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Fire-Detection Requirements for the Boeing 707 Powerplant

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by

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FIRE-DETECTION REQUIREMENTS FOR THE BOEING 707 POWERPLANT

SUMMARY

Many of the fire-detector routings possible in the podded-type powerplant installation were investigated with the objective of providing maximum fire detection with the minimum amount of detector element The investigations included a determination of the direction of airflow and internal flame paths and an ambient air temperature survey. A practical routing was established for an engine-mounted, unit-type system, and a door-mounted and an engine-mounted continuous-type system.

INTRODUCTION

This is the second of a series of reports[1] on fireworthiness studies of the multiengine turbojet transport design in which the engines are mounted in pods on struts underneath the wing. The pod-mounted design is a new concept for separating the fire zones of the engine from the basic airframe structure and the particular one under test was characterized by having a very low ventilation rate. The United States Air Force KC-135 airplane and its commercial counterpart, the Boeing 707, are similar in design and represent the pod-mounted powerplant installation having a low airflow through the nacelle.

Little information was available for locating the sensing elements of various systems for detecting in-flight fires in podded-type powerplants For this reason, a test program was instituted at the CAA Technical Development Center to determine the direction of airflow and flame paths inside the nacelle, to evaluate the current fire-detector system in the KC-135 airplane, and to determine effective locations of sensing elements. Particular emphasis was placed on determining the characteristics of fires and the effect of airflow on detector requirements and performance in podded-type powerplants as compared with turbojet installations tested previously

Actual fire tests were conducted from January through May, 1958. The test program was divided into two phases. The first phase was a study of the characteristics of flame paths inside the nacelle, and the second phase comprised a study of the detection requirements and an investigation to determine the best locations in the nacelle for several types of detector sensing elements

DESCRIPTION OF TEST EQUIPMENT

The test article consisted of the No. 2 engine, pod, strut, and 12 feet of wing section of the KC-135 airplane mounted on a supporting

[1] Allen V. Young, "A Study of Ignition Hazards and Fire Resistance of the Boeing 707 Powerplant," CAA Technical Development Report No. 357, August 1958, is the first report of the series

structure in a test cell as shown in Fig. 1. Several changes were made in the KC-135 cowling to make it conform with the production version of the Boeing 707. These changes consisted of: (1) adding an 8-inch-wide titanium strip along the hinge lines of the cowling thus giving a 90° included angle of fireproof material over the top of the engine; (2) closing the original louvers located just forward of the firewall and near the hinge lines, and replacing them with a single 3 5/8-inch-diameter flush port at a point 15 inches below the engine centerline and 6 1/2 inches forward of the firewall on the right-hand cowl, (3) adding twelve 1/2-inch-diameter holes at the low points of the cowl latch line to provide additional fluid drainage; (4) reworking the nose cowl to allow the introduction of air to simulate anti-icing airflow conditions; (5) installing an air seal at a point 46.8 inches aft of the firewall, (6) adding a 2-inch-diameter hole in the right-hand cowl at 2:30 o'clock 3.8 inches aft of the firewall; and (7) installing a flame seal at the hinge joints

The test facility was revised by the installation of a new starter air supply. To provide dry pressurized air for the engine fuel-air starter, a three-stage air compressor, set to pressurize two 1 1/2-cubic-feet cylinders to 2,000 psi, was installed. These cylinders were connected through a moisture filter to the starter inlet

In some of the tests, airflow conditions prevailing in the Boeing 707 nacelle with anti-icing ON were simulated by supplying 1,100 cfm of air from a variable-inlet centrifugal blower. To duplicate test fires more accurately, a synchronous motor-driven, single-cycle, multicam timer was used to schedule, operate, and control the instrumentation, ignition, fuel flow, and CO_2 discharge

A magnetic tape recorder was connected in the aircraft-type intercommunications system to record test conditions, pertinent test data, and visual observations noted during the course of a test. This information was stored on the tape and later transcribed to a permanent record. An Esterline-Angus operation recorder was used to record the sequence and duration of each individual phase of the tests. The response to a test fire of each individual double-wire, heat-sensitive, unit-type detector was recorded on a second Esterline-Angus recorder. Chromel-Alumel thermocouples using 0.03-inch-diameter wire were connected to individual Brown self-balancing temperature recorders to obtain air temperatures in the nacelle during the tests.

NACELLE INTERNAL FLAME STUDY

Purpose

The purpose of the flame study inside the nacelle was to: (1) obtain normal ambient air temperatures at various nacelle locations under simulated operation to establish detector alarm settings; (2) obtain maximum ambient air temperatures at specific nacelle locations during test fires to aid in detector locations, (3) locate the flame paths in the nacelle when fires originate at given points, and (4) investigate drainage paths of fluids released at various locations in the nacelle

Procedure.

After an investigation of the engine and nacelle configuration to determine the possible source of flammable fluid leakage and ignition, the points shown in Fig 2 were chosen as appropriate locations where in-flight fires could originate. An individually controlled combination fuel discharge nozzle and high-voltage ignitor were placed at each of these locations. Temperature readings at each clock position for a particular nacelle station were obtained simultaneously by locating 12 thermocouples in the compartment free volume Figure 3 shows the various nacelle stations independently surveyed during the study

Tests were conducted by igniting a 10-second discharge of JP-4 fuel flowing at 0.3 gpm. The discharging fuel impinged on a baffle to break up the fuel stream in the immediate vicinity of the nozzle. Table I shows the engine power conditions, fuel release locations, and thermocouple locations used in this study.

Each instrument or component used in conducting a test fire was operated and controlled by the electric timer according to a predetermined schedule Figure 4 shows the recording of the particular schedule for this series of test fires

The temperature data recorded by the Brown temperature recorders during each test were used to determine (1) nacelle ambient air temperature during normal operation, (2) highest air temperature during a test fire, and (3) flame paths. The maximum ambient temperature rise at each thermocouple was obtained by subtracting the normal operating ambient temperature from the highest temperature recorded during a test fire.

To obtain an alarm setting for heat-sensitive detectors in each compartment, the highest normal operating ambient temperature recorded for a compartment was increased 150° Thus, a minimum alarm temperature was obtained which would reduce the probability of false alarms due to higher operating ambient temperatures.

Results

The tests provided the necessary data to make a thermal plot of the maximum ambient air temperature rise in the nacelle for each engine power condition shown in Table I. Figure 5 shows the thermal plot for the maximum rated thrust power condition at fuel release locations Nos 1 and 4 Similar plots are shown in Appendix A for the other engine power conditions and fuel release locations used in the study When fuel was released and ignited at locations 6, 7, and 8, Fig 2, the fuel followed the engine case contour and drained rapidly to the low point in the nacelle. The flame rapidly followed the draining fuel and burned in the bottom of the nacelle

In the compressor compartment, the heat circulation was toward the rear and top on both sides of the engine. The flame path in the compressor compartment was from the point of origin toward the 3 5/8-inch-diameter vent. Very little flame penetrated the nacelle area on the side opposite the vent

Prior to the installation of the aft air seal in the burner compartment, the heat circulation and flame path in this compartment were almost identical. No variation from one side of the engine to the other side was noted in the upward and rearward path in the compartment. The data obtained during this study apply to the nacelle configuration without the aft air seal

A study of the thermal plots, heat circulation, flame paths, and fluid drainage indicated that, regardless of the location of fuel release, the flame soon reached the bottom of the nacelle and the highest temperature rise was concentrated in a volume extending from the 6 o'clock position to the 3 and 9 o'clock positions. The initial placement of detectors in the nacelle was based on this review and examination of data obtained during these tests

Temperature data for normal engine operation shown in Table II indicated that heat-sensitive detector systems in the compressor compartment should have an alarm setting above 500° F. and the same type detector system installed in the burner section should be set to alarm above 600° F.

FIRE-DETECTOR ROUTE STUDY

Purpose

The purpose of the fire-detector route study was to: (1) obtain data which would be helpful in the effective placement of sensing elements or units of various type detection systems in a podded-type turbojet powerplant installation, (2) establish effective routings and locations for detector elements in nacelle designs similar to those of the KC-135 and Boeing 707 airplanes, and (3) evaluate the performance of detector systems using these locations or routings

Procedure

For this phase of testing, the detection equipment and systems of Aviation Products Division, Fenwal Incorporated, Ashland, Mass., were used, consisting of required lengths and temperature settings of the 35500 series continuous-type sensing element, and a Model 35000-X control unit and the necessary quantity of 17343-16, 17343-77, and 17343-78 unit-type detectors.

In preparation for fire testing to evaluate detector locations in the nacelle, the following determinations were made: (1) location of fuel release points in the nacelle, (2) amount of fuel discharge and burning time for the test fire to be used, (3) initial detector system locations, and (4) standardization of a schedule and sequence of events for all test fires

Based on the results of the flame study, the four fuel release locations shown in Fig 6 were chosen as being representative of the general areas where fires could be ignited during flight. At each of these locations, combination ignitor-nozzle units were installed. These units had individual controls for the ignitor and fuel nozzle. The nozzle was set to provide a 0.3-gpm flow of JP-4 fuel.

As the testing progressed, the need for test fires of several magnitudes became apparent. This resulted in establishing a standard test fire with a fuel release time of 10 seconds and a burning time of 18 to 22 seconds. Test fire designation (y), as shown in Table III, used only at the No. 4 location, had a fuel release time of 5 seconds and a burning time of 18 to 22 seconds. Selection of the test fire magnitude was based on (1) the rate at which JP-4 fuel could be burned successfully in the rather limited oxygen supply available in the nacelle, (2) the size which would produce little damage to the test article, and (3) the intensity sufficient to produce temperatures above the alarm setting of the heat-sensitive detector to be tested. Burning time was controlled by discharging CO_2 in the nacelle after the prescribed fire time had elapsed.

Initial detector routings and locations, as shown in Figs. 7 to 10, inclusive, were based on the results of the nacelle internal flame study and observed flame paths or on industry recommendations. As testing progressed, the routings and locations were changed in an attempt to obtain a higher percentage of detection or improve the detector system performance.

Throughout the testing, the sequence of events as scheduled by the electric timer was identical. Figure 11 shows a record of this sequence and of detector response in one test. It also shows the duration of events during a standard test fire and their relation to a common starting point. After selecting one of the fuel release points shown in Fig. 6 and stabilizing the engine at one of the power conditions listed in Table III, the sequence timer was energized. During the cycle, temperature in the vicinity of fuel release was recorded on a Brown temperature recorder. Detector system response and reset times, total burning time, length of fuel discharge, and individual thermal unit detector alarms were recorded automatically on operation recorders.

Results

When the heat-sensitive, continuous-element-type detector was routed as shown in Fig. 7, the percentage of detection for the system was 65. The same type detector routed as shown in Fig. 8 failed to detect standard-magnitude test fires at the idle and simulated taxi power settings. For this system the over-all percentage detection was 50. Initial locations of the double-wire, unit-type, heat-sensitive detector were completely ineffective. These routes and locations were changed to improve the percentage detection for each of the detector systems.

Table IV shows the test conditions and results obtained when the final route or locations were evaluated. Figures 12 to 14, inclusive, show these routes and locations. Figure 12 shows the final routing of the engine-mounted, heat-sensitive, continuous-element-type detector system which gave 96 per cent detection. Several intermediate locations were evaluated and are shown in Appendix B.

A heat-sensitive, continuous-element-type detector system mounted on the doors as shown in Fig 13 detected 93 per cent of the 150 test fires. This final routing was similar to the initial routing. Other routings were evaluated but were much less effective Since effectiveness of location or route was the primary test objective, the longitudinal portions of the door-mounted system were not placed in the same horizontal plane as the longitudinal portions of the engine-mounted system. When comparing the response and reset times for the two continuous-element systems, the differences in mounting should be recognized The initial Fenwal double-wire unit system was altered considerably by relocating several units. The final locations and positions shown in Fig. 14 provided the most effective detection This system had a lower percentage of detection than the continuous system when test fires of standard magnitude were used. Performance of the initial installation was extremely poor. The final locations detected 134 of the 141 standard test fires conducted in the compressor compartment. Performance in the burner compartment with the aft air seal installed could not be improved due to the nature of the fires in the almost-zero airflow. The ambient air temperatures rarely reached the alarm setting of these detectors when test fires of standard magnitude were conducted at the No 4 location.

