.9 | 12.9 | 104 |
| 210.3 | 940.4 | 797.1 | 703.4 | 391.4 | 390.1 | 192.2 | 109.7 | 103.9 | 55.3 | 0.9 | 15.6 | 105 |
| 210.7 | 936.8 | 793.1 | 701.6 | 390.2 | 389.0 | 191.2 | 109.7 | 103.9 | 55.6 | 0.9 | 12.8 | 106 |
| 211.4 | 941.2 | 797.0 | 703.0 | 392.1 | 391.0 | 191.7 | 109.3 | 103.9 | 55.7 | 0.9 | 14.7 | 107 |
| 204.3 | 942.9 | 793.0 | 706.0 | 375.2 | 373.8 | 182.7 | 109.5 | 103.6 | | | | 164 |
| 208.2 | 961.3 | 808.1 | 717.7 | 384.2 | 382.7 | 186.0 | 110.0 | 103.7 | | | | 165 |
| 212.0 | 978.0 | 821.4 | 727.9 | 393.9 | 392.7 | 189.7 | 110.5 | 103.9 | | | | 166 |
| 214.2 | 987.5 | 829.0 | 734.2 | 396.6 | 395.3 | 190.5 | 110.6 | 103.9 | | | | 167 |

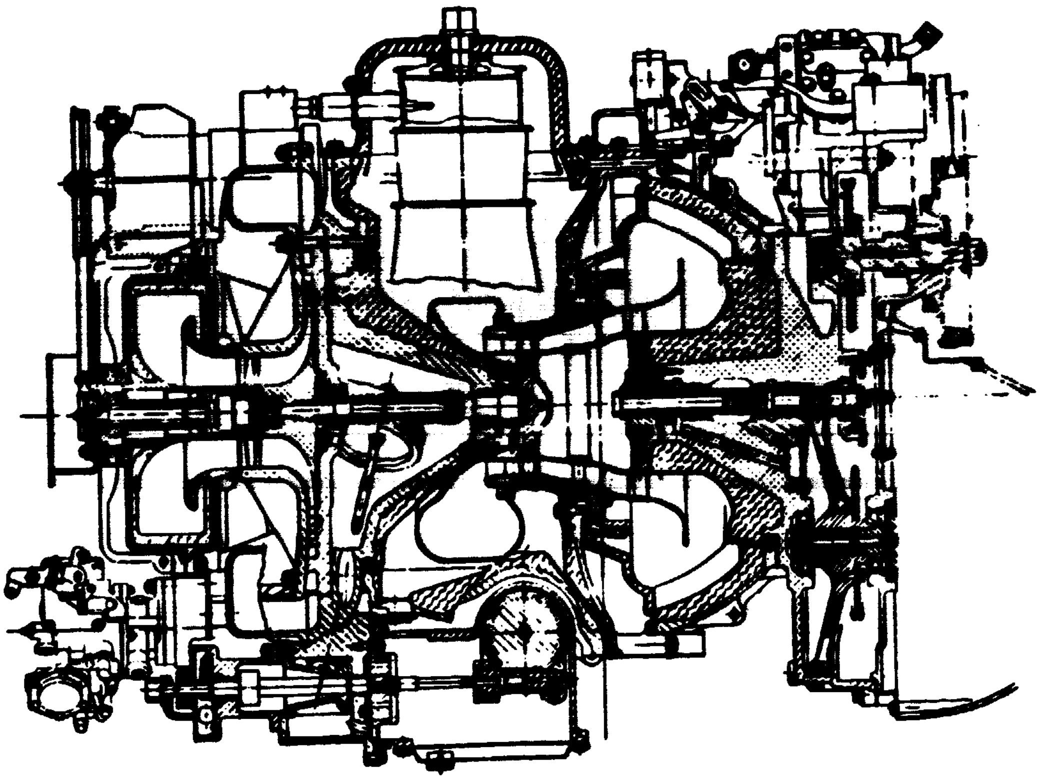
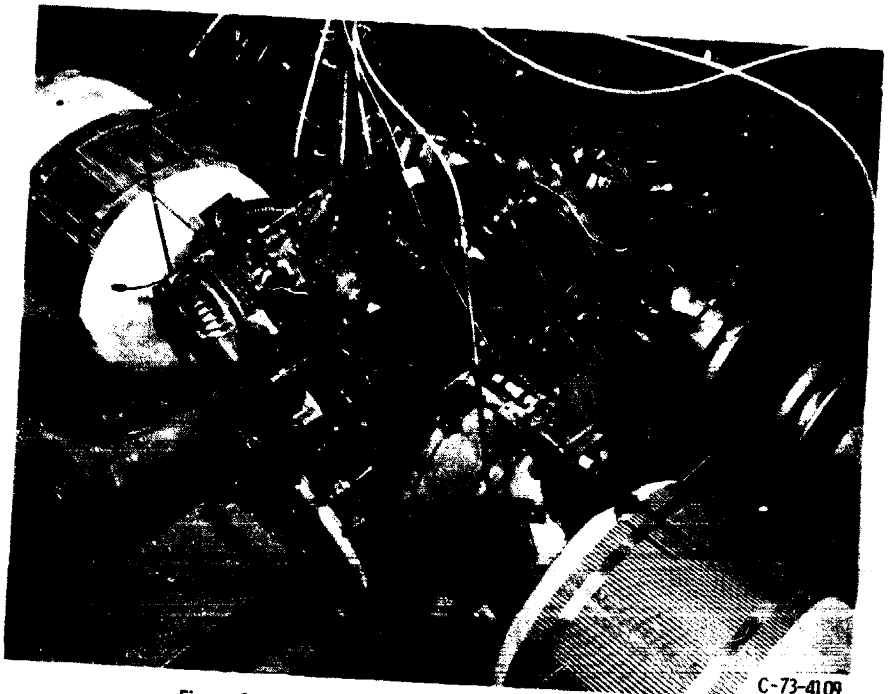


