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SHIPBOARD STUDIES OF FUEL-VAPOR IGNITION BY RADIO-FREQUENCY ARCS

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ABSTRACT

Shipboard studies of radio frequency arcs developed on parked aircraft aboard the CVA 42 have shown that arcs of 0.4 ampere or more drawn from locations with an open-circuit potential greater than 120 volts can ignite flammable concentrations of fuel vapor. Such arcs were observed under conditions which were considered normal for purposes of fueling. Measurements of arc voltage and current are reported for various locations of the aircraft and transmitters. Suggestions are made for reducing the possibility of accidental fires.

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

AUTHORIZATION

NRL Problem C01-03
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SHIPBOARD STUDIES OF FUEL-VAPOR IGNITION BY RADIO-FREQUENCY ARCS

BACKGROUND

Various reports from the fleet have indicated that radio-frequency (rf) arcs are sometimes observed on aircraft located near transmitting radio antennas aboard aircraft carriers. Since planes are fueled in close proximity to such antennas, these arcs obviously threaten the safety of the fueling operation if they can serve as ignition sources.

In the spring of 1958, the authors participated in an rf hazards assessment program sponsored by the Navy Department. Field studies of ignition by rf arcs were made aboard the CVA 42 (FRANKLIN D. ROOSEVELT) during the period April 16-21. Subsequent laboratory studies of some factors involved in arc ignition were previously reported (1); the current work presents the results of the shipboard studies.

THE NATURE OF THE PROBLEM

An aircraft located in an rf field acts as a receiving antenna. As the electromagnetic waves surge past, currents are induced in the airframe. Since these currents are a mass movement of electrons responding to the external field and interacting with the electrical characteristics of the aircraft structure, the highest voltages occur at areas where the electrons tend to accumulate immediately before reversal of their direction of flow. These areas are often associated with portions of the aircraft where sharp edges occur, such as the propeller, ailerons, external rocket fins, or bomb racks.

When the aircraft is touched at a point of high potential by another conductor which can provide an alternate path for discharge of the accumulated electrons, current flows through the junction. On breaking the contact, an arc may be formed if the current is large enough. Such arcs can be drawn out to a distance which depends largely on the electron emission characteristics of the contacting metals, the magnitude of the arc current, the frequency, and the rate of separation.

During daylight conditions, the arcs are not easily seen but are often felt by personnel touching the aircraft, and the resulting sensations are described as rf burns. In the dark, even small arcs are readily visible, and, where a sequence of arcs arise, as when a grounding clip is dragged across a high-potential wing area, the subjective impression is that of a long, continuous spark. Thus, fueling crew members have reported seeing "sparks six feet long."

Measurements of the voltages and currents involved in these arcs were made by personnel of International Electronics Engineering, Inc. aboard the CVA 59 (FORRESTAL) in December 1957. Their results (2) indicated open-circuit voltages as high as 100 volts and currents on the order of 0.6 ampere. Since these observations were incidental to another program, unrelated to vapor ignition, the present test program was designed to investigate the following aspects of the problem:

1. To determine whether rf arcs can ignite flammable concentrations of fuel vapor and, if so, to determine the magnitude of current necessary to cause ignition.

2. To measure the current which can be drawn from aircraft positioned in various relationships to transmitting antennas.

3. To attempt to correlate measured rf currents with independent measurements of field strength.

PROCEDURES AND APPARATUS

Measurements of energy available for arc formation involved positioning an aircraft in the desired relationship to the antenna, transmitting a continuous wave signal, and then measuring the voltage and current at specific points on the aircraft. All test aircraft were tied down and grounded to the deck with stranded steel cables in accordance with the standard procedure of the ship's plane-handling and fueling crews. Preliminary estimates of the voltage were made to determine the areas of greatest interest by attempting to draw arcs to a hand-held pencil or by hand feeling the aircraft. This practice when checked by subsequent voltage measurements was found to provide a reasonably valid index to the high-voltage areas.