The locations of the Fenwal single-wire, heat-sensitive, unit-type detectors shown in Fig. 12 are those of the KC-135 airplane Prior to the aft air-seal installation, the system effectiveness was as follows: compressor compartment, 31.6 per cent; burner compartment, 23 per cent, and complete system, 30.4 per cent No units of this system were relocated during the testing. This system and the double-wire system are similar in operating principle and differ only in the circuitry used. Single-wire units placed at the same locations and positions as the double-wire units would produce equally effective detection. When the aft air seal was installed, the single-wire units located in the burner section were outside the newly formed compartment After the seal installation, no data were collected on the effectiveness of the single-wire system in the No. 4 fuel release area. However, all data obtained from the investigation of the double-wire, unit-type system can be applied to the single-wire system.

As indicated in Table IV, test location No. 4 shows the results obtained when the final locations or routes of the detector systems were evaluated before the aft air-seal installation. A test fire of standard magnitude was used for this evaluation. These data indicate the performance that can be expected when the locations or routes shown in Figs. 12 to 14, inclusive, are used in the KC-135 burner section configuration.

DISCUSSION

The response time of all heat-sensitive detectors installed in the nacelle was longer than for similar systems tested in other turbojet nacelle designs or installations In low airflow nacelles, the limited supply of oxygen available to support combustion affects fire intensity. While this low airflow exists, the rate of increase in fire intensity and ambient temperature rise due to a fire is retarded. The maximum temperature of the fire is lower than under ideal fuel-air ratio conditions.

Installation of the aft air seal during the detection study affected the results and necessitated a change in the testing at the No. 4 fuel release location. Most directly affected were the flame paths, burning characteristics, and intensity of test fires conducted at that location, which in turn affected the detector system effectiveness in the compartment

Because of the very limited oxygen supply available in the altered compartment, test fires of the standard magnitude tended to become overrich. To reduce the effects of this condition, a shorter fuel discharge test fire was used in this location for the remainder of the tests. Results obtained when using test fires with a shorter fuel release time in the altered compartment are shown in Table IV, location 4 (y).

With the air seal installed, available information indicated that the compartment ambient temperature would rise. This necessitated raising the alarm setting for the heat-sensitive detectors above the setting determined in the flame study. The continuous system in this compartment was set to alarm at 765° F. The double-wire units installed in this compartment on production 707 airplanes were set for an alarm temperature of 900° F.

The double-wire, heat-sensitive unit and the single-wire, heat-sensitive unit both utilize the same theory of operation, but due to its circuitry, the double-wire system cannot give false alarms when the circuit is grounded In the KC-135 powerplant installation, the double-wire, heat-sensitive, unit-type detector system should be more reliable For this nacelle configuration, the unit detector locations and alarm settings shown in Fig 15 are recommended.

In a nacelle configuration which incorporates the aft air seal, the tested unit-type systems having a 900° F. alarm setting in the burner section may never be effective. A 900° F alarm setting to avoid false alarm from normal ambient temperature may be too high to detect fires from external fluid leaks because of the nature of fires in this section. The low supply of air to the area limits the size of the fire to a very low intensity However, this is not true for fires resulting from burner can burn-through.

Further investigations were made to improve the percentage detection of the heat-sensitive continuous-element system In the latest nacelle configuration, the percentage detection was reduced noticeably when compared to the systems performance in the nacelle configuration without the air seal. Results obtained before the seal was installed showed the continuous heat-sensitive system detection decreased almost 40 per cent at the No. 4 fuel release location after the air seal was installed In this compartment the fire intensity and temperature were low due to the nearly stagnant condition. To detect these fires, other heat-sensitive detector alarm settings were studied. The alarm setting for the door-mounted route was lowered to a setting of 575° F. No overheat false alarms occurred at any of the power conditions used in the testing. Percentage detection of the system in the burner section increased to 90, as shown in test location 4 (y) of Table IV.

The many equally effective locations of the continuous-type detector in the burner section to detect burner can burn-through precludes a recommendation of a routing to detect this type of fire The routings and locations shown in Figs. 12 and 14 should be supplemented to provide the additional detector coverage if detection of such fires is desired. This possibly could be accomplished by adding a detector loop around the aft portion of the outer front case of the combustion chamber.

An investigation of detector system location for the strut compartment was excluded from the study to avoid intolerable structural damage However, placement of detector elements or units in the strut compartment is desirable and depends primarily on available mounting points adjacent to the fluid or electrical lines. The routes and locations recommended are shown for the engine compartment only. Due to the stagnant air conditions in the compartmented strut, location or routing of heat-sensitive detectors is not considered to be critical.

OBSERVATIONS

During testing, the following observations were made

1. Initial heat circulation in the nacelle is upward and around the engine case rather than outward toward the doors

2. Flames tend to follow the engine profile rather than the doors In small-magnitude fires the flames do not spread outward.

3. Fluid released in the upper portion of the nacelle drained rapidly around the engine case and carried the fire to the lower nacelle area.

4. The continuous-element detector systems can be mounted on the engine without using insulated wire or flexible leads in the fire zone.

5 The engine-mounted, continuous-element system does not require quick-disconnect-type components which can be a source of detector malfunction.

6. Possibilities of door-mounted detector element being recessed and sheltered behind door ribs are avoided by the engine-mounted system.

7. The longer response time of the unit detectors tested can be attributed to the retarded rate of increase in fire intensity and temperature rise due to a fire when a low airflow exists in a nacelle.

8. When the unit-type detectors failed to detect a test fire at the No. 4 location, the ambient air temperature recorded during a fire did not exceed the 900° F. alarm setting.

CONCLUSIONS

Based on the results and data obtained during the tests, it is concluded that:

1 Heat-sensitive-type detectors routed or located as shown in Figs. 12, 13, and 14 are recommended as practical, effective detector systems for the KC-135 - Boeing 707 nacelle.

2 In the KC-135 - Boeing 707 nacelle, the heat-sensitive, continuous-element detector routed as shown in Fig. 13 was the most effective door-mounted route tested.

3 The engine-mounted, heat-sensitive, continuous-element-type detector system had a slightly higher percentage of detection than did the door-mounted system.

4. The continuous-heat-sensitive detector routed as shown in Fig. 12 was the most effective routing tested in the KC-135 - Boeing 707 nacelle.

5. Rapid fluid drainage carried the flames to the lower portion of the nacelle and made the generally longitudinal routing of the continuous-type detector in the lower portions of the nacelle effective regardless of the source of fire.

6 Due to the fire characteristics in a low airflow nacelle, the heat-sensitive-type detectors tested had a long response time when compared to the response times of the same type detectors tested previously in higher airflow nacelles

7. The unit-type detector with an alarm setting of 900° F. was not effective when exposed to small, low-intensity fires.

8 With the aft air seal installed, test fires at the No. 4 location did not cause the ambient temperature to rise above the 900° F. alarm setting This alarm setting is considered necessary to avoid false alarms caused by a higher normal operating ambient temperature in the burner compartment

9. The highest normal ambient temperature for the compartment exists near the engine case. As heat-sensitive detector units or elements are placed nearer the engine, the alarm setting must be raised to a higher temperature to avoid false alarms.

10. When powerplant fires of the magnitude used in the tests are to be detected, the longer detection time required by the heat-sensitive detectors is not critical in low airflow nacelles since structural damage would not occur rapidly except with larger fires

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TABLE I

TEST CONDITIONS AND POINTS OF AMBIENT TEMPERATURE MEASUREMENTS DURING FLAME PATH SURVEY IN NACELLE WITH MODIFIED DOORS

Engine Power and Tunnel Speed Settings	Fuel Release Locations			Thermocouple Locations	
	No	Clock Position	Nacelle Station	Clock Position	Nacelle Station
	1	6	125	1 through 12	105, 121, 137, 153, 169
	2	6	148	1 through 12	105, 121, 137, 153, 169
*I, II, III, IV	3	6	165	1 through 12	105, 121, 137, 153, 169
	4	6	181	1 through 12	191, 211
	5	6	206	1 through 12	191, 211
	6	2	120	1 through 12	137
	7	2 30	125	1 through 12	137
	8	12	130	2, 4, 8, 10	126, 130, 134 124, 130, 138

* I Engine Power Setting - Idle, Tunnel Speed - 0 mph
II Engine Power Setting - 90 Per Cent Normal Rated Thrust, Tunnel Speed - 165 mph
III Engine Power Setting - Maximum Rated Thrust, Tunnel Speed - 165 mph
IV Engine Power Setting - Maximum Rated Thrust with Anti-Icing Airflow, Tunnel Speed - 165 mph

TABLE II

AVERAGE NORMAL OPERATING AMBIENT AIR TEMPERATURE WITHIN THE NACELLE

Nacelle Station	105	121	137	153	169	191	211
Outside Air Temperature	45	39	20	34	34	8	13
Thermocouple Clock Position	Engine Power - Idle, Tunnel Speed - 0						
1	95	100	140	180	185	105	120
2	70	95	120	195	195	110	210
3	80	100	90	155	135	125	175
4		75	75	170	160	145	180
5	75	75	70	85	110	105	175
6	135	85	100	75	110	110	230
7	85	75	105	105	110	120	210
8	135	155	200	160	150	110	210
9	115	135	135	155	140	90	205
10	160	175	215	225	190	250	290
11	100	85	125	155	165	110	200
12	155	75	75	235	210	160	205
Engine Power - 90 Per Cent Normal Rated Thrust Tunnel Speed - 165 MPH							
1	120	165	190	265	275	195	195
2	120	150	165	255	265	365	280
3	105	150	135	225	295	390	370
4		100	105	205	305	395	300
5	75	80	95	165	235	265	340
6	145	100	165	145	215	305	370
7	90	140	130	115	140	290	340
8	145	190	195	210	190	320	360
9	120	140	165	320	240	310	405
10	155	175	245	325	306	590	310
11	110	75	160	260	240	230	180
12	155	75	190	306	220	435	165
Engine Power - Maximum Rated Thrust, Tunnel Speed - 165 MPH							
1	140	210	205	300	360	230	240
2	135	195	195	315	325	420	345
3	115	160	145	280	345	460	435
4		110	130	290	340	430	365
5	75	70	115	210	320	315	390
6	165	105	175	175	275	385	455
7	95	150	145	165	195	360	430
8	140	205	240	315	285	365	460
9	115	160	185	345	330	375	455
10	155	200	270	350	335	650	345
11	115	100	165	285	310	425	265
12	165	95	235	345	265	475	190
Engine Power - Maximum Rated Thrust with Anti-Icing, Tunnel Speed - 165MPH							
1	75	145	205	295	355	245	280
2	75	155	145	305	315	440	385
3	55	70	115	255	335	475	480
4		70	90	285	360	555	435
5	75	60	75	205	365	395	470
6	155	80	135	165	280	390	490
7	105	105	145	145	240	370	475
8	95	175	230	260	230	380	460
9	80	165	165	360	295	370	500
10	125	165	295	365	345	650	355
11	70	125	185	305	315	300	300
12	105	140	240	375	355	495	225

Note All temperatures are in degrees F

TABLE III

TEST CONDITIONS USED DURING
THE DETECTOR ROUTE EVALUATION

No	Location* Nacelle Station	Clock Position	Test Fire Conditions JP-4 Fuel Release Rate (gpm)	Time (sec)	Burning Time (sec)	Engine Power Settings and Tunnel Speeds
1	148	6				
2	130	12				
3	117	8	0 3	10	18-22	**I, II, III, IV
4	181	6				
4(y)	181	6	0 3	5	18-22	I, II, III, IV

* Refer to Fig 6 of this report

** I - Engine power setting - idle, tunnel speed, 0 mph
II - Engine power setting - idle, tunnel speed, 25 mph
III - Engine power setting - 90 per cent normal rated thrust, tunnel speed, 165 mph
IV - Engine power setting - 90 per cent normal rated thrust with nacelle anti-icing airflow, tunnel speed, 165 mph

