CRC Report No. 639

JET FUEL CONTAMINATION WITH DIESEL FUEL DYES

April 2004

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JET FUEL CONTAMINATION WITH DIESEL FUEL DYES

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CRC Aviation Fuel, Lubricant & Equipment Research Committee
of the
Coordinating Research Council, Inc.

SUMMARY

Engine, APU and airframe OEM's and industry representatives have reviewed the results from the GE and Southwest Research Institute (SwRI) red dye in jet fuel test programs and have concluded that red dye contamination in jet fuel at neither 5% nor 2.5% (See Table 2 for red dye concentrations) is acceptable for use on a continuous basis. The test data indicate that a lower level may be acceptable but the acceptable level will require additional testing. The 5% and 2.5% refer to the amount of actual red dye that could be expected in jet fuel if jet fuel were contaminated with red dyed diesel fuel that contained the IRS required concentration of red dye for non-taxed diesel fuel. The conclusions are based on the effect of the red dye alone and not the combined effects of the red dye and diesel. Additional testing will be required if the effects of diesel fuel or diesel fuel plus red dye are to be determined.

History

- 1993 – EPA required blue dye in high sulfur fuels.
- 1993 - IRS required blue dye in tax-free diesel fuel/heating oil .
- No dye required in jet fuel, but cross-contamination resulted in blue jet fuel.
- 1994 - Because of possible misidentification as Avgas 100LL, EPA and IRS switched to red dye.
- IRS dosage about 5 times EPA requirement.
- 1994 – new CRC group to investigate possible effects of dye contamination on jet fuel.
- After red jet fuel appeared at airports, OEMs prohibited use of such fuel in aircraft operation.
- Since 1994 more than 20 instances of red airline jet fuel have been reported, with none since 1999.

Experimental Work

- 1994/1995–14 laboratories ran JFTOT breakpoints on 29 fuels containing maximum IRS dosage of red dye.
  - 10 of 29 fuels showed breakpoint decreases of 10°C or more.
  - Of these fuels, 4 fuels showed similar breakpoint decreases with 10% of IRS dosage.
  - Two of 4 fuels showed such decreases with 1% of IRS dosage.
  - Except for increased electrostatic charging, no other properties significantly affected.
  - Tests requiring visual inspection could not be run because product dyed to IRS levels was opaque.
- 1996 - GE engine runs for 45 accelerated flight cycles for 12 hours on fuel containing 5% of IRS dosage to check nozzle performance.

  10 of 15 nozzles showed significant hysteresis increases, 4 outside of limits.

  After operating engine on neat fuel for 44 hours, 6 nozzles recovered, 2 showed partial recovery, 2 remained outside of limits.
- 2001/2003 – Southwest Research Institute conducted hot engine component tests, using 9 engine fuel nozzles, one torque motor filter screen and one spool valve.

  5% and 2.5% of IRS dosage was added to a sensitive fuel and performance compared to a

fuel just passing D 1655 JFTOT requirements.
Key parameters were nozzle fouling rate, screen plugging and spool valve sticking. Fouling occurred with the 2.5% fuel in some nozzles.

Conclusions by GE

- Red dye in the fuel at relatively low concentration levels can cause incipient deposits in fuel nozzles even with short duration use.
- The presence of these deposits can immediately affect the operation of the fuel nozzles.

Conclusions by SwRI

- Red dye can measurably increase engine nozzle fouling rate.
- Effect is design specific as some nozzles proved more sensitive to red dye than others.
- Filter screens and spool valves appear less sensitive to red dye than engine nozzles.

Current OEM Positions

- Two Boeing service bulletins require that only fuel showing no evidence of red in the White Bucket test can be used to operate aircraft. Other OEM's agree to this restriction.
- In response to possible airport shutdowns Boeing and major engine OEM's have issued procedures for emergency use of dye contaminated fuel.

Future work

- OEM's are agreed that SwRI test data are insufficient to decide on an acceptable limit of red dye in jet fuel. More testing is proposed to establish this limit.
- Additional testing is planned to establish the effects of jet fuel contamination by diesel fuel and by diesel fuel plus red dye.

INTRODUCTION

The purpose of this report is to document the history of aviation turbine fuel contamination with middle distillate fuel dyes and to summarize laboratory studies, engine tests and hot engine component runs made to establish the effect of red dye contamination on aviation turbine fuels. For clarity the various items have been grouped by topics, although that approach can place them out of chronological order.

HISTORY

The problem of jet fuel contamination by middle distillate dye goes back to 1990 when both the Environmental Agency (EPA)[1] and the Internal Revenue System (IRS)[2] moved to require dyeing of middle distillate fuels for differing reasons. EPA wanted high sulfur fuel distinguished from low sulfur on-road diesel fuel to prevent the use of off-road fuel in over-the-road vehicles. IRS wanted untaxed off-road diesel fuel and heating oil to be dyed to catch violators who were avoiding diesel fuel road taxes by using untaxed fuels in on-road trucks. Because the high sulfur fuel is normally untaxed, the same dye could be required for both purposes. However, the mandated dye dosages differed significantly. Aviation turbine fuel was exempted from the dye requirement.

Under these requirements, starting in 1993, both agencies required the addition of a blue dye, 1,4-dialkylaminoanthraquinone, which is approved for aviation gasoline per ASTM D 910. Although two dye levels were required, depending on whether the EPA or the IRS requirements were involved, refiners tended to blend to the higher IRS level to minimize the number of dye blending locations. When advised of the blue dye requirement, CRC members became concerned over the possibility of jet fuel contamination by dyed middle distillate because the resultant blue fuel could be mistakenly identified as AVGAS 100LL which is dyed blue with the same dye. CRC formally advised[3] the Federal Aviation Administration (FAA) of this potential hazard. The FAA contacted the other agencies, pointing out the resultant flight safety hazard involved by misfueling piston engine aircraft with aviation turbine fuel. The reality of such contamination is highlighted in Table 1, which lists locations where blue jet fuel reached airports but was properly identified and disposed of.

In line with CRC recommendations both agencies switched from a blue to a single red dye defined as Solvent Red 164. This is the liquid form of the dye and is composed of entirely of alkyl derivatives of azobenzene-4-azo-naphthol. Again jet fuel was exempted from the dye requirement. From an aviation standpoint red is a more innocuous color because red aviation gasoline, the 80 Grade, is virtually non-existent in the U. S. According to 40 CFR Part 80[4], the EPA required that as of 1 October 1994 all high sulfur middle distillate to be dyed to a visible red color at the refinery. As of the same date the blue dye was no longer to be purchased but existing stocks could be used up. In general the EPA requirement was met by a dye concentration of about 3 mg/L (1.1 lbs/1000 bbls) of liquid red dye. The IRS, on the other hand, wanted to be able to detect down to 10% of dyed, untaxed fuel in on-road undyed diesel fuel. In an IRS regulation dated October 1, 1994[5] the agency required the addition of 11.1 mg/L of solid red dye (Solvent Red 164) at the terminal where the fuel is loaded into transport trucks for distribution. The typical EPA concentration is therefore about 20% of the IRS minimum.

Here it is necessary to point out that this particular red dye is used in both solid or liquid form using the same active ingredient. IRS defines its minimum dosage in terms of the solid red dye but most users find the liquid dye easier to handle and adjust for the difference in the concentration of active ingredient. The commercial liquid dye is identified as Solvent Red 164, while the solid version is Solvent Red 26. Table 2 shows the relationship between the two forms of red dye in terms of lbs/1000 bbls and mg/L at various dye concentrations. As listed in the table both the solid and the liquid form contain the same amount of active ingredient. (For the sake of simplicity and ready comparison, this report shows dye concentrations as a percentage of the minimum IRS requirement.)

It can be seen that middle distillate dyed to the higher IRS minimum easily meets the EPA requirements.

OPERATING HISTORY

Although required only to add red dye to the lower EPA dye concentration, refiners initially dyed all untaxed, high sulfur middle distillates to the higher IRS level to reduce the number of injection points. When this fuel was tendered to multi-product pipelines and other means of transportation, jet fuel dyed various shades of red appeared in the system almost immediately. Several causes were identified. In one set of circumstances jet fuel followed dyed untaxed fuel in a pipeline, but the existing method of identifying batch changes allowed enough dyed fuel into the jet fuel to discolor it. In other cases where batches of dyed diesel were not in direct contact with aviation turbine fuels in the pipelines, the discoloration was caused by red fuel remaining in common components such as pipeline manifolds and pumps. Retention of small volumes of dyed fuel in barge and transport truck shipments of jet fuel produced unacceptable product colors. Finally, inadvertent red injection into jet fuel as well as other human errors occurred. Ultimately most pipelines injected the IRS dosage at terminals to reduce product losses. To eliminate the effects of the EPA dosage, even very slightly discolored jet fuel had to be cut into the dyed middle distillate fuel, resulting in significant jet fuel transit losses.

The ultimate list of red dye contamination incidents is shown in Table 3. Fortunately only three airports had to be shut down, including two in Alaska where airport operation had to wait for a replacement barge load of acceptable fuel. However, major supply problems occurred elsewhere, requiring that extra fuel be flown in on regular flights to minimize local shortages. Probably the worst incident occurred at Dulles International Airport where two out of three receiving tanks were contaminated with some 2.5 million gallons, which had to be trucked out over an eight week period. While no civil contamination incidents have been reported since 1999, the Defense Energy Supply Center rejected four batches for red dye contamination in the 2001 – 2002 period.

When red colored jet fuel began to appear at airports, manufacturers of original aircraft equipment became concerned over possible adverse effects on jet fuel and requested the formation of a CRC group to investigate the matter. The Group was approved by the Aviation Committee and was organized in May 1994. A current membership list is attached as Appendix A.

The first meeting disclosed a uniform position by the three large engine companies and Boeing, prohibiting red dye in jet fuel as an unapproved additive. At that time a CRC letter of June 23, 1994 was sent to the IRS recommending the use of a single red dye formulation (alkyl derivatives of azobenzene-4-azo-naphthol) and suggesting a 50% reduction in the minimum concentration of the red dye from 5.6 to 3 lbs per thousand barrels of Solvent Red 26 to reduce contamination problems. The recommendation was rejected by the IRS who pointed out informally that one year's tax receipts had increased by $1.4 billion since the dye introduction. The IRS also pointed out that their regulations did not require refinery injection.

To reduce the threat of an airport shutdown the airline industry requested its original equipment manufacturers (OEM's) to allow the use of fuel containing 0.5% or less of the minimum IRS requirement or 0.08 mg/L of liquid red dye on a continuous basis and to permit fuel containing between 0.5% and 2.5% (0.08 to 0.4 mg/L) if the fuel passed the JFTOT test at 260°C. This request was under consideration while the following experimental work was carried out.

EXPERIMENTAL WORK

Overall CRC efforts were directed at defining an acceptable level of red dye which could be used on a continuous basis. As its initial effort Group members agreed to carry out the experimental program contained in Appendix B. In the program's first stage the 14 participating laboratories were asked to add 100% of the IRS red dye dosage to a jet fuel meeting ASTM D 1655 and to conduct JFTOT breakpoints on the fuel with and without the dye. If the sample breakpoint decreased 10°C or more, other selected specification tests were to be run on the blends. No attempt was made to select fuels sensitive to the dye. For this program a significant decrease in thermal stability was defined as a change of greater than 5°C. (Based on past experience the reproducibility of the JFTOT breakpoint was taken as 5°C.) Initial studies showed that only thermal stability was adversely impacted. A summary of the JFTOT results is contained in Table 4. Some 10 out of 29 fuels showed a significant reduction in breakpoint. It is worth noting that none of the fuels with a significant breakpoint decrease failed the D 1655 then minimum requirement of 245°C, although four would have failed the current 260°C minimum limit. The work also indicated that fuel with this dosage of red dye could not be inspected visually for trace solid or water contamination because the fuel was almost opaque.

Group members then investigated the effect of reduced dye concentrations. Member laboratories were asked to evaluate 10% of the IRS dosage in those fuels which had shown significant breakpoint decreases with the full dosage and again to measure the change in breakpoint, if any. The results are shown in Table 5. Out of the eight fuel samples, four reflected no dye effect but four still showed significant decreases. In a third series of tests Exxon and Amoco added 2.5% red dye to their fuels and established that even this low contamination level could cause measurable degradation in a sensitive fuel. Table 6 lists red dye effects on other properties, particularly those considered sensitive to trace constituents. As indicated many of these properties are not part of the civil specification (D 1655) but are conducted routinely for quality control. With the exception of electrostatic charging at a 2.5% dye concentration, no significant effects were noted. This effect was not investigated further because subsequent actions by OEM's would prohibit such dye levels.

In reaction to these results and to answer the requests by the airline industry, General Electric conducted engine tests under cycling conditions intended to simulate accelerated flight patterns. The General Electric report is presented in Appendix D. The test fuel was Jet A containing twice the dye concentration requested by the airline for emergency use or 0.80 mg/L (5% of the IRS requirement). A series of "Commercial Operating Cycles" were conducted with the cycle conditions shown in Figure 1. A total of 45 such cycles were run on the dyed fuel in a GE CF60-80C2 engine. The test consumed 14,850 gallons of dyed fuel. Dye effects were detected by hysteresis changes during flow tests made on 15 fuel nozzles before and after engine operation on dyed fuel. In hysteresis testing the fuel nozzle flow rate is measured as nozzle pressure is increased from a minimum to a maximum level and when pressure is decreased from a maximum to a minimum pressure level. Hysteresis is defined as the difference in flow rate between the two test schedules. A clean nozzle shows little or no hysteresis effect; a used nozzle is allowed a band of permitted limits. A nozzle outside these limits has accumulated enough deposits to cause a significant loss in performance.

After 45 cycles, or about twelve hours of engine operation, ten of the fifteen nozzles showed increased hysteresis, four being outside the permitted limits. All nozzles were returned to the engine and the engine was run another 44 hours with undyed fuel. The same 15 nozzles were then again flow tested. Six of the 10 affected nozzles had returned to near pretest hysteresis levels; two had partially recovered and two were unchanged from the post test level. The report concluded that "the presence of red dye in the fuel, and at relatively low concentration levels, less than 1 mg/L, can cause incipient deposits in fuel nozzles even with short duration use. The presence of these deposits can immediately affect the operation of the fuel nozzles." The report then went on to recommend limiting engine operation on fuel containing 0.40 mg/L of red dye to 500 gallons per fuel nozzle and to require a flow check of the nozzles (must pass) before permitting any further use of dyed fuel. This recommendation was superceded by the OEM's agreeing to "Emergency Use" procedures.

METHODS OF DETECTION

Several approaches to field detection of red dye contamination were explored over the 1994 to 1997 period. Visual tests were carried out by White Bucket and glass jar inspections. Both techniques are qualitative. In the first test a white porcelain-coated bucket is two-thirds filled with fuel. Air bubbles are allowed to escape from the fuel through settling and the fuel is stirred enough to concentrate water drops or solids on the bucket bottom. The sample is then visually inspected. In the jar technique, commonly referred to as the "Clear and Bright" rating, fuel is placed into a one-quart wide-mouth clear glass jar and is inspected for turbidity as well as solids or droplets which have settled to the jar bottom. Both techniques are used widely, the White Bucket being preferred by the aviation industry, while the refining industry has standardized on the glass jar (ASTM D 4176). A quantitative approach to dye detection is based upon a portable spectrophotometer developed by Boston Technology under IRS contract to measure dye concentration in diesel fuel down to the 10% level. This device, called the DT 100, has been standardized as ASTM D 6756. As a more accurate backup for enforcement purposes, IRS requires a visible absorption spectroscopic technique (ASTM D 6258).