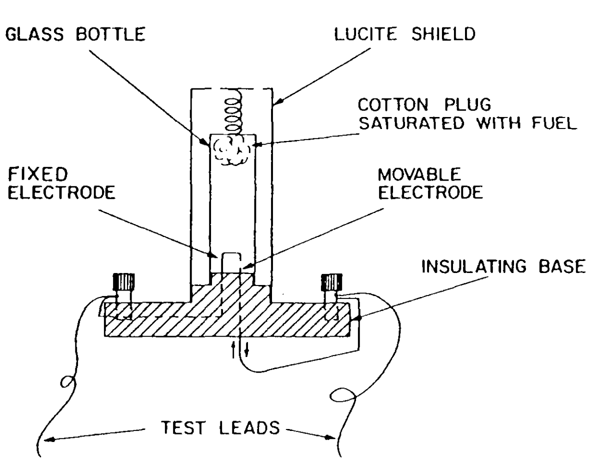
A General Radio Type 727-A vacuum tube voltmeter was used for voltage measurements and a panel-type rf ammeter (range 0 to 1 ampere) was used for the current measurements. Unless otherwise noted, voltages and currents were read independently to eliminate interaction of the measuring devices.

The reader is cautioned against leaping to the conclusion that the product of open-circuit voltage measurements and the subsequently measured short-circuit currents is a valid power index. The experimental probing for locations at which arcs could be drawn indicated that, at points of relatively high-measured potential, short-circuit currents heavy enough to maintain arcs were usually available and where no voltage could be measured, no arcs or measurable current could be observed. It is obvious that grounding a part of the aircraft through an ammeter or a conductor which can permit arc development changes the standing-wave pattern on the aircraft and probably the voltage at the point of measurement.

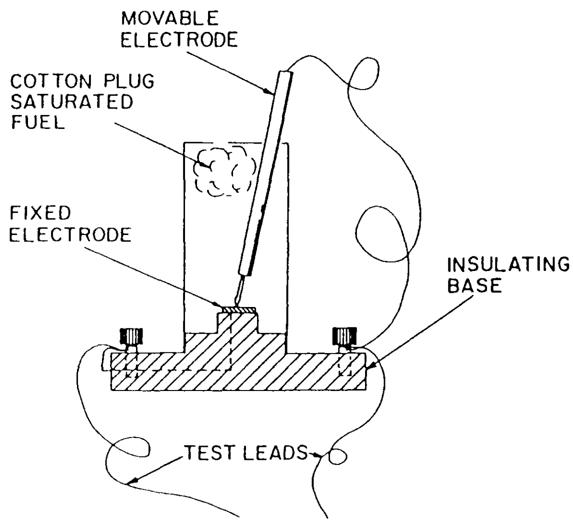
The pairing of open-circuit voltages and currents in the tables is therefore to illustrate the above experimental observation. The ratio of open-circuit voltage to the current which could be drawn from a given point is not constant and would not be expected to be so.

On the other hand, later experiments in which voltage and current measurements were made simultaneously from a single point do yield valid relative-power measurements since the standing-wave pattern was not changed during the course of planned variations in the field intensity and so the phase angle remained constant. Conversion of these relative-power measurements to absolute values would require knowledge of the phase relationships between current and voltage which was not readily accessible.

Ignition tests were made with the apparatus shown in Fig. 1a. The test leads were connected between the aircraft and flight deck while the separable Nichrome electrodes were in contact. The electrodes were then pulled apart so that an arc could develop in the opening gap. Later a modified apparatus (Fig. 1b) provided a scraping separation between brass and solder electrodes. This apparatus permitted ignitions at lower voltages because of the lower internal resistance and better electron emission characteristics of the electrodes. The electrodes were in an atmosphere which was flammable at a spark energy level of 0.3 millijoule. This was achieved by wetting the cotton pad with a mixture of n-heptane and n-octane which gave at the ambient temperature an equilibrium vapor concentration within the concentration limits for ignition at this energy level (1). Blends containing 0, 33, 67, and 100 percent n-octane provided enough overlap to cover the temperature range from 55° to 96°F.



(a) Arc production by separable Nichrome electrodes



(b) Arc production by scraping separation of brass and solder electrodes

Fig. 1 - Ignition test apparatus

EXPERIMENTAL RESULTS

Voltage and Current Measurements

Initial voltage and current measurements were made on an AD-6 aircraft spotted fore and aft at the starboard edge of the flight deck with its wing centered on and extending outboard over the forward TBA whip antenna (frame 6). As expected, wide variations were observed in the measurable voltage from point to point (Fig. 2). These measurements, as well as subsequent measurements, were unpredictably affected by changes in the grounding pattern. For instance, touching the underside of the wing by hand would sometimes change the measured voltage at specific points by as much as 100 percent. Other points, not far removed, would show no change. The highly distorted shape of the observed voltage pattern suggests the impossible complexity of analyzing the airframe in terms of conventional antenna concepts.