TABLE IV

TEST CONDITIONS AND RESULTS OBTAINED USING FINAL CONFIGURATION OF CONTINUOUS- AND UNIT-TYPE DETECTORS

Test Location	Engine and Tunnel Settings*	Continuous-Type Door-Mounted Exposures	Alarms	Average Time(sec) Response	Reset	Continuous-Type Engine-Mounted Exposures	Alarms	Average Time(sec) Response	Reset	Double-Wire Unit-Type Exposures	Alarms	Average Time(sec) Response	Reset
1	I	12	12	15 5	11 1	18	18	21 9	13 3	16	16	11 9	18 0
	II	14	13	15 3	13 5	18	17	19 3	13 2	17	16	17 2	6 9
	III	9	9	9 2	21 3	13	13	8 9	20 9	13	13	6 2	21 5
	IV	9	9	9 3	24 7	10	10	9 8	21 9	10	10	11 5	9 3
	Totals	44	43			59	58			56	55		
Percentage of Detection		97 7				98 4				98 2			
2	I	9	2	12 8	5 8	14	14	14 0	1 6	12	12	12 4	3 2
	II	10	9	15 6	10 7	15	15	12 6	3 5	12	12	10 2	4 3
	III	8	8	10 1	17 6	12	12	11 4	13 8	10	9	16 1	2 3
	IV	7	7	8 8	26 5	9	9			9	9	10 7	5 7
	Totals	34	26			50	50			43	42		
Percentage of Detection		76 4				100				97 7			
3	I	9	9	12 2	16 6	15	15	18 4	7 6	12	12	11 8	16 1
	II	9	9	11 6	14 7	15	15	19 7	7 3	12	11	13 7	13 1
	III	8	8	10 3	15 1	12	12	16 1	13 5	10	7	16 5	5 3
	IV	7	7	10 8	15 5	8	8	13 6	12 8	8	6	12 2	6 8
	Totals	33	33			50	50			42	36		
Percentage of Detection		100				100				85 8			
4(y)	I	10	10	17 2	6 6	10	8	18 2	3 1	10	0	-	-
	II	11	10	13 7	7 6	11	9	18 3	4 3	11	0	-	-
	III	10	10	10 3	13 0	10	7	19 4	2 2	10	0	-	-
	IV	8	8	11 0	23 9	8	7	16 5	9 1	8	2	22 5	0 5
	Totals	39	38			39	31			39	2		
Percentage of Detection		97 4				79 5				5 1			
4**	I	4	1	23 0	1 0	8	5	17 5	2 2	6	0	-	-
	II	3	1	15 0	1 0	9	9	14 6	5 6	5	0	-	-
	III	4	4	11 6	13 6	8	8	10 8	11 0	6	4	14 1	6 7
	IV	2	2	13 0	14 0	-	-			4	3	18 8	2 5
	Totals	13	8			25	22			21	7		
Percentage of Detection		61 5				88 0				33 3			

*I - Engine power setting - idle tunnel speed - 0 mph
II - Engine power setting - idle tunnel speed - 25 mph
III - Engine power setting - 90 per cent normal rated thrust, tunnel speed - 165 mph
IV - Engine power setting - 90 per cent normal rated thrust with nacelle anti-icing airflow, tunnel speed - 165 mph

** Data taken prior to aft air-seal installation

APPENDIX A

During the course of the test program, considerable data not directly related to the program objective were easily and readily obtained These data have been compiled and are presented for informational purposes only.

The 12 thermal plots shown in Figs 16 through 27 are a complete graphical presentation of the effect of the test fires on the ambient temperatures within the nacelle during the internal flame study. The locations of fuel release and temperature measurements shown in the figures may be visualized by rolling the figure to form a cylinder on the outer surface.

APPENDIX B

The door- and engine-mounted, heat-sensitive, continuous-element-type detector routings, shown in Figs 12 and 13, were established by a process of evolution During the development of these routings, a series of changes or relocations were made in the initial routings. Each detector configuration was evaluated in the same manner as described in this report. After obtaining data indicating that the percentage of detection was low, a new routing was used

During the heat-sensitive, continuous-element-type detector route evolution, three individual detector systems were used Each of the following organizations provided a complete detector system:

1 Aviation Products Division, Fenwal Incorporated, Ashland, Mass.

2. Thomas A. Edison Industries, Instrument Division, West Orange, N. J.

3. Walter Kidde & Company, Incorporated, Belleville, N. J

Each detector system was monitored independently and performance data obtained with the element routed in a particular intermediate route used during the study Response and reset times obtained with each system routed as shown are presented with the associated route evaluation results. The percentage-detection results shown represent the effectiveness of the specific route and detector system.

Figure 28 shows one of the intermediate routings of the door-mounted, continuous-element-type detector systems evaluated in the detector route study This routing had a low percentage of detection when fires were conducted at the Nos 1, 2, and 4 fuel release locations and lower engine power settings Table V shows the results obtained using the routing and standard-magnitude test fires.

When routed in the configuration of Fig 28, a Kidde heat-sensitive, continuous-element system, using Series 704 and 706 sensing elements and Model No 871115 control unit, had response and reset times as shown in the table The alarm times are typical for the low airflow nacelle when small-magnitude fires are to be detected Changes in system sensitivity were made at the control unit to determine whether the percentage of detection could be increased. After several changes produced no noticeable improvement in detection, the routing was changed.

Figure 29 shows an intermediate engine-mounted route of the heat-sensitive, continuous-element-type detector. For this configuration, a 575° F. Fenwal element was installed between the engine case and the accessories in the forward compartment and a 765° F. Fenwal continuous-type element was installed in the burner compartment These elements were connected to a Model 35000-X control unit. The effectiveness of the routing when exposed to standard test fires is shown in Table VI along with response and reset times for the Fenwal system. The data for the No. 4 fuel release location were obtained prior to the aft air-seal installation.

Response time is nearly the same as for other continuous-element-type heat-sensitive systems. This Fenwal system contained no adjustable components The alarm signal occurs when the critical temperature of the inorganic salt filler in the element is reached or exceeded. These response times were typical in the low airflow condition which existed in the nacelle.

The percentage of detection at the No 1 fuel release location could be improved slightly by installing a lower alarm setting element (375° F.) in the forward portion of the route in the compressor compartment The effects of this change were not investigated since the evaluation of the route was discontinued The difficulties in installing, maintaining, or replacing elements routed in this manner far outweigh the advantages

An intermediate engine-mounted route using an Edison 54G continuous-type sensing element and a control unit, P/N 227-28-2, was installed as shown in Fig 30. A 40-ohm resistor was installed at the control unit to obtain an alarm temperature of 570° F.

The basic principle of operation for this system is similar to that used by the Kidde system Both depend on a decrease in element resistance when the sensing element is subjected to a temperature rise This particular Edison system did not incorporate a rate-of-rise feature. Table VII gives the conditions used in the tests and the performance obtained with the Edison continuous-type element routed as shown in the figure. Response times of this detector were typical for heat-sensitive detector elements installed in nacelles which have (1) a low airflow, (2) a low fire intensity, and (3) a slow rate of rise in ambient temperature due to a fire.

The low percentage of detection of test fires at the Nos. 1 and 2 locations indicated the routing was not satisfactory. The evaluation was discontinued and the detector element located in another configuration.

TABLE V

TEST CONDITIONS AND RESULTS FOR INTERMEDIATE ROUTING OF KIDDE CONTINUOUS-TYPE DETECTOR ELEMENT MOUNTED ON THE DOOR

871115 Control Unit Setting

Fuel Release Location	Engine and Tunnel Setting*	800 Ohms				860 Ohms				950 Ohms				1 200 Ohms			
		Exposures	Alarms	Average Time(sec) Response	Reset	Exposures	Alarms	Average Time(sec) Response	Reset	Exposures	Alarms	Average Time(sec) Response	Reset	Exposures	Alarms	Average Time(sec) Response	Reset
1	I	1	0			2	0			3	0			3	0		
	II	1	0			3	0			3	0			3	0		
	III	1	1	14	6	2	2	16 7	3 7	3	3	16	4 7	1	1	17	4 0
	IV	1	1	18 5	4	2	2	18 5	3 0	2	2	18 5	5 0	1	1	17 5	3 0
	Totals	4	2			9	4			11	5			8	2		
Percentage of Effectiveness		50				44 5				45 5				25			
2	I	1	0			2	0			2	0			3	1	29 5	3 0
	II	1	0			2	0			2	0			3	1	25 5	1 5
	III	1	1	13 5	2	2	2	13 2	2	2	2	14	3	1	1	13 0	2 0
	IV	1	1	12 5	2 5	2	2	13	1 7	2	2	13	2	1	1	12 0	4 0
	Totals	4	2			8	4			8	4			8	4		
Percentage of Effectiveness		50				50				50				50			
3	I	1	1	17	3	2	2	15 7	1 7	2	2	16	2 7	4	4	14 8	2 8
	II	1	1	14	6 5	2	2	15 2	2 2	2	2	16 5	2 5	4	4	16 0	4 5
	III	1	1	14 5	2 5	2	2	15 2	2 2	2	2	16 2	2 0	1	1	17 0	2 0
	IV	1	1	15	4	1	1	20	2 0	2	2	18 2	2 0	1	1	19 5	2 0
	Totals	4	4			7	7			8	8			10	10		
Percentage of Effectiveness		100				100				100				100			
4	I	1	0			2	0			3	0			3	0	-	-
	II	1	0			1	0			3	0			3	0	-	-
	III	1	1	15	8	2	0			3	1	15 5	5 5	3	0	-	-
	IV	-	-	-	-	1	1	22	0	1	1	17 5		2	1	-	-
	Totals	3	1			6	1			10	2			11	1		
Percentage of Effectiveness		333				16 7				20				9 1			

*I - Engine power setting - idle tunnel speed - 0 mph
II - Engine power setting - idle tunnel speed - 25 mph
III - Engine power setting - 90 per cent normal rated thrust tunnel speed - 165 mph
IV - Engine power setting - 90 per cent normal rated thrust with anti-icing airflow tunnel speed - 165 mph

TABLE VI

TEST CONDITIONS AND PERFORMANCE OF INTERMEDIATE ROUTING OF FENWAL CONTINUOUS-TYPE DETECTOR MOUNTED ON THE ENGINE

Location	Test Conditions Engine and Tunnel Setting*	Exposures	Performance Alarms	Average Time (sec) Response	Reset
1	I	11	10	13 3	13 8
	II	10	8	10 9	16 3
	III	7	1	15 0	-3 5
	Totals	27	19		
Percentage of Detection		75.0			
2	I	8	8	11 7	9 6
	II	8	8	10 3	14 6
	III	7	7	10 1	16 0
	Totals	23	23		
Percentage of Detection		100			
3	I	7	7	14 7	12 1
	II	7	7	13 9	10 6
	III	7	7	10 0	15 1
	Totals	21	21		
Percentage of Detection		100			
4	I	9	7	16 6	3 8
	II	8	7	14 8	3 9
	III	8	8	10 9	11 3
	Totals	25	22		
Percentage of Detection		88 0			

*Engine and Tunnel Setting

I - Engine power setting - idle, tunnel speed - 0 mph

II - Engine power setting - idle, tunnel speed - 25 mph

III - Engine power setting - 90 per cent normal rated thrust, tunnel speed - 165 mph

TABLE VII

TEST CONDITIONS AND PERFORMANCE OF AN INTERMEDIATE ROUTING OF EDISON CONTINUOUS-TYPE DETECTOR ELEMENT MOUNTED ON THE ENGINE

Location	Test Conditions * Engine and Tunnel Setting*	Exposures	Performance Alarms	Average Time (sec) Response	Reset
	I	14	8	18 6	2 0
1	II	13	0		
	III	12	12	13 1	4.5
	IV	10	9	15 1	3 5
	Totals	49	29		
Percentage of Detection		59 2			
	I	11	0		
2	II	11	0		
	III	11	11	13 5	1 7
	IV	9	9	12 4	1 9
	Totals	42	20		
Percentage of Detection		47 6			
	I	12	11	17 0	3 9
3	II	12	11	18 5	3 5
	III	10	10	15 7	7 0
	IV	8	8	13 7	6 2
	Totals	42	40		
Percentage of Detection		95 3			

*Engine and Tunnel Setting

I - Engine power setting - idle, tunnel speed - 0 mph
II - Engine power setting - idle, tunnel speed - 25 mph
III - Engine power setting - 90 per cent normal rated thrust, tunnel speed-165 mph
IV - Engine power setting - 90 per cent normal rated thrust with nacelle anti-icing airflow, tunnel speed - 165 mph

