Development of Fire Protection for Airesearch Model GTP 70-2 Gas-Turbine Auxiliary-Power Unit

by

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DEVELOPMENT OF FIRE PROTECTION FOR AIRESEARCH MODEL GTP70-2 GAS-TURBINE AUXILIARY-POWER UNIT*

SUMMARY

This report summarizes the results of an investigation which was made to find means of providing better fire protection for airborne gas-turbine auxiliary-power units Specific recommendations are made for adequate fire control in the AiResearch Model GTP70-2 unit These recommendations involve revisions and changes to the fire-detection and -extinguishing systems Fire-prevention measures also are recommended for use in modification of the Model GTP70-2 unit and for incorporation in the design of later models These measures include use of ducted-air inlets to the compressor and cooling fan, prevention of oil-dumping into the turbine exhaust, and drains for the burner cans and center section Incorporation of the recommended fire-prevention measures will change and simplify the fire-control requirements, therefore, separate fire-control recommendations are made for modified models of auxiliary-power units and for new models designed to incorporate these fire-prevention measures

INTRODUCTION

An AiResearch Manufacturing Company Model GTP70-2 gas-turbine auxiliary-power plant was submitted to the Technical Development Center of the Civil Aeronautics Administration by the Department of the Navy for evaluation from the fire-protection standpoint Power plants of this type were scheduled for installation in naval aircraft types RV7-1 and -2 (Lockheed Constellation) and R6D-1 (Douglas DC-6). These aircraft must be certificated by the Civil Aeronautics Administration before their acceptance by the Department of the Navy The specific purpose of this evaluation was to determine the acceptability of the GTP70-2 auxiliary-power plant in its present configuration It was intended to use this unit in these aircraft to provide electrical power required by the aircraft on the ground and to provide a standby source of electrical power during landings and takeoffs At the time the evaluation was requested, these power units were not intended for use under flight conditions other than those mentioned, except in emergencies After a portion of a Navy order for aircraft was consigned to the Department of the Air Force, however, in-flight operation of the gas-turbine auxiliary-power plant was considered imperative The general purpose of this evaluation, therefore, was to recommend measures which would ensure safe operation of gas-turbine power plants under all conditions

More specifically, the objectives of the investigation were

1 To determine the adequacy of the present provisions for fire protection and control in the GTP70-2 unit
2 To test some proposed fire-control systems which were suggested for this auxiliary-power plant by several aircraft manufacturers
3 To determine minimum provisions necessary to provide adequate fire protection and control for this type of gas-turbine auxiliary-power plant
4 To provide information which would be useful to designers of these and similar auxiliary-power plants

TEST ARTICLE

The GTP70-2 auxiliary-power plant was a self-contained unit See Fig 1 The turbine, together with all accessories, was confined in a stainless-steel enclosure It was a compact

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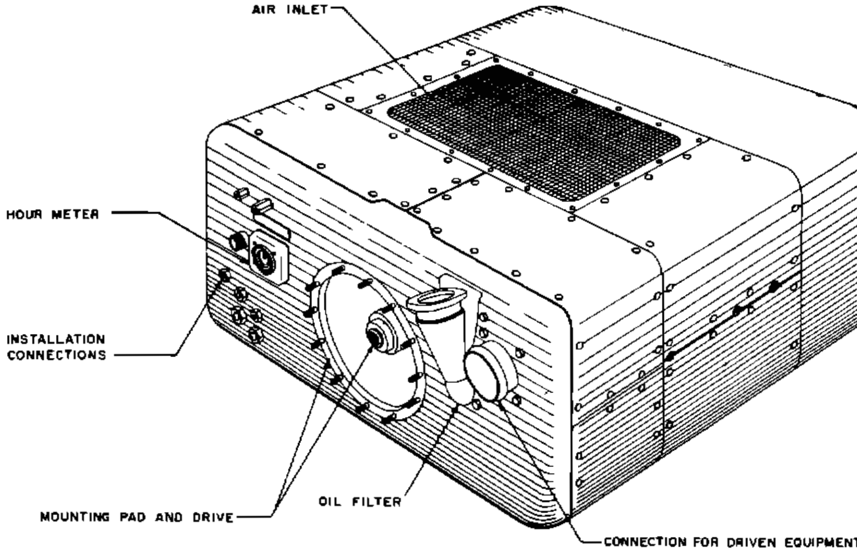
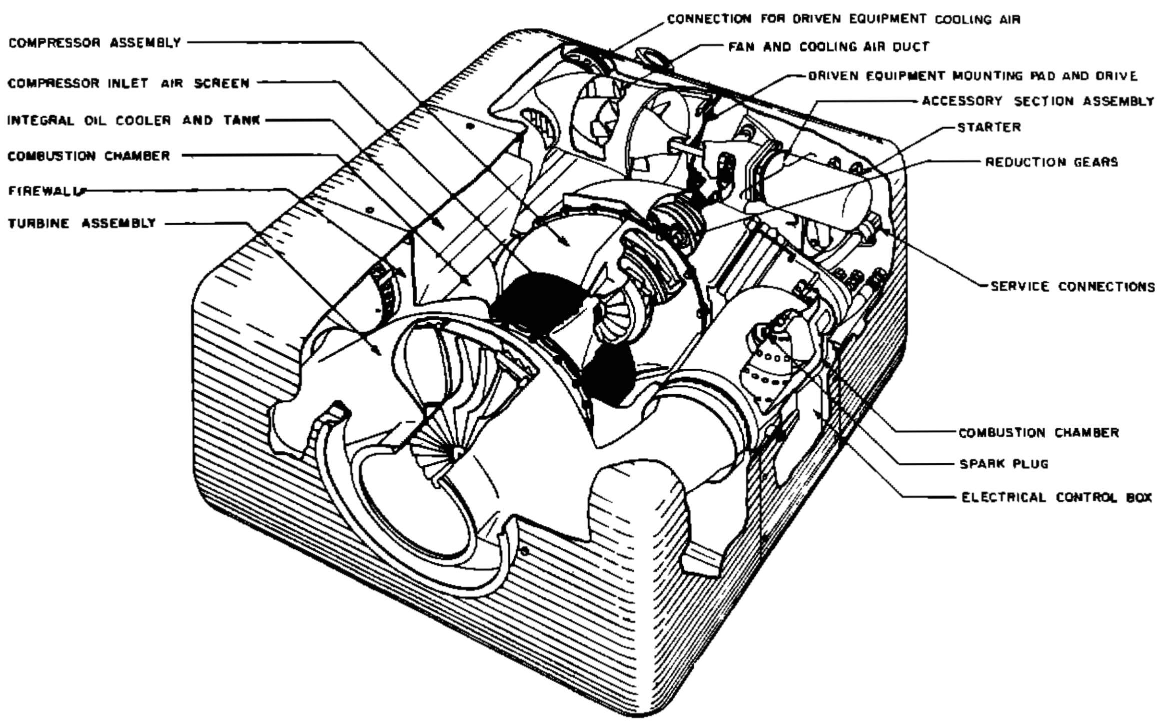


FRONT VIEW



REAR VIEW

Fig. 1 Gas-Turbine Power Unit (Model GTP70-2) and lightweight prime source of constant-speed-shaft power, designed primarily to drive either an alternator or a d-c generator. It had automatic starting and automatic control Normal rated power for continuous operation under standard sea-level conditions is 70 hp at a speed of 6,000 rpm at the power-takeoff shaft. The power unit was capable of delivering 84 hp (maximum rated power) for periods of 5 minutes under standard conditions. The basic dry weight of the auxiliary-power unit was 195 pounds. It was 14 1/8 inches deep, 25 1/2 inches wide, and 28 1/4 inches long. With the generator and regulator used in the tests, the total weight was 312 pounds and the over-all length was 49 1/4 inches.

The complete gas-turbine power unit consisted of a turbine, a compressor, accessories, two combustion chambers, an integral oil cooler and tank, and a fan and cooling-air duct, all housed within the stainless-steel enclosure.

Turbine Assembly.

The turbine was the radial-inward-flow type with a single-stage turbine wheel. The turbine developed the power required to drive the compressor and the accessories, including a fan which provides cooling air for the driven equipment, it also developed the power delivered at the power-takeoff spline.

Compressor Assembly

The compressor was a two-stage type, with backward-curved blades. The compressor, which was driven by the turbine, furnished all of the combustion air requred for operation of the unit.

Accessory-Section Assembly.

The accessory section was located between the compressor and power-takeoff pad, and all accessories were gear-driven from the output shaft. The accessory housing also included the power-takeoff flange as well as mounting pads for the starter, over speed switch, governor, fuel pump, oil pump, and duplex-scavenge oil pump. The cooling-air fan was driven by the accessory-drive shaft

Combustion Chambers

The two combustion chambers were the straight-through can type They utilized tapered-aluminum outer shells, high-temperature-alloy flame tubes, and fixed-area fuel nozzles Ignition was provided by two spark plugs and a coil during starting only, and combustion was self-maintained during operation.

Integral Oil Cooler and Tank.

The integral oil cooler and tank was of mechanically-bonded aluminum-tube construction, with oil passing outside the tubes and air passing through the tubes The air was forced through the oil cooler by the fan.

Fan and Cooling-Air Ducts.