In October 1994 the Group recommended the development of colored acetate strips which would be used to define acceptable fuel quality. The work was undertaken by Gammon Technical who showed early samples to the Group[6]. However, visual interference by the initial fuel color, ranging from water-white to light yellow, complicated the development of this technique and it was abandoned in October 1995 following the development of the portable quantitative spectrophotometer.

Test work by Buckeye Pipeline, described in Appendix C, indicated the White Bucket to reveal lower red dye concentrations than did the glass jar. In fact, in the White Bucket one volume of fully dyed fuel was visible in 1600 volumes of water-white jet fuel, representing a dye level of about 0.06%. The DT 100 was not designed to detect such low concentrations so the instrument manufacturer developed the more sensitive JT 100. This instrument also operated in the visible spectrum and depended on filters to block out other colors. However, evaluations of the JT 100 in various laboratories gave conflicting results, particularly with dye levels that were barely visible in the White Bucket. Thus significant differences were noted between different instruments in the dye range at the visible threshold in the White Bucket. One difficulty was caused by the fact that the instrument responded to all red colors, not only the EPA/IRS dye. As a result a number of otherwise acceptable samples gave a positive reading when no dye had been added to the fuel. Such results in the field would disqualify a fuel batch until the type of red colorant could be identified by gas chromatography in a laboratory. The resultant loss of time is considered unacceptable by the aviation industry. There has also been no agreement on the acceptability of fuel where the meter shows the presence of dye at levels well below the visible level. As a result the JT 100 has not been accepted by the aviation industry to date.

Several batches of West Coast jet fuel showed reddish colors not caused by dye. Instead the problem was traced to a hydrofining catalyst nearing the end of its operating life. Informal studies established that this particular discoloration faded in sunlight after only 5-10 minutes, while red dye did not fade. Sunlight exposure of reddish White Bucket contents became part of quality control procedures, eliminating laboratory testing on fuel which faded in sunlight.

OEM POSITIONS ON RED DYE CONTAMINATION

The JFTOT breakpoint results and the General Electric engine tests highlighted the possibility of high temperature engine problems due to red dye but did not define an acceptable dye concentration. As a result the engine companies and Boeing continued to object to the presence of dye in jet fuel supplied to aircraft. Boeing resolved the issue by issuing two service bulletins [7,8] which defined acceptable fuel as fuel showing no red or pink color in the White Bucket test. The passing criterion was based on the absence of engine or aircraft problems with such fuels. However, this approach did not deal with the situation where red dyed fuel had been loaded aboard an aircraft. Acting on a CRC letter of December 15, 1994 each engine company then issued a set of "Emergency Use" procedures to be followed in such cases. Pratt and Whitney incorporated them in a service bulletin [9], while General Electric [10] and Rolls Royce [11] circulated service advisories to their users. To the same purpose Boeing[12] and Fokker[13] issued service letters, while Airbus[14] distributed an information telex. Each document specified how often such fuel could be burned in an engine and how each engine was to be followed and checked to assure the absence of problems. All engine companies used the Boeing definition for acceptable fuel.

Fuel which failed the inspection test could only be used if laboratory testing showed red dye to be absent and the fuel passed all specification tests. These "Emergency Use" procedures are still in place at the time of this writing (Fall 2003). The FAA[15] also issued a letter on emergency use of contaminated fuel.

In several Group meetings the engine companies emphasized the importance of engine or component tests to arrive at an acceptable, quantitative dye level; in fact as a matter of policy the red dye would only be approved after complete testing as an additive and could then be used on a continuous basis with an approved maximum concentration. At that point the Southwest Research Institute proposed a program of evaluating red dye effects in a number of engine fuel components which would be heated to temperatures selected by each engine company. This program [16] is described in more detail in the next section.

SOUTHWEST RESEARCH INSTITUTE HOT ENGINE COMPONENT PROGRAM

The program was funded by a number of government agencies and industry organizations and funds were administered under contract with the Research Division of the Federal Aviation Administration. The following is a summary of the program.

The program consisted of three phases, the first being the selection of test fuels, the second consisting of the experimental work, while the third phase was to establish the relationships of various small-scale laboratory tests (such as JFTOT and QCM) to the nozzle test results. Phases one and two have been completed as of this writing.

Fuel Selection

The fuel selection process was designed to obtain samples of Jet A fuel representing various combinations of crude types and refinery processing. A total of 19 samples were acquired from eleven suppliers and were extensively tested for properties relating to high temperature stability. Sensitivity to red dye was of particular concern and was tested at 5% red dye concentration of the IRS requirement. With the JFTOT breakpoint as the primary criterion, dye sensitivity was found in 8 samples. Interestingly, as shown in the earlier CRC work, no particular crude type or refinery processing was relatable to such sensitivity which appears caused by unidentified trace constituents in the fuel. Five fuels went through a further screening process, with the final fuel selection based on consistency of fuel sensitivity and reliability of supply of the fuel over a period of time.

The effect of adding a poor quality diesel fuel to the Jet A samples was evaluated by JFTOT testing. Even without the red dye, as little as 0.5% of this diesel fuel caused two Jet A's to fail the 260°C specification minimum, while slightly over 2% diesel fuel caused JFTOT failure in all five Jet A products. As pointed out later, only the red dye effect was established in the engine component tests. Although scheduled, the diesel fuel effect could not be determined in the engine component tests because of insufficient funds.

Engine Component Tests

The engine manufacturers selected engine nozzles, spool valves and very fine torque motor filter screens as potentially the most sensitive components in their systems. Engine nozzles are the hottest components. Spool valves, while running cooler, have the tightest internal clearances and are therefore very sensitive to deposits. The filter screens have larger openings but cannot be removed without removing and disassembling the entire fuel control. Each engine manufacturer nominated the nozzle types to be evaluated, while the spool valve and screen was selected by a fuel control manufacturer. Nozzles from large and small main engines, as well as an APU engine, were in the program, which also included military engines. Ultimately the components shown in Table 7 were chosen for the program. As shown the program covered four basic nozzle designs.

In the testing the nozzle is immersed in a fluidized sand bath for uniform heating. Fuel is pumped through a separate heater into the nozzle. Figure 2A illustrates the heating sand bath, while 2B shows the entire nozzle test apparatus. Fuel flow, pressure drop and temperatures are monitored. Fuel temperature is controlled independently of the sand bath temperature. The temperature of the nozzle's outer metal surface is at bath temperature. Each nozzle was modified to collect the entire fuel outflow which was discarded. (There is no fuel combustion in these tests.) Flow rates and temperatures of the outer wall of the component were set by the manufacturer. For the air atomizers the air flow and temperature were also specified. The nozzles as well as the operating conditions are not identified in the report. Both the mechanical nozzle modifications and the test operating conditions represented unavoidable compromises. The nozzle modifications probably resulted in temperature profiles somewhat different from the engine, while the fuel temperatures had to be set above maximum engine conditions to get deposits in a reasonable time but not so high that deposits were formed by a different mechanism.

Test Program Fuels

The fuels selected for the component test program are shown in Table 8. They included the sensitive base fuel mentioned earlier, the same fuel plus 0.55 mg/L red dye (5% of IRS requirements) and with 0.275 mg/L red dye (2.5% of the IRS requirement). The program was rounded out with a reference fuel which just passed the minimum specification thermal stability requirements of 260°C. This fuel served as a baseline for red dye degradation, if any, in terms of specification compliance. The reference fuel was also needed because there was no advance knowledge of the relationship between the engine component performance and JFTOT breakpoint. Four other fuels blends, i.e. the sensitive fuel plus two diesel fuel contamination levels and two diesel fuels plus corresponding red dye levels, could not be evaluated because of insufficient funds.

Test Program – Nozzle Tests

Each nozzle was operated on the base fuel at three fuel temperatures and at the same three fuel temperatures with the base fuel + 0.55 mg/L of red dye (5% of IRS minimum concentration). Fuel temperatures differed from nozzle to nozzle but in each case reflected some performance degradation. Performance was measured in terms of Flow Number (FN) as defined in Equation 1 and Fouling Rate (FR) per Equation 2:

$$FN = \frac{m_{fuel}}{\sqrt{\Delta p}} \qquad \text{Equation 1}$$

where FN = flow number
m_{fuel} = fuel mass flow
Δp = pressure drop across the nozzle

Fouling rate was defined as the slope of FN or

$$FR = \frac{dFN}{dt} \qquad \text{Equation 2}$$

When the plot of flow number versus temperature showed significant degradation for the 5% red dye blend, the red dye tests were repeated with the dye at 2.5% concentration. An example of the results from one nozzle (Nozzle T-ND) tested at two concentrations is shown in Figure 3. The same results are repeated in Figure 4 as an Arrhenius plot where the data plot as parallel straight line, indicating a consistent degradation mechanism.

The SwRI analysis then normalized the fouling rate results to a relative fouling rate in which the base fuel is assigned a value of 1.0 and red dye fouling rates are adjusted accordingly. These values are shown in Table 9, which also includes two other parameters. Relative life is the inverse of relative fouling and assumes that the nozzle will see an constant red dye contamination over its life. In a different approach the analysis attempts to estimate the effect of a single "emergency" flight on the indicated red dye dosage. For this nozzle the deposits laid down in such a flight would be the same as 2.2 flights on uncontaminated fuel and would therefore result in the loss of 1.2 flight over the nozzle lifetime (2.2 – 1 flights).

Detailed results for all nozzles are given in the appendices of the cited report. However, results for 6 nozzles are summarized in Table 10 and are plotted in Figure 5. The differences in nozzle response to the red dye are readily apparent. It is worth emphasizing that the results represent the unlikely situation where the red dye is in all fuels at the given concentration. The more likely situation is plotted in Figure 6 which represents one measure of possible flights lost due to a single use of the red dye on an emergency basis.

Test Program – Torque Motor Filter Screen Tests

The torque motor screen is a stainless steel mesh about one inch long and ¼ inch in diameter. Mesh size was not given in the report. For the test the screen was mounted in a heated block as shown in Figure 7. The block was insulated and heated by the fuel passing through the filter screen. Typically the block temperature was 3°C below the fuel temperature.

The same test fuels were used as had been used for the nozzle tests. Eight hour runs were made at fuel temperatures of 154, 165 and 177°C. Data were analyzed in a similar fashion and the results are plotted in Figure 8. Clearly, the screen is much less sensitive to the red dye than were all but one of the fuel nozzles.

Test Program – Spool Valve

Spool valves are flow-controlling valves, which open and close ports with a spool sliding inside a sleeve. These valves operate under elevated pressure and depend on very tight clearances to seal the mating spool surfaces against the sleeve interior. A schematic diagram of a spool valve is shown in Figure 9. During operation line pressure is exerted against the spool on the fuel inlet side and is resisted by the spring on other end of the spool. Such valves operate by being in either of two positions, depending on whether the line pressure is greater or less than the spring force. Either position will cover and uncover different ports which will exert different hydraulic signals by changes in pressure. Deposits on the inner mating surfaces will increase the force required to move the spool and will cause erratic or intermittent valve operation resulting in unpredictable control response. A complete hang-up of the spool valve results in a loss of ability to properly schedule fuel flow. This inability to properly schedule the fuel flow results in no fuel flow, erratic fuel flow or full fuel flow to the engine in an unpredictable direction, causing unpredictable engine behavior.

Fuel was heated externally to a given test temperature and, in turn, heated the block containing the valve. The block was insulated and its temperature was about 3°C below the fuel temperature. During testing fuel flow was maintained at 15 lb/hr and was pulsed twice at 35 lbs/hr at two hours intervals. The relatively long interval between exercising was intended to duplicate cruise conditions where absence of control movement is considered the most stringent condition.

Valve performance was measured at the beginning and end of each 100 hour test by conducting hysteresis tests. Here the valve was exercised over its full stroke and the flow coefficient, C_n, was established as a function of control pressure. This coefficient is similar to the nozzle flow number except it is based on flow volume rather than mass flow. During the exercise the inlet pressure was increased until flow shut-off occurred. The pressure was then decreased gradually and the corresponding flow increase through the valve was recorded. When the spool was against the stop and maximum flow occurred, the inlet pressure was increased again until the fuel flow was shut off. Exercising the flow from zero to maximum and back to zero was one hysteresis cycle. The first hysteresis cycle was intended to remove loosely adhering deposits which, in actual service, would be removed by a valve movement. The second cycle would establish the effects of any adherent deposits. A clean valve will exhibit some slight hysteresis – a different flow curve on the return part of the cycle – so that significant hysteresis has to occur to establish deposit effects.

The same fuels were used for the spool valve evaluation as had been in the nozzle program. The test matrix showing the fuels and test operating conditions are in Table 11. Basically there was a slight but noticeable difference in valve performance between the base fuel and the base fuel plus 0.55 g/L of red dye (5% of IRS minimum dosage) when the valves were tested at fuel temperatures of 177°C. The results of Cycle 2 testing at the beginning and end of 100 hours are plotted in Figure 10, which shows a slight but significant degradation with the dyed fuel. On the other hand, valve performance was definitely poorer with the reference fuel even at test temperatures of 163°C., as reflected in Figure 11. Only when the test temperature was lowered to 135°C were the results comparable to the base fuel. The overall results, therefore, tracked fuel thermal stability as defined by the JFTOT because both the base fuel as well as the base fuel containing 0.55 mg/L had significantly higher breakpoints than did the reference fuel.

SwRI Program Conclusions

The conclusions which follow deal only with the effects of red dye on hot engine components and are based on the data shown in Figures 3 – 6, 8, 10 and 11. The effects of diesel fuel contamination on engine components as well as quantitative relationships between the component tests and small-scale laboratory tests have yet to be established.

The data from the engine hardware testing of this project shows that the fouling rates of fuel nozzles and filter screens can be quantified and correlated with the thermal stability of the jet fuel. This provides a basis for evaluating the effect of red dye contamination on the fouling rate of the hardware. A method for quantifying the degradation of hysteresis in spool valves was not developed due to a shortage of funds, although such a method seems possible."

Generally speaking the fouling characteristics of the torque motor filter screens were found to be less sensitive to both thermal stability and fuel temperature than the fouling characteristics of fuel nozzles.

Based on the component fouling tests conducted in this program, the presence of red dye in jet fuel can measurably increase the fouling rates of engine fuel nozzles, and to a lesser extent, the filters. The effect is design specific as not all nozzles were affected at the 0.55 mg/L contamination level. At 177°C, the presence of red dye was found to cause a small but noticeable increase in the hysteresis of spool valves; this increase was considered very small compared to the increase caused by a fuel of minimal thermal stability. It is thought that at system fuel temperatures more typical of engine operation, that 0.55 mg/L of red dye would not increase the hysteresis of spool valves.

CURRENT STATUS and FUTURE WORK (Winter 2003)

The OEM's agreed that the above results are insufficient to decide on an acceptable limit of red dye in jet fuel. More testing is proposed to establish this limit. The existing limitations and procedures as defined by the OEMs are therefore still in place.

Additional testing is planned to establish the effects of jet fuel contamination by diesel fuel and by diesel fuel plus red dye.

LIST OF TABLES

LIST OF FIGURES

REFERENCES

[1] Environmental Protection Agency, 54 Federal Register 35276, August 21, 1990 Regulation for Fuel and Fuel Additives.