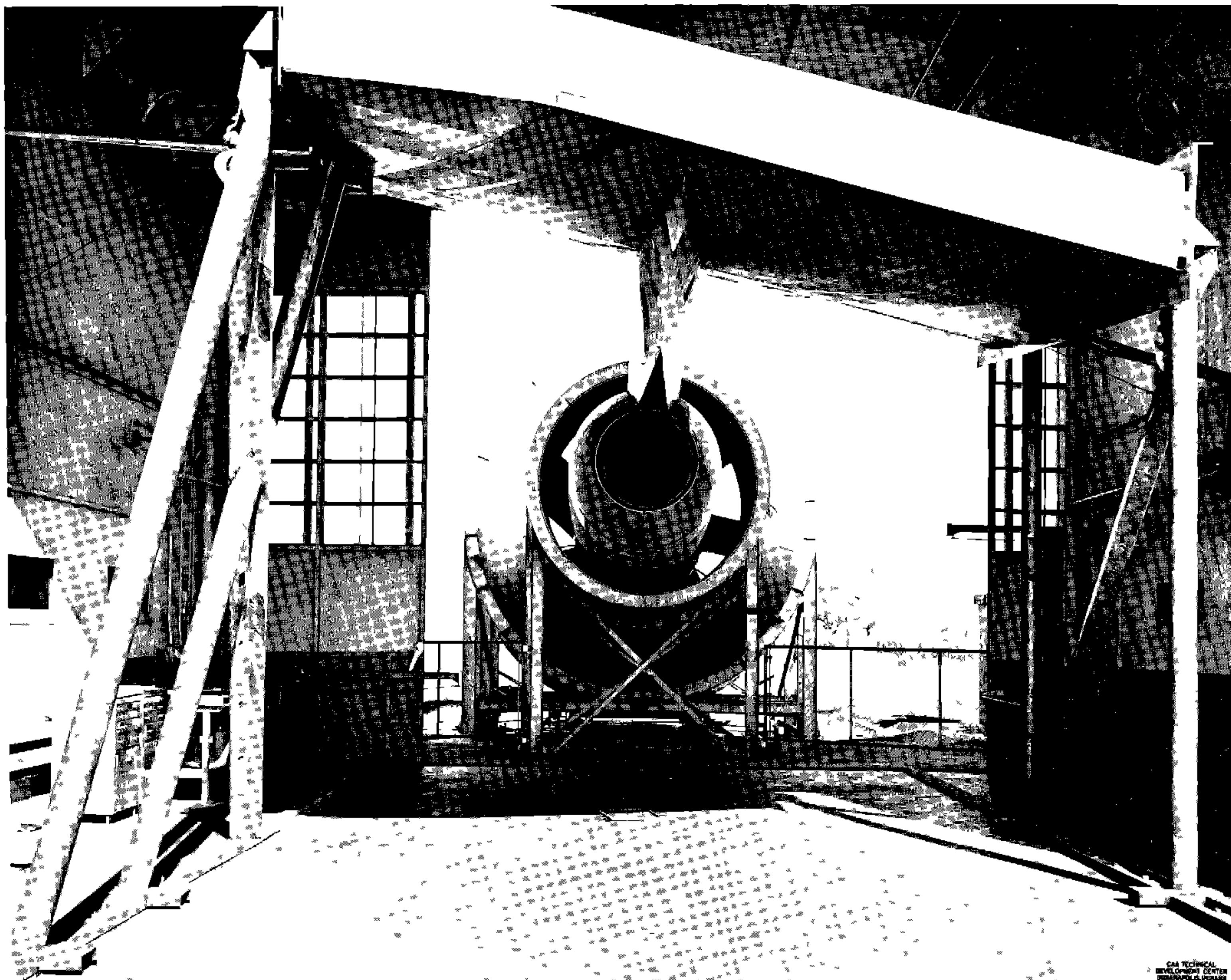


FIG 1 PODDED TURBOJET FIRE-TEST FACILITY

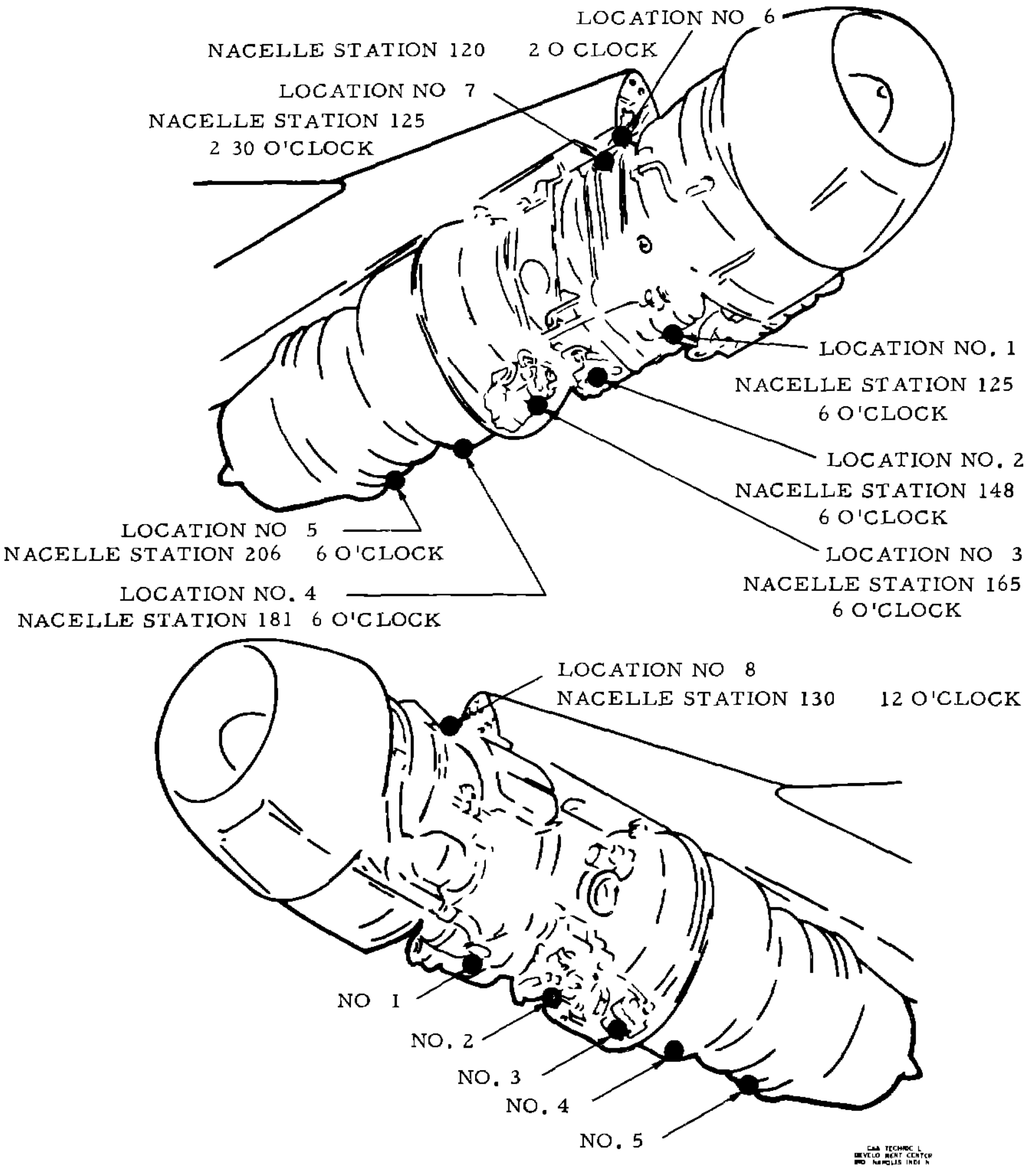


FIG. 2 FUEL RELEASE LOCATIONS FOR NACELLE INTERNAL FLAME STUDIES

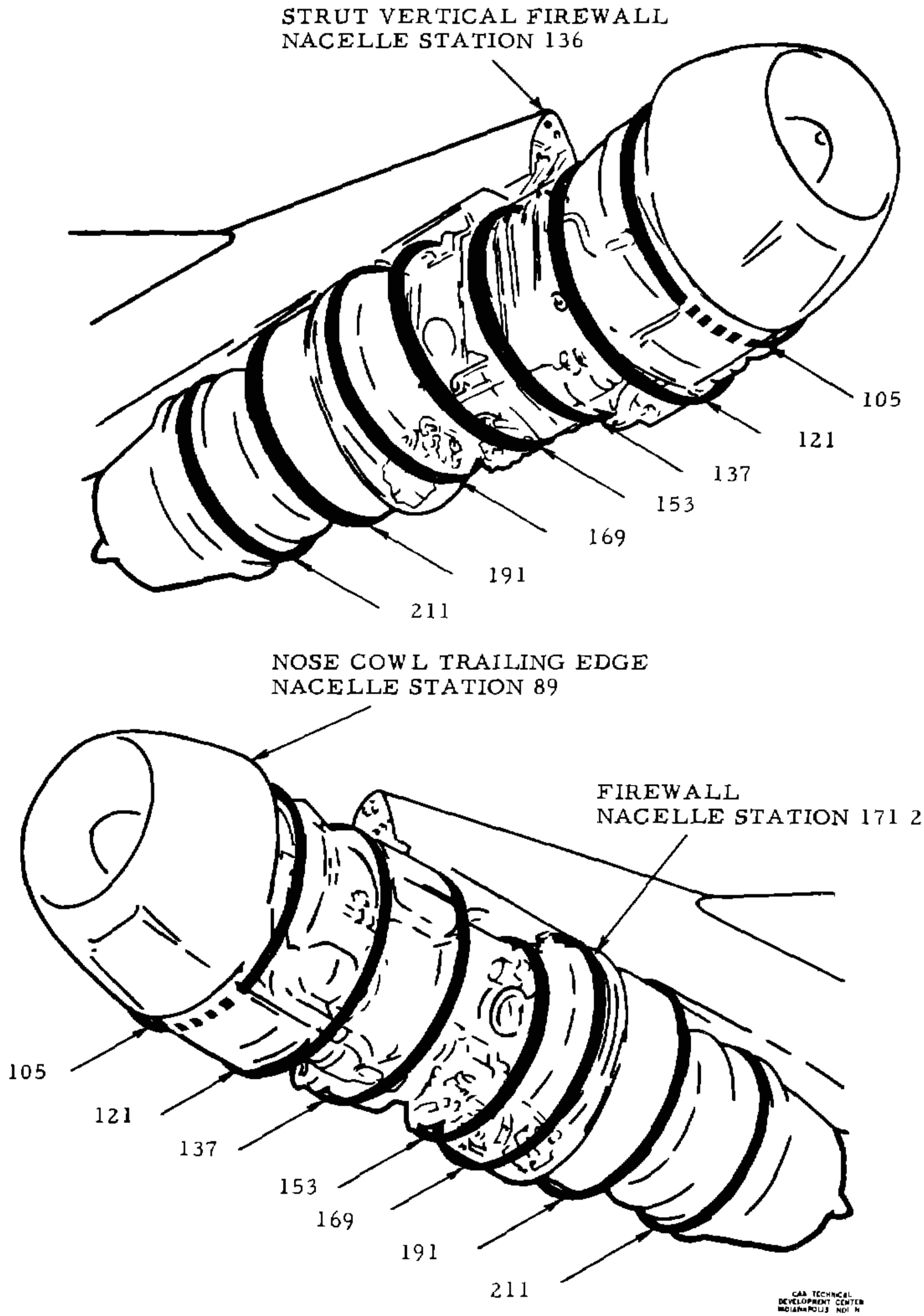


FIG 3 NACELLE STATIONS USED FOR TEMPERATURE SURVEY

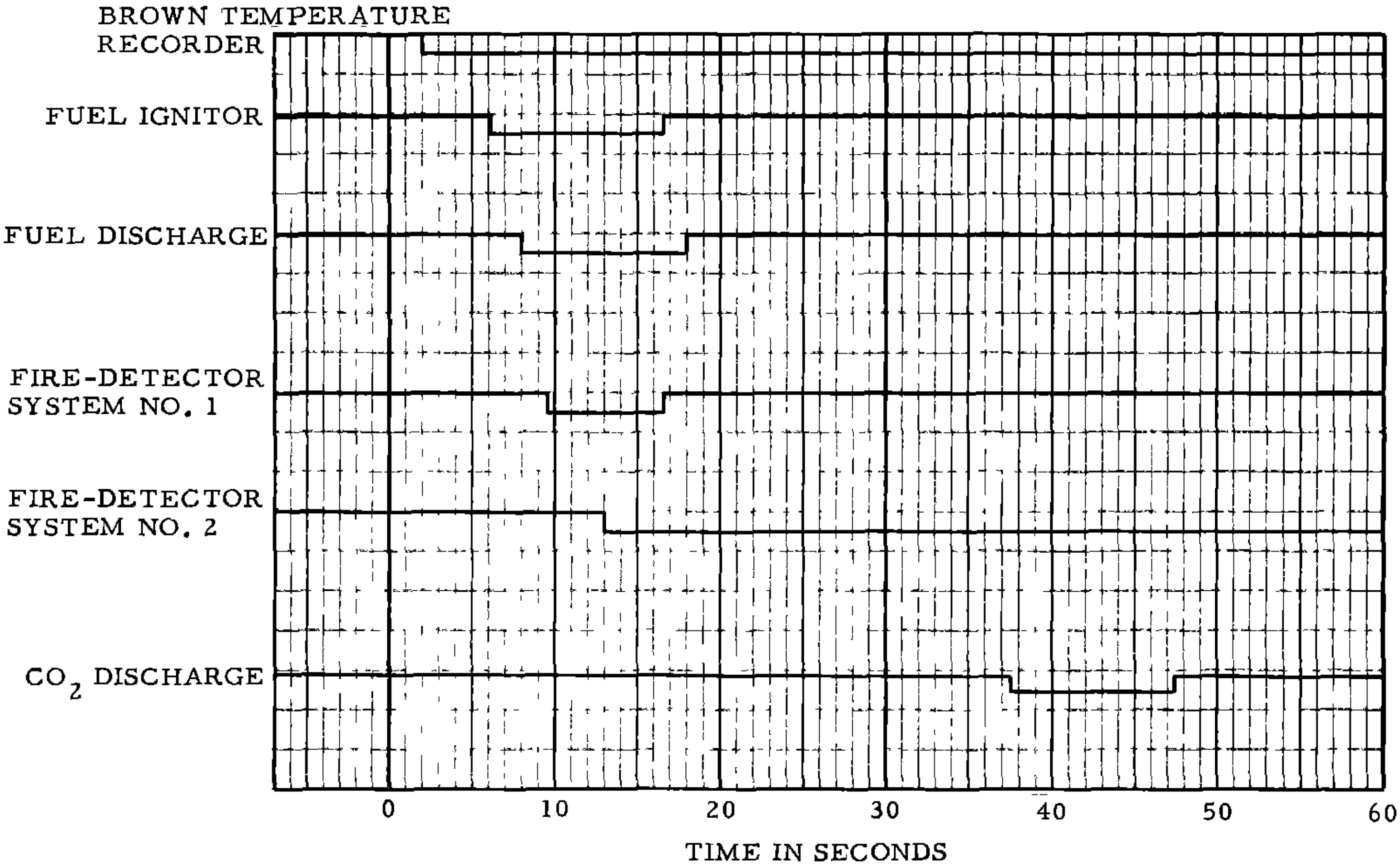
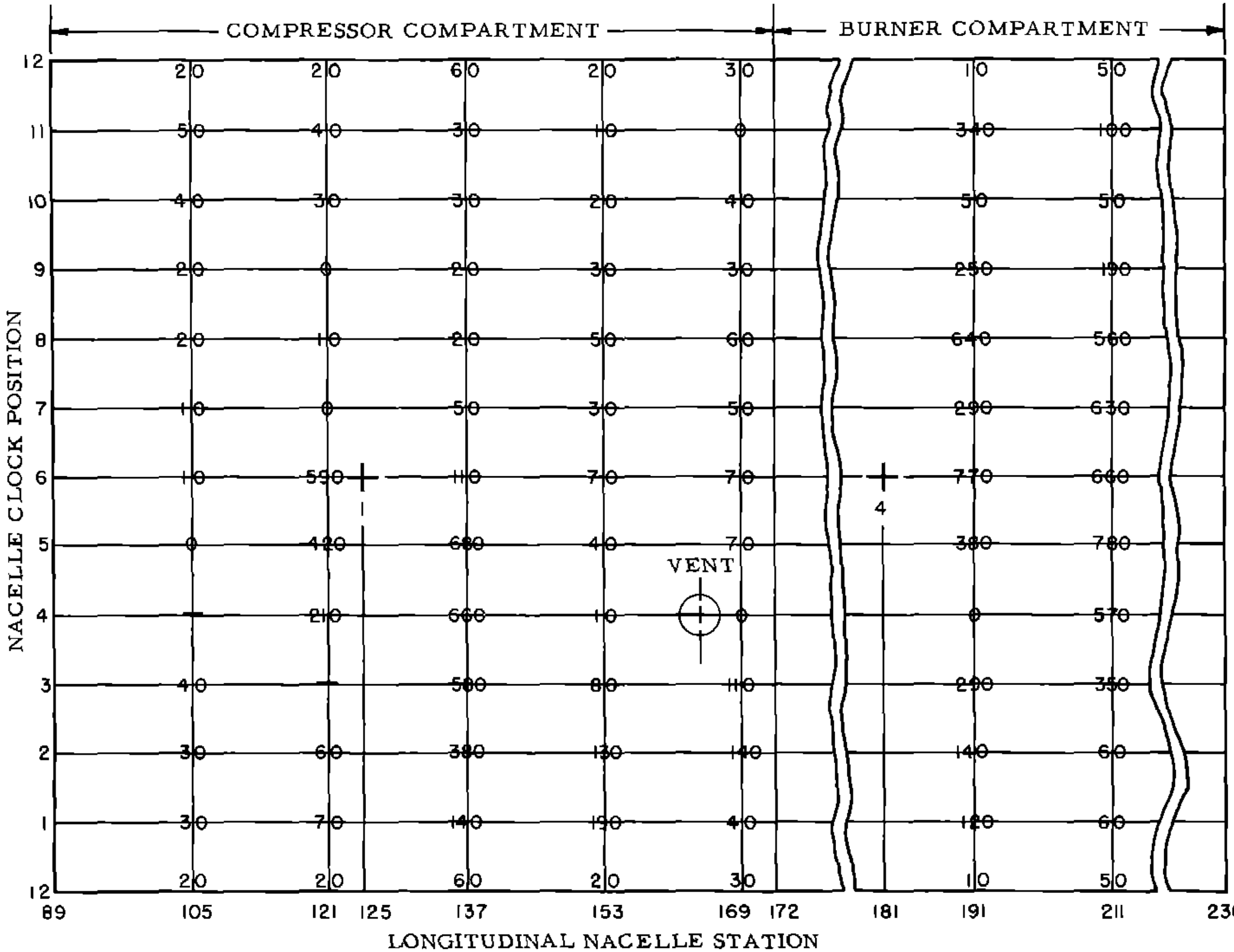


FIG. 4 SCHEDULE OF EVENTS FOR STANDARD TEST DURING NACELLE INTERNAL FLAME STUDY



TEST CONDITIONS

ENGINE POWER - MRT (MAX RATED THRUST)
TUNNEL SPEED - 165 MPH
TEST FIRE - JP-4 FUEL, 0 3 GPM
RELEASED FOR 10 SEC

NOMENCLATURE

PLUS SIGN INDICATES LOCATION OF FUEL RELEASE PLOTTED VALUES INDICATE MAXIMUM TEMPERATURE RISE (°F) ABOVE AMBIENT READINGS PRIOR TO THE FIRE

FIG. 5 EFFECT OF NACELLE FIRE ON AMBIENT TEMPERATURES WITHIN THE NACELLE (MODIFIED DOORS)