The axial-flow fan was designed to supply cooling air for the unit and for the alternator or other driven equipment. Air entered the fan entrance from within the enclosure, and ducting carried the fan-discharge air in two parallel streams, one directly to an outlet for connection to the driven equipment and the other to the oil-cooler inlet. The oil-cooler air was discharged into the turbine components and finally escaped through an annular opening around the turbine-exhaust duct

Enclosure

The enclosure housed the basic unit and accessories, providing a packaged power unit with a minimum number of external connections. This design permitted easy installation and removal of the unit. Service and inspection panels were provided. The stainless-steel enclosure was divided into three sections by an internal firewall and an internal bulkhead. These sections are shown in Fig. 2. The compressor was separated from the turbine by a firewall, and a portion of the accessory section was separated from the remainder of the unit by internal baffling

Fire-Detection and -Extinguishment Provisions

One detector was installed on the horizontal baffle extending into the enclosed portion of the accessory section. This fire detector was a unit of a Type A fire-detecting system made by

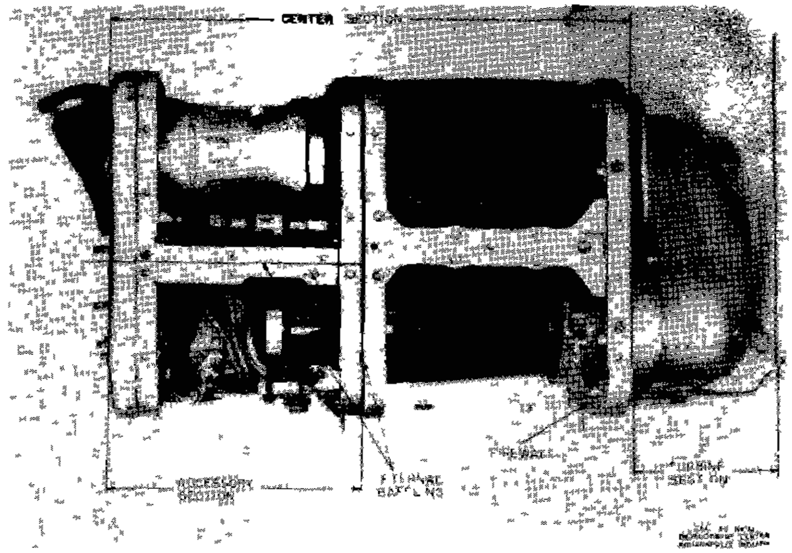


Fig 2 Internal Firewalls and Baffling Dividing the Unit Into Three Sections (Side View, Enclosure Removed)

Thomas A Edison, Inc A threaded fitting was provided on the connection panel for the installation of a fire-extinguisher line This fitting discharged an extinguishing agent into the enclosed portion only of the accessory section.

Test Load

A General Electric Company Model 2CM212A1, 30-kva, 120-volt, 3-phase, alternating-current generator with a Model CR7930NA109G1 voltage regulator was attached to the GTP70-2 unit The power output was absorbed by a salt-water rheostat consisting of 0 25 per cent salt solution contained in three 55-gallon steel drums, with center electrodes, Y-connected.

Test Operation.

During the testing, the GTP70-2 unit was mounted on a test stand. An inlet duct four feet in height, with a cross-sectional area equal to that of the air-inlet opening, was attached.

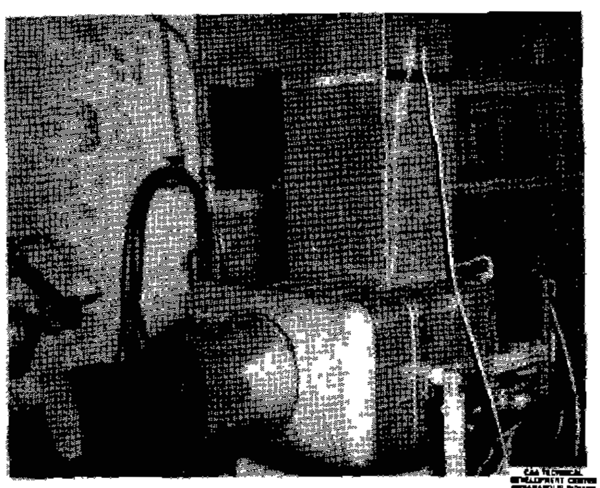


Fig. 3 GTP70-2 Unit Prepared for Testing (Sections of the Enclosure Removed and Replaced with Plexiglas)

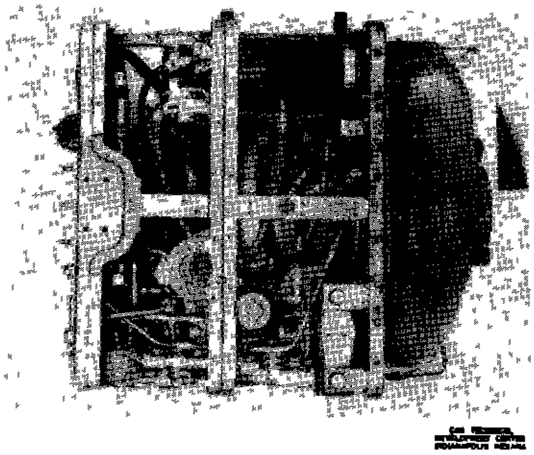


Fig. 4 Propinquity of Oil Lines to Compressor Entrance
(Bottom View, Enclosure Removed)

A three-foot exhaust pipe with an outer cooling-air shroud also was attached. The necessary connections were made for fuel intake, 24-volt d-c power, and instruments. A photograph showing the GTP70-2 unit as tested is shown in Fig. 3.

FIRE HAZARDS

Survey.

A thorough inspection was made of the GTP70-2 auxiliary-power unit for the purpose of noting potential fire or explosion hazards. The following conditions were noted

1 Lines carrying lubricating oil for the aft bearing passed within four inches of the compressor inlet, as shown in Fig 4.

2. The cooling fan drew air from the center section of the unit which contained lines carrying fuel and lubricating oil. The cooling fan delivered air from this section to a T duct. One leg of the T supplied cooling air to the alternator, and the other leg supplied cooling air which passed through the oil-cooler air passages and then into the turbine compartment to cool the turbine housing. This system is shown in Fig. 5.

3. Oil-tank- and cooler-vent lines opened into the turbine exhaust at a location one inch behind the turbine wheel, as shown in Fig 6. Overfilling the oil tank caused oil to flow through the vent line and into the turbine-exhaust duct. Oil also entered the turbine-exhaust duct when the oil tank was filled to the proper level, as indicated on the bayonet gage attached to the cap, and then the GTP70-2 unit was tilted 35° or more upward from the generator end.

4 There were no provisions for drainage in the bottom of the center section of the unit.

5. The terminals on the d-c starter were exposed. See Fig. 5.

6. There were no drains in the burner cans

7. Internal baffling between the accessory section and the remainder of the unit consisted largely of aluminum sealed with rubber and sponge-rubber strips

After inspection of the unit, it was concluded that

1. It is poor practice to have lines carrying lubricating oil in any section from which inlet air to a turbine engine is drawn. Leakage of these lines, from either failure or neglect of maintenance personnel to tighten fittings, would allow oil to be drawn into the engine, causing overheating, overspeeding, and subsequent turbine-wheel failure

2 Alternators are definite sources of ignition, therefore, they should be isolated from all flammable fluids and vapors. The turbine housing was considered a potential ignition source and tests were made to determine the existing hazard

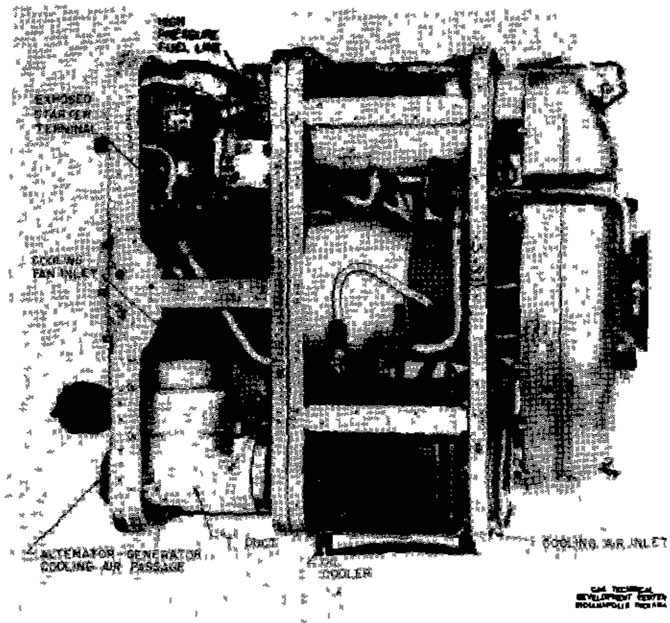


Fig 5 Location of Fuel Lines and Oil Lines in Relation to the Cooling Fan, Oil Cooler, and Starter (Top View, Enclosure Removed)

3. Tests should be conducted to determine what degree of hazard exists, if any, as a result of lubricating oil entering the exhaust duct

4 Since the center section of the unit contains fuel lines and lubricating-oil lines, provisions should be made to carry overboard any leakage from those lines.

5. The exposed terminals on the d-c starter could be a source of ignition for leaking flammable fluids if the outer enclosure became damaged in the vicinity of the starter and it contacted the terminals.

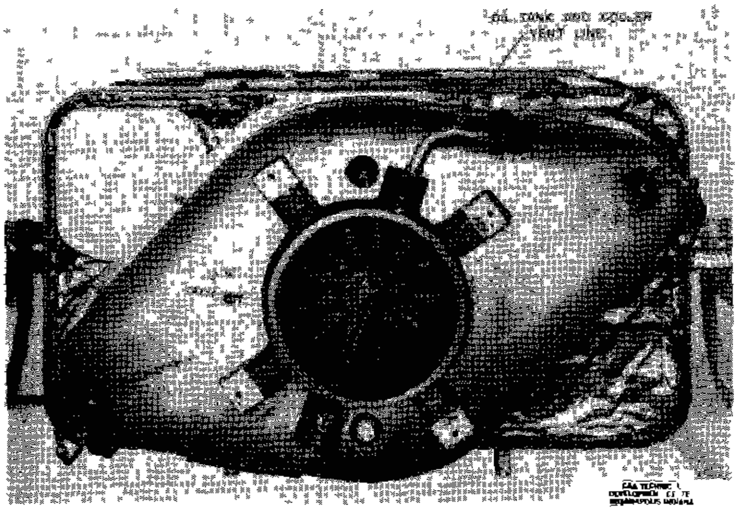


Fig. 6 Oil-Tank and Cooler Vent Line Routed to Turbine Exhaust (Rear View, Enclosure Removed)

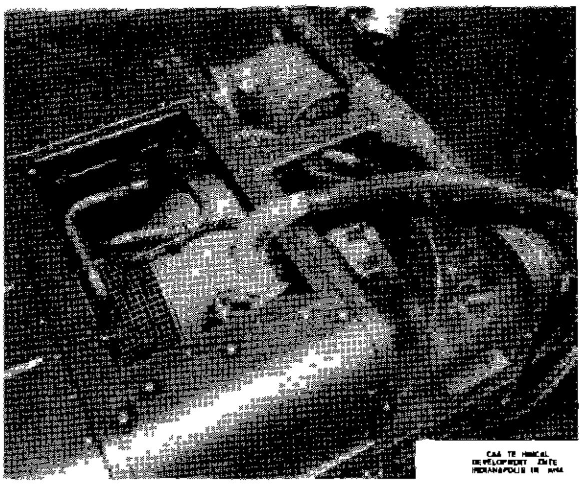


Fig. 7 Method of Conducting Airflow and Vapor-Flow Tests (Plexiglas Replacing Enclosure Sections)

6. Combustion chambers should be drained to prevent accumulation of fuel and resultant hot starts.

7. Although not in the most desirable location, the internal baffling isolates a part of the flammable-fluid systems from compressor and cooling-fan entrances and from areas of potential ignition. It also should aid fire control by isolating fires occurring within the section. It would quickly lose its integrity, however, during a fire caused by failure of materials from which it is constructed

Testing.