Figure 1. - Schematic Chrysler baseline engine.

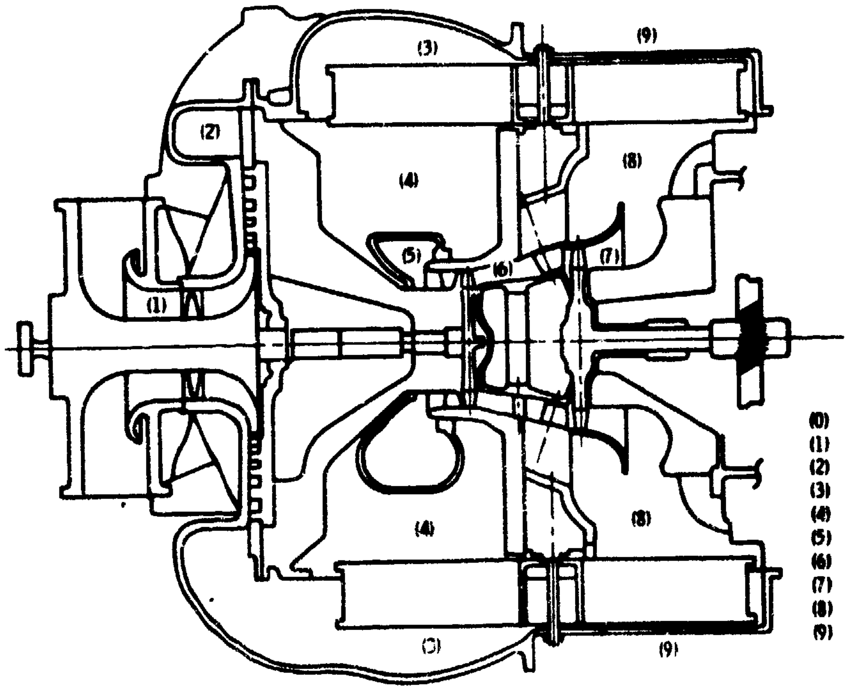


C-73-4109

Figure 2. - Chrysler baseline engine installed in test cell.


C-74-471

Figure 3. - Picture of water nozzle location on engine.




(0) Ambient
(1) Compressor inlet
(2) Compressor outlet
(3) Regenerator inlet (cold side)
(4) Burner inlet
(5) Compressor turbine inlet
(6) Power turbine inlet
(7) Power turbine outlet
(8) Regenerator inlet (hot side)
(9) Regenerator outlet

Figure 4. - Chrysler baseline engine station notation.