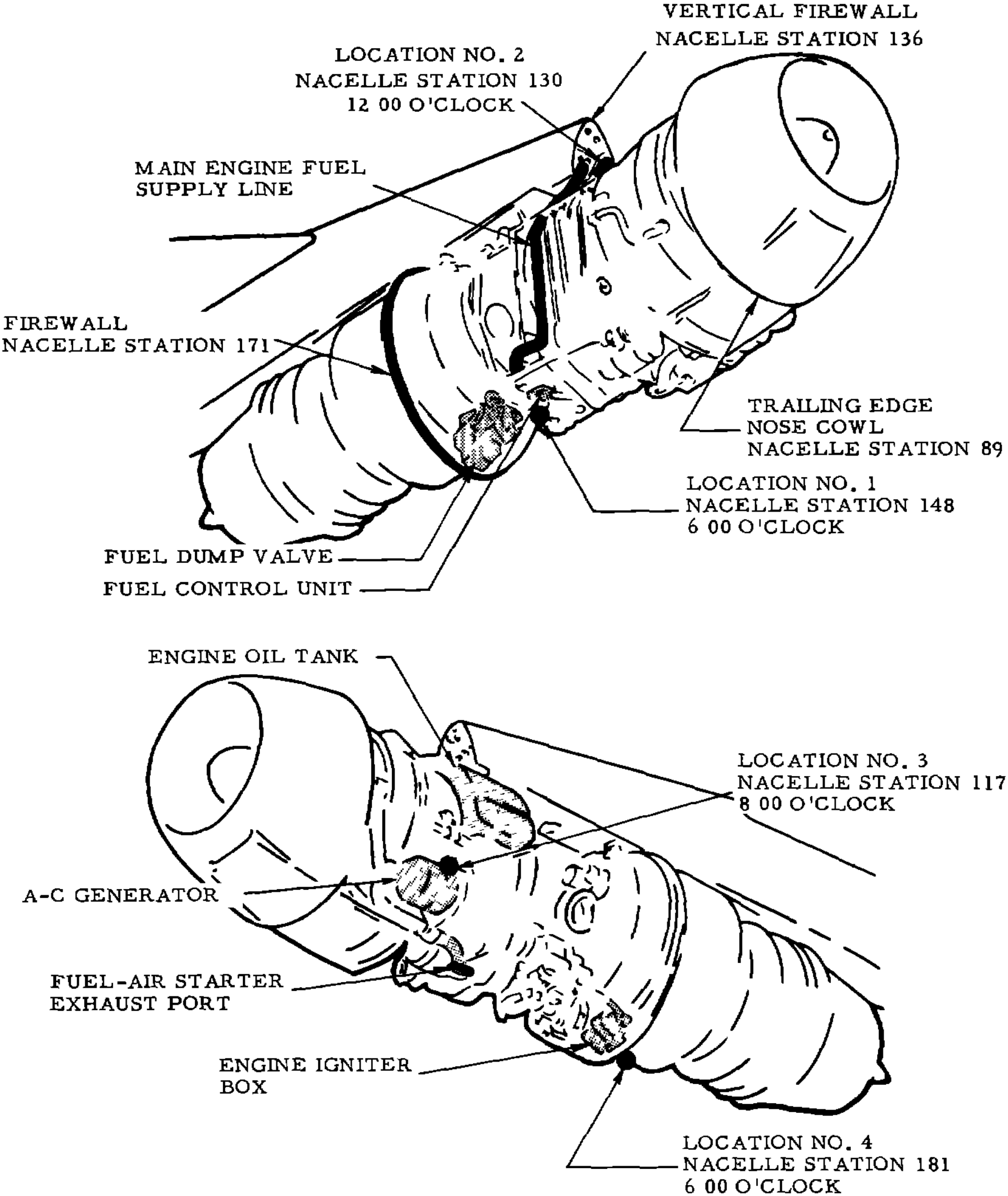


FIG. 6 FUEL RELEASE LOCATIONS RELATIVE TO FUEL AND IGNITION SOURCE

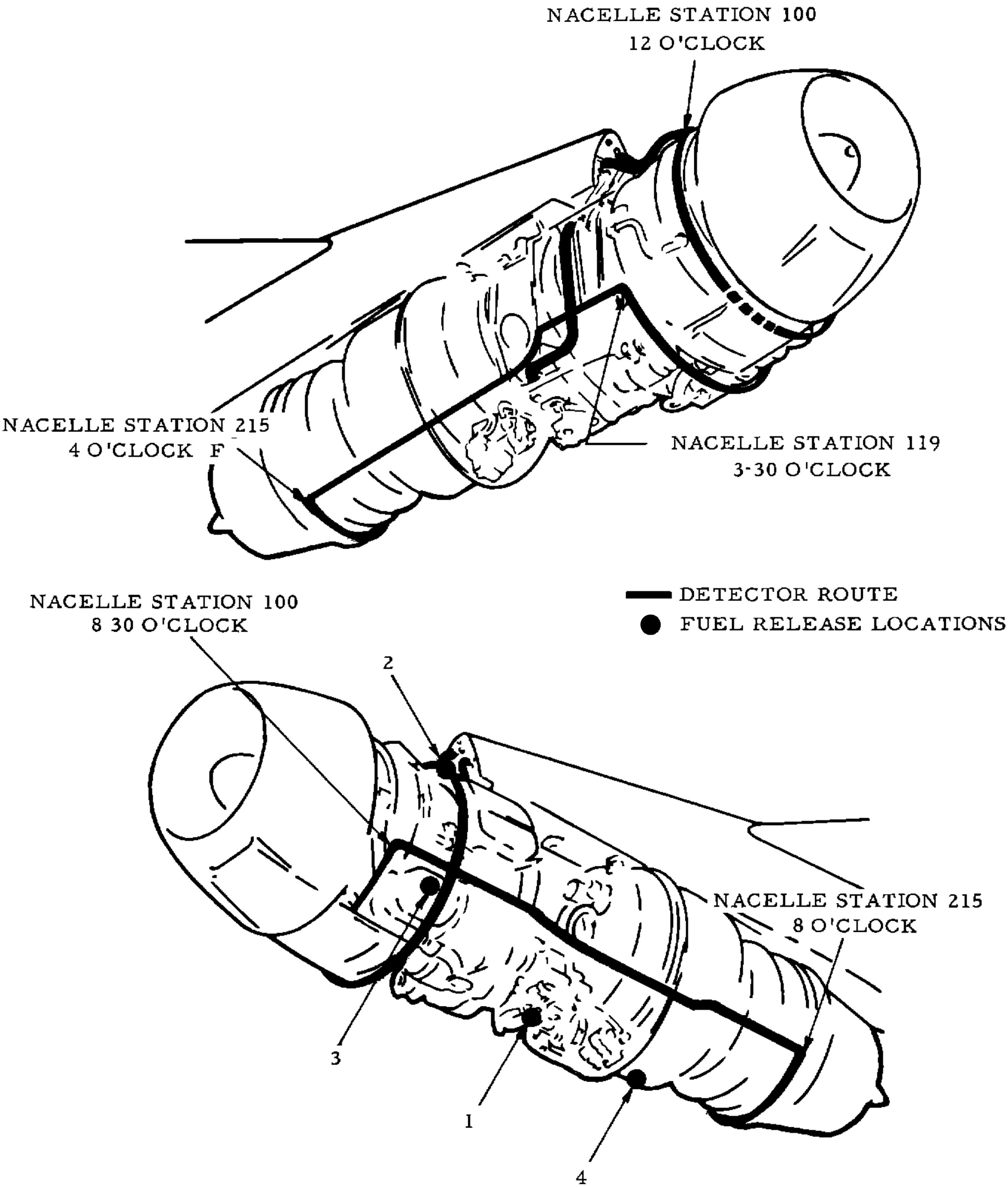


FIG. 7 ORIGINAL ROUTING OF ENGINE-MOUNTED CONTINUOUS-TYPE DETECTOR

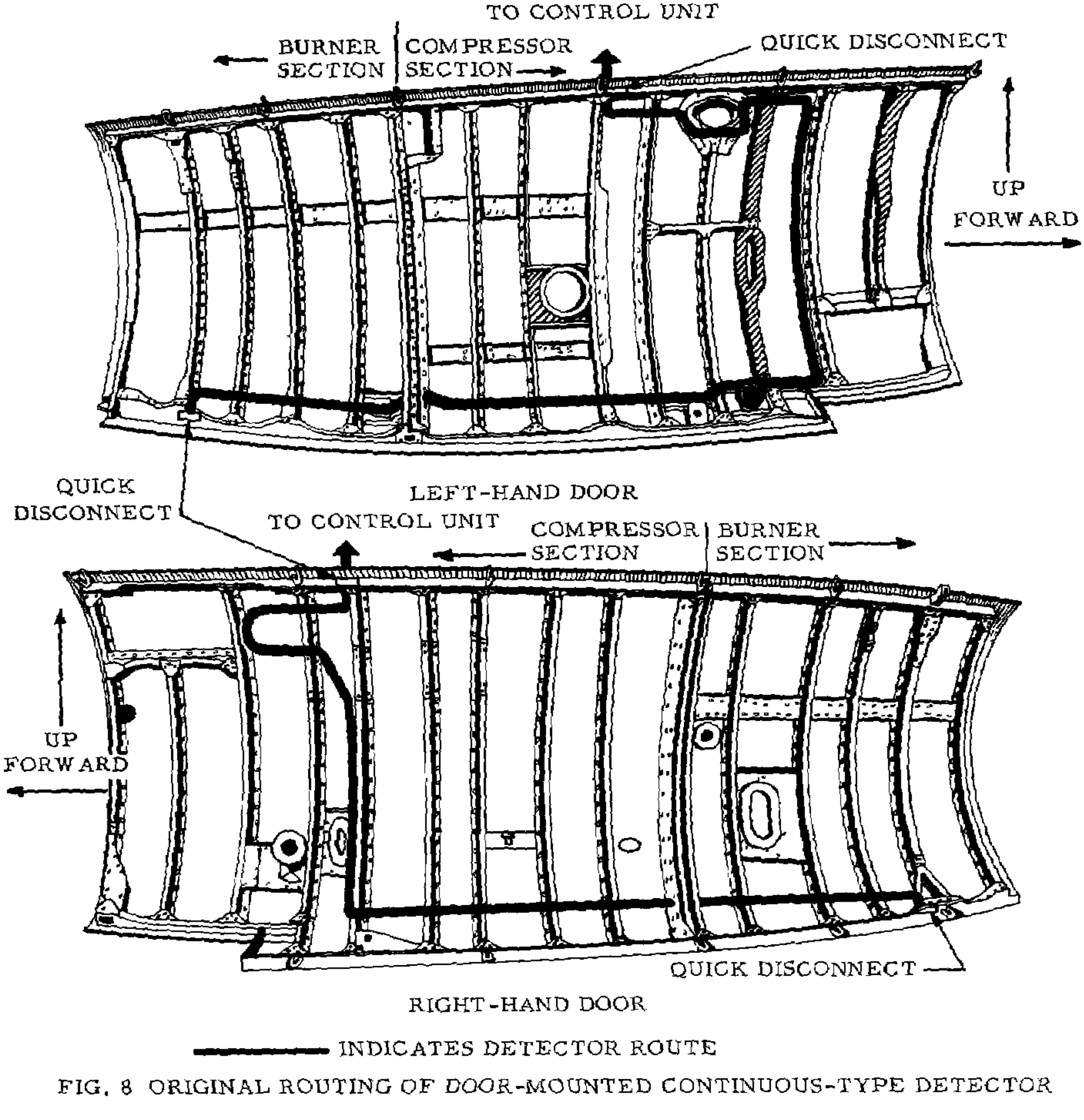


FIG. 8 ORIGINAL ROUTING OF *DOOR*-MOUNTED CONTINUOUS-TYPE DETECTOR

