

<sup>3</sup>Harman, W.H., "Air Traffic Density and Distribution Measurements," FAA Rept. No. RD-78-45, May 1979.

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## Ground Contamination by Fuel Jettisoned from Aircraft in Flight

Harvey J. Clewell III\*

*Air Force Engineering and Services Center  
Tyndall AFB, Florida*

### Introduction

THE term "fuel jettisoning" refers to the discharge of unburned fuel directly into the atmosphere by an airborne aircraft. Fuel jettisoning usually occurs as the result of an in-flight emergency or unforeseen operational requirement and is performed to reduce the aircraft's gross weight and facilitate a safe, expeditious landing. Jettisoning incidents, although infrequent, involve considerable quantities of fuel. Depending upon the aircraft, the fuel released in a single incident can range from a few thousand liters to well over 50,000 liters.<sup>1</sup> The jettisoned fuel readily breaks up into small droplets and begins to evaporate. From an environmental standpoint, the principal concern is what fraction of the fuel reaches the ground before it can evaporate and disperse. A previous analysis<sup>1</sup> showed that the effect of the evaporated fuel vapors in the atmosphere is negligible. If liquid fuel reaches the ground, however, there is a potential for negative environmental consequences such as crop damage or water pollution.

The Air Force has been investigating the environmental ramifications of fuel jettisoning for several years. Air Force aircraft jettison fuel nearly 1000 times a year, and the fuel released to the atmosphere by these aircraft amounts to more than 7000 metric tons (16 million pounds) per year—averaging 26,000 liters (7000 gal) per day.<sup>1</sup> Fortunately, the fuel discharged by Air Force aircraft is generally JP-4, a highly volatile fuel which is readily evaporated and dispersed, minimizing ground contamination by liquid fuel.<sup>2,3</sup> On the other hand, Jet A, the fuel currently in use by commercial aircraft in the United States, is a kerosene-type fuel much less volatile than JP-4. Recently the Air Force has converted many of its NATO aircraft to JP-8, a military fuel very similar to Jet A. Any fuel jettisoning involving these fuels can be expected to entail greater ground contamination than that involving JP-4 owing to the lower tendency to evaporate. In recent years, Air Force aircraft in NATO have jettisoned fuel approximately 80 times per year, for a total of over 500 metric tons (over a million pounds) of fuel per year.<sup>1</sup> Commercial aircraft also jettison fuel, but complete records are not kept. Maintenance reports provided to the FAA by the commercial airlines<sup>4</sup> show 485 records of fuel jettisoned over the 5-year period ending March 1980. Unfortunately, these records do not indicate the amount of fuel jettisoned, and only fuel jettisoning incidents associated with aircraft maintenance are

included, not those occasioned by weather or scheduling imperatives. Nevertheless, we can conclude that the level of fuel jettisoning by commercial aircraft is significant. The purpose of this study was to determine the increased likelihood of ground contamination from commercial jet fuel and JP-8 as compared to JP-4.

### Procedure

In order to assess the differential impact of fuel jettisoning involving JP-4 and Jet A/JP-8, a computer model was employed which simulates the evaporation and free-fall of fuel droplets in the atmosphere. This model was developed and validated during a previously reported study of the droplet formation and evaporation of JP-4 fuel jettisoned from an aircraft in flight.<sup>2,3</sup> The model, which is described in detail in Ref. 3, breaks up a droplet's fall into a series of small time intervals. During each interval the distance of fall and loss of mass are calculated, providing the initial conditions for the next interval. This stepwise approximation continues until the droplet impacts on the ground or evaporates completely. To simulate fuel jettisoning, the model is run for a series of droplets based on actual experimental measurements of the fuel droplet size distribution produced by aircraft fuel jettisoning.<sup>3</sup> A detailed composition of the jettisoned fuel must be input into the model for use in the evaporation calculations. The model then keeps track of the changing composition as the more volatile components evaporate preferentially, leaving the denser, slower-evaporating components behind. In previous reports,<sup>1,3</sup> only a composition for JP-4 was used. In this study the effect of changing the jettisoned fuel composition to that of a representative Jet A fuel<sup>5</sup> (shown in Table 1) was determined.