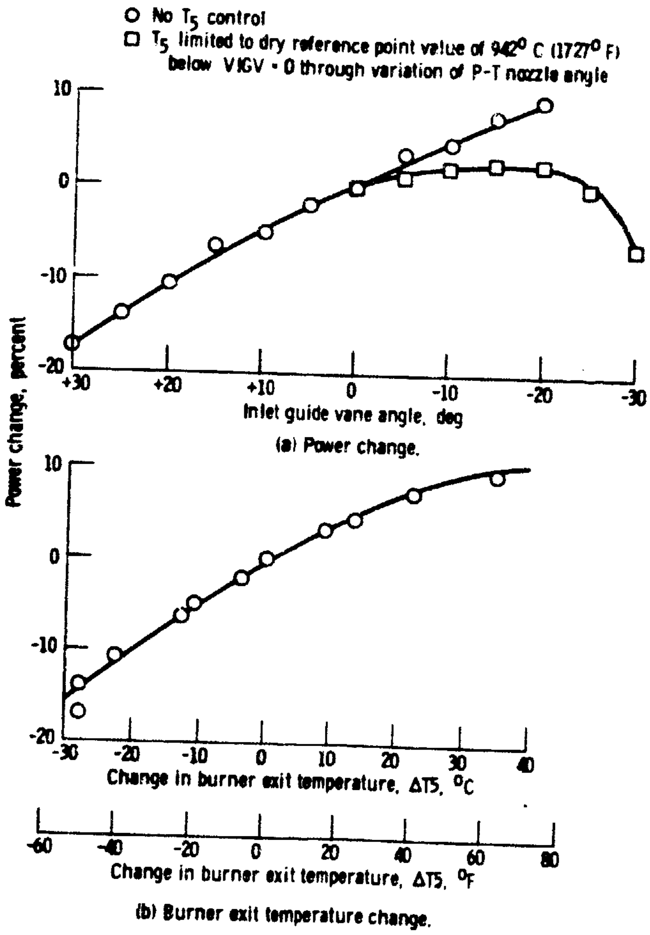
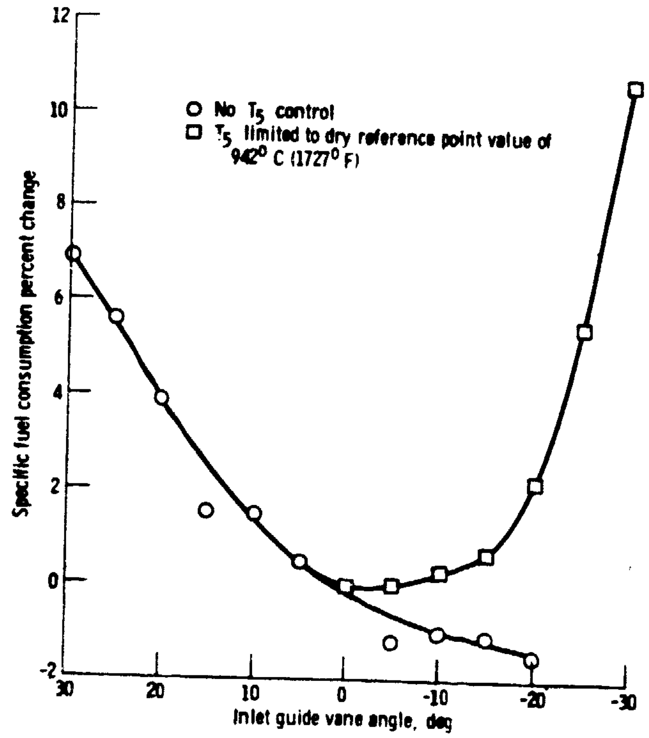



Figure 5. - Effect of varying VIGV angle at 95 percent $N_{GG}$ - no water injection.




(c) Change in SFC.

Figure 5. - Concluded.