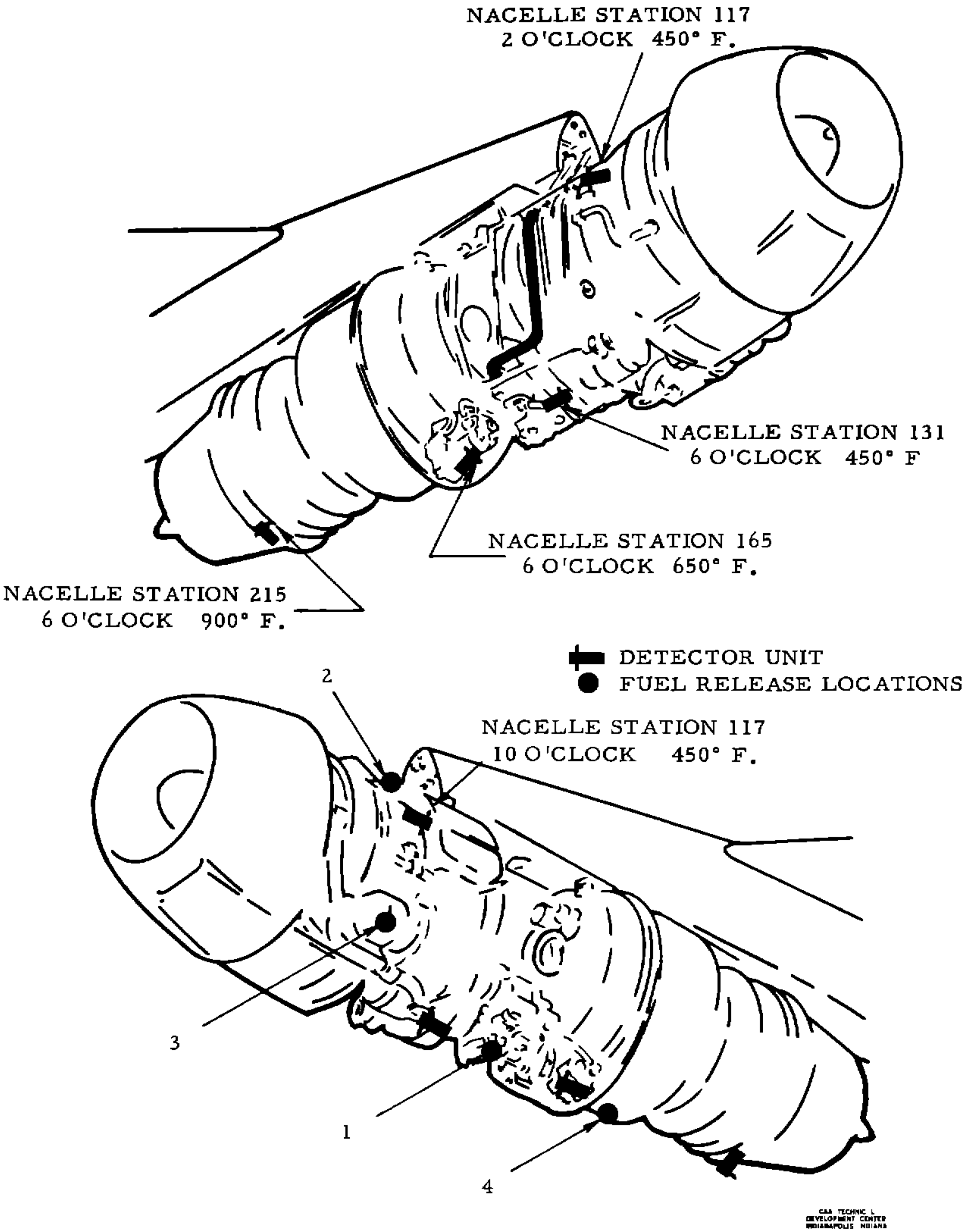


FIG 9 ORIGINAL LOCATIONS OF DOUBLE-WIRE UNIT-TYPE DETECTORS

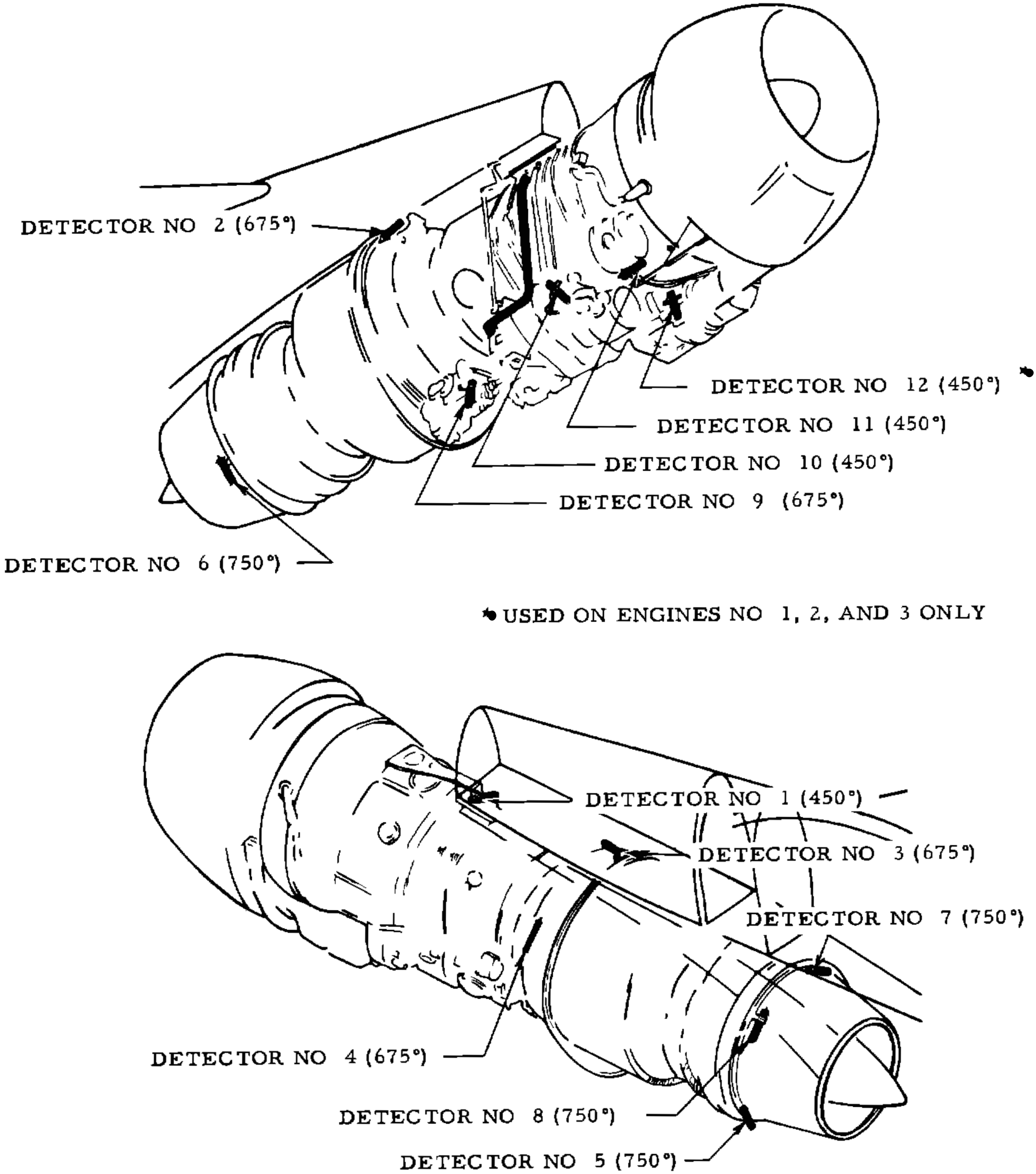


FIG 10 SINGLE-WIRE UNIT-TYPE DETECTOR LOCATIONS AS INSTALLED IN KC-135 NACELLE

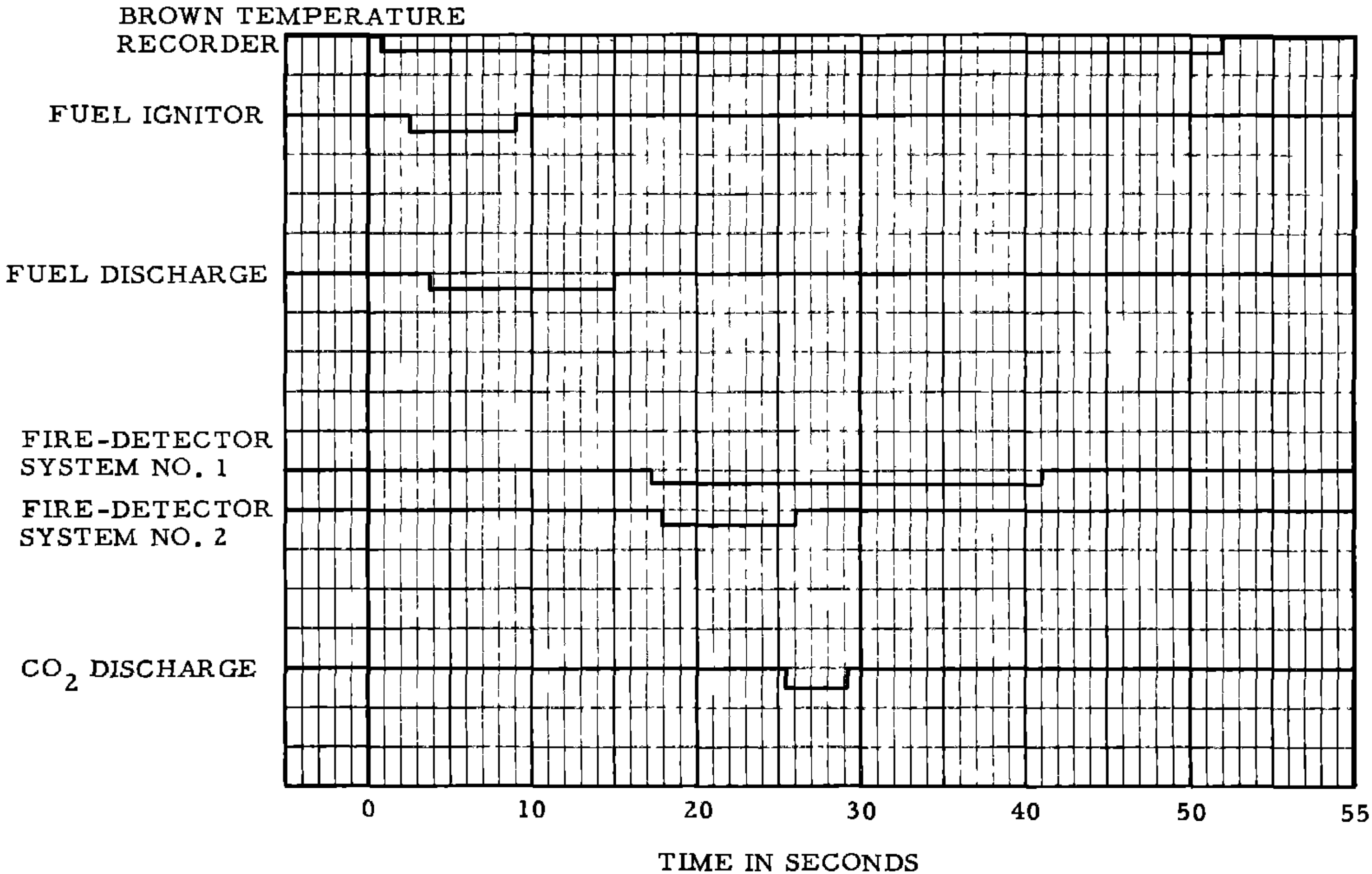
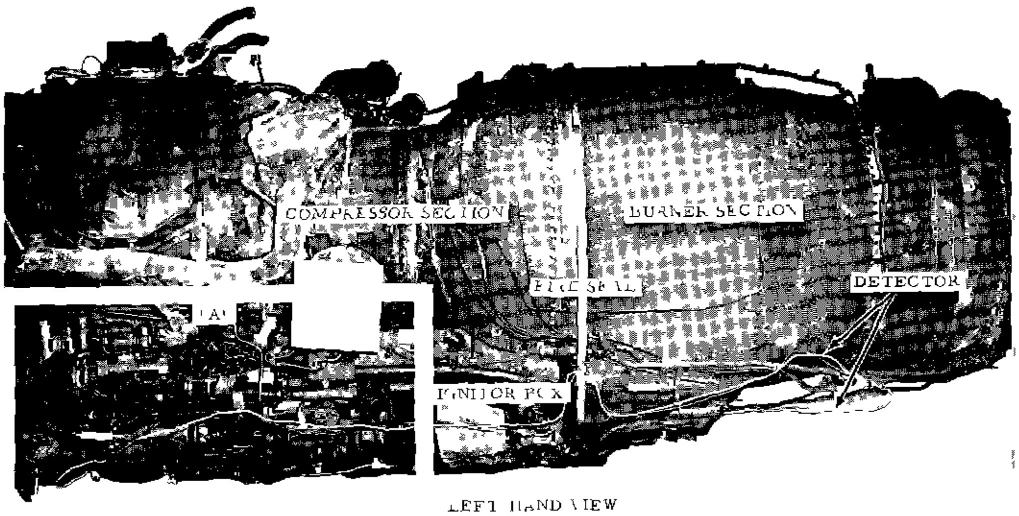
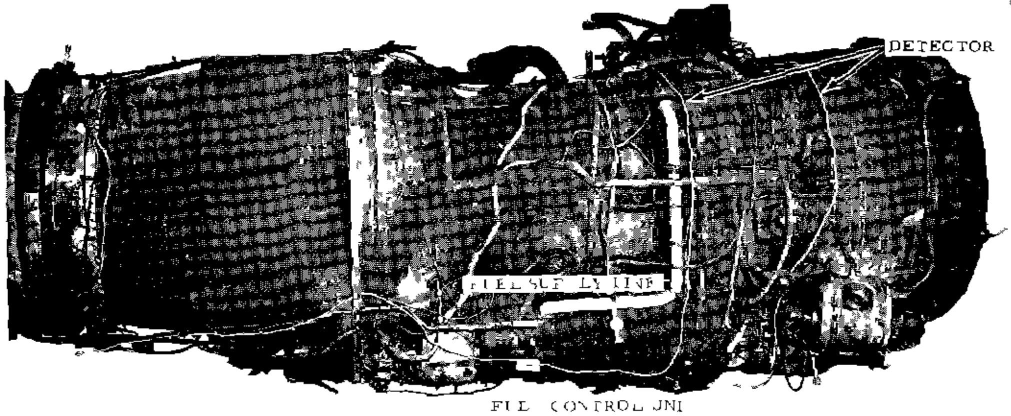