Equipment and Procedure.

Smoke was used to determine the route of air and flammable vapors within the enclosure while the unit was being operated A smoke generator was utilized which consisted of a can in which punk was burned. A one-inch tube carried the smoke to the point of release To permit observation of the smoke streamlines, sections of the stainless-steel enclosure were replaced with similar sections made of Plexiglas, as shown in Fig. 7 At a rate of approximately 0 2 gallons per minute (gpm), water was released at the same locations where the smoke was discharged to approximate the influence of airflow on leaking fuel and lubricating oil while the unit was being operated In the GTP70-2 unit, lubricating oil could be dumped into the turbine-exhaust duct by way of the oil-cooler-vent line by overfilling the oil tank or by tilting the unit upward 35° or more This condition was simulated by release of measured quantities of Grade 1010, MIL-0-6087A lubricating oil into the exhaust duct through the oil-cooler-vent line. Later, the tank was purposely overfilled during the tests Also during other tests with the oil tank filled to the normal level, the unit was tilted upward 35°

To investigate the ignition hazard presented by hot surfaces in the turbine section, Grade 1010, MIL-0-6087A lubricating oil and Grade 100-130 aviation gasoline were released at the cooling-fan entrance so that they would be carried through the oil cooler by the airstream and would be dumped into the turbine section. Leakage from fuel or lubrication lines in the center section reached the turbine section in the same manner These tests were conducted at maximum rpm, both with no load and with an attached 30-kva alternator under load. To investigate the possibility of ignition hazard in the turbine section more conclusively, temperature-indicating paint was applied directly to the turbine-wheel housing and the unit was operated under load conditions. The location at which the turbine-wheel housing reached the highest temperature was found and this temperature was measured with a thermocouple pyrometer. An oil line was installed to discharge oil directly at the point of highest temperature on the turbine-wheel housing Additional tests were conducted with various rates of oil flow from 0 1 to 1.0 gpm.

Results.

The results of the studies of airflow characteristics within the enclosure, during which the streamlines were made visible by use of smoke, were as follows

1. Most of the air entering the enclosure at the inlet screen was drawn downward, around, and into the compressor inlet, but the air which entered within two inches of the edge of the opening nearest the accessory section passed through the unit, around the fuel and oil lines, and into the cooling-fan duct.
2. Airflow was very rapid at all points in the center section of the unit.
3 Airflow in the sealed-off accessory section was negligible.
4 Water released within the center section of the unit followed the same path as that of the airstream lines.

The data obtained during tests conducted when oil was dumped into the turbine exhaust are shown in Table I. During the tests in which ignition of the oil occurred, the resultant flames were visible approximately eight feet behind the turbine wheel. The flame did not pass back through the vent line to ignite oil in the cooler and tank during any of the tests.

The data obtained during the ignition-hazard tests on the turbine section are shown in Table II Temperature-indicating paint showed that the 6 o'clock position on the turbine housing was the point of highest temperature. Measurements taken with a pyrometer indicated the temperature to be 1,020° F. Although 1,020° F is above the ignition point of lubricating oil in still air on a hot surface, oil released directly on this point did not ignite because of the rather large airflow through the turbine section.

Conclusions.

When the GTP70-2 unit is operating, any leakage from the lubricating lines to the aft bearing would be drawn into the engine. This is dangerous and should be prevented by isolating the compressor entrance

Any leakage from the high-pressure fuel line to the top burner-can nozzle or to the lubricating lines in the forward portion of the center section would be drawn into the cooling fan and to the alternator and turbine section. Alternators are a constant source of ignition for flammable fluids, therefore, air used for cooling the alternator should not be drawn from a section containing fuel and lubricating lines. In the turbine section, the airflow was sufficient to decrease the dwell-time of the oil and fuel on the hot turbine-housing surfaces, therefore, it prevented ignition.

FIRE DETECTION

Survey.

The fire-detection system on the GTP70-2 unit submitted for testing was comprised of one temperature-sensing unit which signifies the rate-of-rise. This sensing unit was part of an Edison Type A fire-detection system, and it was located in the accessory section. Although this detector was well located for detection of fires originating in the accessory section, it was determined that fires originating in either the turbine or the center section would not be detected by the system until they had progressed to the extent of destroying internal baffling. Therefore, it was decided to test only those systems with a sensing unit in each section.

Testing.

Equipment and Procedure.

A fire nozzle was fabricated. This consisted of a 1/8-inch-OD, open-end copper tube, which released a stream of Grade 100-130 aviation gasoline, and a spark ignitor for ignition The rate-of-flow of the gasoline was 0.172 gpm. The fire nozzle was constructed so that it could be moved to various locations in the enclosure of the GTP70-2 unit to simulate fires resulting from the ignition of leaking fuel lines, lubrication lines, and components. The test fire locations were as follows

Location A, at fuel-nozzle line connection on top burner can
Location B, front right-hand corner of oil tank.
Location C, accessory section at fuel nozzle of lower burner can
Location D, accessory section at fuel valve.
Location E, lower side of compressor entrance adjacent to control box

TABLE I

OIL-VENT-OVERFLOW IGNITION TESTS

Test No	Oil 1010, MIL-0-6087A Rate (gpm)	Oil 1010, MIL-0-6087A Temperature (degrees F)	Operating Conditions	Results
1	0 1	60	Normal governed speed	Oil was vaporized in the exhaust duct but did not ignite
2	0 1	200	Normal governed speed	Oil was vaporized in the exhaust duct but did not ignite
3	0 2	200	Normal governed speed	Oil was vaporized in the exhaust duct but did not ignite
4	0 3	200	Normal governed speed	Oil was vaporized in the exhaust duct but did not ignite.
5	0 4	200	Normal governed speed	Oil was vaporized in the exhaust duct but did not ignite
6	0 1	200	Starting	Oil was ignited immediately
7	0 4	200	Starting	Oil was ignited immediately.
8	0 4	60	Starting	Oil was ignited immediately
9	0 1	60	Starting	Oil was ignited immediately
10	0 1	60	Shut down	Oil was vaporized in the exhaust duct but did not ignite
11	0 1	190	Shut down	Oil was vaporized in the exhaust duct but did not ignite
12	0 3	190	Shut down	Oil was vaporized in the exhaust duct but did not ignite
13	0 4	190	Shut down	Oil was vaporized in the exhaust duct but did not ignite
14	0 1	70	Starting	Oil was ignited immediately
15	0 4	70	Starting	Oil was ignited immediately
16	Oil tank overfilled before starting the unit		Starting	Oil was ignited immediately
17	Oil tank overfilled before starting the unit		Starting	Oil was ignited immediately
18	Oil tank overfilled before starting the unit		Starting	Oil was ignited immediately
19	Front of unit tilted upward 40°		Starting	Oil was ignited immediately
20	Front of unit tilted upward 40°		Starting	Oil was ignited immediately
21	Front of unit tilted upward 40°		Starting	Oil was ignited immediately

TABLE II

TESTS OF TURBINE COMPARTMENT AS AN IGNITION SOURCE FOR LEAKING FLAMMABLE FLUIDS*

Test No.	Type	Rate (gpm)	Release Location	Power Output (kva)
1	Oil (1010)	0.1	Oil-cooler air inlet	0
2	Oil (1010)	0.4	Oil-cooler air inlet	0
3	Oil (1010)	0.1	Oil-cooler air inlet	0
4	Oil (1010)	0.4	Oil-cooler air inlet	0
5	Oil (1010)	0.1	Oil-cooler air inlet	0
6	Oil (1010)	0.4	Oil-cooler air inlet	0
7	Aviation gasoline (100-130)	0.4	Top burner-can fuel line	0
8	Aviation gasoline (100-130)	0.1	Top burner-can fuel line	0
9	Aviation gasoline (100-130)	0.3	Top burner-can fuel line	0
10	Aviation gasoline (100-130)	0.4	Top burner-can fuel line	0
11	Aviation gasoline (100-130)	0.3	Top burner-can fuel line	0
12	Aviation gasoline (100-130)	0.1	Top burner-can fuel line	0
13	Aviation gasoline (100-130)	0.4	Top burner-can fuel line	0
14	Aviation gasoline (100-130)	0.1	Top burner-can fuel line	0
15	Aviation gasoline (100-130)	0.1	Top burner-can fuel line	30
16	Aviation gasoline (100-130)	0.4	Top burner-can fuel line	30
17	Aviation gasoline (100-130)	0.4	Top burner-can fuel line	30
18	Oil (1010)	0.1	Oil-cooler air inlet	30
19	Oil (1010)	0.4	Oil-cooler air inlet	30
20	Oil (1010)	0.3	Oil-cooler air inlet	30
21	Oil (1010)	0.4	Oil-cooler air inlet	30
22	Oil (1010)	0.4	Oil-cooler air inlet	30
23	Oil (1010)	0.1	Against turbine housing at 6 o'clock position	30
24	Oil (1010)	0.3	Against turbine housing at 6 o'clock position	30
25	Oil (1010)	0.4	Against turbine housing at 6 o'clock position	30

*Tests were conducted at normal governed speed. No ignition occurred under these test conditions.