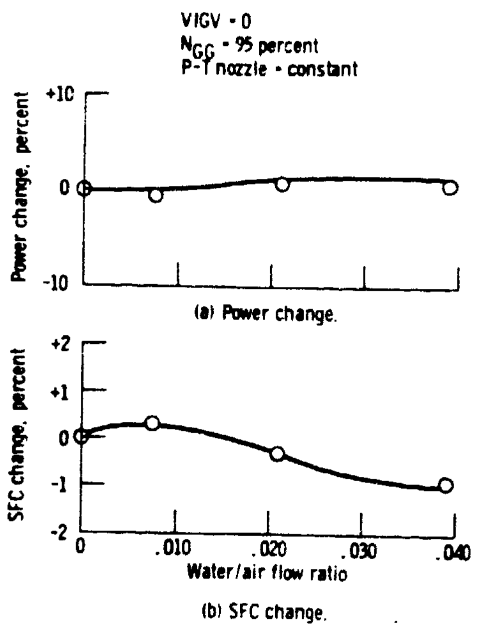
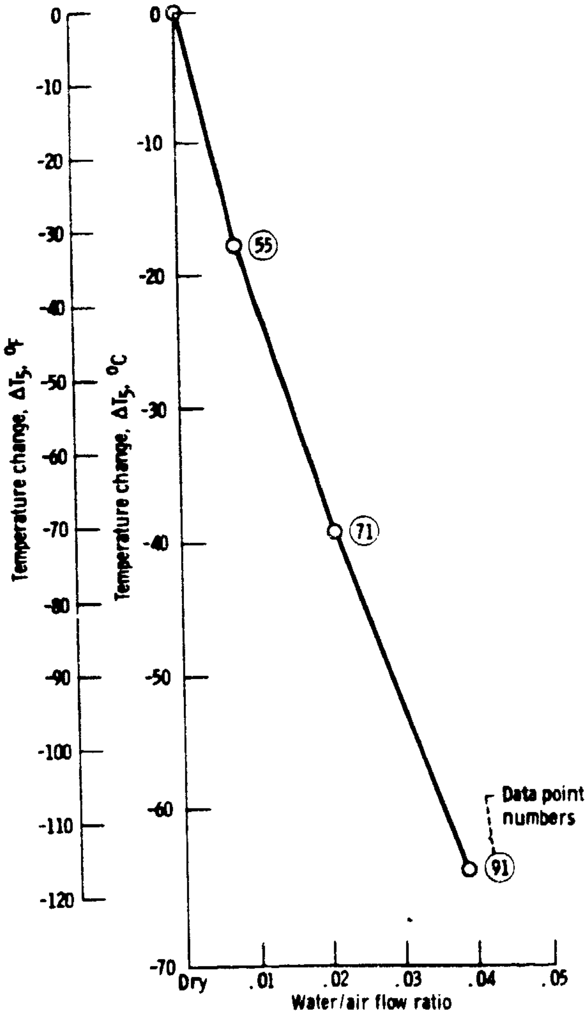
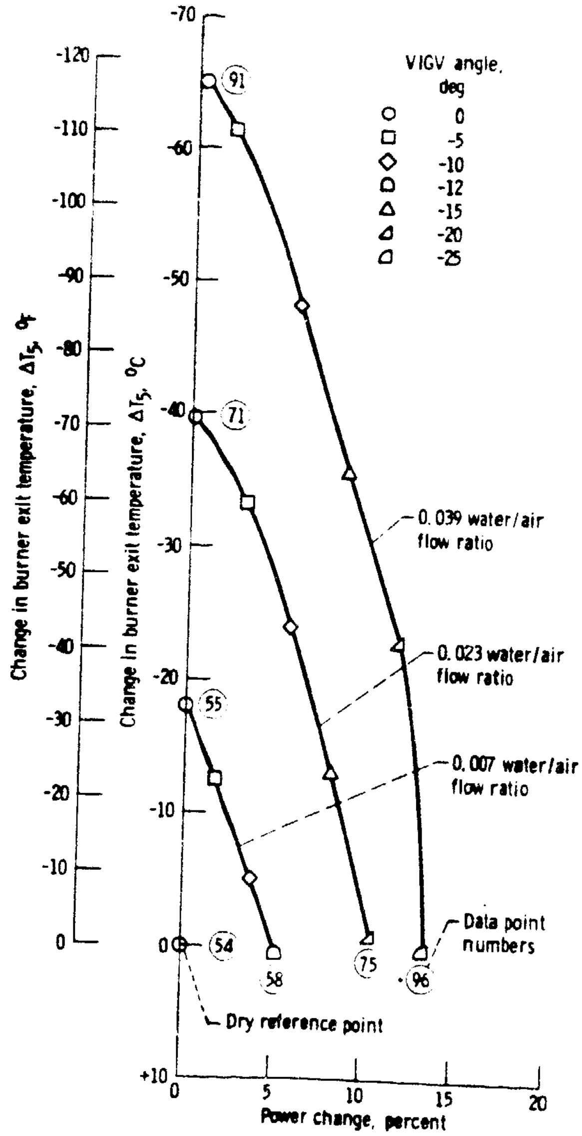



Figure 6. - Effect of water injection.



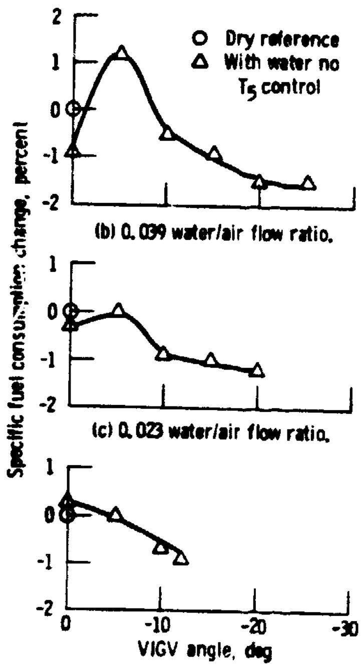

(c) Burner exit temperature change.

Figure 6. - Concluded.




(a) Burner exit temperature change.

Figure 7. - Effect of varying both water injection and VIGV angle.




(d) 0.0076 water/air flow ratio.

Figure 7. - Concluded.