### Results

The predictions of the fuel droplet evaporation and free-fall model for JP-4 and JP-8/Jet A are compared in Figs. 1

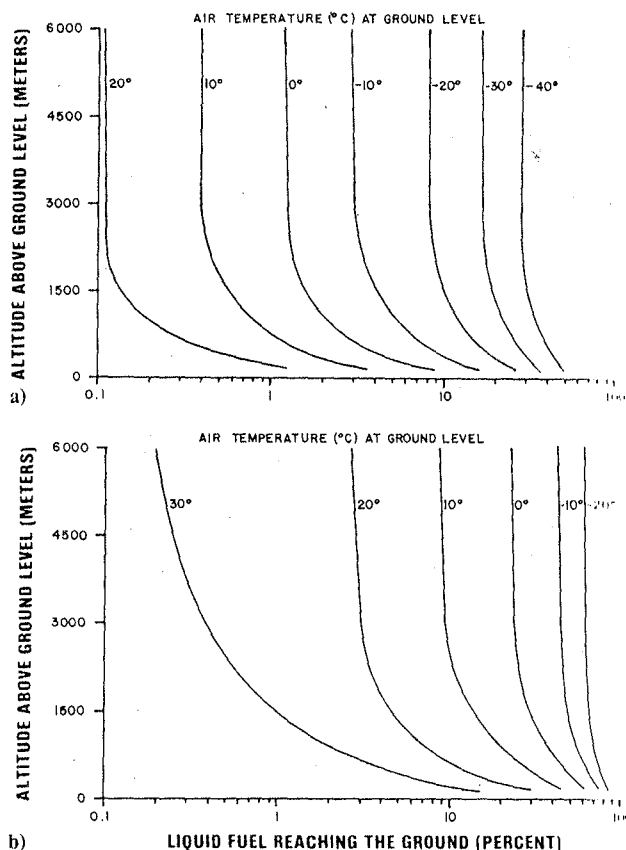


Fig. 1 Effect of release altitude on the percent of fuel reaching the ground. a) JP-4, b) JP-8/Jet A.

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\*Research Chemist, Environics Division. Present address: Toxic Hazards Division, Air Force Aerospace Medical Research Laboratory, WPAFB, Ohio.

and 2. Figure 1 shows the effect of the altitude (above local ground level) at which the fuel is jettisoned on the fraction of fuel reaching the ground. In all cases the effect diminishes as the altitude increases, and above 3000 m (10,000 ft) there is essentially no change in the amount of liquid fuel reaching the ground for different release altitudes. Below 1500 m (5000 ft), the fraction of fuel reaching the ground increases sharply because the fuel no longer has sufficient time to evaporate before it strikes the ground. The temperature shown in the figures is that measured at ground level. The model uses a standard lapse rate to calculate the temperature at higher altitudes. The effect of temperature is very strong: a 20°C (16°F) change in temperature can produce as much as a factor of 10 change in the amount of liquid fuel reaching the ground. Some corresponding predictions for the two different fuels as a function of temperature are compared in Fig. 2. The jettisoning altitude in this case is 1500 m. At the same temperature, considerably more JP-8/Jet A reaches the ground than JP-4.

The composition of the fuel droplets which reach the ground is no longer the same as that of the fuel which was jettisoned. The more volatile, lower molecular weight

components evaporate off preferentially, and the droplets end up containing a residual mixture of the higher molecular weight components. Typical compositions for fuel droplets reaching the ground are presented in Ref. 5. In general, when ambient temperatures are sufficiently low so that a significant fraction of jettisoned JP-4 will be unable to evaporate, the composition of the droplets reaching the ground resembles Jet A more than JP-4. This is because the more volatile components have been stripped away. Similarly, when JP-8 or Jet A is jettisoned, the liquid fuel reaching the ground resembles diesel fuel more than JP-8/Jet A. This fact is important in considering the effect of the liquid fuel in water/soil environments.

### Conclusions

A previous study of the environmental impact of fuel jettisoning considered only JP-4 fuel, and concluded that the effect of the evaporated fuel vapors in the atmosphere is negligible.<sup>1,2</sup> The only concern for detriment of the environment stemmed from the possibility of liquid fuel contaminating ground or water resources. In the case of JP-4, this is not a likely event. However, for jettisoning of JP-8 or Jet A, the likelihood of significant quantities of liquid fuel reaching the ground is much higher. Figure 1 shows that when the temperature at the ground is below freezing (0°C), more than 20% of jettisoned JP-8 or Jet A will reach the ground before evaporating, regardless of the jettisoning altitude. Even for temperatures above 20°C (70°F), several percent of the jettisoned fuel will reach the ground in liquid droplets. Although the effects of the evaporated JP-8 or Jet A vapors can be neglected, the possibility of surface contamination cannot.

Air Force aircraft in NATO and commercial aircraft in the United States jettison JP-8 and Jet A regularly. The Air Force jettisoning occurs primarily over the North Sea, but much of it is directly over England.<sup>1</sup> Responsible personnel in this area should be aware of the increased potential for ground contamination as a result of conversion from JP-4 to JP-8. The locations and circumstances of commercial fuel jettisoning have never been surveyed, despite the recommendation of the U.S. General Accounting Office.<sup>6</sup> Because of the higher

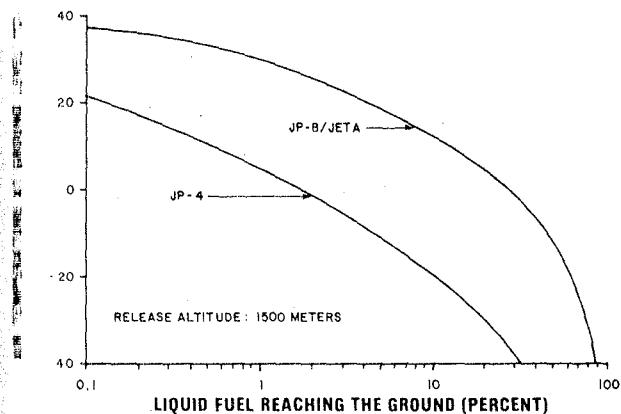


Fig. 2 Effect of temperature on the percent of fuel reaching the ground.