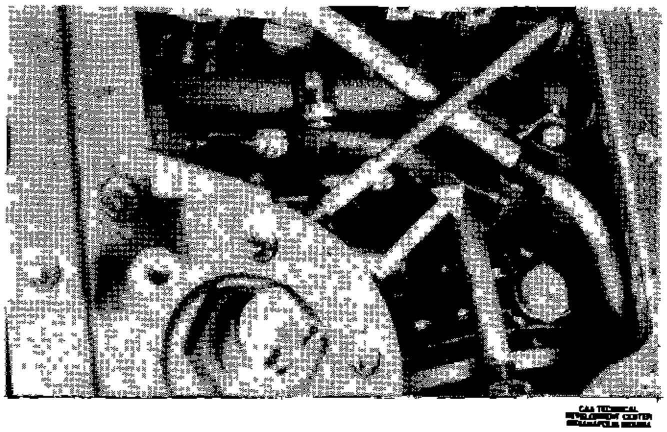


Fig 8 Detector Location No 1, Accessory Section

Location F, lower side of compressor entrance under oil tank
Location G, in turbine compartment at air outlet of oil cooler
These were selected as representative of locations of potential fire hazards such as flammable-fluid leaks

The test sequence was as follows

1 Operating conditions were established for the test
2 The test-fire ignitor was switched on
3 Fuel flow for the test fire was started
4 Fuel flow for the test fire was stopped after 10 seconds or after an alarm from a fire detector, depending on which occurred first

The time required for the fire-detection system to alarm was recorded by an Esterline-Angus recorder. The time recorded was the period between the start of fuel flow to the test fire and the alarm given by the detection system

The operating conditions under which tests were conducted were

1 GTP70-2 unit operating at normal governed speed (6,000 rpm)
2 GTP70-2 unit starting, with d-c starter energized but with insufficient engine rpm to create airflow to the compressor entrance and cooling fan

Tests were conducted on a fire-detection system designed for R7V-1 and R7V-2 aircraft The system consisted of five Model 17343-62-450F Fenwal fire detectors and one Model 17343-34-600F Fenwal fire detector One of the Model 17343-62-450F detectors was located in the accessory compartment, three were in the center section, and one was in the generator-cooling duct. The Model 17343-34-600F detector was located in the cooling-air annular-exhaust passage of the turbine section These locations are shown in Figs 8, 9, 10, 11, 12, and 13

Because fire detectors should be preset to alarm at temperatures of not less than 150° F above the ambient temperature during normal conditions, thermocouples and recording pyrometers were used to determine temperatures at various locations within the enclosure of the unit Those locations were as follows

Thermocouple No 1, accessory section
Thermocouple No 2, cooling-fan entrance
Thermocouple No 3, inlet-air duct.
Thermocouple No 4, cooling-air duct of generator
Thermocouple No 5, cooling-air annular-exhaust passage in turbine section

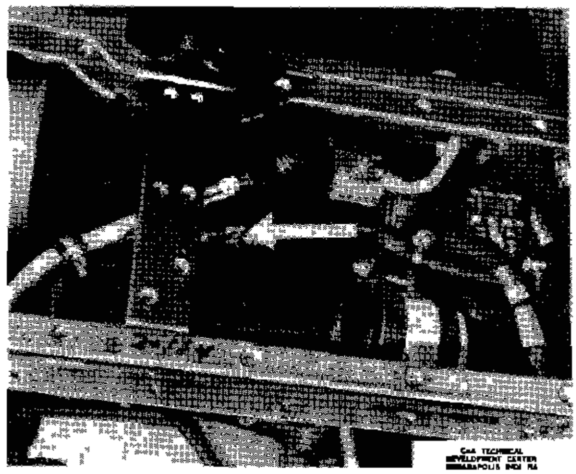


Fig 9 Detector Location No. 2, Center Section at Cooling-Fan Entrance

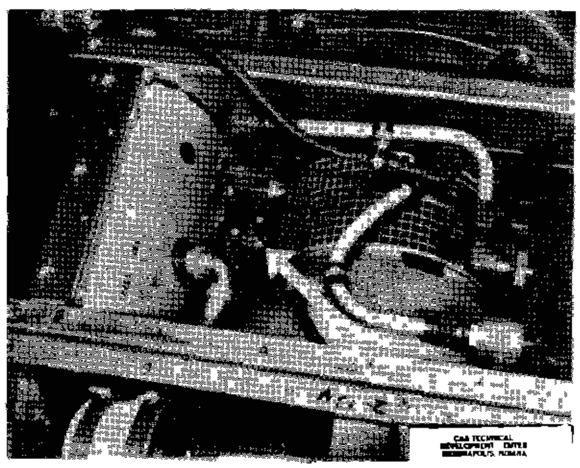


Fig 10 Detector Location No. 3, Center Section Between Top Burner Can and Compressor Entrance

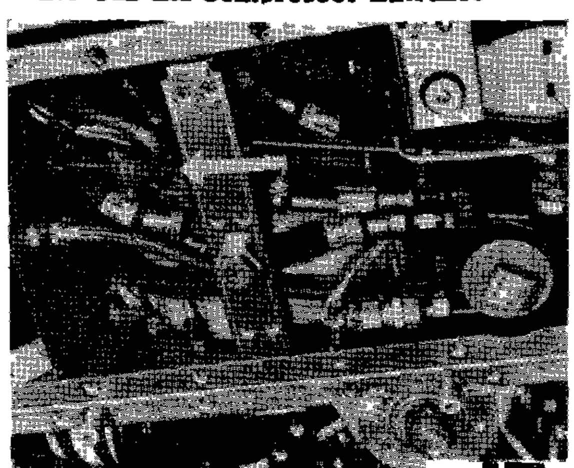


Fig 11 Detector Location No 4, Center Section Between Lower Burner Can and Compressor Entrance

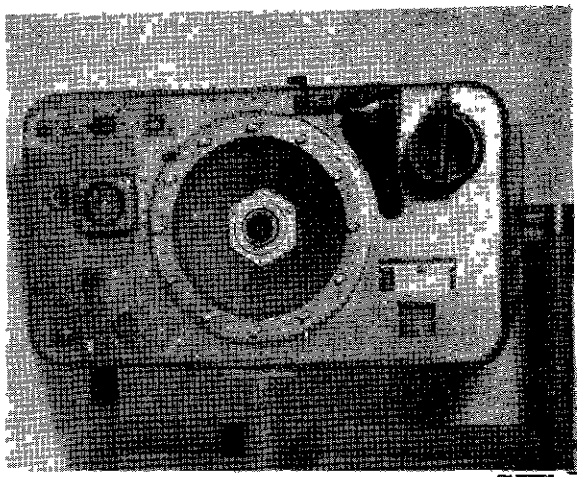


Fig 12 Detector Location No 5, Generator Cooling-Air Duct

Thermocouple No 6, oil-cooler-air outlet in turbine section
Thermocouple No 7, cooling-air exit of generator
Thermocouple No 8, turbine-exhaust outlet

The fire-sensing element of a continuous fire-detection system was installed in the GTP70-2 unit Information resulting from the airflow investigation, the unit-detector tests, and the temperature recordings was utilized in choosing the installation configuration The location of the sensing element as installed in the GTP70-2 unit for the tests is shown in Fig 14 The system used for the installation was manufactured by Thomas A. Edison, Inc

Results

The data obtained during fire tests on the system for the GTP70-2 unit in R7V-1 and R7V-2 aircraft are given in Table III, and detector locations are shown in Figs 8 through 13 Detector No 1 alarmed during all fires in the accessory section. Detector No 2 alarmed during three of four fires ignited at Location A All of the fires at that location alarmed detector No 5 Fires at Location B passed into the cooling-fan entrance and alarmed detector No. 5 without alarming detector No. 2 Detector No. 3 alarmed during all fires at

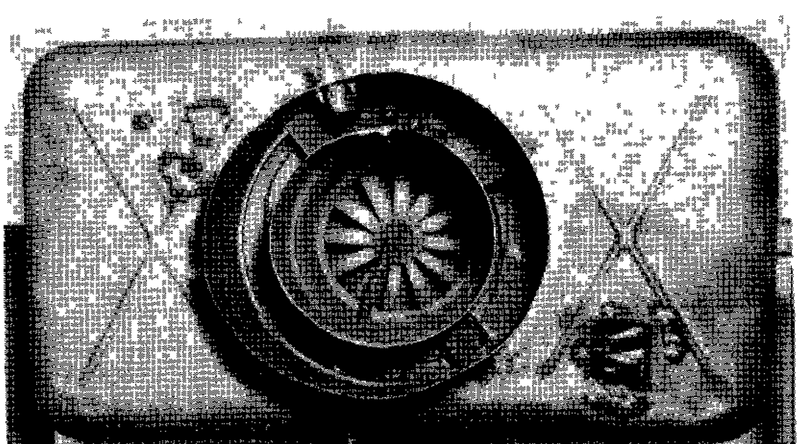


Fig 13 Detector Location No 6, Exhaust Cooling-Air Annular Passage

TABLE III

RESULTS OF FIRE TESTS ON UNIT-DETECTOR SYSTEM

Test No	Fire Location	Test Conditions	Location of Detector Unit Alarmed and Time Required No. 1 (seconds)	No 2 (seconds)	No 3 (seconds)	No 4 (seconds)	No 5 (seconds)	No 6 (seconds)
1	A	Operation		6	6		4	
2	B	Operation					4	
3	B	Starting					8	
4	B	Operation					4	
5	A	Operation		8			8	6
6	A	Starting					19	17
7	A	Starting		3	8		14	14
8	C	Operation	3					
9	D	Operation	7					
10	E	Operation			4			
11	E	Operation			6			
12	E	Starting			6			
13	F	Starting				3		
14	F	Operation				3		
15	C	Starting	5					
16	D	Starting	9					
17	G	Starting						10
18	G	Operation						3

Location E, and it was the only unit alarmed by fires at that location Detector No 4 alarmed during all fires at Location F, and it was the only unit alarmed by fires at that location Detector No. 5 alarmed during all fires at Locations A and B, and it was the only unit which detected fires at Location B. Detector No 6 alarmed during all fires in the turbine section

The data obtained during the temperature survey are given in Table IV. These data indicate that no excessive temperatures existed in the areas at which the thermocouples were installed

The data obtained during tests on the continuous detector system are given in Table V The test fires were detected during all the tests Time required for detection was short, and no false alarms were reported

Conclusions

1 The Fenwal fire-detection system for GTP70-2 units in R7V-1 and R7V-2 aircraft is satisfactory.

2 Elimination of the detector at Station No 2 would not materially decrease the effectiveness of the system

3 As indicated by the tests and the temperature survey, detector stations shown in Figs 8 through 13 are satisfactory for installation of any type of unit detector