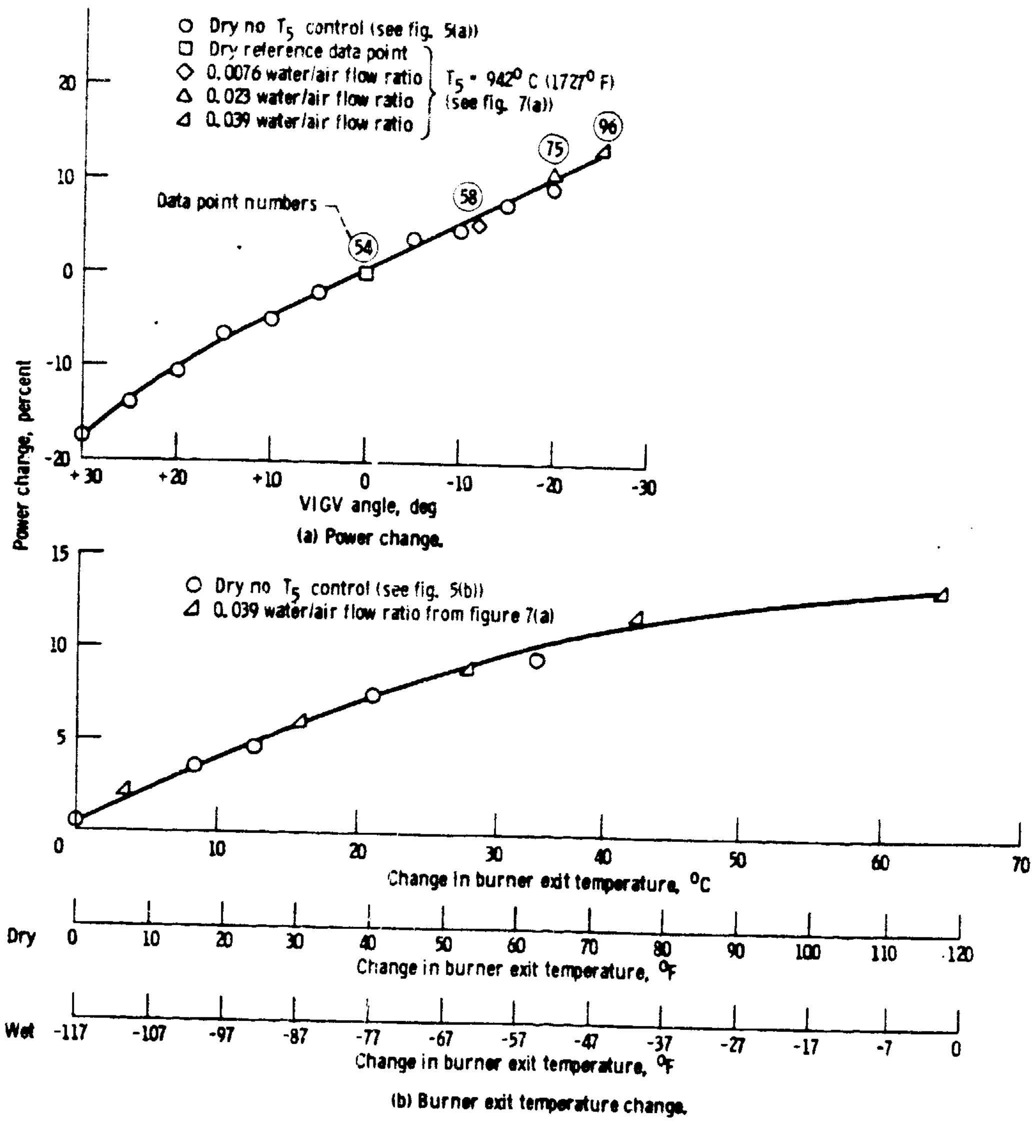
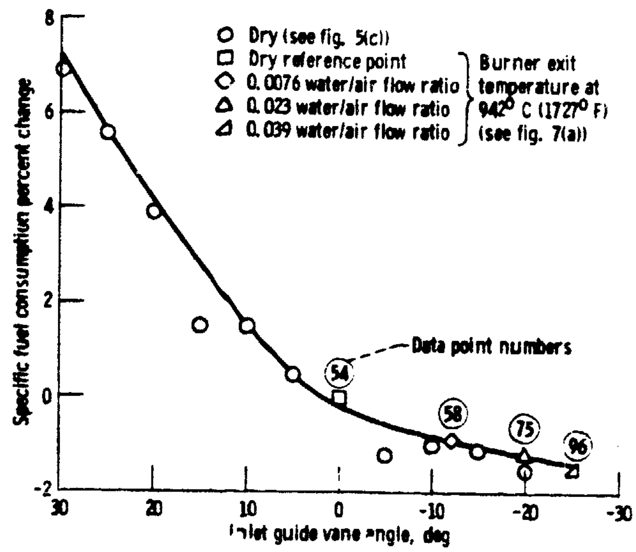
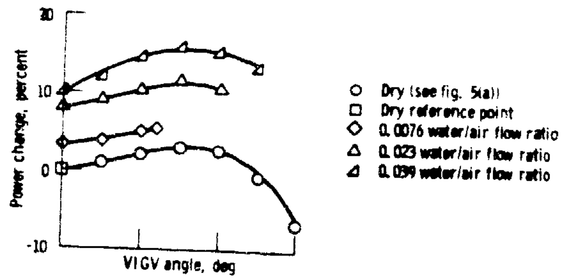



Figure 8. - Comparison of VIGV angle effect with and without water injection.