Relatively high voltages were found on this aircraft at various points, particularly on such appendages as the external wing tanks, mounted rockets or bomb racks, the propeller, and the empennage. Some of these measurements are shown in Table 1. The major subdivisions of the table indicate the effects of folding the wings and raising the ship antenna to a vertical position, and also the effect of moving the airplane twenty feet toward the centerline of the ship. Folding the wings changed the energy distribution on the aircraft but had little effect on the magnitude of the available energy. These findings were essentially duplicated with the AD-6 positioned similarly in relation to the TBM whip antenna located aft of the island structure at frame 205 (Table 2). Similar, though less comprehensive, measurements were made on three other types of aircraft (Table 3). Except for the FJ-3, which was incompletely checked, the energy levels noted are of the same order of magnitude as those observed on the AD-6.

The possibility of field interactions which might reinforce, cancel, or shift the standing-wave pattern when an aircraft is exposed to the fields of two simultaneously transmitting antennas was investigated. The AD-6 was therefore positioned with its outboard wing extending over the SRT antenna (frame 200) located aft of the island and 18.5 feet

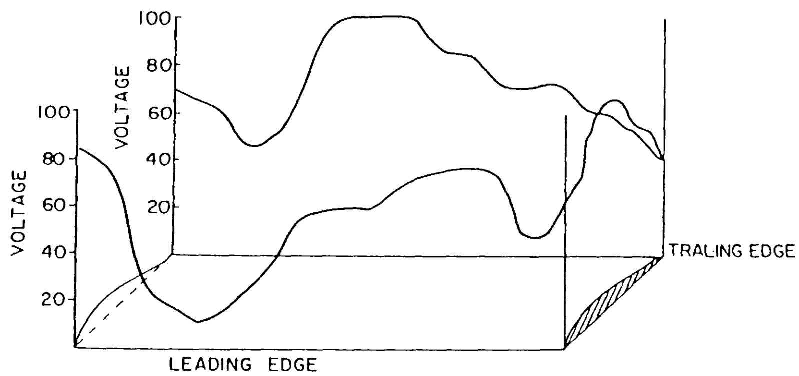


Fig. 2 - Voltage distribution on port-wing edges of an AD-6 aircraft

Table 1
RF Arc-Voltage and Current Determinations on an AD-6 Aircraft Located in the Vicinity of the Starboard Whip Antenna (Frame 6) of a TBA (1000 watts, 13.551 Mc) Transmitter

Aircraft Position and Measurement	Test Area				
	Propeller-Blade Edge	Wing-Tank Nose	Starboard-Wheel Tiedown	Starboard-Wing-Tank Tail Fin	Fuel Tank Vent
Wings Spread, Antenna Horizontal					
Voltage (volts)*	245	80	48	200	60-110
Current (amp)	0.66	-	1.00	0.70	0.35
Wings Folded, Antenna Vertical					
Voltage (volts)*	155	250	20	230	62
Current (amp)	0.20	0.80	0.09	0.78	0.26
Wings Spread, Antenna Horizontal, Craft Moved 20 ft Toward Centerline					
Voltage (volts)*	160	145	-	120	20
Current (amp)	0.30	0.42	-	0.36	0.10
Wings Folded, Antenna Vertical, Craft Moved 20 ft Toward Centerline					
Voltage (volts)*	80	50	-	54	14
Current (amp)	0.13	0.10	-	0.12	0.08

*Open circuit.

Table 2
RF Arc-Voltage and Current Determinations on an AD-6 Aircraft Located in the Vicinity of the Starboard Whip Antenna (Frame 205) of a TBM (500 watts, 11.8 Mc) Transmitter

Aircraft Position and Measurement	Test Area			
	Propeller-Blade Edge	Wing-Tank Nose	Starboard-Wing-Tank Tail Fin	Fuel Tank Vent
Wings Spread, Antenna Horizontal				
Voltage (volts)*	225	195	120 (24)†	30
Current (amp)	0.35	0.69	0.60 (0.22)†	0.15
Wings Folded, Antenna Vertical				
Voltage (volts)*	100	65	38	46
Current (amp)	0.240	0.185	0.125	0.33
Wings Folded, Antenna Horizontal				
Voltage (volts)*	60	45	44 (28)†	110
Current (amp)	0.37	0.15	0.15 (0.22)†	0.245
Wings Folded, Antenna Horizontal, Craft Moved 18.5 ft Forward				
Voltage (volts)*	160	60	50	60
Current (amp)	0.26	0.26	0.23	0.31