4 The continuous detector system provided better coverage at the compressor entrance and at the cooling-air annular exit of the turbine than could be provided by unit detectors in these areas, and the time required for detection was less than for unit detectors

TABLE IV

TEMPERATURE SURVEY

Test No.	Voltage	Load Amperes Phase 1	Phase 2	Phase 3	Ambient Air Temperature (degrees F)	Recorded Temperature at Each Thermocouple Location (degrees F) 1	2	3	4	5	6	7	8
1	200	26	25	27	30	120		40		150			650
2	200	47	46	48	30	140		40		180			720
3	200	59	60	61	30	150			100	200			750
4		No Load			32	100	80		50		100	70	
5	200	47 1/2	47 1/2	50	32	150	110		80		210	100	
6	200	55	55	57 1/2	32	160	110		100	250	230	140	
7	200	58 3/4	58 3/4	62 1/2	30	170	110		100	250	240	150	
8	200	46 1/4	46 1/2	48 3/4	40	120	100		85	230	220	90	
9	200	52 1/2	52 1/2	55	40	150	110		90	270	240	130	
10	200	53 1/2	53 3/4	63 3/4	40	150	100		90	270	240	140	

FIRE EXTINGUISHMENT

Survey

The only fire-extinguishment provision of the GTP70-2 unit as received for testing was a fitting for the connection of tubing from a supply of fire-extinguishing agent This fitting was

TABLE V

TIME REQUIRED FOR FIRE DETECTION WITH PROPOSED CONTINUOUS SYSTEM

Test No.	Fire Location	Test Conditions	Alarm Time (seconds)
1	A	Starting	4
2	A	Operating	2
3	B	Starting	5
4	B	Operating	2
5	C	Starting	3
6	C	Operating	3
7	D	Starting	3
8	D	Operating	3
9	E	Starting	2
10	E	Operating	1 5
11	F	Starting	4
12	F	Operating	2
13	G	Starting	5
14	G	Operating	1 5

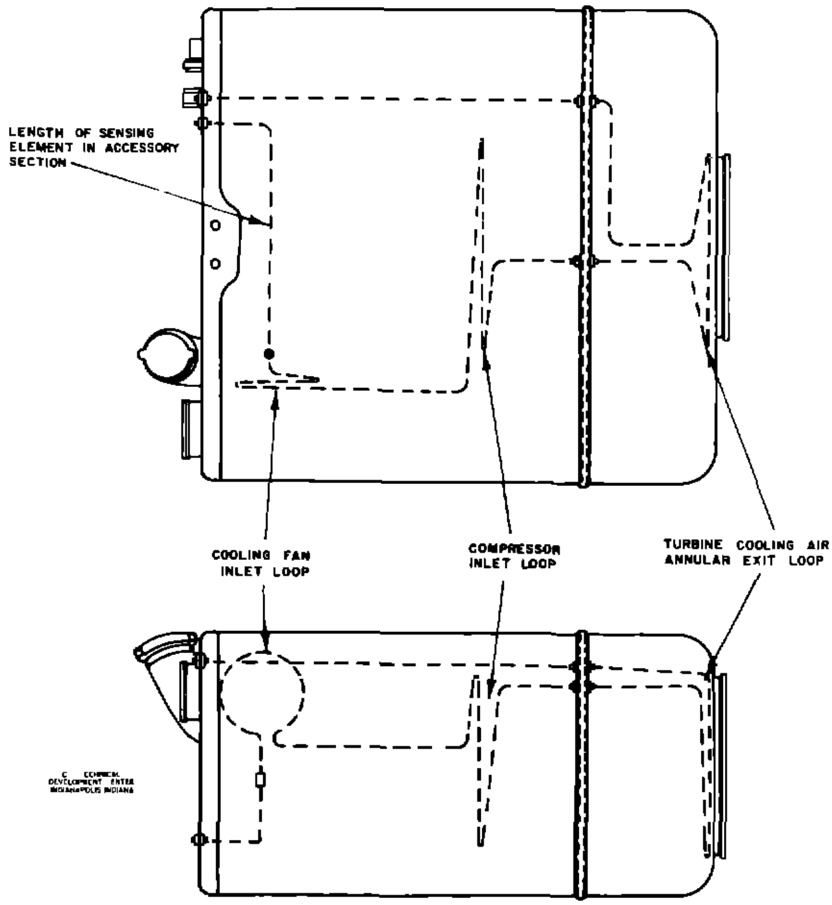


Fig 14 Location of Continuous Detector-Sensing Element

located on the connection panel, and it discharged the agent into the accessory section See Fig 1 The passage of extinguishing agent from the accessory section to other parts of the power plant was prevented by the baffling which isolated the accessory section Because fires could occur in other sections of the GTP70-2 unit owing to the presence of flammable-fluid lines in those sections, this fire-extinguishment fitting was considered inadequate

Testing

Equipment and Procedure

Extinguishing systems designed by airframe manufacturers for use on GTP70-2 power plants in their aircraft were fabricated, installed in the test article, and evaluated Also, one experimental High-Rate-Discharge (HRD) system was tested These systems are shown in Fig 15

The first system tested was designed for installation on GTP70-2 power plants in R7V-1 and R7V-2 aircraft. It provided two fire-extinguishment connections in the power plants, one was a 3/8-inch-OD tube to the inlet-air duct, and the other was a 1/4-inch-OD tube which led to the connection into the accessory section provided with the unit These tubes were connected by 90 feet of 3/8-inch-OD tubing to the main power-plant supply of 37 5 pounds of carbon dioxide (CO_2). Later, during the tests, the 3/8-inch main feedline from the carbon-dioxide supply was replaced by the same length of 5/8-inch-OD tubing.

A system designed for installation on Model GTP70-2 power plants in R6D-1 aircraft was tested It provided three fire-extinguishment connections to the power plant and one

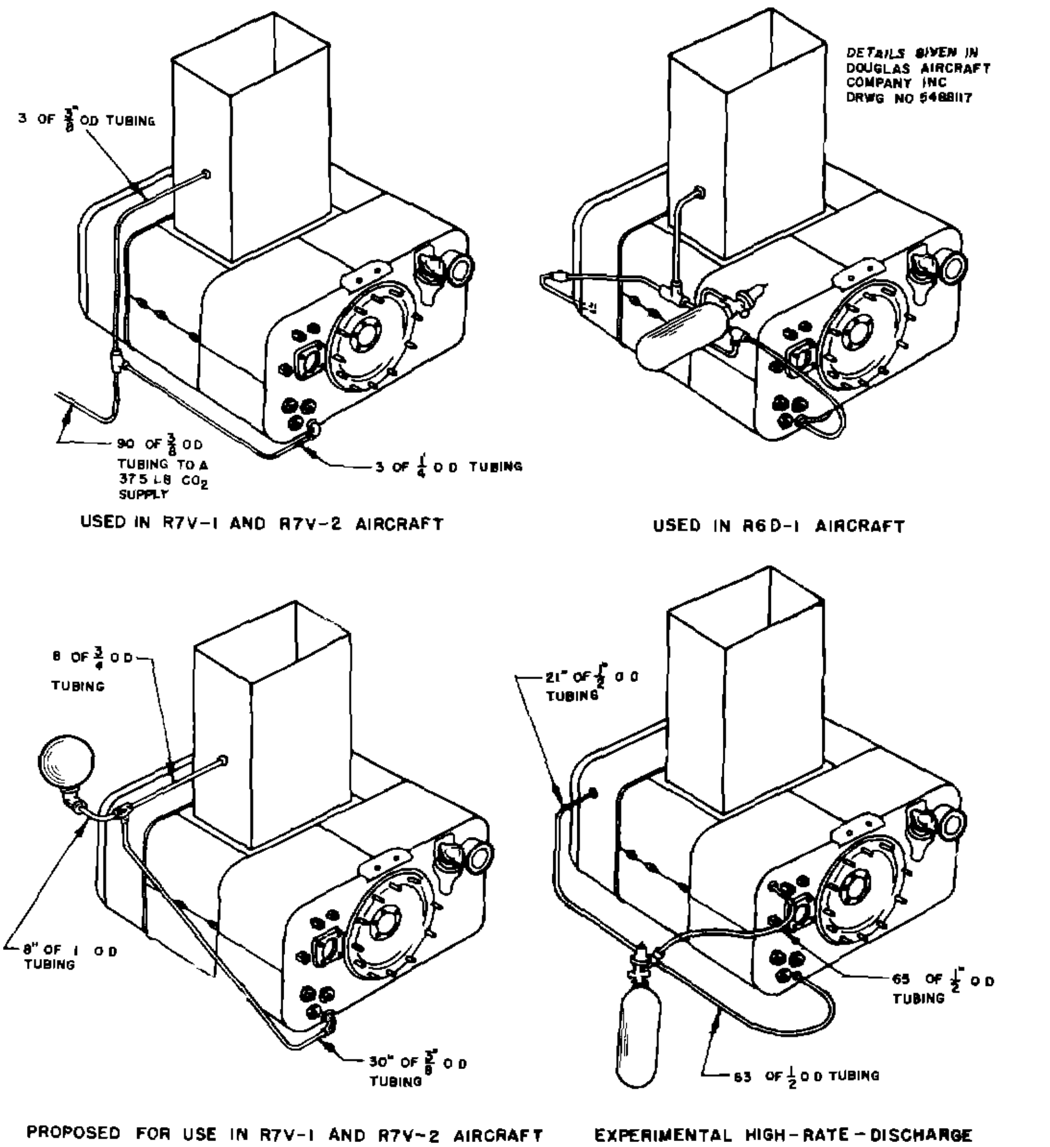


Fig 15 Fire-Extinguishing Systems Tested

connection to a drip pan under the power plant. One 1/2-inch-OD tube, with a nozzle area of 0 074 square inch, was connected to the inlet air duct, a 1/4-inch-OD tube, with a nozzle area of 0 0065 square inch, was connected to the accessory section, and a 1/4-inch-OD tube, with a nozzle area of 0 0139 square inch, was connected to the turbine section The connection to the drip pan was a 1/4-inch-OD tube with a nozzle area of 0 0053 square inch The extinguishing charge was 3 7 pounds of carbon dioxide in a 205-cubic-inch cylindrical container equipped with a 3/4-inch flood valve The carbon-dioxide container was mounted adjacent to the power plant