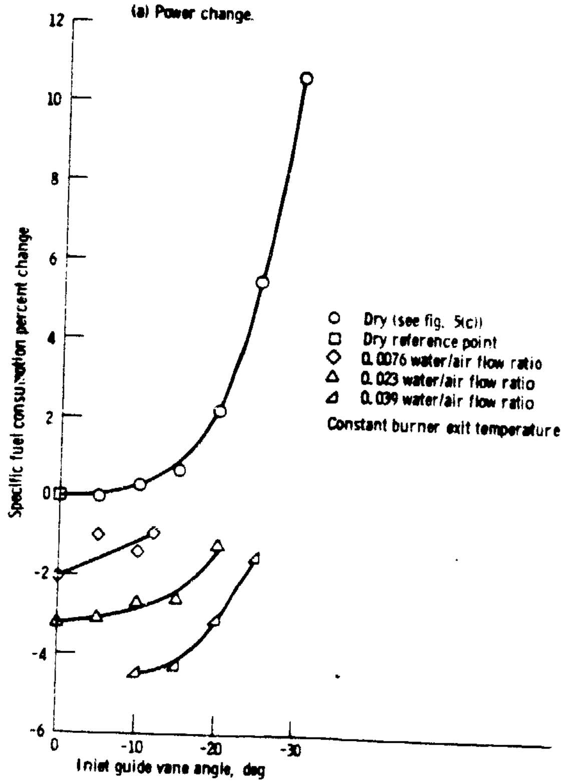



(c) SFC change.

Figure 8. - Concluded.




(a) Power change.




(b) SFC change.

Figure 9. - Effect of variation of water injection and VIGV angle at 95 percent gas generator speed with burner exit temperature held constant by varying power turbine nozzle angle.

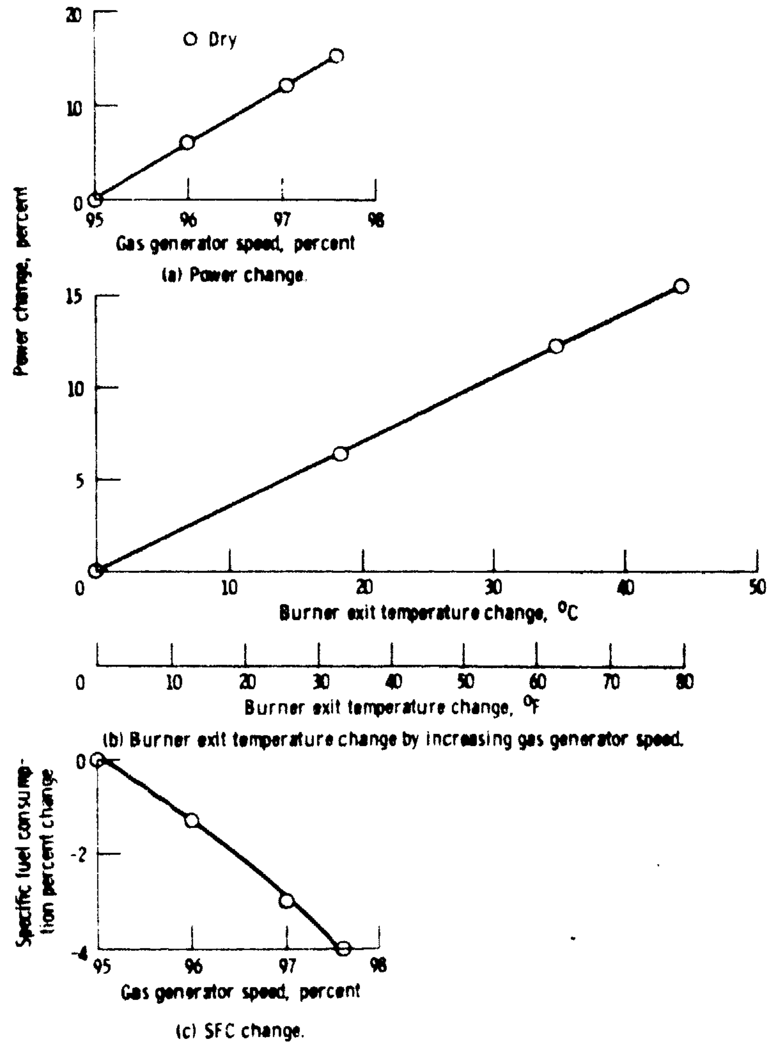



Figure 10. - Effect of varying gas generator speed (without water injection, 0 VIGV angle, constant power turbine nozzle angle).

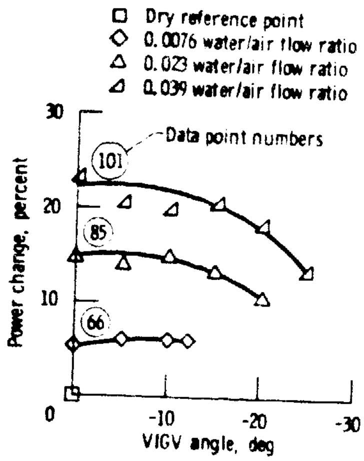



Figure 11. - Effect of variation of water injection and VIGV angle with burner exit temperature held constant by varying gas generator speed.