[2] Department of the Treasury, Internal Revenue Service, 58 FR 63069, 26 CFR Parts 40, 48 and 602, dated 30 November 1993 and amended as 58 FR 68304, dated 27 December 1993, Diesel Fuel Excise Tax: Registration Requirements Relating to Gasoline and Diesel Fuel Excise Tax.

[3] Letter of W. F. Taylor and K. H. Strauss to Peter McHugh, Federal Aviation Administration, ASA-300, April 27,1994

[4] Environmental Protection Agency, 40 CFR Part 80, Regulation for Fuel and Fuel Additives; Fuel Quality Regulations for Highway Diesel Fuel Sold in 1993 and later Calendar Years, Interim Final Rule.

[5] Department of the Treasury, Internal Revenue Service CFR Title 26 part 48.4082-1 "Diesel Fuel and Kerosine, Exemption for Dyed Fuel", October 1, 1994.

[6] Minutes of the Group on Dye in Aviation Turbine Fuel, April 26, 1995

[7] Boeing Service Letter, "Aircraft Use of Fuels Contaminated with Dye", Model 707, 727,. 737, 747, 757, 767, 777 Series, 22 November 1996.

[8] Boeing Service Letter, "Aircraft Use of Fuels Contaminated with Dye", Model 707, 727,. 737, 747, 757, 767 Series, 27 August 1998

[9] Pratt & Whitney Service Bulletin No. 2016, Revision 27, "Engine Fuel Control – Fuel and Additives – Requirements for , and Approval of", Revision 27, January 9, 2003.
(Note: The original procedures were contained in an earlier revision but have been maintained in all subsequent revisions.)

[10] General Electric Aircraft Engines, Commercial Engine Service Memorandum No. 203, "CF6 Commercial Engine Service Memorandum", April 29, 1998.
(Note: Similar memoranda were issued for all commercial GE engines.)

[11] Rolls Royce Customer Service telex, dated 6 May 1998, to all RB 211, Trent and Tay operators, Boeing, Lockheed, Airbus, Fokker, Gulfstream representatives.

[12] Boeing Service Letter, "Airplane Use of Dyed Fuel", All DC-8, DC-9, MD-80, MD-10, KC-10A and MD-11 Aircraft, December 18, 1998.

[13] Fokker 70/100 Service Letter 231, "Fuel – The Emergency Usage of Contaminated Aviation Turbine Fuel", January 29, 1999.

[14] Airbus Industrie Operator Information Telex, "A319/320/321/A300/ A300-600/A310/A330/A340 ATA28 – Use of Dyed Fuel on Airbus Aircraft", June 8, 1999.

[15] FAA Letter "Emergency Usage of Aviation Fuel Contaminated with Red Dye", Category 1 Aircraft, Pardee to Benjamin, January 29, 1999.

[16] Moses, Clifford, Draft FAA Report, "The Evaluation of Red-Dye Contamination in Jet Fuel and Identification of a Screening Method for Thermal Stability", currently under review.

LIST OF APPENDICES

TABLES AND FIGURES

TABLE 1 - BLUE DYE CONTAMINATION INCIDENTS

Date	Location	Remarks
Oct. 1993	Milwaukee WI	Pipeline and airport
Jan. 1994	Milwaukee WI	Pipeline and airport
Jan. 1994	Honolulu HA	Airport
Apr. 1994	Oakland, CA	Airport
May 1994	Milwaukee WI	Pipeline and airport. Shipment rejected at airport

Table 2 – RED DYE CONCENTRATIONS IN DIESEL FUEL/HEATING OIL

(active ingredient)

Percent of IRS required Red Dye in non-taxed diesel fuel	Solid* Lbs/1000 bbls	Liquid** Lbs/1000 bbls	Solid* Mg/L	Liquid** Mg/L
100%	3.9	5.6	11.1	16.0
50%	1.95	2.8	5.55	8.0
20%#	0.78	1.12	2.22	3.2
10%	0.39	0.56	1.11	1.6
5.0%	0.19	0.28	0.55	0.80
2.5%	0.098	0.14	0.28	0.40
2.0%	0.078	0.11	0.22	0.32
1.0%	0.039	0.056	0.11	0.16
0.5%	0.019	0.028	0.055	0.08

* Solvent Red 26
** Solvent Red 164
\# Approximate EPA requirement

TABLE 3 – RED DYE CONTAMINATION INCIDENTS*

Date	Location	Remarks
Dec 1994	Sitka AS	Airport shut down until new fuel arrived by barge
Dec 1994 into 95	numerous locations	22 cases, including 4 at airports
Jan. 1995	Charleston SC	Truck delivery to airport
Mar. 1995	Houston TX	Pipeline delivery
Apr. 1995	Madison WI	Airport delivery
June 1995	Oakland CA	Terminal and airport
June 1995	New York NY	Pink fuel, not dye related
July 1995	Washington DC	Terminal and airport
Dec. 1996**	Boeing Field, Seattle	Eight Alaska Air Lines aircraft immobilized until fuel removed
Dec. 1996**	Everglades Terminal, FL	Did not reach Miami A/P
June 1997**	Miami Airport FL	Fuel was removed by truck
June 1997**	Honolulu terminal	Did not reach Honolulu Airport
June 1997**	Midwestern airport	Dye contam. reported by AAL
June 1997**	Midwestern airport	Dye contam. reported by AAL
June 1997**	Port Everglades FL	Fuel pink but did not contain red dye
Dec. 1997	Moline IL	Airport, trucked out
Mar. 1998	New York, NY	Green dye at LGA and JFK airports
Jan. 1999	Dulles Airport VA	Airport able to operate on remaining tanks over 8 week period
Jan. 1999	Linden, NJ	Same batch as Dulles shipment. Did not reach Newark A/P
May 1999**	Miami FL Airport	Several incidents. No other details.

* Civil fuel incidents only, military fuel incidents are not included

**Date reported in committee meeting. The incident would have occurred earlier.

TABLE 4 – THERMAL STABILITY RESULTS

100% of Minimum IRS Concentration of Red Dye

Laboratory	Breakpoint w/o Red Dye	Breakpoint with Red Dye	Decrease
Amoco	360°C	270°C	-90°C
Ashland	375°C	335°C	-40°C
Alcor	295°C	300°C	+5°C
	295°C	295°C	0°C
Chevron	295°C	285°C	-10°C
	315°C	320°C	+5°C
Exxon	290°C	265°C	-25°C
	265°C	245°C	-20°C
Mobil	290°C	280°C	-10°C
Phillips	350°C	350°C	0°C
Pratt & Whitney	282°C	280°C	-2°C
Rolls Royce	285°C	280°C	-5°C
	290°C	285°C	-5°C
	295°C	290°C	-5°C
	290°C	290°C	0°C
	250°C	250°C	0°C
	255°C	255°C	0°C
	260°C	260°C	0°C
	265°C	255°C	-10°C
Texaco	300°C	285°C	-15°C
	290°C	275°C	-15°C
US Navy	293°C	293°C	0°C
	293°C	293°C	0°C
	293°C	293°C	0°C
	274°C	274°C	0°C
	274°C	268°C	-6°C
	274°C	282°C	+8°C
	277°C	268°C	-9°C
	268°C	260°C	-8°C

TABLE 5 – THERMAL STABILITY RESULTS

10% and 2.5 % of Minimum IRS Concentration of Red Dye

Laboratory	Breakpoint w/o Red Dye	Decrease with Red Dye		
		With 100%[A]	With 10%	With 2.5%
Amoco	360°C	-90°C	-75°C	-105°C
Ashland	375°C	-40°C	0°C	-
Chevron	295°C	-10°C	-5°C	-
Exxon	290°C	-25°C	-10°C	N.A.
	265°C	-20°C	-15°C	N.A.
Mobil	290°C	-10°C	-5°C	-
Texaco	300°C	-15°C	0°C	-
	290°C	-15°C	-10°C	

[A] Taken from Table 4

TABLE 6 – EFFECT OF RED DYE ON OTHER PROPERTIES OF CIVIL FUELS

Laboratory	Property	Effect
Phillips	Haze test (D 4176)*	no effect
	Existent gum (D 381)	no effect
	Freezing point (D 2386)	no effect
Pratt & Whitney	Microseparometer (D 3948)*	no effect
	Haze test (D 4176)*	no effect
	Freezing point (D 2386)	no effect
	Membrane filtration (D 2276)*	slight effect
US Navy (JP-8 and JP-5 fuels)	Lubricity (D 5001)*	no effect
	Membrane filtration (D 2276)*	no effect
	Microseparometer (D 3948)*	no effect
	Accelerated storage (D 5304)*	no effect
	Shipboard contamination detector*	no effect
Boeing	Dye solubility*	no problems
Rolls Royce	Elastomer compatibility*	
	Nitrile	no significant effect
	Silicone	no significant effect
	Fluorocarbon	no significant effect
	Fluorosilicone	no significant effect
Octel America	Electrostatic charging*	no significant effect with 2% dye significant charging with 10% dye

* Not a specification requirement in D 1655

TABLE 7 – COMPONENTS IN SwRI PROGRAM

Engine Mfr.	Engine Model	Aircraft Used on	Atomizer Type	Flow Circuit
GEAE	CFM56	B737, A319	Pressure	Dual orifice
GEAE	CT7/T700	Saab 340, Various helicopters	Low Pressure	Single orifice
GEAE	F414	F18 (USN)	Pressure	Dual orifice
P&W	PW2040	B757	Airblast	Single orifice
P&W	F100	F15 (USAF)	Hybrid Airblast	Dual orifice
P&W (Canada)	PT6	Saab 2000 Cessna Cit. 10	Pressure	Dual orifice
Rolls Royce	RB211-535	B757	Airblast	Single orifice
Rolls Royce	AE3007	Embraer 135/145	Hybrid Airblast	Dual orifice
Sundstrand	APU	A330, B767	Pressure	Single orifice
Honeywell	Spool valve	various aircraft		
Honeywell	Filter screen	various aircraft		

TABLE 8 - FUELS USED IN THE SwRI COMPONENT TEST PROGRAM

Fuel Description	JFTOT Breakpoint
Reference fuel with minimum JFTOT rating	260 - 265°C
Base fuel found sensitive to red dye	285 - 290°C
Base fuel + 0.55 mg/L red dye (5% IRS minimum level)	
Base fuel + 0.275 mg/L red dye (2.5% IRS minimum level)	
Base fuel + 2 contamination levels of diesel fuel *	
Base fuel + 2 contamination levels of diesel fuel and red dye*	

* Planned but not carried out at time of writing

TABLE 9 – EFFECT OF RED DYE ON FOULING OF NOZZLE T-ND

Red Dye (mg/L)	Correlation Equation	Fouling Rate	Relative Fouling Rate	Fouling Life Ratio	Equivalent Flights Lost
0.0	$1.65E+22 \times \exp(-25{,}440/T_{fuel})$	0.0142	1.0	1.0	0.0
0.275	$1.438E+27 \times \exp(-30{,}540/T_{fuel})$	0.0181	1.3	0.78	0.3
0.55	$1.659E+22 \times \exp(-24{,}600/T_{fuel})$	0.0312	2.2	0.46	1.2

Note: E+22 is shorthand for 10^{22}

TABLE 10 – EFFECT OF RED DYE ON RELATIVE FOULING RATE OF SIX NOZZLES

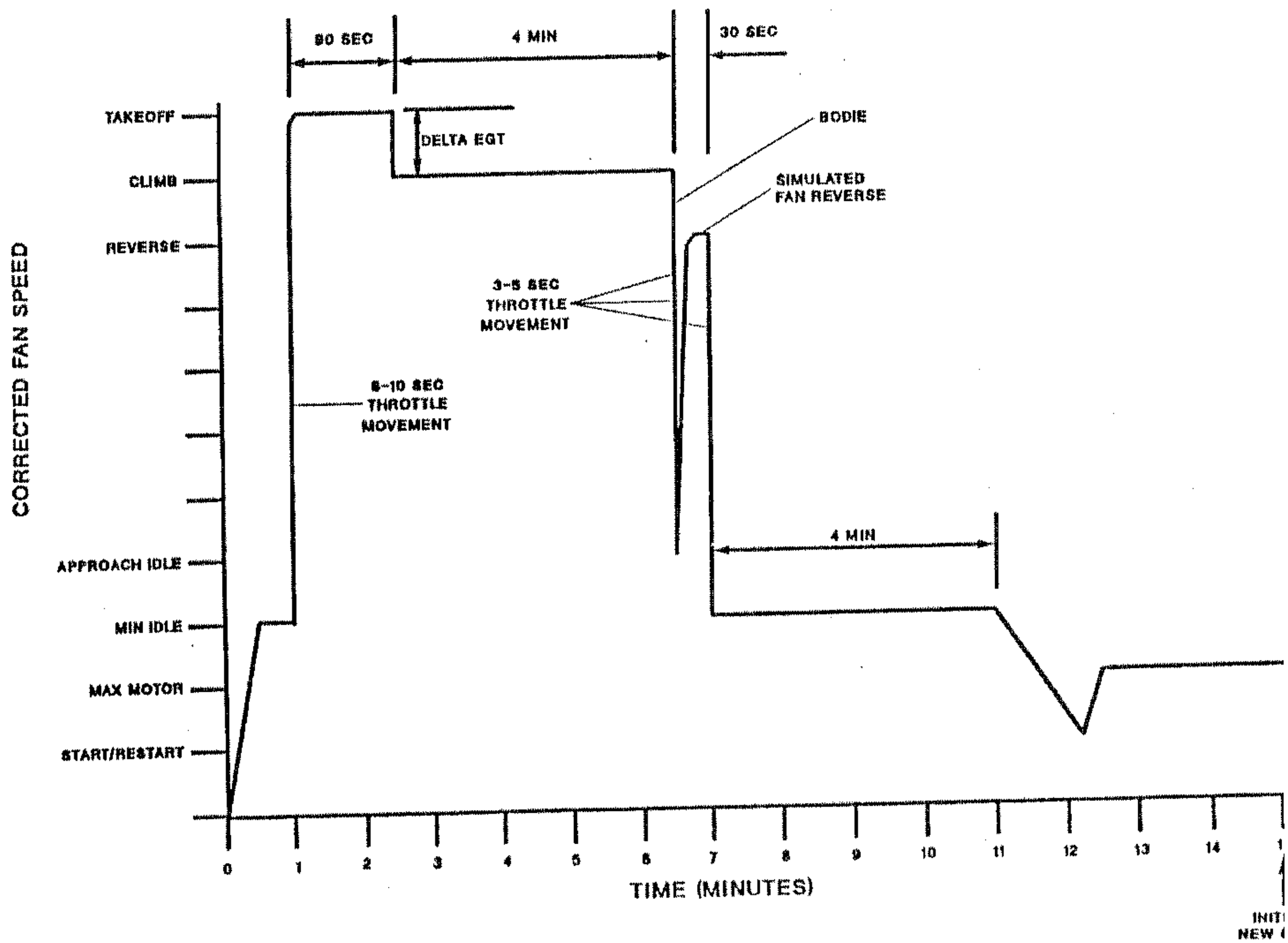
Test Nozzle	Relative Fouling Rate			Fouling Life Ratio			Equivalent Flights Lost		
	0.0	0.275	0.55	0.0	0.275	0.55	0.0	0.275	0.55
TN-A	1.0	-	1.16	1.0	-	0.86	0	-	0.2
TN-B	1.0	-	1.0	1.0	-	1.0	0	-	0
TN-C	1.0	2.50	3.96	1.0	0.40	0.25	0	1.5	3.0
TN-D	1.0	1.28	2.19	1.0	0.78	0.46	0	0.3	1.2
TN-E	1.0	-	1.49	1.0	-	0.67	0	-	0.49
TN-F	1.0	-	3.02	1.0	-	0.33	0	-	2.0
TN-G	1.0	-	1.0	1.0	-	1.0	0	-	0
TN-H	1.0	inc[1]	inc[1]	1.0	inc[1]	inc[1]	0	inc[1]	inc[1]
TN-I	1.0	2.52	3.20	1.0	0.40	0.31	0	1.5	2.5