Later, a system was tested for use either with dibromodifluoromethane (CF_2Br_2) pressurized with nitrogen to 400 psi or with bromotrifluoromethane (CF_3Br) pressurized with nitrogen to 600 psi, both of which have been proposed for use on GTP70-2 power plants in R7V-2 aircraft It provided for two connections in the power-plant enclosure Agent was injected into the air-intake duct through a 3/4-inch-OD tube and into the accessory section through a 3/8-inch-OD tube The estimated weight of agent required was 0 75 pound, but a container capable of holding 2 pounds was used because it was the smallest available The container was mounted adjacent to the power plant

In conjunction with the tests on the systems proposed by the airframe manufacturers, an HRD system was designed and tested It provided three fire-extinguishment connections to the power-plant enclosure. A 1/2-inch-OD tube was connected in the center section by installing a fitting in the top portion of the connection panel, a 1/2-inch-OD tube was connected to a fitting provided for the accessory section, and a 1/2-inch-OD tube was connected to a fitting in the enclosure adjacent to the baffle behind the oil cooler

The fire tests of the extinguishment systems were conducted using the same fire nozzle, fire locations, and operating conditions as were used during the fire-detection tests A different test sequence was used, however, as follows

1 The operating condition for the test was established
2 The test-fire ignitor was switched on
3 Fuel flow for the test fire was started
4 As soon as fire detection occurred, the engine-stop switch was pushed and the extinguishment system was discharged
5 Fuel flow for the test fire was not stopped until after completion of the test.

In addition to conducting fire tests, measurements of extinguishing-agent concentrations in the various sections of the GTP70-2 auxiliary-power plant were made with a gas analyzer [1] Sampling tubes were installed at six different locations within the enclosure of the GTP70-2 unit These locations are shown in Figs 16 and 17

Results

The data obtained during fire tests conducted on the extinguishment system used on GTP70-2 units in R7V-1 and R7V-2 aircraft are given in Table VI Owing to the length of tubing between the carbon-dioxide supply and the extinguishment system, the delay between

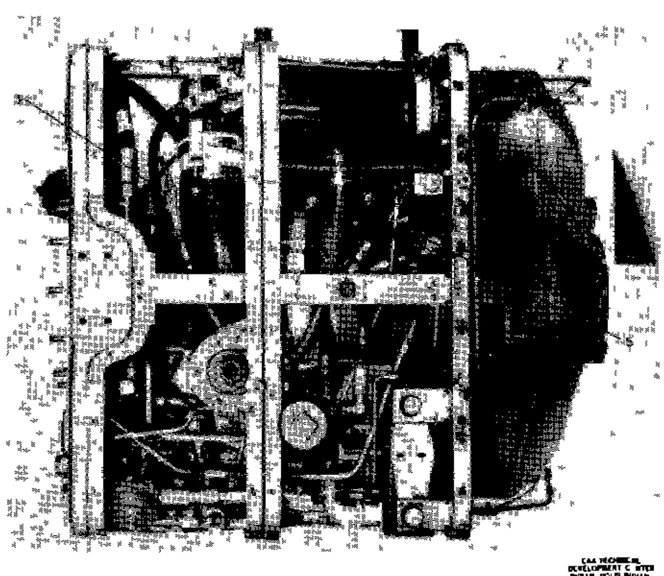


Fig 16 Extinguishing-Agent Concentration Measurement Points (Bottom View of Auxiliary-Power Unit)

[1] James D New and Charles M. Middlesworth, "Aircraft Fire Extinguishment, Part III, An Instrument for Evaluating Extinguishing Systems," CAA Technical Development Report No 206, June 1953.

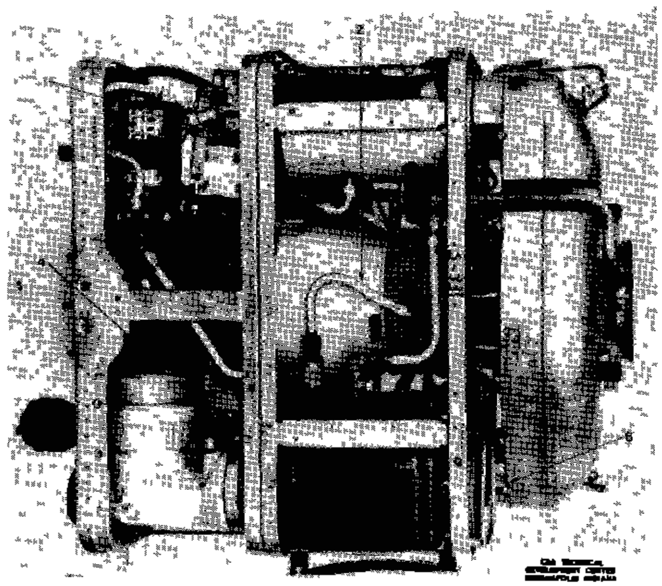


Fig 17 Extinguishing-Agent Concentration Measurement Points (Top View of Auxiliary-Power Unit)

opening of the carbon-dioxide valve and the beginning of discharge averaged approximately 2 1 seconds The total duration of discharge averaged 71 seconds The duration of dense discharge was 55 seconds.

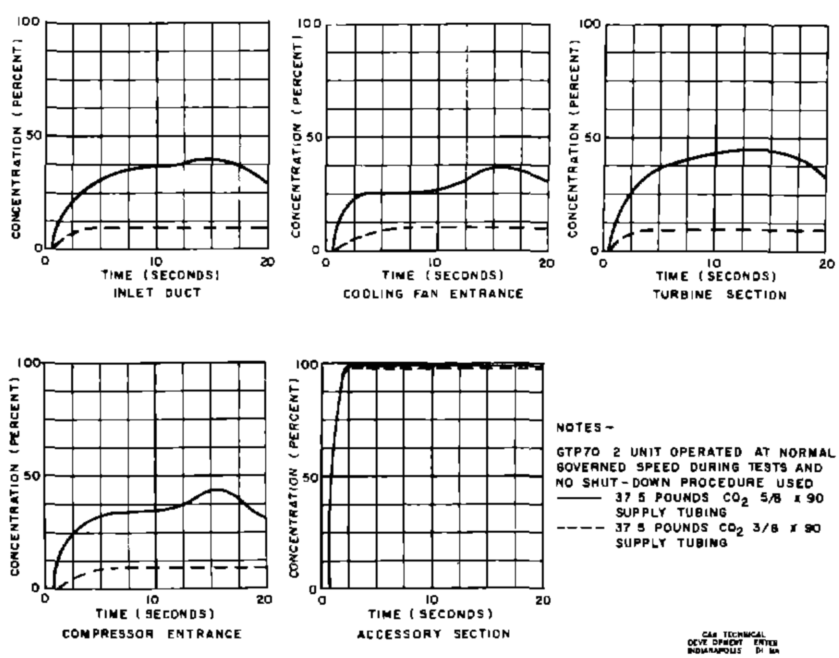


Fig. 18 Carbon-Dioxide Concentrations During Discharge of the System Used on GTP70-2 Units in R7V-1 and R7V-2 Aircraft

TABLE VI

RESULTS OF FIRE TESTS ON EXTINGUISHMENT SYSTEM USED IN GTP70-2 UNITS IN R7V-1 AND R7V-2 NAVAL AIRCRAFT

Test No	Fire Location	Test Conditions	Fire Extinguished
1	A	Starting	Yes
2	A	Operation	No
3	A	Operation	No
4	B	Starting	Yes
5	B	Operation	No
6	B	Operation	No
7	C	Starting	Yes
8	C	Operation	Yes
9	C	Operation	Yes
10	D	Starting	Yes
11	D	Operation	Yes
12	D	Operation	Yes
13	D	Operation	Yes
14	E	Starting	Yes
15	E	Operation	No
16	E	Operation	No
17	F	Starting	Yes
18	F	Operation	No
19	G	Starting	Yes
20	G	Operation	No
21	G	Operation	No
22	G	Operation	No

Additional fire tests were conducted on the system after replacing the 3/8-inch-OD supply tubing with the same length of 5/8-inch-OD tubing. The data obtained during these tests are given in Table VII. The delay between opening of the carbon-dioxide valve and the beginning of discharge averaged approximately 1 8 seconds The total duration of discharge averaged 50 seconds The duration of dense discharge was 28 seconds Concentrations of carbon dioxide in the various sections of the GTP70-2 auxiliary-power plant during the discharge of these systems are shown in Fig 18

The data obtained during fire tests conducted on the extinguishment system proposed for use on GTP70-2 units on R6D-1 aircraft are given in Table VIII Measurements of carbon-dioxide concentration provided by the R6D-1 system are shown in Fig. 19

The data obtained during fire tests conducted on the extinguishment system, using either dibromodifluoromethane or bromotrifluoromethane in R7V-2 aircraft, are given in Table IX Extinguishing-agent concentrations for both dibromodifluoromethane and bromotrifluoromethane are shown in Figs 20 and 21

The data obtained during fire tests conducted on the HRD extinguishment system are given in Table X Extinguishing-agent concentrations provided by this system are shown in Fig 22

TABLE VII

RESULTS OF FIRE TESTS ON EXTINGUISHMENT SYSTEM USED IN GTP70-2 UNITS IN R7V-1 AND R7V-2 NAVAL AIRCRAFT*

Test No.	Fire Location	Test Conditions	Fire Extinguished
1	A	Starting	Yes
2	A	Operation	Yes
3	A	Operation	Yes
4	B	Starting	Yes
5	B	Operation	Yes
6	B	Operation	Yes
7	C	Starting	Yes
8	C	Operation	Yes
9	D	Starting	Yes
10	D	Operation	Yes
11	E	Starting	Yes
12	E	Operation	Yes
13	E	Operation	Yes
14	F	Starting	Yes
15	F	Operation	Yes
16	G	Starting	Yes
17	G	Operation	Yes
18	G	Operation	Yes

*The 3/8-inch-OD supply line replaced with 5/8-inch-OD line

Conclusions

1 The fire-extinguishment system simulating that used to protect the Model GTP70-2 installations in Navy Model R7V-1 and R7V-2 aircraft was found to be adequate for extinguishing all fires under static conditions but inadequate for extinguishing all fires that can occur during engine operation. Increasing the size of supply-line tubing from 3/8-inch-OD to 5/8-inch-OD tubing resulted in a system that was adequate under all conditions Elimination of the 90-foot supply line, by providing a separate extinguishing-agent supply adjacent to the auxiliary-power-unit installation and an extinguishing-agent connection to the turbine section, would be preferable, however Testing of other systems indicated that extinguishing-agent requirements were greatly reduced, owing to a higher rate of discharge and better distribution of the extinguishing agent, after the suggested changes were made.