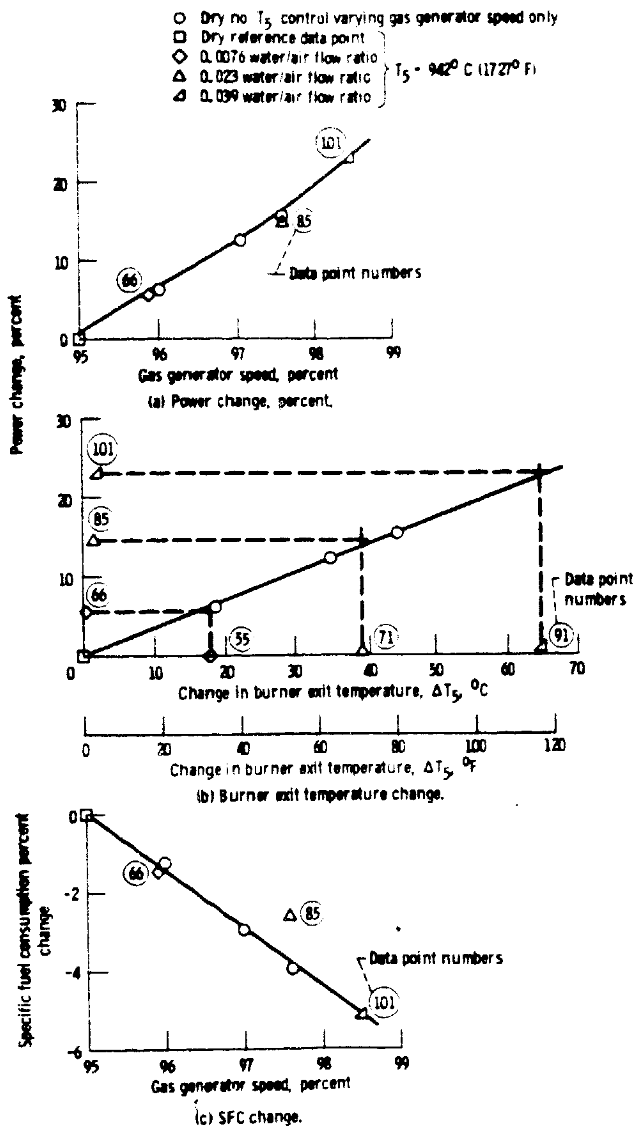



Figure 12. - Comparison of gas generator speed effect with and without water.

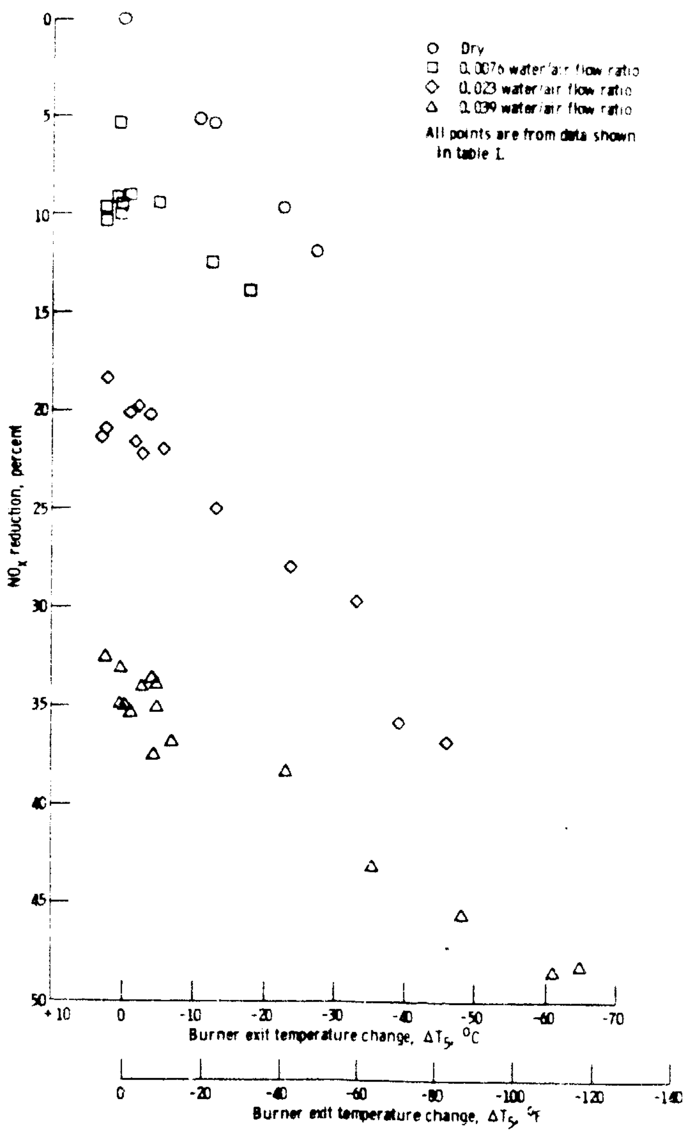



Figure 13. - Effect of water injection on $NO_x$.