*Open circuit.
†Determined with craft moved 20 ft toward centerline.

forward of the TBM antenna. The 500-watt SRT and TBM transmitters were each tuned to 11.8 megacycles at maximum power. The results of voltage and current measurements are shown in Table 4. The energy levels were comparable in magnitude with those reported in Tables 1 and 2. At all points measured, the voltage decreased slightly, but, in most cases, the current remained the same or actually increased. This observation indicates a shift in phase of the standing-wave pattern and suggests that in this particular case the interaction of the transmitters tended to decrease rather than increase the energy available at the measurement points. It is likely that a complete survey of the aircraft would have indicated other specific points on the airframe where the reverse was true. This was borne out in later measurements at the port-wing bomb racks where voltages and currents measured with both transmitters in operation exceeded the sum of the values measured with each operating independently.

The study of transmitted wave interaction was continued by attaching both the voltmeter and ammeter between the tail fin of the starboard wing tank and the flight deck to avoid accidental changes in measurement geometry. The AD-6 was spotted with its outboard wing centered over the TBM antenna. The SRT and TBM were operated under independent and simultaneous conditions (Table 5). It is obvious that the energy levels of simultaneous transmission are not simply the arithmetic sum of those noted with each transmitter operating independently. The table also reports measurements made with grounding cables attached to two additional points on the plane, one on the propeller and

Table 3
RF Arc-Voltage and -Current Determinations of Various Aircraft Located in the Vicinity of the Starboard Whip Antenna (Frame 6) of a TBA (1000 watts, 13.551 Mc) Transmitter

Aircraft	Aircraft Position and Test Area	Measurement	
		Voltage (v)*	Current (amp)
A4D	Wings Spread, Antenna Vertical, Fuselage Centerline 24 ft from Antenna Base		
	Centerline Bomb Launcher	145	0.45
	Stbd-Wing Leading Edge (near fuselage)	145	0.39
	Stbd-Wing Fuel-Tank Mount	150	1.00
	Stbd-Wing Rocket Mount	200	0.86
A3D	Wings Spread, Antenna Vertical, Fuselage Centerline 18 ft from Antenna Base		
	Bomb-bay Door	60	0.48
	Starboard-Engine Nacelle	115	0.55
	Weapons Case (Mounted in Bomb Bay)	235	0.34
FJ-3	Wings Spread, Antenna Horizontal		
	Wing-Rocket Tail Fin	60	0.39
	Wing-Rocket Nose	70	0.60

*Open circuit.

the other on the nose of the wing tank to which the instruments were attached. This additional grounding did little to decrease the energy available and, contrariwise, accomplished the opposite effect in one case.

Without moving the plane from the above test location, a series of measurements (Table 6 and Fig. 3) were made to relate the transmitter power to the energy available on the aircraft. The transmitter power was decreased in equal increments of 3 decibles as measured by a PRM-1 field-strength meter located near the plane. The available energy is obviously a linear function of the field strength (and transmitter power). In this case, the product of voltage and current is a reliable relative power index, because the measuring geometry and transmitted frequency are unchanged and the phase angle of the current and voltage remains constant. This test was repeated with a ground lead

Table 4
RF Arc-Voltage and -Current Determinations on an AD-6 Aircraft Located in the Vicinity of the Starboard Whip Antennas (Frames 200 and 205) of the Simultaneously Transmitting TBM (500 watts, 11.8 Mc) and SRT (500 watts, 11.8 Mc) Transmitters

Aircraft Position and Measurement	Test Area			
	Propeller-Blade Edge	Wing-Tank Nose	Starboard-Wing-Tank Tail Fin	Fuel Tank Vent
Wings Spread, Antenna Horizontal				
Voltage (volts)*	215	110	90	12
Current (amp)	0.46	0.38	0.435	0.11
Wings Folded, Antenna Horizontal				
Voltage (volts)*	175 (160)†	80 (60)†	85 (50)†	95 (60)†
Current (amp)	0.25 (0.26)†	0.26 (0.26)†	0.28 (0.23)†	0.10 (0.31)†
Wings Folded, Antenna Vertical				
Voltage (volts)*	200	80	50	85
Current (amp)	0.24	0.23	0.17	0.365

*Open circuit.
†Determined with only TBM transmitter in operation.