2. The fire-extinguishment system simulating that used to protect the auxiliary-power-unit installation in R6D-1 aircraft was found to be adequate to extinguish all test fires under all conditions The extinguishing-agent concentrations were entirely adequate

3 The fire-extinguishment system proposed for use of either dibromodifluoromethane or bromotrifluoromethane in auxiliary-power-unit installations in R7V-1 and R7V-2 aircraft was adequate in all sections of the unit except in the turbine section. In that section, extinguishing-agent concentrations were low during static or starting conditions Although two pounds of either agent extinguished the test fires, the results of the gas-analyzer tests indicated that extinguishing-agent concentrations were very low in the turbine section during starting Therefore, it was concluded that an extinguishment connection into the turbine section is desirable

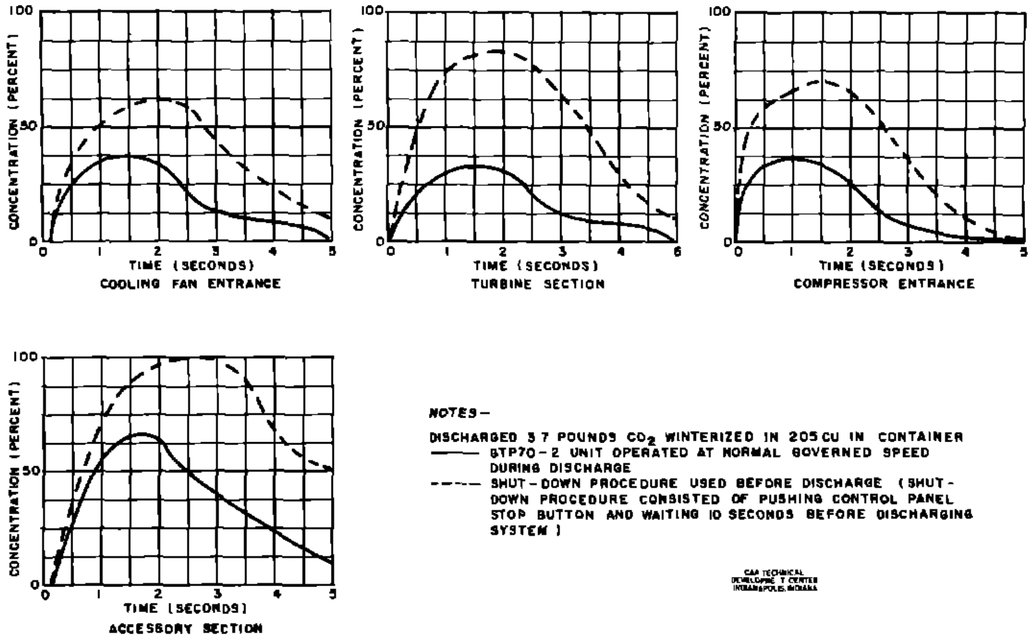


Fig 19 Carbon-Dioxide Concentrations During Discharge of the System Used on GTP70-2 Units in R6D-1 Aircraft

4 The HRD system adequately extinguished all test fires Concentration measurements with the gas analyzer indicated that concentrations were high in all sections

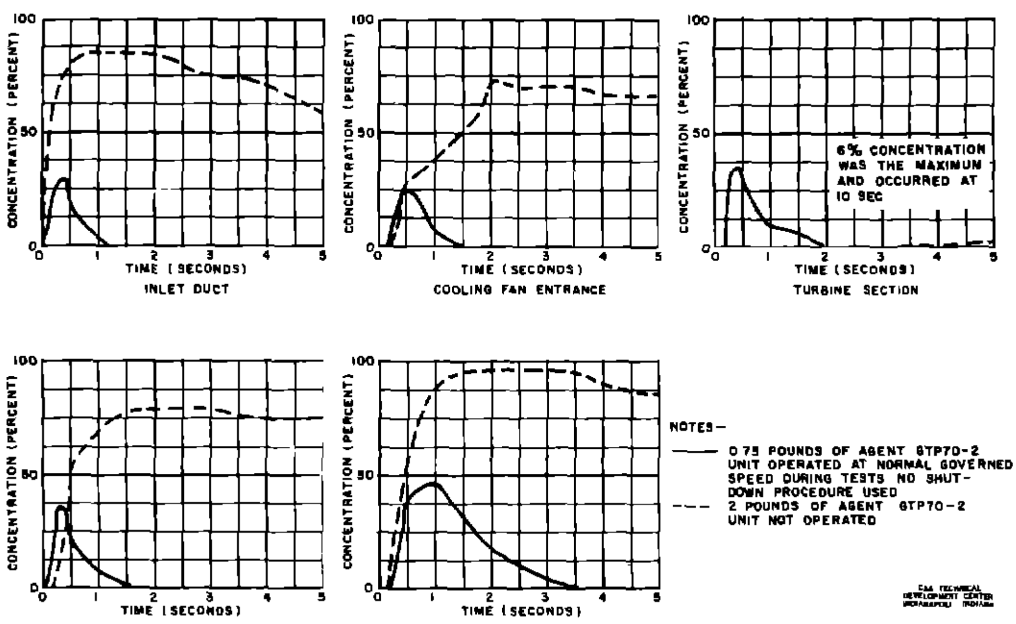


Fig. 20 Dibromodifluoromethane Concentrations During Discharge of the System Proposed for Use on GTP70-2 Units in R7V-2 Aircraft

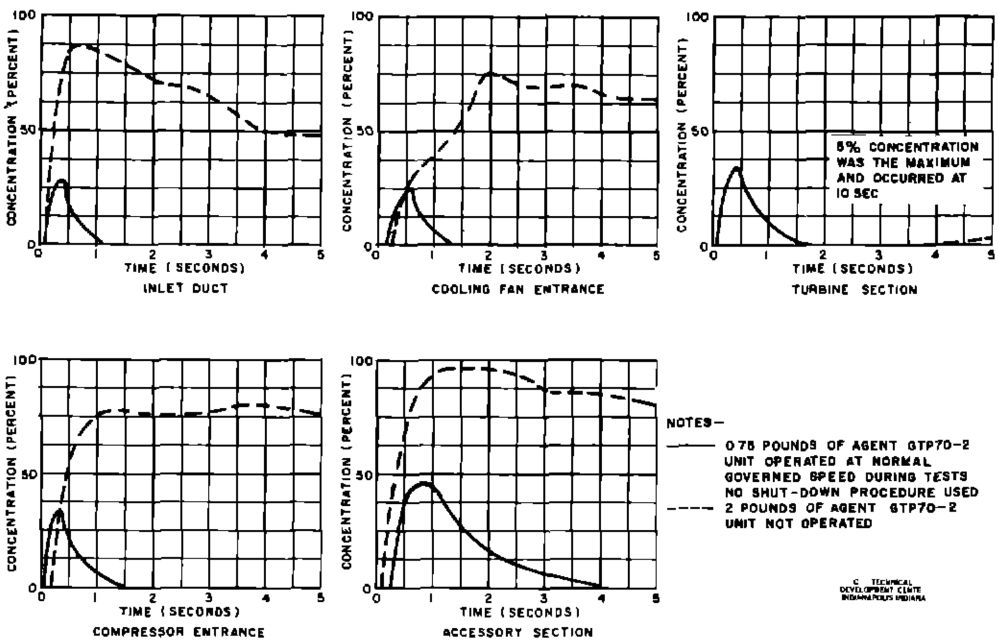


Fig 21 Bromotrifluoromethane Concentrations During Discharge of the System Proposed for Use on GTP70-2 Units in R7V-2 Aircraft

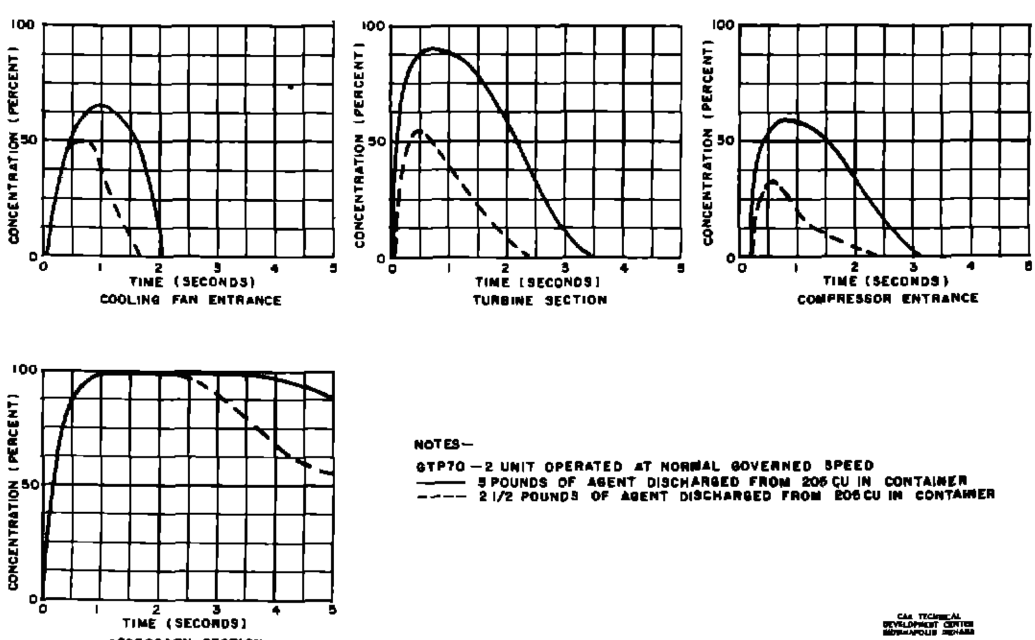


Fig. 22 Carbon-Dioxide Concentrations During Discharge of an Experimental HRD System

TABLE VIII

RESULTS OF FIRE TESTS ON EXTINGUISHMENT SYSTEM USED IN GTP70-2 UNITS IN R6D-1 NAVAL AIRCRAFT

Test No.	Fire Location	Test Conditions	Fire Extinguished
1	A	Starting	Yes
2	A	Operation	Yes
3	A	Operation	Yes
4	A	Operation	Yes
5	B	Starting	Yes
6	B	Operation	Yes
7	B	Operation	Yes
8	B	Operation	Yes
9	C	Starting	Yes
10	C	Operation	Yes
11	D	Starting	Yes
12	D	Operation	Yes
13	E	Starting	Yes
14	E	Operation	Yes
15	E	Operation	Yes
16	F	Starting	Yes
17	F	Operation	Yes
18	F	Operation	Yes
19	G	Starting	Yes
20	G	Operation	Yes
21	G	Operation	Yes
22	G	Operation	Yes

RECOMMENDATIONS

Fire Detection

1 A continuous-type fire-detection system is recommended, with the elements passing through the lower accessory (fuel system) section and encircling the entrance to the cooling fan, the engine-air inlet, and the annular exit for the cooling air in the turbine section This is the system shown in Fig. 14.