[1] Test results on this nozzle were inconclusive

TABLE 11 – TEST MATRIX FOR SPOOL VALVE PROGRAM

Test Number Set	Test Fuel	Temperature, °F (°C)	Valve Block	Spool
1	Base Fuel	325 (163)	009	X033
2	Base Fuel	350 (177)	008	X031
3	Base Fuel + 0.55 mg/L red dye	325 (163)	008	X032
4	Base Fuel + 0.55 mg/L red dye	350 (177)	008	X031
5	Reference Fuel	325 (163)	008	X032
6	Reference Fuel	300 (149)	008	X031
7	Reference Fuel	275 (135)	008	X030

Figure 1 – Profile of GE Commercial Engine Operating Cycle



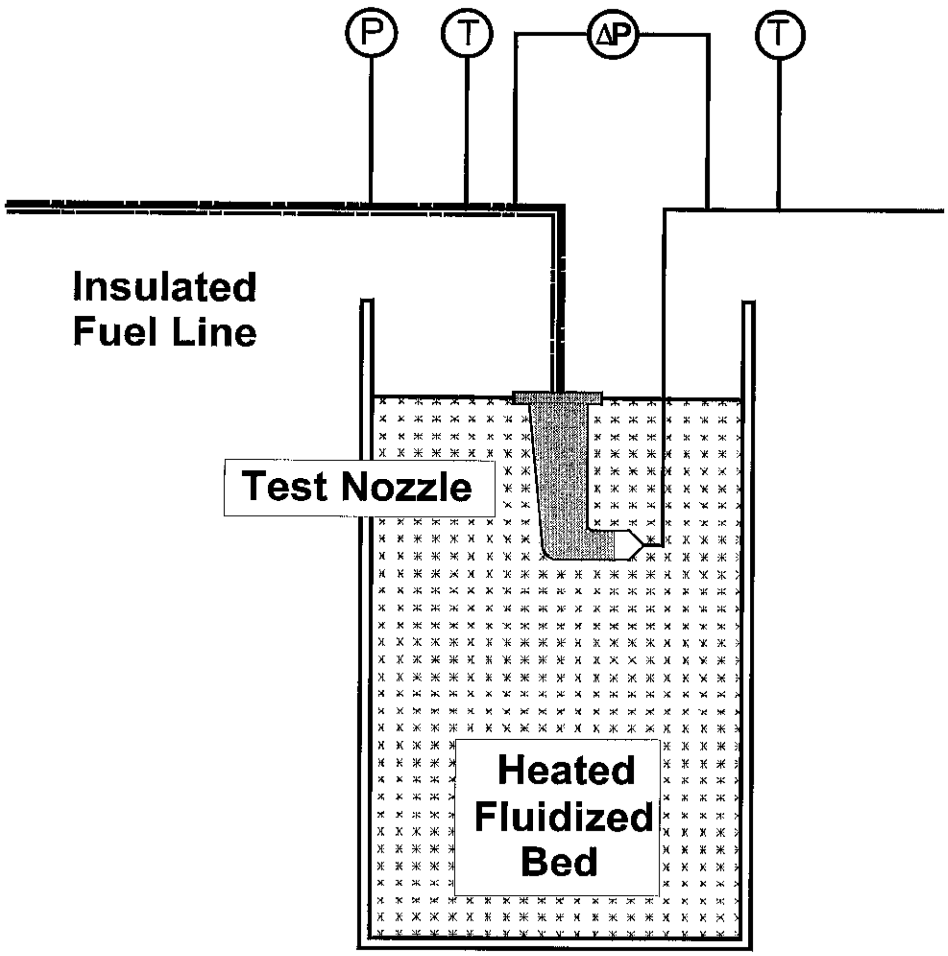
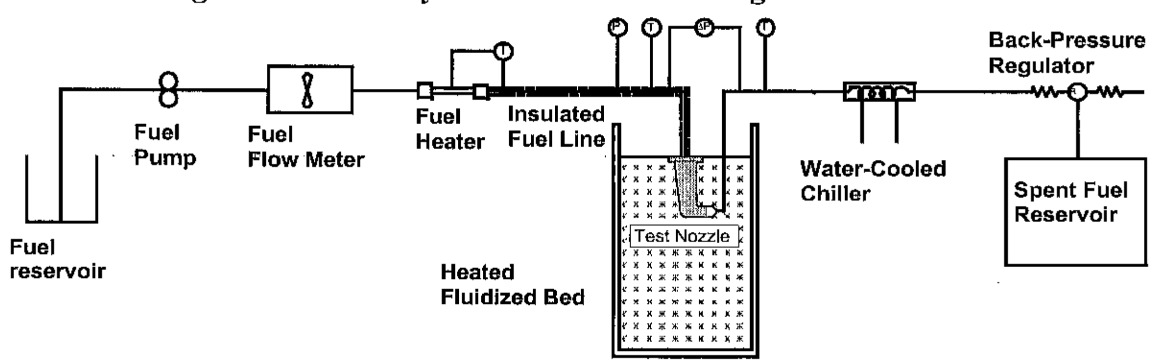


Figure 2A. Heated Fluidized Bed for Nozzle Fouling Tests

Figure 2B. Flow System for Nozzle Fouling Tests



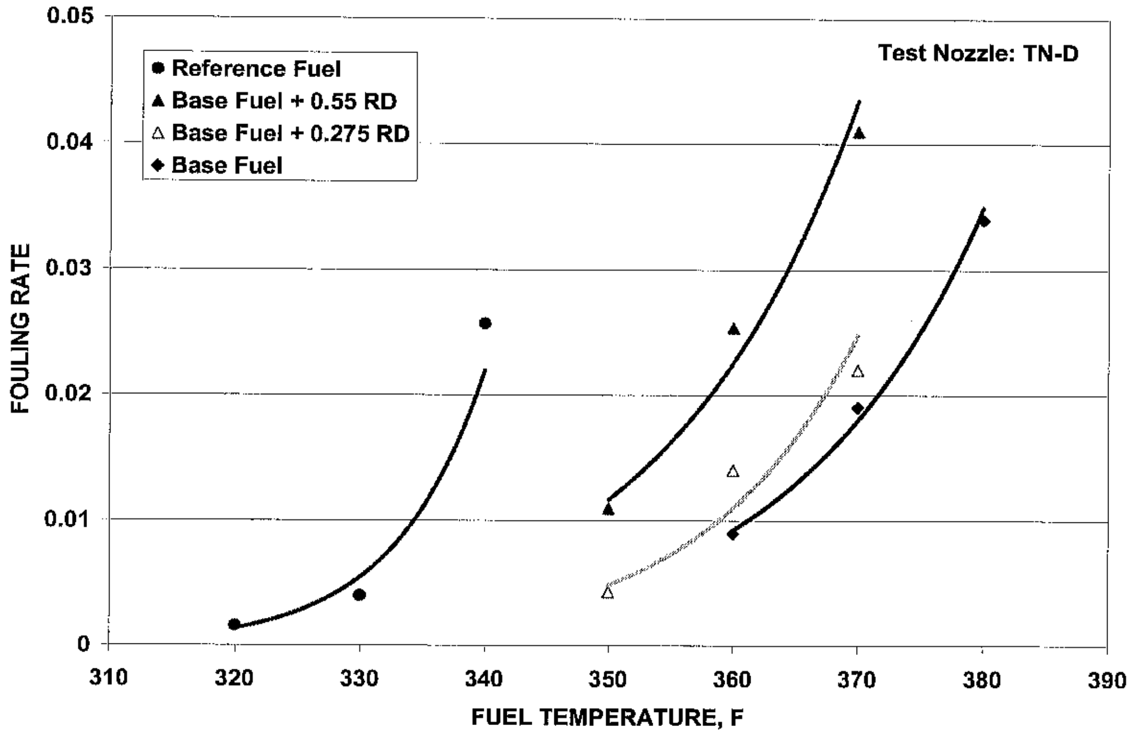


Figure 3. Fouling Rates for a Test Nozzle Sensitive to Red Dye (TN-D)

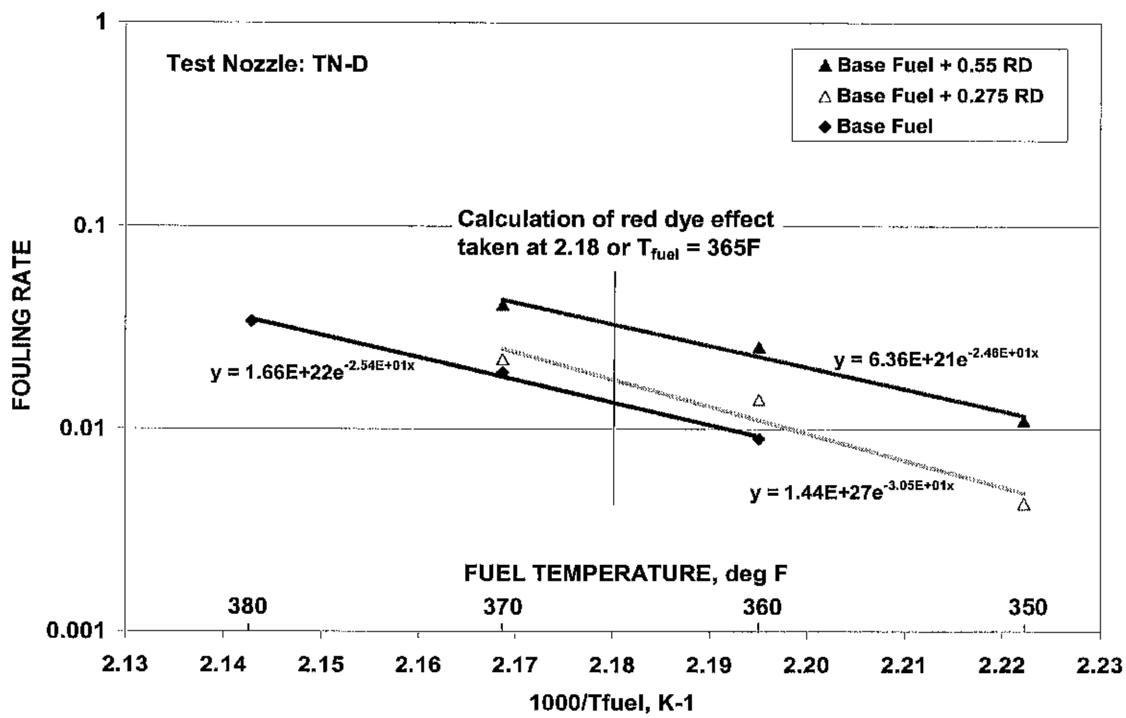


Figure 4. Arrhenius Plot of Fouling Rates for Nozzle Sensitive to Red Dye (TN-D)