Table 5
RF Arc-Voltage and -Current Determinations at the Starboard-Wing-Tank Tail Fin of an AD-6 Aircraft Located in the Vicinity of the Starboard Whip Antennas (Frames 200 and 205) of the Separately or Simultaneously Transmitting TBM (500 watts, 11.8 Mc) and SRT (500 watts, 11.8 Mc) Transmitters

Transmitter	Measurement	
	Voltage (v)*	Current (amp)
SRT only	22	0.15
TBM only	90	0.64
TBM and SRT	120	0.68
TBM only (additional ground lead from propeller to deck)	110	0.78
TBM only (additional ground lead from wing-tank nose)	80	0.60

* Measured with ammeter connected.

Table 6
RF Arc-Voltage and -Current Determinations on an AD-6 Aircraft Located in the Vicinity of the Starboard Whip Antenna (Frame 205) of an Incrementally Power-Reduced TBM (500 watts, 11.8 Mc) Transmitter

Calculated TBM Output (watts)	Field-Strength Meter Reading (db)	Measurement		Relative Power
		Voltage (v)*	Current (amp)	
Starboard-Wing-Tank Tail Fin				
500	20	88	0.725	64
250	17	60	0.50	30
125	14	43	0.36	16
62.5	11	33	0.26	9
31.25	8	20	0.15	3
Additional Ground Lead to Nose of Starboard Wing Tank				
500	20	100	0.85	85
250	17	75	0.65	49
221	16.5	69	0.60	41
198	16	62	0.56	35
157	15	58	0.52	30
125	14	50	0.44	22
99	13	48	0.42	20
78	12	42	0.37	16
70	11.5	35	0.30	11
40	9	28	0.24	7

* Measured with ammeter connected.

connected to the nose of the wing tank. The results (Table 6) paralleled those obtained above but, in spite of additional grounding, were slightly higher. After each measurement, the ground lead from the wing-tank nose was disconnected and scratched on the flight deck to see whether an arc would form. Visible arcs were noted at all power levels except the lowest (PRM-1 reading of 9) where arcs were observed in only about one trial out of five. These data illustrated once more the futility of trying to eliminate rf energy concentrations by conventional grounding techniques.

Because of the high probability of flammable concentrations of fuel vapor at the filler pipe of the aircraft, a simulated fueling was run and voltage and current measurements made between the hose nozzle and the ground jack connection. After connecting the ground jack, a variable potential ranging from 100 to 150 volts was measured at currents of 0.1 to 0.2 ampere. When the nozzle was placed in contact with the filler pipe, the voltage fell to 4 to 5 volts, but no change in current was noted. Repeated attempts were made to draw arcs from the nozzle to the filler pipe or fuselage, but none could be observed. However, in this area arcs could be drawn to a wire grounded to the flight deck.

Ignition Studies

During the course of the voltage and current measurements, numerous attempts were made to ignite the vapors in the ignition apparatus. The results of tests made with the apparatus (Fig. 1a) are shown in Table 7. In addition to these data, a series of tests were made with the modified apparatus (Fig. 1b) connected between the propeller blade and the flight deck (Table 8). The latter tests were designed to show the least severe conditions which could ignite the vapors. For these tests an AD-6 was positioned with its wing extending over the forward TBA whip antenna, and the transmitter power was incrementally reduced.

The data of Tables 7 and 8 are plotted in Fig. 4. All of the observed ignitions fall in the outlined area where the current exceeded 0.4 ampere and the voltage exceeded 120 volts.