2. Also recommended is a unit-type detector system consisting of five detector units located as follows one detector in the lower accessory section, see Fig 8, Location 1, one detector in the cooling-fan discharge to the generator, see Fig 12, Location 5, one detector in the upper region of the annular exit for turbine-section cooling air, see Fig 13, Location 6, and two detectors in the engine-air-inlet area, see Figs 10 and 11, Locations 3 and 4

Fire Extinguishment

1 As a result of the fire-extinguishment tests and extinguishing-agent-concentration measurements on various systems, it is recommended that extinguishment nozzles be placed in the lower accessory section, the main inlet duct, and the turbine compartment. When the

TABLE IX

RESULTS OF FIRE TESTS ON PROPOSED EXTINGUISHMENT SYSTEM FOR USE IN GTP70-2 UNITS IN R7V-2 NAVAL AIRCRAFT

Test No.	Fire Location	Test Conditions	Extinguishing Agent Type	Extinguishing Agent Quantity (pounds)	Fire Extinguished
1	A	Starting	CF_2Br_2*	0.75	Yes
2	A	Operation	CF_2Br_2	0.75	Yes
3	B	Starting	CF_2Br_2	0 75	Yes
4	B	Operation	CF_2Br_2	0 75	Yes
5	C	Starting	CF_2Br_2	0.75	Yes
6	C	Operation	CF_2Br_2	0.75	Yes
7	D	Starting	CF_2Br_2	0.75	Yes
8	D	Operation	CF_2Br_2	0.75	Yes
9	E	Starting	CF_2Br_2	0 75	Yes
10	E	Operation	CF_2Br_2	0 75	Yes
11	F	Starting	CF_2Br_2	0 75	Yes
12	F	Operation	CF_2Br_2	0 75	Yes
13	G	Starting	CF_2Br_2	0 75	No
14	G	Operation	CF_2Br_2	0.75	Yes
15	G	Starting	CF_2Br_2	1 0	No
16	G	Starting	CF_2Br_2	1 5	No
17	G	Starting	CF_2Br_2	2.0	Yes
18	A	Starting	CF_3Br **	0 75	Yes
19	A	Operation	CF_3Br	0 75	Yes
20	G	Starting	CF_3Br	0 75	No
21	G	Operation	CF_3Br	0 75	Yes
22	G	Starting	CF_3Br	1 6	No
23	G	Starting	CF_3Br	1 8	No
24	G	Starting	CF_3Br	2.0	Yes
25	G	Starting	CF_3Br	2.0	Yes
26	G	Starting	CF_3Br	2.0	Yes
27	G	Starting	CF_3Br	2.0	Yes

* Dibromodifluoromethane.
**Bromotrifluoromethane.

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installation includes a drip pan below the auxiliary-power unit, an additional extinguishment nozzle should be included to provide extinguishing agent to that area Evaluation of the different systems indicated that small quantities of agent will extinguish fires if the discharge rate is high. The discharge rate for carbon dioxide should be 2 1/2 pounds per second, for dibromodifluoromethane and bromotrifluoromethane, it should be 0 75 pound per second

2. A shutdown procedure, consisting of pushing the stop button on the control panel and waiting 10 seconds before discharging the extinguishment system, is recommended because

TABLE X

RESULTS OF FIRE TESTS ON EXPERIMENTAL HIGH-RATE-DISCHARGE EXTINGUISHMENT SYSTEM

Test No	Fire Location	Test Conditions	Extinguishing Agent Type	Extinguishing Agent Quantity (pounds)	Fire Extinguished
1	A	Starting	CO_2*	5 0	Yes
2	A	Operation	CO_2	5 0	Yes
3	A	Operation	CO_2	2 5	Yes
4	A	Starting	CO_2	2 5	Yes
5	A	Starting	CO_2	1 5	Yes
6	A	Operation	CO_2	1 5	No
7	A	Starting	CO_2	2 0	Yes
8	A	Operation	CO_2	2 0	Yes
9	A	Operation	CO_2	2 0	Yes
10	B	Starting	CO_2	2 0	Yes
11	B	Operation	CO_2	2 0	Yes
12	C	Starting	CO_2	2 0	Yes
13	C	Operation	CO_2	2 0	Yes
14	D	Starting	CO_2	2 0	Yes
15	D	Operation	CO_2	2 0	Yes
16	E	Starting	CO_2	2 0	Yes
17	E	Operation	CO_2	2 0	No
18	E	Operation	CO_2	2 5	Yes
19	E	Operation	CO_2	2 5	Yes
20	F	Starting	CO_2	2 5	Yes
21	F	Operation	CO_2	2 5	Yes
22	G	Starting	CO_2	2 5	Yes
23	G	Operation	CO_2	2 5	Yes
24	A	Starting	CF_2Br_2**	1 0	Yes
25	A	Operation	CF_2Br_2	1 0	Yes
26	E	Starting	CF_2Br_2	1 0	Yes
27	E	Operation	CF_2Br_2	1 0	Yes
28	E	Starting	CF_2Br_2	0 75	Yes
29	E	Operation	CF_2Br_2	0 60	No
30	E	Operation	CF_2Br_2	0 75	Yes
31	A	Starting	CF_2Br_2	0 75	Yes
32	A	Operation	CF_2Br_2	0 75	Yes
33	B	Starting	CF_2Br_2	0 75	Yes
34	B	Operation	CF_2Br_2	0 75	Yes
35	C	Starting	CF_2Br_2	0 75	Yes
36	C	Operation	CF_2Br_2	0 75	Yes
37	D	Starting	CF_2Br_2	0 75	Yes
38	D	Operation	CF_2Br_2	0 75	Yes
39	F	Starting	CF_2Br_2	0 75	Yes
40	F	Operation	CF_2Br_2	0 75	Yes
41	G	Starting	CF_2Br_2	0 75	Yes
42	G	Operation	CF_2Br_2	0 75	Yes
43	E	Starting	CF_3Br***	0 75	Yes
44	E	Operation	CF_3Br	0 75	Yes
45	A	Starting	CF_3Br	0 75	Yes
46	A	Operation	CF_3Br	0 75	Yes
47	B	Starting	CF_3Br	0 75	Yes
48	B	Operation	CF_3Br	0 75	Yes
49	C	Starting	CF_3Br	0 75	Yes
50	C	Operation	CF_3Br	0 75	Yes
51	D	Starting	CF_3Br	0 75	Yes
52	D	Operation	CF_3Br	0 75	Yes
53	F	Starting	CF_3Br	0 75	Yes
54	F	Operation	CF_3Br	0 75	Yes
55	G	Starting	CF_3Br	0 75	Yes
56	G	Operation	CF_3Br	0 75	Yes

*Carbon dioxide
**Dibromodifluoromethane
***Bromotrifluoromethane

it decreases the airflow through the unit. This allows larger concentrations of extinguishing agent to build up.

Fire Prevention

1 The incorporation of a fireproof, ducted-air inlet containing no flammable-fluid lines is recommended because it was concluded that the original provisions for the isolation of engine-inlet air from lines containing flammable fluid are inadequate

2 Separate fireproof ducting of the cooling-fan-inlet air is recommended because this would avoid the possibility of flammable fluids passing into the generator with the cooling air in the event of leakage from lines in the upper portion of the center section Under the present configuration of the GTP70-2 model, discharge overboard of the generator-cooling air is desirable This would not reduce the fire hazard within the unit, but it would protect the airplane

3 Venting of the oil tank overboard instead of into the turbine exhaust is recommended. Other desirable features would include the incorporation of an oil-level "full" mark which is visible during the filling operation or shortening the oil-filler tube to the full level and adding a scupper with an overboard drain.

4. Although the tests which were conducted indicate that airflow in the turbine section had enough velocity to make ignition of hydrocarbons improbable, the turbine-housing surface temperature exceeded that required for ignition at low rates of airflow For this reason, it is recommended that in the design of new units, provision be made for the air now utilized for oil cooling to be dumped overboard instead of being utilized also for cooling the turbine housing.

5 It is recommended that the burner cans be provided with drains similar to those on main-turbojet power plants.

6. Provision of a drain for the center section of the unit is recommended.

7. It is recommended that all flammable fluids drained from the unit be routed overboard of the airplane.

8. An insulating cover for the positive-terminal connection on the starter is recommended.

9. Internal baffling and firewalls should be as tight as possible and should be constructed of fire-resistant material. They should isolate all flammable-fluid systems from ignition sources. In this unit, if the engine-inlet air and the cooling-fan-entrance air are ducted as recommended, the need for the internal baffling which separates the accessory section no longer will exist.

Implementation of Recommendations.

If the fire-prevention measures recommended above are incorporated, recommendations for fire detection and extinguishment are as follows

1 The continuous sensing elements should be used as shown in Fig 14, except that the length of element required to encircle the cooling-fan entrance and the compressor entrance may be replaced with a straight section of element through the center section from the accessory section to the turbine section Unit detectors would be required at Locations 1, 4, and 6 as shown in Figs 8, 11, and 13

2 One fire-extinguishment connection should be provided which would lead into each separate section, that is, to the turbine section, the accessory section, the center section, and to the drip pan, if included