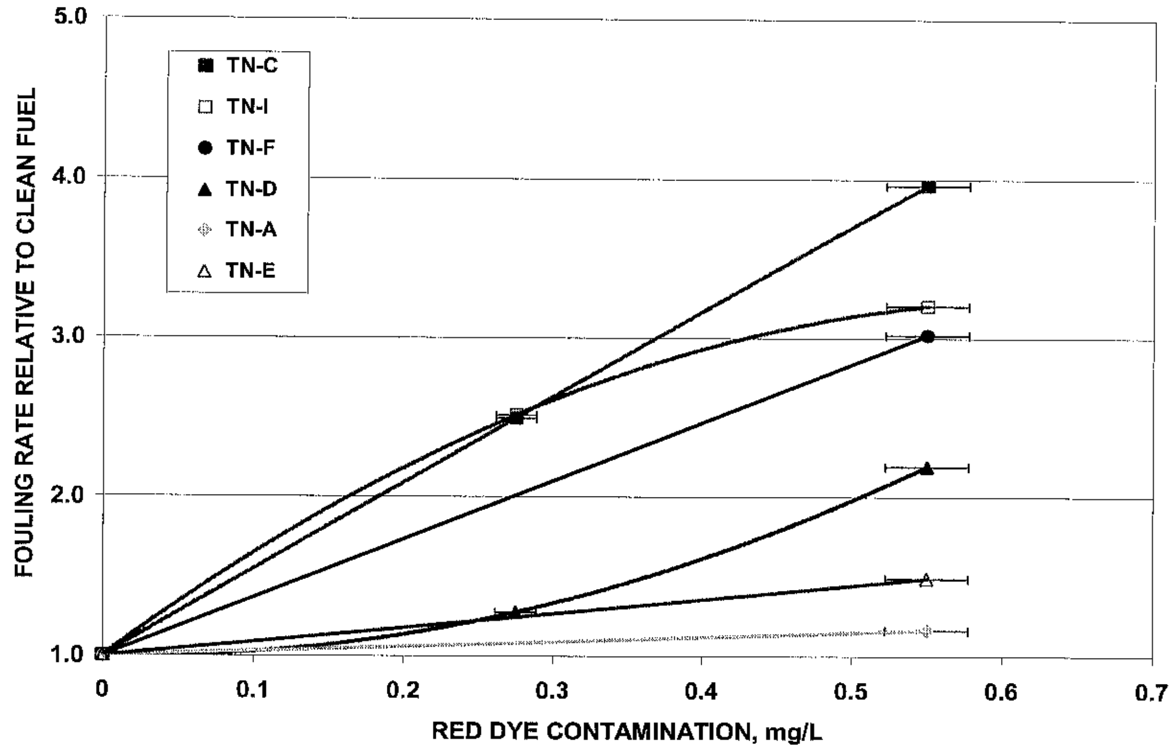


Figure 5. Effect of Red Dye on Relative Fouling Rates of Six Nozzles

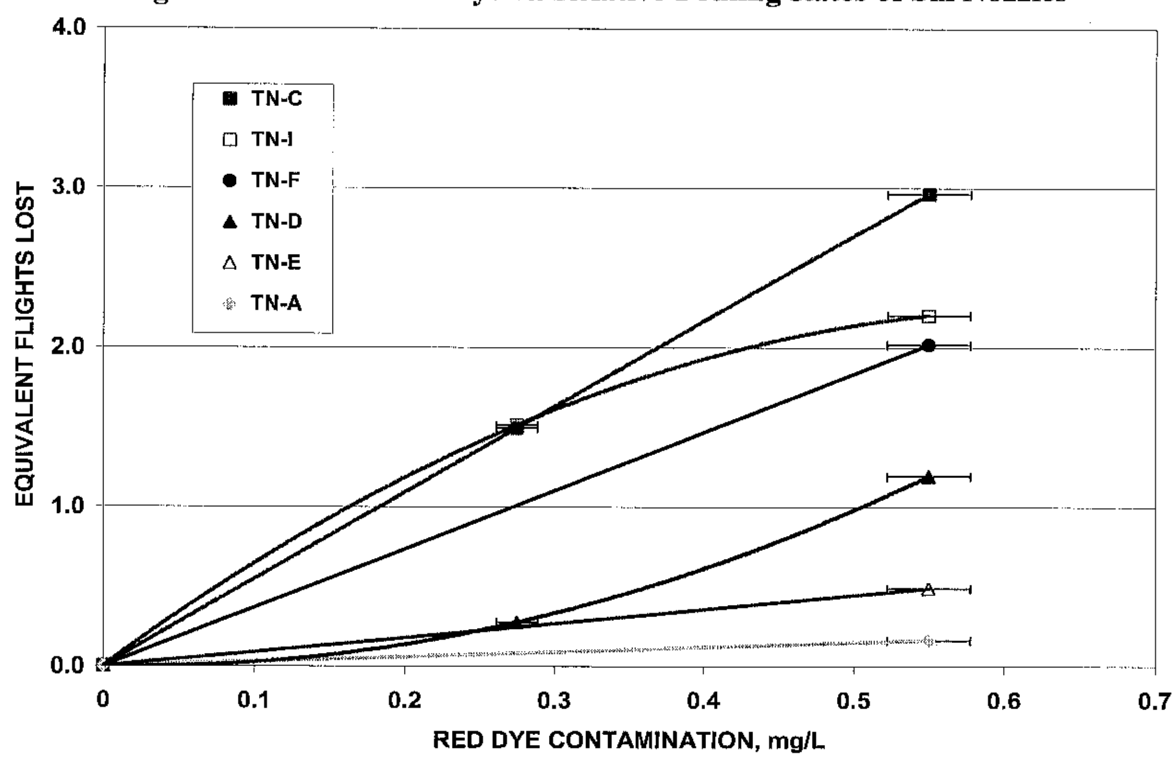


Figure 6. Summary of Effect of Red Dye Contamination on Equivalent Flights Lost

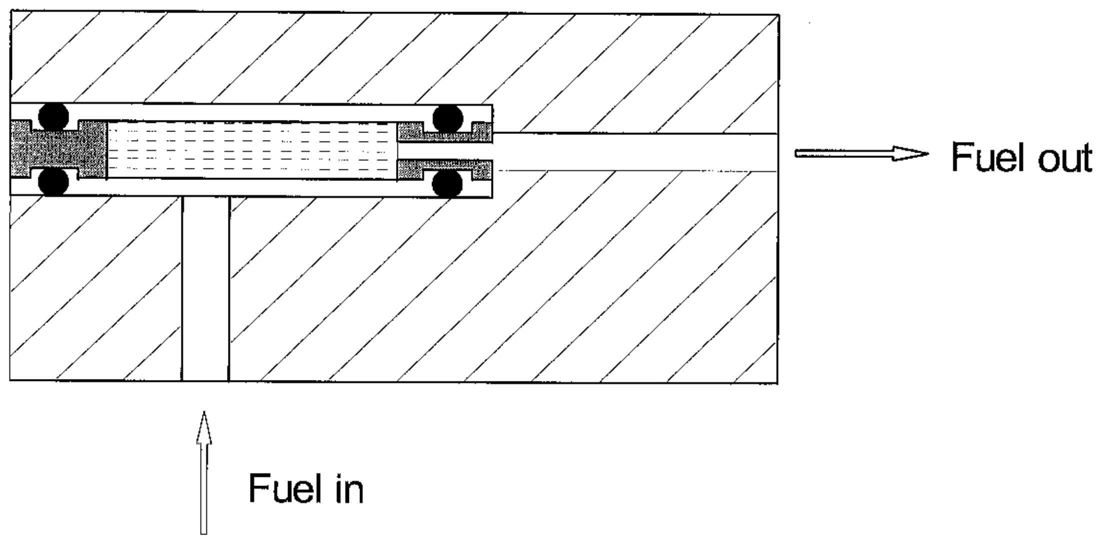


Figure 7 . Schematic of Fixture for Torque-Motor Filter Screen Tests

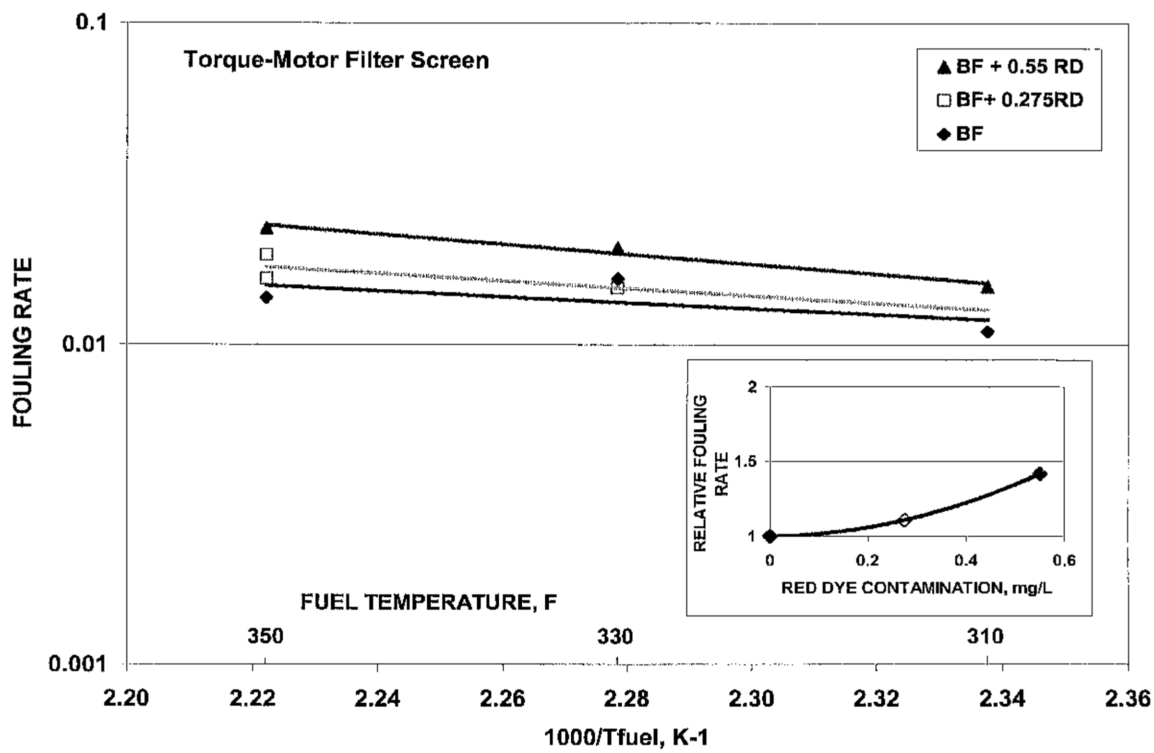


Figure 8. Effect of Red-Dye Contamination on the Fouling of Torque-Motor Filter Screens

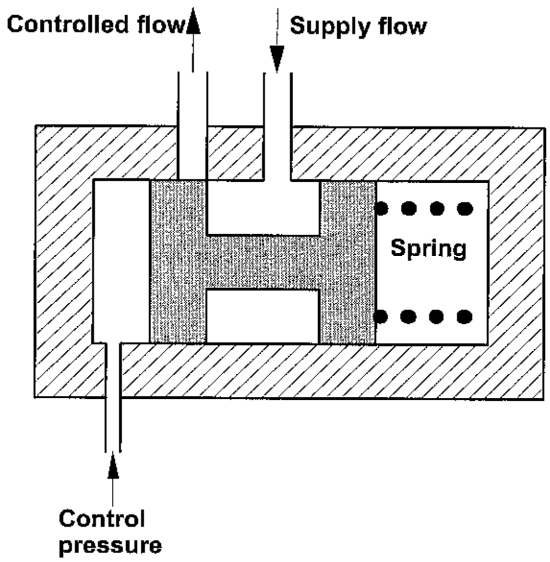


Figure 9. Schematic of Spool Valve

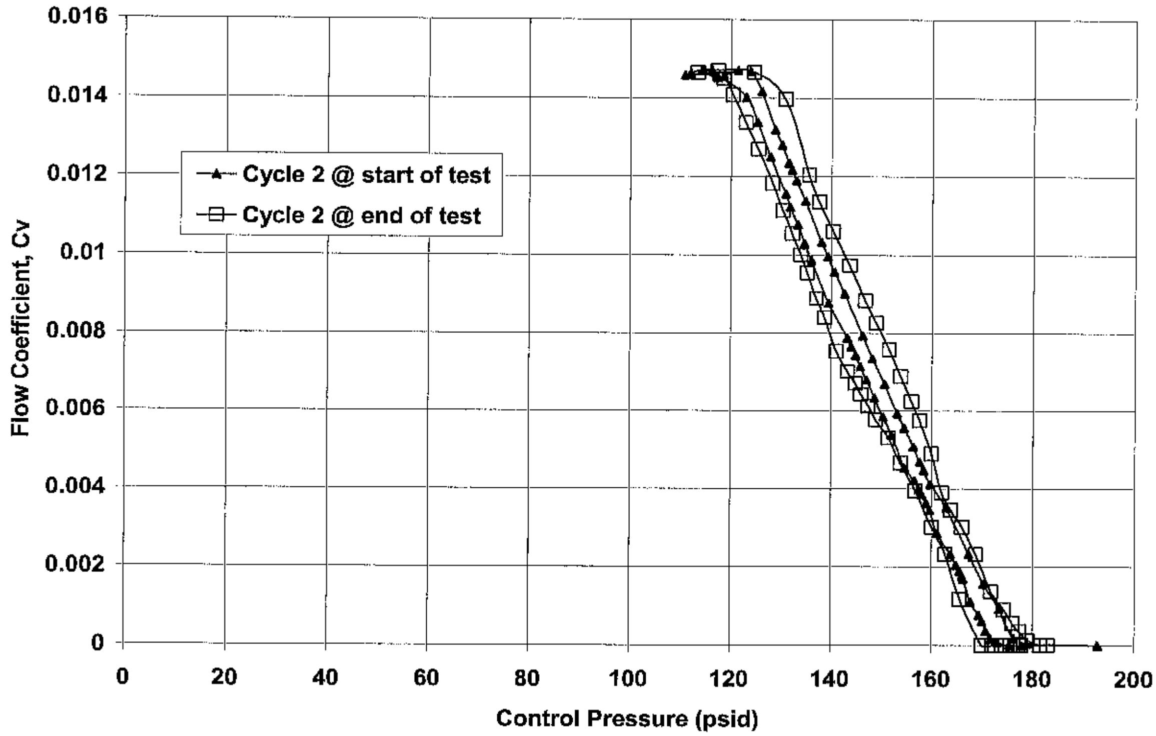


Figure 10. Cycle 2 Hysteresis Curves for Base Fuel plus Red Dye at 177°C

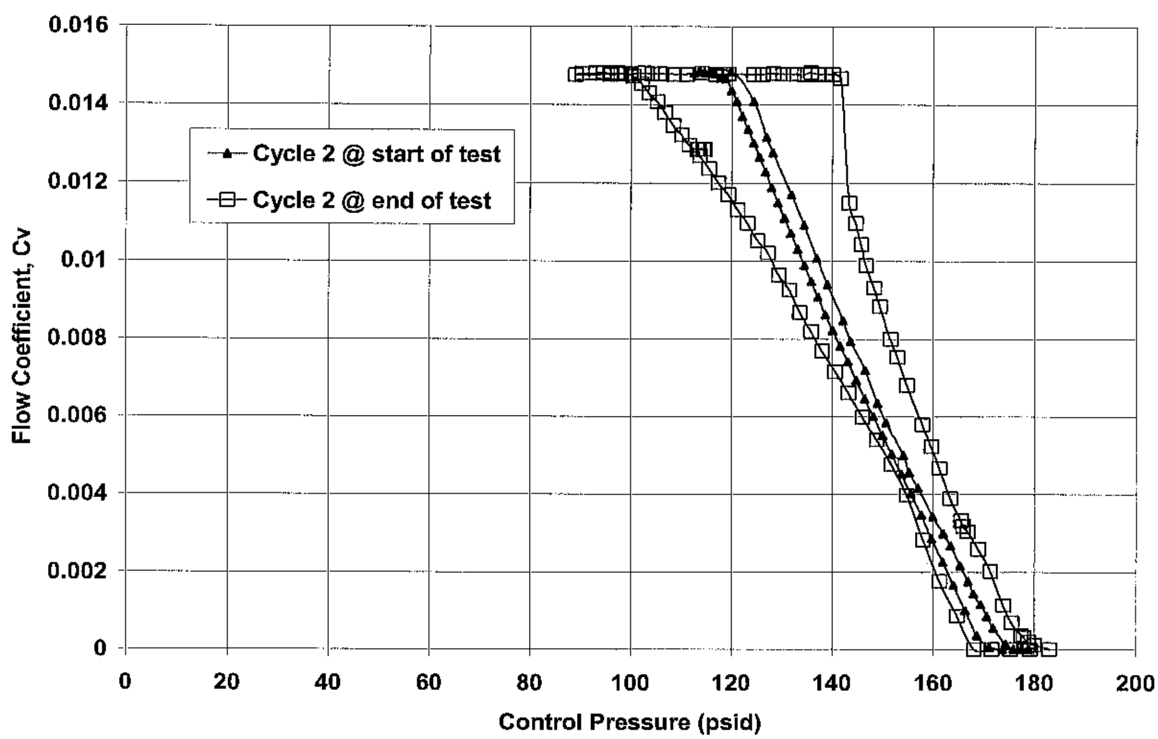


Figure 11. Cycle 2 Hysteresis Curves for Reference Fuel at 163°C

APPENDIX A

CRC GROUP ON DYE IN AVIATION TURBINE FUELS

APPENDIX A

CRC GROUP ON DYE IN AVIATION TURBINE FUELS

KURT STRAUSS, Ldr	Consultant
STEVE ANDERSON	Air BP
FRED BARNES	Consultant
TEDD BIDDLE	Pratt & Whitney
PETER S. BROOK	QinetiQ
GUS BURMEISTER	Buckeye Pipe Line Co.
CLARENCE CHANG	NASA – Glenn Research Ctr.
JIM EVANS	Shell Global Solutions, US
DAVID FABRY	Marathon Ashland
MIKE FARMERY	Shell Aviation Ltd.
DAVID FORESTER	The Lubrizol Corporation
HOWARD GAMMON	Gammon Technical Products
OREN HADALLER	Boeing - Seattle
GREG HEMIGHAUS	ChevronTexaco Global Aviation
CY HENRY	Associated Octel
DENNIS H. HOSKIN	ExxonMobil Res. & Engrg.
VIC HUGHES	Vic Hughes Associates
TUULA HUJANEN	Fortum Oil and Gas, Finland
RICK KAMIN	Naval Air Systems Team
CHRIS LEWIS	Rolls-Royce
FRANK P. O'NEILL	United Airlines
ROGER ORGAN	ChevronTexaco – Caltex AMEA
DIDIER PIGEON	Petroleum Analyzer Co.
JOHN RHODE	Facet USA
MARK A. RUMIZEN	FAA-New England Region
WALLY SCHREPFER	Consultant
PAM SERINO	DESC
STANFORD SETO	GE Aircraft
DAVID SOFFRIN	API
CLAUDE TAUCHER	American Airlines
WILLIAM TAYLOR	W. F. Taylor Associates
RON THARBY	Tharby & Associates
MELANIE THOM	Baere Aerospace
RANDY THOMPSON	ConocoPhillips
GEORGE WILSON	Southwest Research Institute
DALE WISEMAN	Colonial Pipe Line