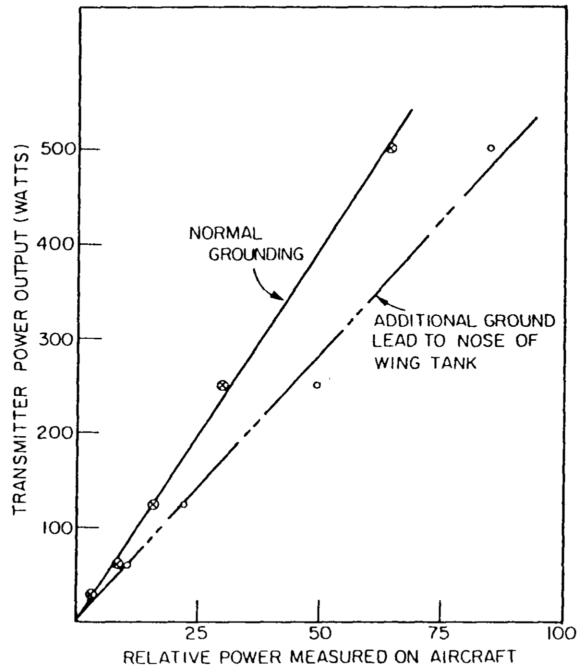


Fig. 3 - Transmitter output vs relative power measured on aircraft

Field-Intensity Measurements

Field-intensity measurements are plotted in Fig. 5 as a function of distance from the antenna base along an athwartship projection of the forward TBA whip antenna. The measurements were made by International Electronics Engineering, Inc. personnel with a PRM-1 field-intensity meter. Separate measurements of the electrostatic and magnetic component were necessary because the measurements were made close enough to the antenna so that the nonpropagating near field of the antenna represented a significant portion of the total field. Theoretically, the near field and the propagating field are of equal magnitude at a distance of 1/6 wavelength from the antenna. The propagating field decreases as a reciprocal function of the distance from the antenna, while the near field falls off in accordance with the law of inverse squares. The theoretical attenuation appears as the dotted line in the figure.

DISCUSSION AND RECOMMENDATIONS

Without question, the most significant finding of this study is that rf arcs which can be drawn from aircraft under conditions known to occur during the fueling are capable of igniting fuel vapors. The fact that no fires are yet known to have originated from this cause is fortuitous and should in no way be construed as an excuse for complacent acceptance of a potentially dangerous situation.

At present, only two fuels are used for fueling aircraft on carriers, JP-5 jet fuel and Avgas. The vapor pressure of JP-5 jet fuel which meets the 140°F flash-point specification is low enough so that, at ordinary temperatures, there is virtually no chance of an accidental fire from rf arcs. This limits the area of concern to fuelings which involve Avgas. However, one important exception to this rule must be pointed out. Aircraft which land on board with the more volatile JP-4 jet fuel in their tanks and then refuel with JP-5 can vent flammable concentrations of JP-4 vapor from their tank vents or filler pipe. This is a particularly hazardous situation because, unlike Avgas, tanks containing JP-4

Table 7
Results of Attempts to Ignite Fuel Vapors at Various RF Arc Voltages and Currents

Measurement		Ignition	Data Source
Voltage (v)*	Current (amp)		
250	0.80	Smoke only	Table 1
250	0.80	yes	†
250	0.60	yes	†
250	0.41	yes	†
245	0.66	yes, yes, yes	Table 1
230	0.78	no	Table 1
215	0.46	no	Table 4
210	1.0	yes, yes, yes	Table 2
200	0.70	no	Table 1
195	0.69	yes	Table 2
160	0.30	no	†
155	0.20	no	Table 1
145	0.42	no	†
120	0.36	no	†
110	0.38	no	Table 4
80	0.13	no	†
70	0.60	no	†
60	0.39	no	†
54	0.12	no	†
50	0.10	no	†
48	1.0	no	Table 1
22	-	no	†
20	0.10	no	†
14	0.08	no	†

*Open circuit.
†From daily notes of F. J. Woods.

Table 8
Ignition Studies of Fuel Vapors at RF Arc Voltages and Currents Determined at the Propeller-Blade Edge of an AD-6 Aircraft Located in the Vicinity of the Starboard Whip Antenna (Frame 6) of a TBA (1000 watts, 13.551 Mc) Transmitter

Measurement		Relative Power	Ignition
Voltage (v)*	Current (amp)		
300	1.0	300	yes
170	0.64	109	yes
170	0.60	102	yes
165	0.58	96	yes
140	0.50	70	†
128	0.46	59	no
120	0.42	50	yes
110	0.38	42	no
50	0.15	8	no

*Measured with ammeter connected.
†Small arcs and smoke curls were noted but no visible flame.