Table 1 Fuel composition: JP-8/Jet A  
(density of mixture, 0.81 g/ml; average carbon number, C12; total aromatics, 19.6%)

Components	Vol. %	Molecular weight	Boiling point, °C	Density, g/ml
C8 paraffins	0.3	114.2	118	0.70
C8 cycloparaffins	0.2	112.2	124	0.78
C8 aromatics	0.1	106.2	139	0.87
C9 paraffins	2.4	128.3	142	0.72
C9 cycloparaffins	1.5	126.2	154	0.80
C9 aromatics	1.0	120.2	165	0.88
C10 paraffins	5.6	142.3	160	0.72
C10 cycloparaffins	3.5	140.3	171	0.80
C10 aromatics	2.3	134.2	177	0.86
C11 paraffins	8.7	156.3	196	0.74
C11 cycloparaffins	3.3	154.3	196	0.80
Dicycloparaffins	3.1	152.3	201	0.89
C11 aromatics	3.6	148.2	205	0.86
C12 paraffins	10.8	170.3	216	0.75
C12 cycloparaffins	8.0	166.3	221	0.88
C12 aromatics	4.6	162.3	216	0.86
C13 paraffins	11.5	184.4	235	0.76
C13 cycloparaffins	8.5	182.4	225	0.80
C13 aromatics	4.9	176.3	234	0.87
C14 paraffins	5.9	198.4	254	0.76
C14 cycloparaffins	4.4	192.4	290	0.94
C14 aromatics	2.5	186.3	295	1.03
C15 paraffins	1.4	212.4	271	0.77
C15 cycloparaffins	1.0	206.4	300	0.90
C15 aromatics	0.6	200.4	305	0.95
C16 hydrocarbons	0.2	226.4	287	0.77
Residual hydrocarbons	0.1	202.3	393	1.27

likelihood of ground contamination following jettisoning of these fuels, the choice of jettisoning locations becomes more critical than with JP-4.

Air Force command directives specify that, when circumstances permit, fuel jettisoning should be carried out over unpopulated areas and more than 1500 m (5000 ft) above the ground.<sup>1</sup> As can be seen in Fig. 1, jettisoning above 1500 m is preferred to allow sufficient time for the fuel to evaporate as much as possible. For the larger fuel dumps performed by tanker and bomber aircraft, release altitudes above 6000 m (20,000 ft) are specified. While increasing the release altitude from 1500 to 6000 m does not significantly decrease the fraction of fuel reaching the ground, it does allow considerably more time for atmospheric processes to disperse the fuel. (A discussion of the role of atmospheric dispersion in determining the area over which the jettisoned fuel is spread can be found in Refs. 1-3.) The FAA guidelines for jettisoning by commercial aircraft suggest only a 600-m (2000-ft) minimum altitude.<sup>6</sup> However, following Air Force guidance of 1500 m (6000 m for large aircraft such as the Boeing 747) would help to minimize any detriment to the environment from the jettisoning of Jet A by commercial aircraft.

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## EXPERIMENTAL DIAGNOSTICS IN COMBUSTION OF SOLIDS—v. 63

*Edited by Thomas L. Boggs, Naval Weapons Center, and Ben T. Zinn, Georgia Institute of Technology*

The present volume was prepared as a sequel to Volume 53, *Experimental Diagnostics in Gas Phase Combustion Systems*, published in 1977. Its objective is similar to that of the gas phase combustion volume, namely, to assemble in one place a set of advanced expository treatments of diagnostic methods that have emerged in recent years in experimental combustion research in heterogeneous systems and to analyze both the potentials and the shortcomings in ways that would suggest directions for future development. The emphasis in the first volume was on homogeneous gas phase systems, usually the subject of idealized laboratory researches; the emphasis in the present volume is on heterogeneous two- or more-phase systems typical of those encountered in practical combustors.

As remarked in the 1977 volume, the particular diagnostic methods selected for presentation were largely undeveloped a decade ago. However, these more powerful methods now make possible a deeper and much more detailed understanding of the complex processes in combustion than we had thought feasible at that time.

Like the previous one, this volume was planned as a means to disseminate the techniques hitherto known only to specialists to the much broader community of research scientists and development engineers in the combustion field. We believe that the articles and the selected references to the literature contained in the articles will prove useful and stimulating.

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