APPENDIX B

ORIGINAL EXPERIMENTAL PROGRAM AND LIST OF COOPERATORS

APPENDIX B

ORIGINAL EXPERIMENTAL PROGRAM & LIST OF COOPERATORS

Draft 2, June 14, 1994 (taken from Group minutes of June 21, 1994)

I. Laboratory tests

A. Possible chemical reactions with dye materials (theoretical review only)

B . Establish dye solubility in jet fuel

C . Establish feasibility of dye identification test and develop such a test

D. Thermal stability
   1) At least 6-8 laboratories using their own fuel, including marginal fuel, if possible
      a) to obtain breakpoints on clear fuel and same fuel with maximum diesel fuel dye
      b) all labs to use same dye sample supplied by dye manufacturer
      c) report Saybolt color on neat fuel

E. **If dye does not adversely affect thermal stability breakpoint**
   1) At least 6 labs to run MSEP with and without max dye concentration in same fuel as A 1)
   2) At least 2-3 labs run white bucket test on following fuels (test intent is to establish whether dye masks ability to conduct test. Results also reflect ability of test to show presence of dye.)
      a) neat fuel (same as fuel A 1)
      b) fuel with max dye concentration
      c) fuel with 20% of max dye concentration
      d) fuel with 1% of max dye concentration
   3) At least 2-3 labs run haze test per D 4176, using same fuel with and without Max concentration of dye (same intent as B 2)
   4) At least 2-3 Labs to run laboratory membrane filtration per D 2276 on same fuel containing max concentration of red dye.
   5) At least 2-3 labs run existent gum on same fuel with and without max dye concentration
   6) At least one lab to run lubricity tests per D 5001 on same fuel with and without max dye concentration
   7) At least one lab to run freezing point per D 2386 with fuel containing max concentration of red dye to assure test can be conducted and results of clear fuel are unaffected.
   8) At least one lab run Ministatic or similar charging test

F. **If dye at maximum concentration causes thermal stability breakpoint decreases** establish acceptable maximum allowable dye level which will not affect breakpoint adversely

    1)At least one lab run breakpoints on same fuel as above with 10% and 1% of maximum dye dosage

    2) Using the information from F 1) have 6-8 labs run breakpoints on fuel with and without the maximum acceptable dye dosage

    3) Conduct B 2) through B 7) using fuel with the maximum allowable dye dosage

II. Component Tests

A. Dye concentrations to depend on results from laboratory test screening program

    1) with maximum mandated dye concentration

    or

    2) with maximum allowable dye concentration

B. Details to be established after completion of laboratory studies

    1)these tests should include tests for dye/elastomer interactions

III. Engine Test

A. Details to be established after component tests

LIST OF PROGRAM COOPERATORS

Alcor	G. Wilson
Amoco	L. Wolf
ARCO	J. Kubrich
Ashland	D. Fabry
Boeing	J. Schmidt
Chevron	J. Muzatko
DFSC	L. Turner
Exxon	W. Taylor
Mobil Research	D. Hoskins
Pratt & Whitney	T. Biddle
Rolls Royce	S. Bullock
Shell Chemical	B. Visser
Texaco	P. Dorn
Total	W. Spitzley

APPENDIX C

BUCKEYE PIPE LINE EVALUATION OF WHITE BUCKET AND GLASS JAR TEST

APPENDIX C
BUCKEYE PIPE LINE EVALUATION OF WHITE BUCKET AND GLASS JAR TESTS

(Copied from fax of June 20, 1996 from Gretchen Albright to Claude Taucher and Howard Gammon and taken from Group minutes of June 25, 1996)

"On Thursday, June 20, I conducted jet fuel dye visibility studies as you had requested.

Samples

Samples of jet fuel interface that followed dyed heating oil in the pipeline were taken at Buckeye Pipe Line, Highspire Junction. Composite samples of water white jet fuel were obtained from the Macungie Station sample retain building.

All samples were tested for dye content with the Petrospec JT-100 jet fuel dye analyzer. Results were as follows in mg/L active red dye:

Dye Content, mg/L

A	B	C	D	E	F	G
0.095	0.072	0.024	0.145	0.000	0.034	0.020

Summary

Three former pipeline operators were recruited to determine whether red dye could be detected in each sample. Samples were viewed in a glass jar, white paper covered hydrometer jar, and a five gallon white plastic bucket. Testing was completed outside on a hazy day in natural sunlight against a white concrete background.

Yes = dye is present
No = dye is not present

Quart Jar

A quart jar was filled with product and viewed from the top and sides to distinguish whether the samples appeared to contain red dye.

Sample	mg/L	Dave	Rick	Dennis
A	0.095	No – straw	No – straw	Yes/no
B	0.072	Yes/no –straw	No	No
C	0.024	No – straw	No	No
D	0.145	Yes	Yes	Yes
E	0.000	No – water white	No – water white	No – water white
F	0.034	No	No	No
G	0.020	No	No	No

Hydrometer Jar

A glass hydrometer jar was covered with white paper. A white plastic disk was inserted in the bottom. The sample was viewed from the top.

Sample	mg/L	Dave	Rick	Dennis
A	0.095	No – straw	No	No
B	0.072	No – straw	No	No
C	0.024	No – yellow	No	No
D	0.145	Yes	Yes	Yes
E	0.000	No	No	No
F	0.034	No	No	No
G	0.020	Yes	No	No

White Bucket

A one gallon sample was viewed in a white plastic bucket from the top. Depth was not recorded but appeared to be 3 – 5 inches.

Sample	mg/L	Dave	Rick	Dennis
A	0.095	Yes	Yes	Yes
B	0.072	Yes	Yes	Yes
C	0.024	Yes	Yes	Yes/no – slight
D	0.145	Yes	Yes	Yes
E	0.000	No	No	No
F	0.034	Yes/no – slight	Yes	No
G	0.020	No	No	No

Conclusions

The red dye was detected to lower concentrations in the white bucket test than in the hydrometer or quart jar.

The lower limit for red detection appears around 0.024 mg/L by the white bucket test and greater than 0.09 mg/L for the hydrometer jar and quart jar methods."

Signed,

Gretchen A. Albright
Measurement and Quality
Control Engineer

APPENDIX D

GENERAL ELECTRIC ENGINE TEST PROGRAM

This document has been released by GE for inclusion in this report.

FLEET HIGHLITES ARTICLE - RED DYE IN FUEL

CF6-All - Recommendation on Emergency Use of Red Dye Contaminated Fuel

The purpose of this article is to inform all CF6 operators of the accepted limits and procedures for emergency use of aviation turbine fuel contaminated with red dye and to communicate the release of CF6 CESM 203 containing the details of GE's official recommendation.

As background and in summary, since October 1994, the U.S. Government has required red dye be added to certain diesel fuels (high sulfur "off-road" fuels). Since 1994, there have been cases of dye contaminated fuel being delivered to U.S. airports on average of one airport per month. The dye contaminant occurs in multi-use pipelines and from contaminated (but not cleaned) barges/trucks. Dye contaminant is generally small (less than 2.5% of mandated level of 11.2 ppm solvent Red 26 solid dye standard) but is easily detected visually as low as 0.36% concentration. Per GE Fuel Specification D50TF2, red dye is not a certified additive and therefore is currently not allowed.

Work has been completed to allow limited use of dye contaminated fuel. A series of thermal stability tests, fuel nozzle flow testing, and test cell engine runs were performed with dye contaminated fuel. As a result of these tests, GE, in conjunction with the Aerospace Industry Propulsion Committee, developed an industry reviewed and approved standard guideline for emergency use of aviation turbine fuel contaminated with red dye. The official detailed guidelines are released in CESM 203 for all of the CF6 engine models.

CESM 203 defines an "emergency" situation, maintenance and service criteria, and reporting instructions. An emergency situation exists only when an aircraft will be grounded due to no alternate source of uncontaminated fuel available. An emergency does not exist and will not be approved if uncontaminated fuel is available by any other means. The guideline allows for three (3) emergency uplifts of dye contaminated fuel without restrictions. Each of these uplift actions must be reported to GE on the day it occurs. The fourth emergency uplift requires immediate (within 48 hours) contact with GE for appropriate maintenance action. After the fourth uplift, the aircraft can remain in service, but no further uplifts of dyed fuel are permitted. Refer to CESM 203 for further details on the recommendation and requirements.

GE Aircraft Engines

Commercial Engine Service Memorandum.

CF6-8OC2 COMMERCIAL ENGINE SERVICE MEMORANDUM APRIL 29, 1998

MODEL:	CF6-80C2 .
MAINTENANCE:	XX
SUBJECT:	Red Dye in Fuel Recommendation
DATE:	April 29, 1998

PURPOSE

This Commercial Engine Service Memorandum (CESM) serves to communicate the industry approved "Manufacturer Recommended Limits for Emergency Usage of Aviation Turbine Fuel Contaminated with Red Dye" for all GE CF6 engines. In addition, this CESM will define the "emergency" determination, service criteria and reporting requirements for emergency usage of red dye contaminated fuel.

BACKGROUND

Since October 1994, the U.S. Government has required red dye be added to certain diesel fuels (high sulfur "off-road" fuels). Since 1994, there have been cases of dye contaminated fuel being delivered to U.S. airports on average of one airport per month. The dye contaminant occurs in multi-use pipelines and from contaminated (but not cleaned) barges/trucks. Dye contaminant is generally small (less than 2.5% of mandated level of 11.2 ppm solvent Red 26 solid dye standard) but is easily detected visually as low as 0.36% concentration. Per GE Fuel Specification D50TF2, red dye is not a certified additive and therefore is currently not allowed.

Due to occurrences of dye contaminated fuel, airport and airline personnel have asked for guidance. Testing has been conducted in various fuel batches and in various dye concentrations. Testing for thermal stability, fuel nozzle flow testing, and test cell engine runs were performed. Test results have been reviewed and a limited emergency use of dye contaminated fuel has been determined to be allowable in the GEAE CF6 (CFM/GE90) engine.

A standard guideline for emergency. usage of aviation turbine fuel contaminated with red dye has been developed as part of the Aerospace Industry Propulsion Committee. This industry approved guideline serves as GEAE's official recommendation on red dye contaminated fuel. The official guideline provides the definition of an "emergency" situation, service criteria and reporting requirements for emergency usage of red dye contaminated aviation turbine fuel.

RECOMMENDATION

"Manufacturer Recommended Limits for Emergency (1) Usage of Aviation Turbine Fuel Contaminated with Red Dye"

General Electric Aircraft Engines is willing to accept, for "emergency" use only, Aviation Turbine fuel containing a maximum of 0.41 milligrams per liter (0.14 lb. Per 1000 bbls.) of C. 1. Solvent Red 164 (or 2.5% of the full EPA-IRS mandated dye concentration specified for off-road high sulfur diesel fuel), subject to the following restrictions and/or actions:

Service Criteria

a) That the concentration of dye in the fuel be measured "in situ" and in at least three widely separated locations along the airport distribution system, using the Petrospec Analyzer Model JT-100S (2). Values of concentration to be reported out which then defines the *"emergency."* And, that these measurements be verified by a laboratory analysis of the fuel sample in (e) below.

b) That the number of emergency fuel uplifts be limited to three (3) without restrictions for Category I aircraft as defined below.

c) That the fourth emergency fuel uplift for Category I aircraft be followed immediately (within 48 hours) by, contact with the engine manufacturer for maintenance action, which might include immediate removal and inspection of critical fuel system components. Aircraft can remain in service, but no further emergency uplifts of dyed fuel are allowed.

Reporting Requirements

d) That the airline report each emergency fuel uplift action to the engine manufacturer on the same day that it occurs. Report detail to include types of aircraft, numbers of aircraft, tail numbers, engine serial numbers and number of uplifts to each aircraft during duration of Emergency.

e) That the airline(s) secure samples (3) of the dyed fuel in sufficient quantity, and have performed on that fuel the characteristic tests defined by ASTM D1655, Standard Specification for Aviation Turbine Fuels, for Thermal Stability (Test Method D 3241,260 C Breakpoint limit), Distillation (D 86), Existent Gum (D 381), Freeze Point (D 2386) and have the laboratory verify the concentration of dye in the fuel. Results (4) to be reported to the engine manufacturers within 72 hours.
That a full analysis of the fuel sample to all the characteristics of ASTM D1655 be completed and results sent to the engine manufacturers within two weeks."

(1) - An unexpected and unforeseen situation that requires urgent and prompt action, the situation being where dye contaminated fuel has gotten into that part of the airport distribution system where it can not be segregated or isolated for remediation without halting airport operations,

(2) - A meter reading of 0.28 mg/l. Scale on this instrument is calibrated to solid red dye standard. To obtain liquid red dye equivalent value, multiply the meter reading by 1.446. (1.446 X 0.28 = 0.41 mg/L). The Petrospec JT 100S is manufactured by Varlen Instruments Inc., Bellwood, Illinois.

(3) - If the fuel system contaminated serves several airlines, only one sample for analysis need be drawn, from the point in the fuel system which has the highest level of dye contamination.

(4) - Information for data bank entry to establish overall sensitivity of U.S. produced fuels to the dye (and diesel fuel). Long range goal is possible relaxation of requirement.

Category I Aircraft - Large Wide Body - B747, DC 1O, MD ll, B777, A330, A340.
Medium Wide Body - A300, A310, B767, DC 1O, L1011.
Medium Narrow Body - B707, B757, DC 8, A319, A320, A321, MD 90
Small- BAE 146, B737, B727, DC 9, BAC 111, MD 80's, Fokker 70/100.

30 January 1998

REFERENCES

GE Aircraft Engines Specification D50TF2 "Aviation Turbine Fuels" g **Aircraft Engines**

Technical Memorandum

Operation AEED/AEPD/Advanced Combustion Design	
Project CF6-80	T.M.Number Unassigned
GE Class 2I	
Title: CF6-80C2 Engine ESN 690146 Test with Red Dyed Fuel	
Prepared By: Stanford Seto	Date: 01 July 2003
Approved By:	Date:

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1.0 Introduction

In August, 1990, the EPA (Environmental Protection Agency) proposed using dye to identify high sulfur diesel fuel, effective 1 October, 1993. Simultaneously, the IRS (Internal Revenue Service) proposed using dye to identify non-taxable diesel fuel and heating oils.

The CRC (Coordinating Research Council) started a cooperative program in June 1994, to identify the effects of the red dye in aviation turbine fuel. The overall results of these tests indicated that the presence of the dye reduced the fuel breakpoint temperature, the temperature above which the fuel begins to deposit impurities on hot metal surfaces which would later become carbon deposits. This is a serious effect, especially from the small sample of fuels tested.

It should be noted that this is just the effect of the dye. The specific effect of the diesel fuel that comes along with the dye is to degrade jet fuel freeze point. Boeing tests indicate that when the diesel is present in concentrations of 5% or higher, freeze point degrades from a degree or two at 5% to 20 deg. F at 10% diesel.

The engine test, which is the subject of this report, was the result of a feeling that the CRC test results while necessary were not sufficient to provide the basis for use permission of dyed fuel. The thermal stability tests were only indicators of the presence of problems and there is no definitive link between that testing and fuels effects on actual engine hardware exposed to real operating environments. The engine test was proposed to the CF6 Systems group in 1994. Permission to test on a non-interfering basis and via pick-a-back with on-going tests was granted in 1995, and the actual test was obtained in 1996.