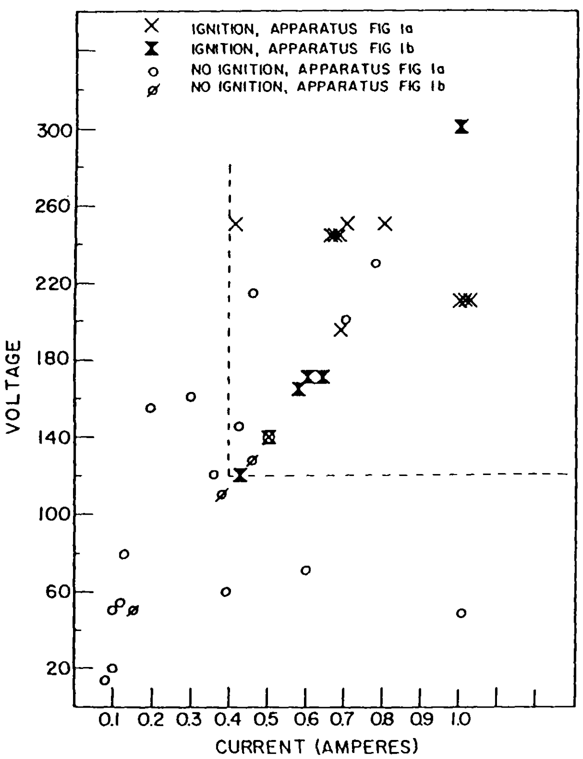


Fig. 4 - Ignition studies at various arc voltages and currents

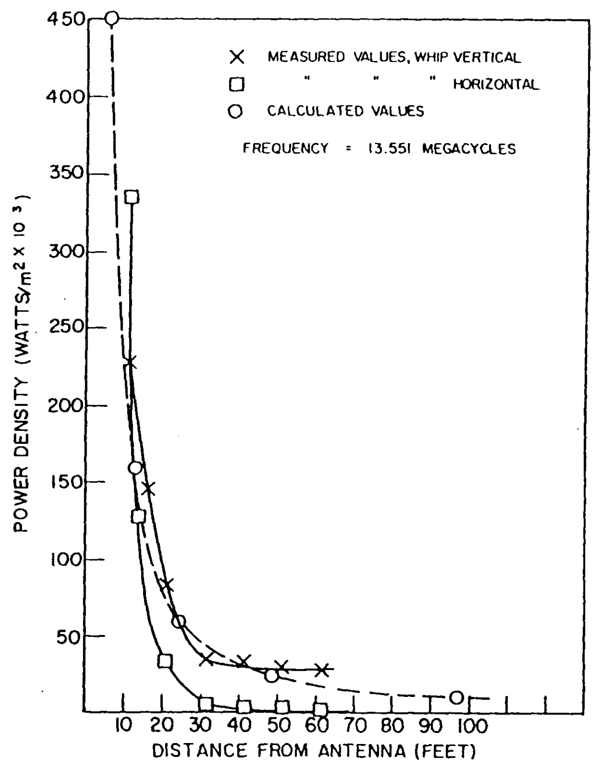


Fig. 5 - Field intensity vs distance from antenna

fuel support a flammable mixture of air and fuel vapor over the liquid surface at usual temperatures, and so an externally ignited fire can flash back into the tank with results which may be disastrously explosive.

The total elimination of the rf arc hazard can be accomplished by either of two simple procedures: (a) securing all transmitters during the fueling operation or (b) restricting hazardous fuel handling to an rf-field-free area of the hangar deck. Unfortunately, both of these suggestions impose restrictions on flight or ship operations, and, in view of the low probability of rf-initiated fires, less stringent measures must be considered. Two lines of approach suggest themselves: (a) the energy received by the aircraft can be reduced to a point where dangerous arcs are unlikely and (b) situations which are likely to produce arcs can be avoided.

The situation is further defined by the necessity for a flammable atmosphere at the ignition source. The distribution of flammable vapors was studied by Neill et al. (3) during carrier fueling operations. Under normal wind-velocity conditions, it was found that flammable vapors could not be detected except within a few inches of the filler pipe or tank-vent outlet. Under stagnant wind conditions, flammable concentrations of vapor flowed downward from the filler pipe along the fuselage and across the immediately adjacent area of the wing. As the vapors flowed down from the trailing edge of the wing, they dissipated; at a few inches below the level of the wing, the vapors were dilute enough to be nonflammable. Vapors from the tank vents followed the same pattern of downward flow to dissipation. Where puddles of spilled liquid were involved, the vapors under stagnant conditions would travel horizontally for several feet but seldom rose more than a few inches above the surface. It is obvious that safety measures adopted in critical areas where flammable vapors occur will be most fruitful.

One highly encouraging result of the present studies was that the maximum voltage measured did not exceed the minimum sparking potential for air. It seems, therefore, unlikely that any discharges will occur spontaneously, and that the mechanical breaking of a contact between conductors will be necessary to initiate an arc. The likelihood of a break can be minimized by careful observance of good housekeeping, for example, tie-downs should be tight enough to ensure good electrical contact and to prevent rocking or shifting with the ship's movements. Also, loose wires or cables in the critical areas should be avoided, controls should be fixed so that no movement of control surfaces will occur, and persons not needed for the fueling operation should be excluded from the critical areas during fueling. In addition, the hose-nozzle operator should avoid idle tapping of his foot against the plane or jangling key chains or metal objects on his person which could swing into contact with the plane.