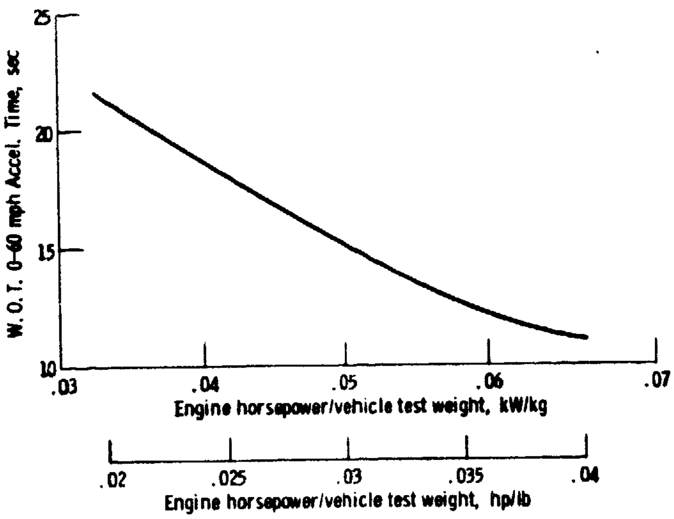



Figure 14. - Typical Auto. Accel. Time vs hp/wt Ratio: 3 Speed Automatic Transmission.

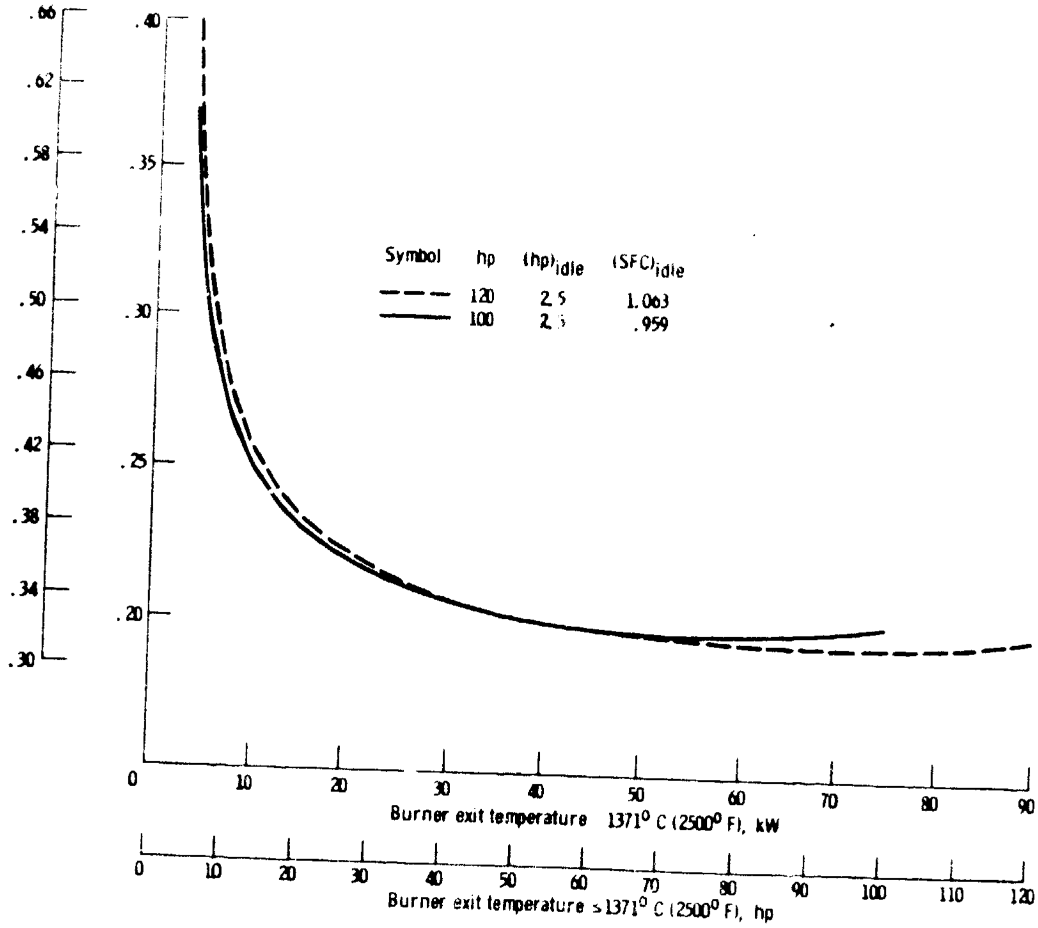



Figure 15. - Effect of design power on SFC's.

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