2.0 Summary

2.1 - Objective: The objective of the test was to provide a supply of dyed fuel to the engine, and run as many C cycles as would be permitted, but with a goal of achieving at least 50 each. To increase test severity the concentration of dye in the fuel was to be two times the level asked by the airlines for "emergency" use, or 0.80 mg/L. The purpose of the test was to accrue sufficient operating time on the engine to be assured of no deleterious effects from the dye when used in short duration.

2.2 - Results: Engine Serial Number 690146/54 was run on PTO Site 3C. 45 C cycles were achieved in about 12 operating hours, and about 14850 gallons of Jet A fuel were consumed. The dye concentration in the fuel was 0.85 - 0.87 mg/L. Fuel system and hot flowpath inspections occurred prior to and after the test. Fifteen of thirty fuel nozzles were flow checked during these inspections. Ten of the fifteen fuel nozzles had higher hysteresis after the test. Three were outside the tolerance band permitted. On average, the hysteresis increased from 3.7 pph to 8.8 pph and the limit is 14 pph. The fuel nozzles were returned to the engine for continued testing. After an additional 44 hours of engine testing with undyed fuel, the same fifteen fuel nozzles were removed again and flow checked. Six of the ten nozzles effected had returned to near pretest hysteresis levels. Two of the ten parts had partially recovered, and two parts were unchanged from post test levels of hysteresis. On average, the hysteresis for all fifteen parts was 4.5 pph.

The fuel was tested for quality with and without dye in it. In either form, the fuel met all the requirements of GE Fuel Specification D50TF2. The thermal stability limit the fuel has to meet is no deposits up to 260 deg. C . All the fuel samples tested had stability temperature limits of 290 deg. C, well above the requirement, even with the dye added.

2.3 - Conclusions: The presence of the red dye in the fuel, and at relatively low concentration levels, less than 1.0 mg/L, can cause incipient deposits in the fuel nozzles even with short duration use. The presence of these deposits can immediately effect the operation of the fuel nozzles.

2.4 - Recommendations: With regard to the airline's request for an emergency use rule, which would allow them use of fuel contaminated up to 0.40 mg/L of red dye, limit the through put of fuel to any engine on the aircraft to 500 gallons per fuel nozzle. Require that an inspection, flow check, of the fuel nozzles be done (must pass) before allowing use of any more contaminated (dyed) fuel.

3.0 - Test Report

3.1 - Hardware Description: The engine used for this test was a CF6-80C2, ESN 690146/5A, a non-FADEC development engine used, most recently as a cell correlation engine. Its current mission is also cell correlation for PTO test stands 3C, 5A and 5B.

The fuel nozzles used in this engine were Part number (P/N) 9331M72P20. The specific serial numbered parts that were removed and flow checked before and after the test were: SN's 2635, 2104, 2113, 2906, 2110, 2898, 2903, 2895, 3058, 2900, 2109, 2629, 2634, 2106, and 2108. The fuel nozzle serial numbers are shown in the order they appear on the flow check sheets. The fuel nozzles are dual cone design.

The fuel for this test was stored in an 8,000 gallon trailer, adjacent to the test stand. The trailer had eight 1,000 gallon compartments, separated by steel bulkheads, but communicating through cut-out in the bulkheads. To mix the red dye in the fuel, a pump was attached to the trailer center compartment discharge line, and hoses were tee'd off the pump discharge and run back to the compartments at either end of the trailer.

3.2 - Test Set-up: The engine was set up on the test site per standard test instructions.

3.3 - Instrumentation: There was no special instrumentation requested for the engine, due both to the nature of the test and the engine mission. The engine carried all the standard instrumentation necessary to monitor health, performance and for safety

The one piece of special equipment brought in for the test was an instrument to measure directly, the concentration of dye in the fuel. This instrument, designated as a JT100, was supplied by ALCOR Petroleum Instruments, a division of Varlen Instruments Inc., San Antonio, Texas. Mr. George Wilson, a product manager for Varlen, came along to provide instructions on the use of the instrument, its care and handling requirements. The method of operation of this detector is laser derived. A sample of the fuel is poured into the sample cell, which has clear windows at either end. The sample cell is placed into the instrument and it is turned on. A laser beam is passed through the cell, and the wavelength absorption (510 -520 Hz.) is converted into concentration level and displayed electronically. The range of detection is consistent with the typical ranges of dye found in the aviation jet fuel, due to incidental mixing in the pipelines and single load carriers, 0.01 up through 0.75 mg/L. The instrument can also compensate the reading over a fuel color range of -16 to +30 Saybolt. The JT100 was used to establish the level of dye in the fuel before testing started, and that the dye concentrations were constant throughout the trailer.

3.4 - Test Location and Site: The test was run at the Peebles Test Operation, Peebles, Ohio, and at Test Site 3C.

3.5 - Chronological History: The test site preparation was started on or about 7 May 1996, and completed by 17 May. The fuel nozzles were flow checked on 14 May 1996. The engine was installed by 22 May.

Idle leak check and mechanical checkout started on 24 May.

Mixing of the dye in the first trailer load of fuel started on 23 May and was completed on 27 May. The first 20 milliliters(ml) of Oil Red B liquid was poured into the trailer compartments at 10:30 AM. The trailer dump-in points were rearranged to go to the ends of the trailer by 2:00 PM. 16 mg/L were added near midnight. 2.0 mg/L of the dye were added on the 24th and on the 27th of May to fine tune the mixture.

The red dye cyclic test started on the 29th of May and 23 cycles were completed on 30 May. The second load of fuel had dye mixed into it starting on the 30th of May and was completed by 3 June.

The second half of the dyed fuel test started on 3 June and was completed on second shift that day. 22 cycles were run for a total of 45 cycles in all.

On 4 June, a short vibe test was run still using the dyed fuel. For both tests, the number of cycles run was limited by the capacity of the trailer in the sense that testing had to stop when a certain level of fuel in the trailer was reached to assure the engine could be decelled and cooled off before it was shutdown, without running the trailer out of fuel. So the trailer was never run dry.

The fuel nozzles were posttest calibrated on 6 June, 1996 and reinstalled in the engine.

The engine MEC (Main Engine Control) was removed and sent to Woodward for bench check and partial tear down inspection, on 6 June 1996.

The engine then was used for cell calibration of Cells 3C , 5A and 5B. On 30 August, the fuel nozzles were returned to the fuel nozzle lab for re-calibration after running 44 operating hours on clean fuel.

3.6 - Results of the Test Program

3.6.1 - Mixing of the Dye: The dye that was supplied for this test came from Morton International, Chicago, Ill. The product is called - Automate Red B. It contains Solvent Red 164 (the coloring agent), as 65% of the product mixed with a carrying agent, xylene, 28% of the product, and other inert ingredients, 7%. The Automate Red B was added to the Jet fuel in high enough concentrations to get 0.80 -0.90 mg/L of the coloring agent. However the JT100 reads out the dye concentrations as if it were the solid red dye coloring agent, and not the liquid. This is because of a stand taken by the petroleum refiners and pipeline companies, to have a standardization between the JT100 and the diesel dye detector they were already using, the DT100. So the JT100 readout would be a value 1.45 times (5.64/ 3.9 = 1.446) lower than the calculated liquid red dye concentration in the sample being measured.

The first load of fuel was estimated to be 7784 gallons (185.3 barrels), supplied by BP Petroleum. By definition, 1.0 lb. of a substance per 1000 barrels is 2.85 mg/L. **Table 1** shows the calculations which resulted in the initial amount of dye added to the fuel. The amount was reduced to 36 milliliters to be conservative and was added in two doses, 20 ml. and when a uniform coloring had been reached, 16 ml. more were added. The initial dosage resulted in a color level of 0.29 mg/L versus a goal of 0.5655 mg/L. The additional 16 ml. resulted in a reading of 0.50 mg/L. As noted above, 2 ml were added late on the 24th, and increased the meter reading to 0.52 -0.53 mg/L. 2.0 ml. were added on the 27th and yielded a meter reading of 0.58 - 0.59 mg/L, which indicated that the previous 18 ml. of dye probably had not been given enough mixing time. The total amount of Automate Red B added to the first load of fuel was 40 ml. The final amount of dyeing agent in the fuel was 0.84 mg/L versus a goal of 0.80 - 0.82 mg/L.

The second trailer load of fuel was measured to be 7450 gallons (177.4 barrels). The dye was measured and added on that basis, but the end result was a slightly higher concentration of dye in the fuel, 0.604 mg/L meter reading, or 0.87 mg/L of the dyeing agent, versus a goal of 0.80 - 0.82 mg/L, but within the objective of 0.80 -0.90 mg/L.

Fuel samples were take from the trailer, or from the delivery truck, prior to and after the dye was added. All four samples were analyzed per the requirements of GE Fuel Specification D50TF2. All four samples passed the thermal stability test at 260 deg. C. and a breakpoint temperature was measure. Breakpoint temperature was 290 deg. C. for each of the fuels neat and with the dye added. So there was demonstrated margin.

Table 1 - Calculation of Dye Concentration

- By Definition - 1.0 Lb. per 1000 Barrels(42 gal./Bbl.) = 2.85 mg/l

7748 gal. in Trailer = 185.3 Barrels of fuel

Goal is to dye fuel with 0.8 mg/l (active ingredient) of red dye.

$$\frac{185.3 \text{ Bbls}}{1000 \text{ Bbls}} \times \frac{0.8 \text{ mg/l}}{2.85 \text{ mg/l}} \times 1.00\text{Lbs} = 0.05201 \text{ Lbs of active ingredient.}$$

The active ingredient is in dilute (65%) solution with a carrier, xylene (28%) in the dye.

Dye specific gravity is 99%

$$\frac{0.05201 \text{ Lbs}}{0.65\ (.99)} = 0.08082 \text{ Lbs of the dye, which equals } 1.29328 \text{ oz. of the dye.}$$

One gallon = 128 oz. = 3785 milliliters; 29.57 ml/ oz.

Amount of dye needed - (29.57 X 1.29328) = 38.24 ml. of the Morton's Automate Red B.

Samples from the first trailer resulted in values of 0.83 mg/L, 0.84 and 0.87. Samples from the second trailer load yielded values of 0.87 mg/L and 0.83.

The engine consumed 14,850 gal. of the total 15,195 gal. supplied. The remaining 345 gal. were drained and consumed in ground based equipment. The mass average dyeing agent concentration level was 0.858 mg/L. or about 7% higher than the goal.

3.6.2 - Engine Test: As noted in the Chronology above, the engine ran 45 "C" cycles and a vib test, using the dyed fuel throughout. Total run time was 12 hours. The type of C cycle run is shown in **Figure 8.** There are different types of C cycles, depending on EGT level and bleed extraction. There was no attempt to increase the severity of the cycle, because the idea was to limit fair wear and tear on the hardware. Once started, the cycles were run off without incident. At the end of the test, a boroscope inspection was made of the hot section. The person doing the inspection had also done the pre-test inspection. He reported no changes. The fifteen fuel nozzles flow checked prior to the test were removed and sent to the Fuel Lab. for retesting. The engine control was removed and sent to Woodward for bench testing and partial teardown and inspection. Another control was put on the engine and it was returned to test when the fuel nozzle testing was completed.

3.6.3 - Data Analysis: To determine if any changes had occurred to the engine, inspection was made of the hot flow path hardware, the transient data and the fuel system hardware (fuel nozzles and the control).

The hot flow path was boroscoped. The inspector commented that there were no significant changes.

During the test, certain key performance parameters are continuously recorded on tape. After the test, data was hard copied for the first cycle, the 23rd cycle and the 45th cycle. Plots of the accel from Idle to Takeoff power and for the parameters of throttle angle (PLA), fuel flow (Wfmain), Fan speed and Core speed were made and compared (data not provided in this report). From the throttle push to steady state, there is little different among the three sets of data.

There is a hitch in the fuel flow with an associated change in accel rate about a quarter of the way into the accel, but it appears to be consistent throughout and was later determined to be a control glitch. The engine response to the Bodie and Chop-to-Idle at the end of the cycle were also examined. Overlaying these plots shows little or no difference in the three sets of recorded data(data not provided for this report). Sanborn (a continuous strip chart recording) data was also scanned, but showed little or no change in transient operation. The engine operation appeared to be unchanged from the use of the dye.

3.6.4 - The Main Engine Control - The MEC was removed from the engine and sent to the manufacturer, Woodward Governor Company, Rockton, Ill., for operational checkout and partial teardown inspection. The control is Part Number 1538M66P03, Serial Number WYG49994, was manufactured in April, 1988, and has not been off-engine since.

Woodward tested the control in accordance with TSP-7525, that is: all the schedules, such as VSV (Variable Stator Vanes), VBV (Variable Bleed Valves), Start and Accel, N1 (Fan Speed) and N2 (Core Speed) PLA, and Electrical Speed Trim. Several minor discrepancies were found, but none seemed to be significant. The control was then partially disassembled and inspected. Filter screens, Servos and Valves, Pistons and Sleeves were all found to be without defect. The seals, Fluorosilicones and Viton, were found to have some mild compression set in face seal application (a normal finding), but had no abnormal swelling or material degradation. Durometer testing indicated material hardness was within limits.

A reddish or reddish-brown residue was found on surfaces of the Full Throttle Sensor and cover, and on the valve plunger of the VBV Sub-assembly. It was assumed to be red dye, but was easily wiped off, and did not appear to be interfering with part movement, and was not located near any metering or wiping lands of the valves.

The study conclusion is that the control was not effected by short term exposure to 0.85 mg/l of red dye concentration.

3.6.5 - Fuel Nozzle Flow Checks - As noted earlier, the fuel nozzles were flow checked three times, prior to testing with the red dye, just after testing with the red dye was completed and after an additional 44 hours of engine testing had been done with undyed fuel. All the engine testing was essentially cyclic, that is, not a lot of time was spent at a single high power throttle setting. The engine probably spent most of its steady state operating time at idle power.

During these flow checks, the first thing ascertained is fidelity to schedule (fuel flow versus fuel nozzle pressure drop), a standard set of test points called out on the part drawing. In the case of these parts, P/N 9331M72P20, the fuel flow is normally checked at 52 psi(ΔP), 100 psi, 335 psi, 472 psi and 545 psi. In addition, the flow at 335 psi is measured again as flow schedule is decreased, to measure flow schedule hysteresis. Hysteresis is the band width variation of the flow schedule, from nominal, between an increasing flow and a decreasing flow. It is defined in **Figure 15.** The following was noted in the data. The fuel nozzle secondary flow increased with clean fuel usage and after being exercised from time in storage. The values measured were within the allowable range, even with the increases, **Table 6.** The fuel nozzle average hysteresis increased dramatically (more than doubled) after the red dye testing. But, after an additional amount of engine testing with clean fuel, was reduced to nearly the initial value. Individually, some of the fuel nozzles returned to normal levels of hysteresis, but others did not. This data is shown in **Table 7.** Note from Figure 8 that 335 psid is just above the cut-in of the secondary flow valve (pressure where valve comes off the seat).