With these precautions, the moment of greatest concern is the insertion of the hose nozzle into the filler pipe. (It is assumed that the grounding connection will be made before removal of the filler cap to discharge dc electrostatic potentials.) Since the measurements detected rf potentials as high as 150 volts and currents as high as 0.12 ampere, it is possible that unusually severe conditions might lead to rf pickup in the antenna circuit formed by the nozzle, grounding cable, and air-frame which could cause a dangerous arc. Once contact between the hose nozzle and filler pipe is made, it should not be broken unnecessarily. Two suggestions which might eliminate spark formation are (a) to coat the outside of the nozzle with a nonconducting jacket which would prevent metal-to-metal contact – the grounding connection will continue to provide electrostatic protection and (b) to build an rf shunt into the grounding cable with an indicating device such as an rf ammeter or a properly chosen glow discharge tube which would indicate to the operator the existence of a hazardous voltage.

The linear relationships developed between transmitter power output, field strength, and available energy in the aircraft suggest several techniques which would reduce the likelihood of developing dangerous arcs.

The principal source of rf energy seems to be the deck-level whip or tower-mounted antennas used for communications. While these antennas do not handle the high powers transmitted by radars, radar energy is intermittent and is beamed at elevations greater than that of the aircraft. It would be unwise to fuel planes which for one reason or another were located directly in the path of a radar beam.* Leakage fields from the radar were found to be of insignificantly low intensity on the flight deck.

Since communications antennas are physically located within a few feet of the flight deck near normal fueling stations, planes are often spotted nearby. The rapid increase in field strength as the antenna is approached was shown in Fig. 5. It follows that the energy taken up by the aircraft will decrease markedly with distance from the antenna. Unfortunately, the full effect of separation may not be realized at specific points on the aircraft because changes in the geometry of the situation will inescapably result in shifts in the standing-wave pattern on the aircraft. The total energy picked up by the aircraft will, of course, decrease. As a guiding principle, it is safe to say that the farther a plane is from a transmitting antenna, the less likely it is to generate hazardous arcs.

The field studies did not develop enough data to prescribe a safe distance. Moving the plane twenty feet inboard (Tables 1 and 2) reduced the maximum voltage and current measured to values which, with one exception, fall outside the hazardous limits indicated in Fig. 4. It is therefore likely that a separation of 25 feet between a transmitting antenna radiating not more than 500 watts and the nearest point of approach of the plane would not permit generation of dangerous arcs. Greater distances would give a larger margin of safety. Securing of all transmitters located within the quadrant of the flight deck in which fueling is being conducted may be considered as almost completely safe.

The effect of transmitter frequency was not extensively investigated. No reports of arcs at frequencies outside the 7 to 15 megacycle range were made by fueling crews. On theoretical grounds, half wavelengths approximately equal to the dimension of the planes should be most effectively received, and the efficiency of pick-up would fall off rapidly as the transmitted wavelength became longer than aircraft dimensions. An attempt was made by personnel of International Electronics Engineering, Inc. to determine the resonance peaks of the AD-6 over the range of 7 to 12 megacycles. These tests did not indicate marked peaking at any specific frequency and showed very little shift over the whole range. Thus, the aircraft acts as an untuned, broad-band antenna which adjusts to the specific wavelength by shifts in the standing-wave pattern.

SUMMARY

Shipboard studies of the ignition capabilities of rf arcs drawn from aircraft located in fueling positions showed that such arcs are capable of igniting flammable concentrations of fuel vapor.

The probability of fires resulting from such arcs is low because of the rather limited distribution of flammable concentrations of fuel vapor and the necessity of breaking an electrical contact to generate an arc.

The possibility of accidental fires can be reduced by such measures as halting transmission on antennas adjacent to fueling aircraft, excluding from the fueling area personnel and material which might accidentally contact the plane in an area of flammable vapor,

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*"Approach" (The Naval Aviation Safety Review), NavAer 00-75-510, April 1958, reports an instance where antenna radiation ignited oil which had seeped into the radome of a ZPG-2 containing loose metal objects. The fire started ten minutes after the radiating antenna ceased rotating.

increasing the physical separation of the plane and the transmitting antenna, reducing the power output of nearby antennas, and alerting fueling personnel to the possibility of accidental fires from rf arcs.

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