Table 6 - Fuel Nozzle Average Flow vs. Pressure Drop

Calibr. Press. psid	52	100	335	472	545
Pre-Test Flow, pph	27.5	41.9	151.0 (154.3) Up (Down)	625.0	877.0
One Sigma, pph	1.3	1.4	6.9	11.5	13.5
Post-Test Flow, pph	28.1	42.0	142.7 (150.4)	622.0	873.0
One Sigma, pph	1.2	1.3	7.6	12.7	12.6
After 44 Hrs., pph	27.7	41.9	155.8 (160.4)	638.0	882.0
One Sigma, pph	1.1	0.7	6.4	10.2	13.4
New Part Limits, pph	25-31	-----	129-163	614-666	840-910

Table 7 - Nozzle Hysteresis, pph, at 335 psid

Part No. 9331M72P20 - 15 Nozzles

Nozzle Serial No.	Pre-Test Value	Post-Test Value	After 44 Hrs/Clean Fuel
2635, Posit. 1	4.0, pph	3.0, pph	3.0, pph
2104, Posit. 2	4.0	3.0	2.0
2113, Posit. 3	3.0	1.0	3.0
2906, Posit. 4	7.0	25.0*	6.0
2110, Posit. 5	6.0	8.0	4.0
2898, Posit. 6	4.0	4.0	3.0
2903, Posit. 7	3.0	8.0	5.0
2895, Posit. 8	3.0	3.0	3.0
3058, Posit. 9	9.0	16.0*	9.0
2900, Posit. 25	7.0	11.0	10.0
2109, Posit. 26	2.0	8.0	9.0
2629, Posit. 27	1.0	15.0*	3.0
2634, Posit. 28	0.0	12.0	1.0
2106, Posit. 29	2.0	9.0	2.0
2108, Posit. 30	0.0	6.0	3.0
Average	3.7	8.8	4.5
One Sigma	2.6	6.3	2.8

Limits: New Part - 14.0 pph, Ultimate - 21.0 pph , * - out of New limits.

From Table 6, at the pressure drop of the hysteresis check, and in all three flow tests of the nozzles, the average flow during the increase (up) of pressure and flow was slightly lower that the average flow measured during the decreasing (down) part of that measurement. The percentage of flow change during the upward legs was -5.6% between pre-test and post-test, increasing to +9.1% between post-test and “after clean fuel”. During the down leg of the check, the differences were smaller, -2.5% from pre-test to post-test and +6.8% between post test and the “after clean fuel”. What is of more interest, is that at other pressure levels there was much less flow variation exhibited by the nozzles, on average. For example, at 52 and 100 psid, the measured flow is in the middle of the range and varies by much less than one percent. At 472 psid, the flow change is less than half a percent between the “pre-” and “post-” test measurements and is only 2.5% higher from “post-” to “after clean fuel”. At 545 psid, a similar finding occurs, the increase after “post-” being even less, at 1.03%.

The information in Table 7 indicates that the hysteresis of five fuel nozzles was unaffected by the presence of the dye, fuel nozzle serial number’s 2835, 2104, 2113, 2898 and 2895. A look at the flows measured at pressure, a breakout of the Table 6 data, indicates that the actual flows of these nozzles was lower after the dyed fuel testing, and subsequently recovered, **Table 8.**

Table 8 - Flow of Nozzles with Little Hysteresis Variation

Flow @ 335 psid, During (Down) Check

Nozzle Serial No.	Pre-Test Flow	Post-Test Flow	After Clean Fuel
2635	151.7 pph	147.0 pph	156.1
2104	166.2	163.0	172.4
2113	157.0	146.0	163.9
2898	153.3	149.0	162.6
2895	148.2	145.0	155.7

New Part Limits - 129.0 -163.0 pph

Table 8 data shows that relative to the pre-test flows, these five nozzle experienced a flow reduction of 2.0 - 8.0% and a subsequent recovery of 3.0 - 6.0%. One nozzle, 2104, exceeded new part limits on the high side.

Table 7 data shows further, that ten fuel nozzles experienced increases in their hysteresis values after the dyed fuel, and of those, six returned to pre-test limits after the clean fuel, two demonstrated half level reductions toward the pre-test levels and two nozzles had little further change. A relook at the flow data at 335 psid indicates that most of the change in hysteresis value was measured during the (up) portion of the flow check, with the flow at pressure generally being higher during the (down) portion of the flow check. One of the nozzles had lower flow during the (down) portion of the check.

The two nozzles that had little or no change in hysteresis after the clean fuel test, had the same flow at pressure after both the pre-test check and the dyed fuel test. But had 6.0% increase in flow at pressure after the clean fuel test, indicating that the increase in hysteresis was the result of a reluctance for the secondary valve to unseat during the (up) portion of the flow check.

On the basis of the data seen, the dye contamination would seem to be collecting on or near the secondary spool and valve seat, as the effects of this accumulation are most noticeable at or near the secondary valve cracking pressure. The secondary flow seems much less effected at higher pressures, and the primary circuit appears to be completely unaffected.

3.7 - Conclusions

The purpose of the test was to run a short period of time with dye in the fuel to simulate an emergency usage situation. The expectation was that in concentration levels less than 1.0 mg/l, no effects would be seen in the engine hardware. At the end of the test, the engine performed as well as it was performing at the start of the test.

However the presence of the red dye in the aviation turbine fuel, even in trace (<1.0 mg/l) amounts, had the effect of reducing the secondary flow of the engine fuel nozzles at local pressure drops and causing valve sticking of the secondary valve during unseating, as fuel flow increases. These effects were measured after a relatively short engine test at rather nominal ambient conditions. The effects noted were mitigated in most, but not all, of the fuel nozzles after clean fuel was introduced into the engine and it was run for approximate four times longer than the dyed fuel test.

After the clean fuel test, all the fuel nozzles demonstrated higher flow at pressure, indicating that the most highly effected part of the fuel nozzle appears to be the valve seat for the secondary valve, which resulted in a slow unseating as cracking pressure is exceeded.

The presence of the dye in the fuel did not have any noticeable operational effect on the control system, other parts of the fuel system, or on parts (combustor, turbine or exhaust) in the hot gas stream. Residue of the dye did appear to be present on some of the control surfaces. If the test had been run for longer periods of time, the possibility exists that these residues would build-up and harden, and that control operability would eventually be compromised.

The fuel nozzle performance deviations noted would not be expected to significantly alter engine performance. The fact that <u>any</u> effects were measured after this test was surprising and disturbing. Failure to achieve 100% recovery of performance after the clean fuel testing was equally disturbing. Clearly, the presence of even trace amounts of the dye in the fuel can cause the start of performance deviations in the engine fuel nozzles. Long term effects are open to speculation.

3.8 - Recommendations

Basically, a quantity of contaminated fuel was run through the engine with negligible effect. There were indicators that continued use of the contaminated fuel could have lead to measurable performance effects in the engine. It was also noted that not all the indicators were obviated by a return to, and prolonged use of, clean fuel. The purpose of the test was to establish that short term use of fuel contaminated with trace levels of red dye would not detrimentally effect engine operability and performance. That objective was achieved. Test results indicated that the presence of the dye in the fuel was, however, beginning to have an effect.

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The first recommendation generated was that a limit for the contamination with red dye be established at concentrations of 0.40 mg/L or less.

The second recommendation generated was that the consumption of fuel at this concentration level be limited on the basis of the engine test reported above. Specifically, that the amount of dyed fuel permitted through the engines be limited by the number of fuel nozzles, which were the effected part. GE AE and CFMI have engine models in commercial service which range in size is from the CT7/T700 (twelve low pressure nozzles) to the GE90 (thirty dual tipped pressure atomizing fuel nozzles).

The usage limitation could be defined by the amount of through-put fuel the CF6-80 engine fuel nozzles each experienced. In round numbers that was 15,000 gals and 30 fuel nozzles, or 500 gallons per nozzle.

The third recommendation was that after consuming the amount of fuel per nozzle in the second recommendation, that the engine fuel nozzles be removed and flow checked before any further consumption of red dye contaminated fuel is permitted. If an effect is noted, then the particular aircraft should not received any more contaminated fuel.

Figure 8 - Commercial Operating Cycle, C-Cycle

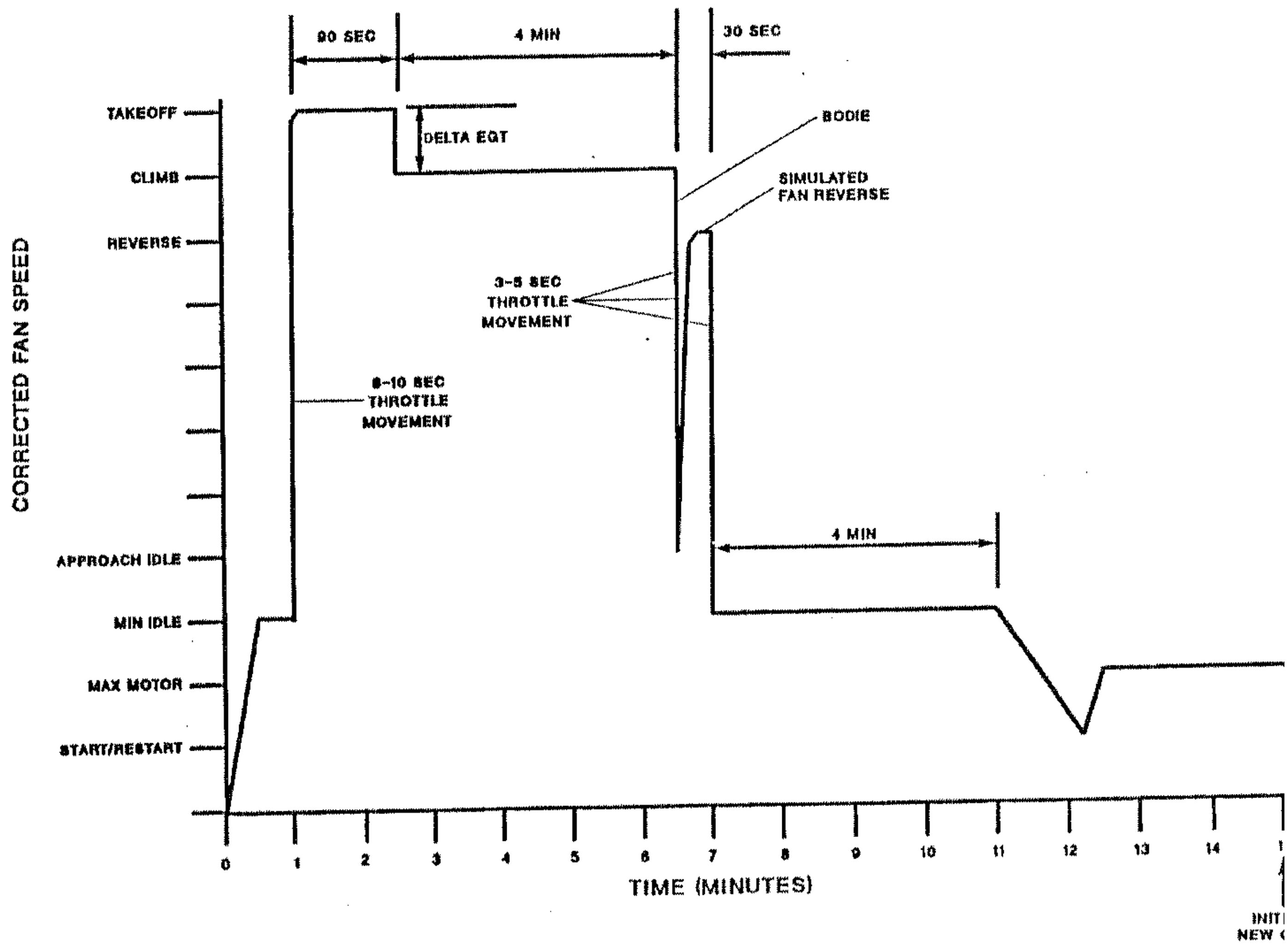
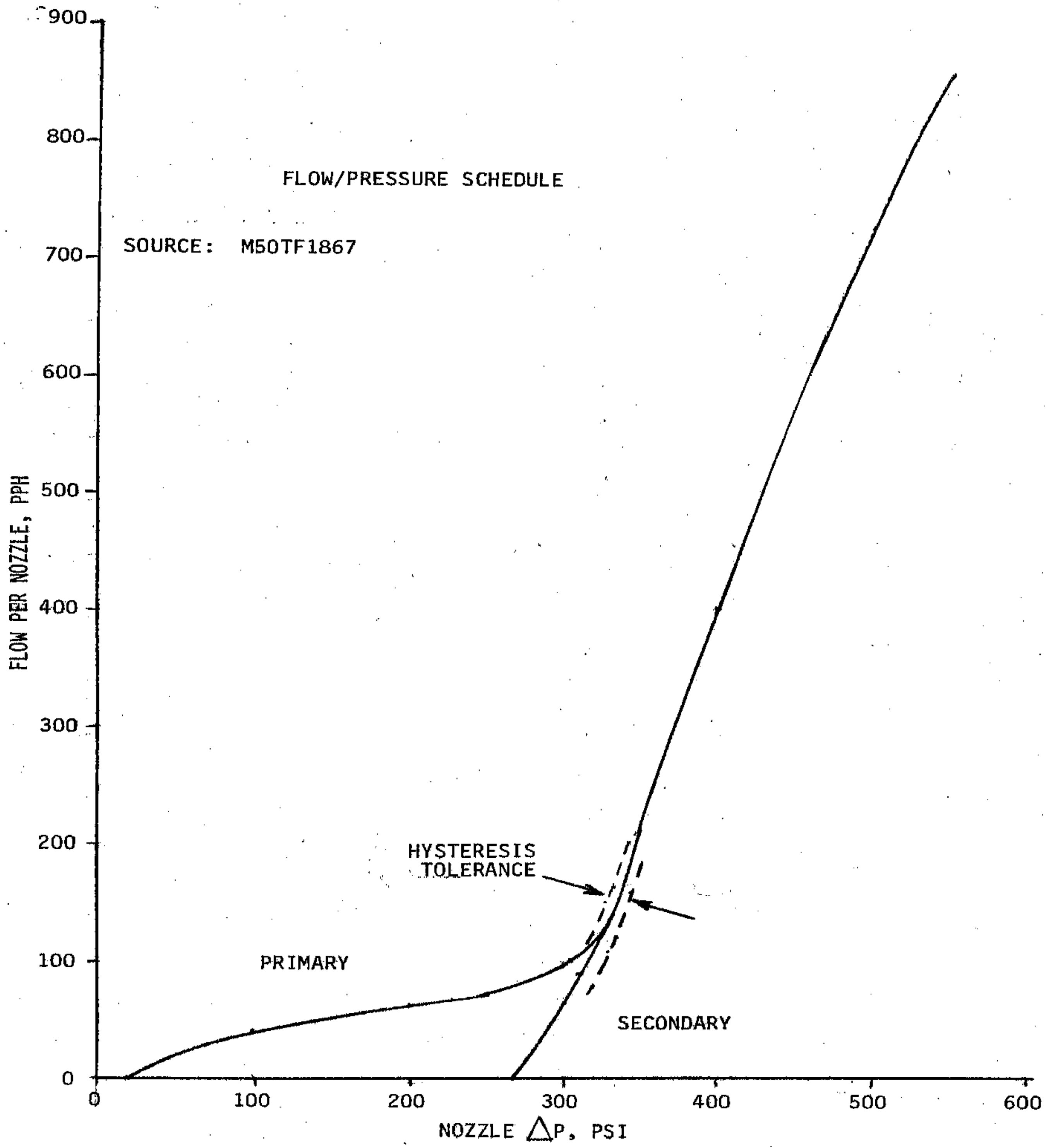


Figure 15 - Fuel Nozzle Flow Schedule with Hysteresis Limits Shown.



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