FIG. 11 SEQUENCE OF EVENTS AS SCHEDULED FOR STANDARD TEST DURING DETECTOR ROUTE EVALUATION



LEFT HAND VIEW



RIGHT HAND VIEW

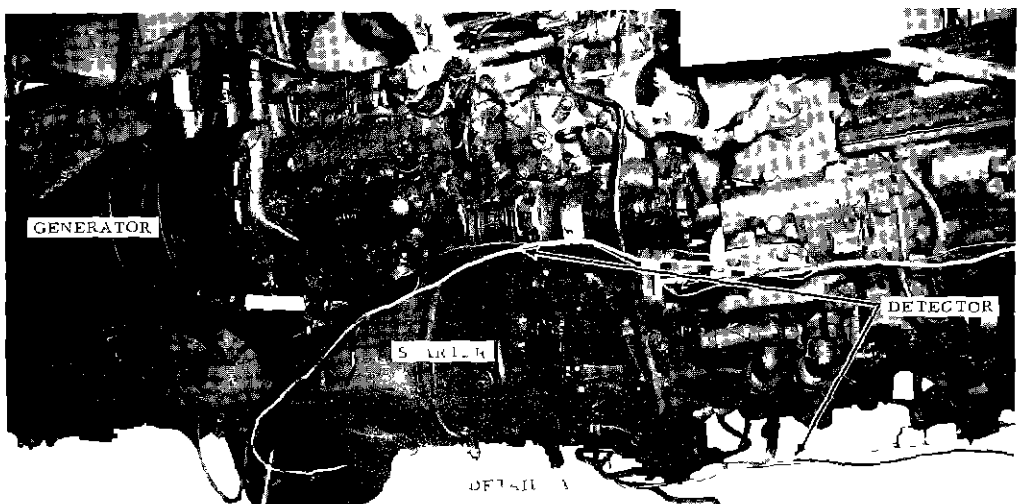


FIG. – FINAL ROUTE OF ENGINE MOUNTED CONTINUOUS TYPE DETECTOR

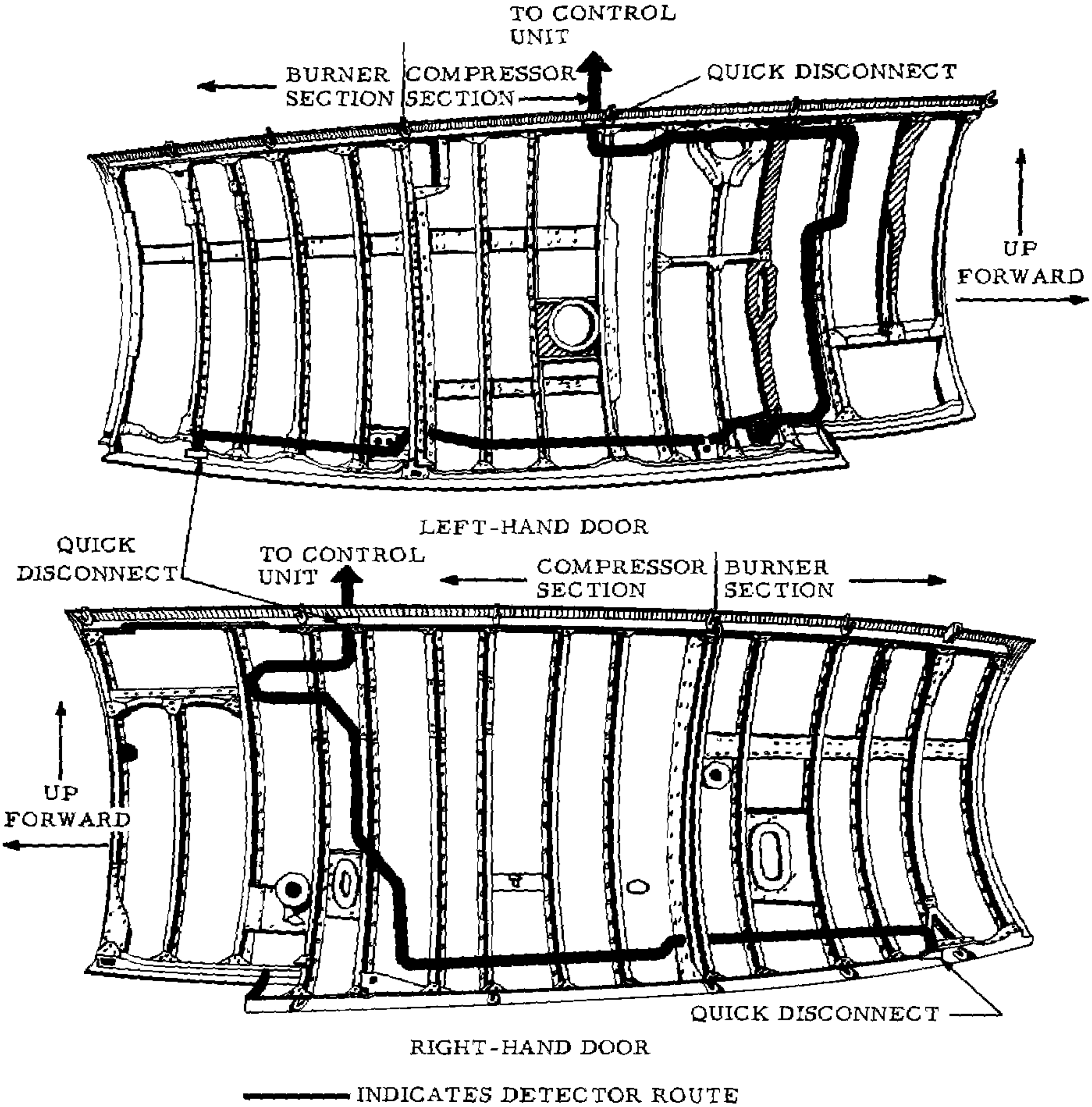


FIG 13 FINAL ROUTING OF CONTINUOUS-TYPE SENSING ELEMENT ON DOORS

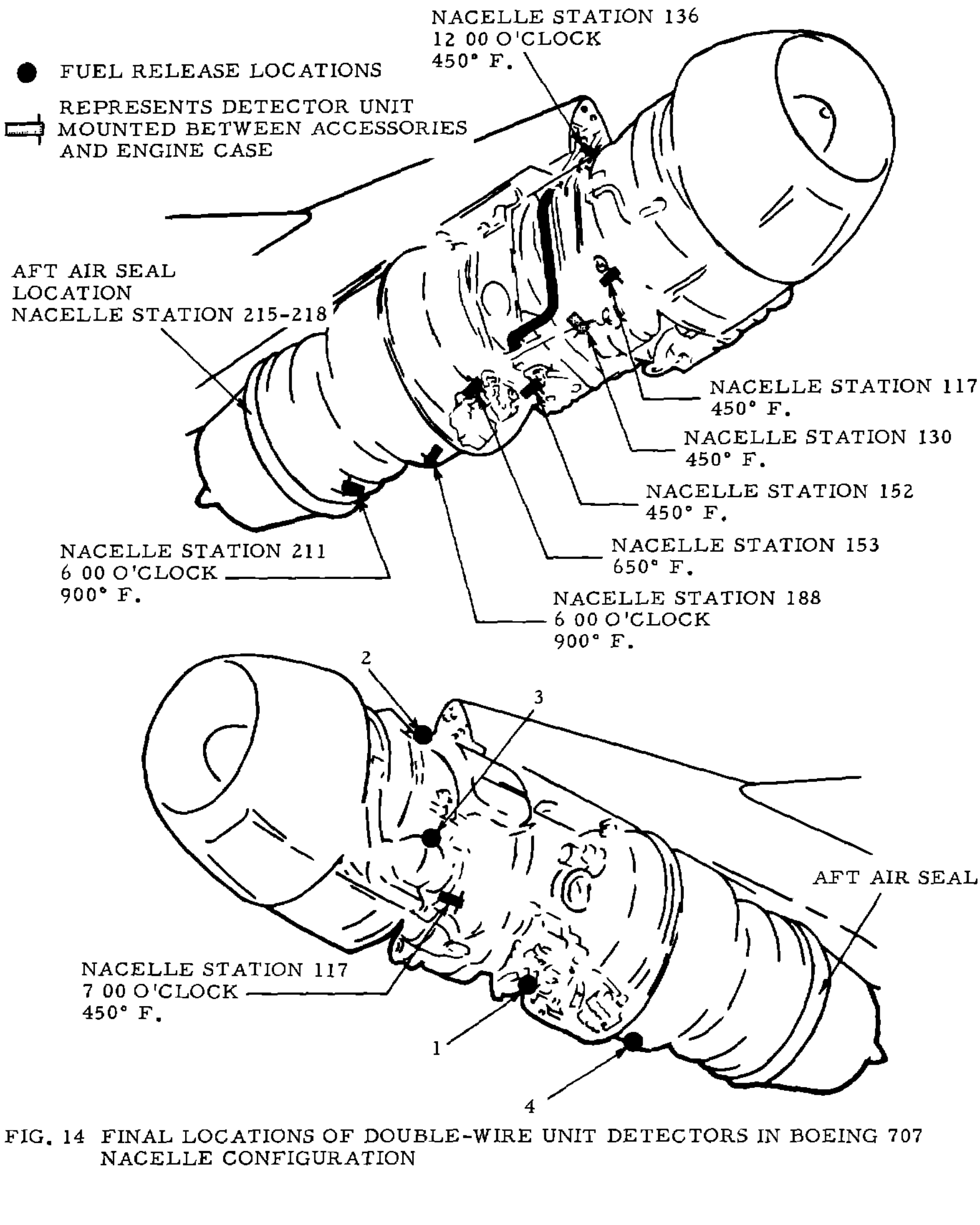


FIG. 14 FINAL LOCATIONS OF DOUBLE-WIRE UNIT DETECTORS IN BOEING 707 NACELLE CONFIGURATION

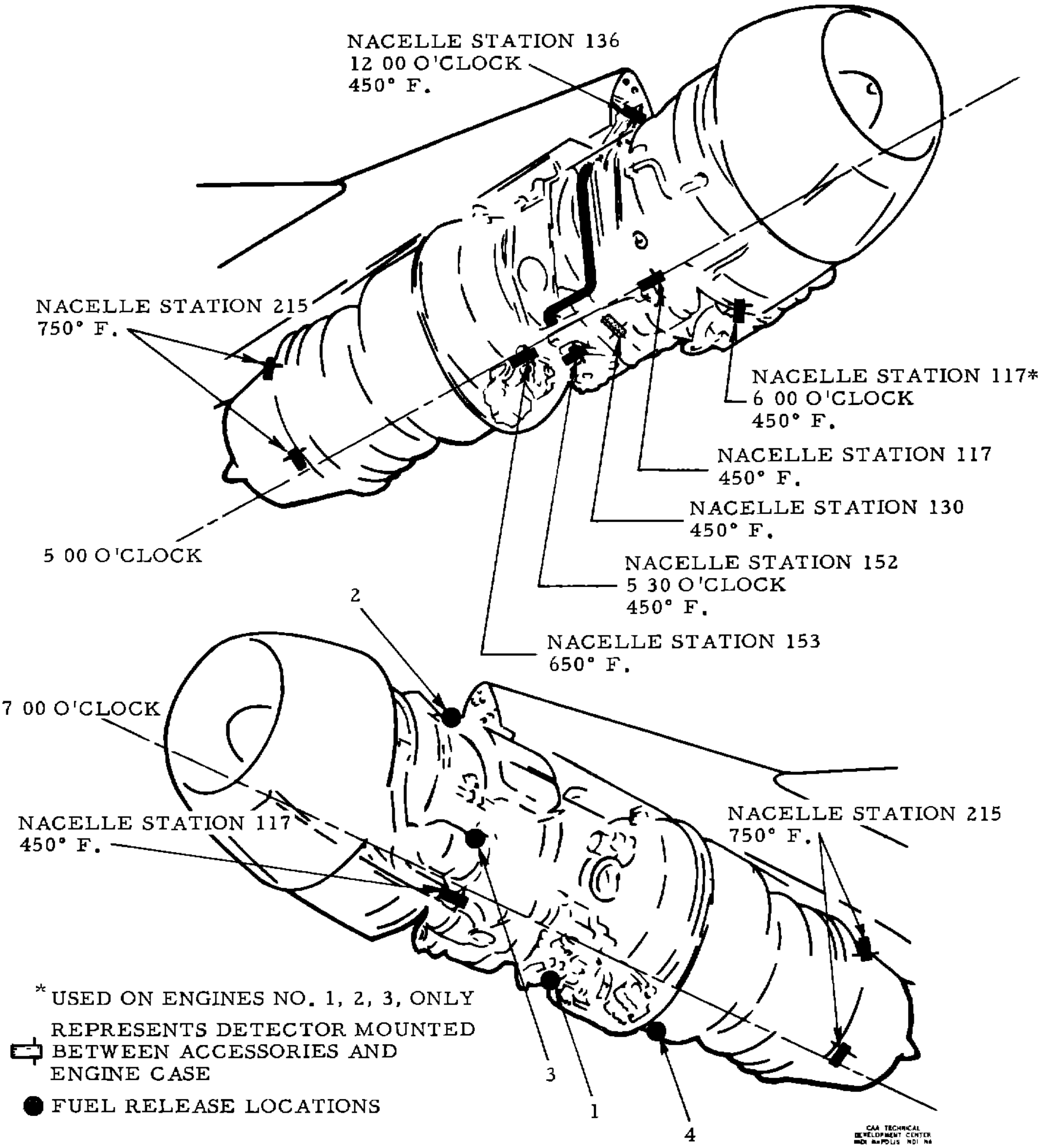
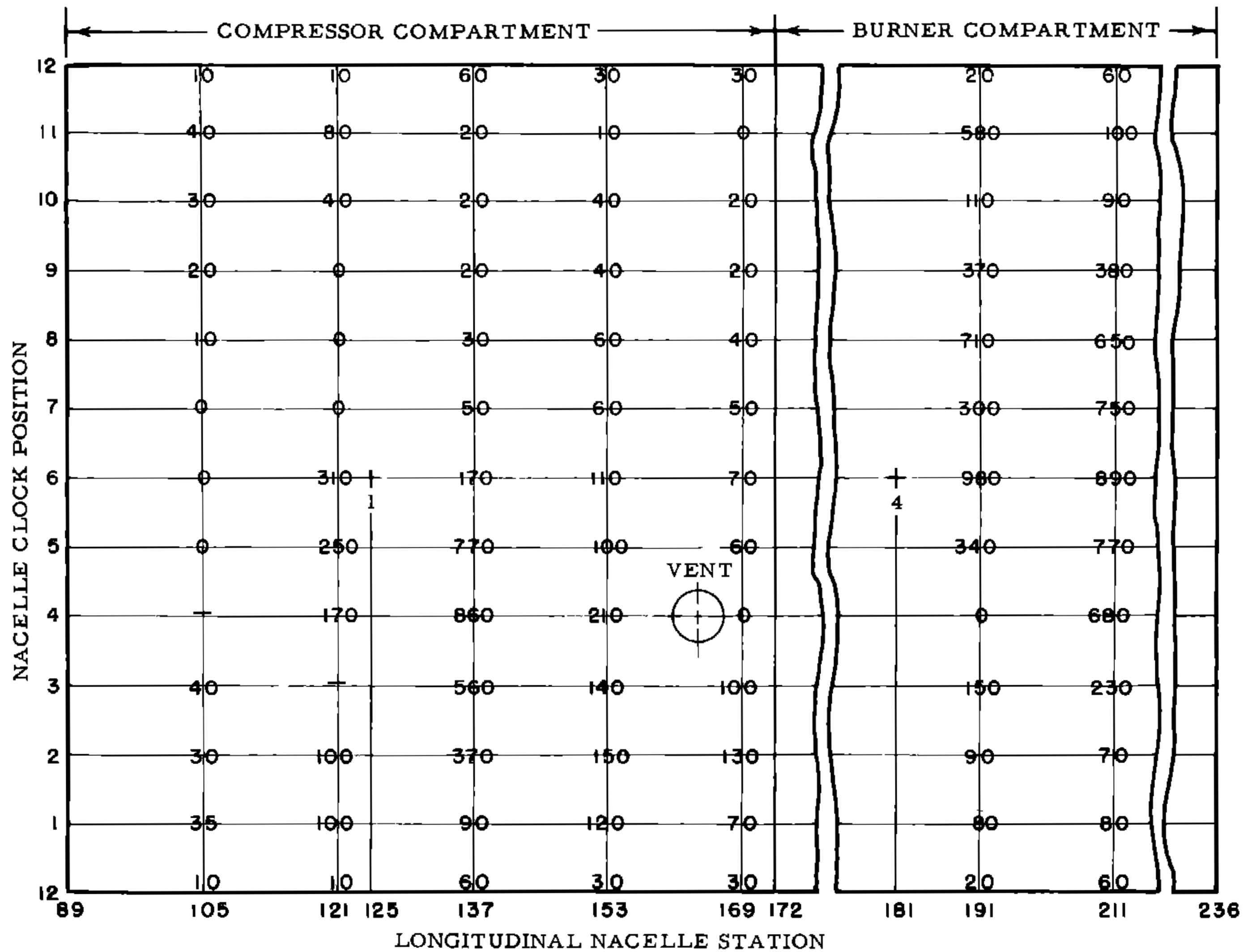


FIG. 15 RECOMMENDED UNIT-TYPE DETECTOR LOCATIONS AND ALARM SETTING FOR THE KC-135 NACELLE CONFIGURATION



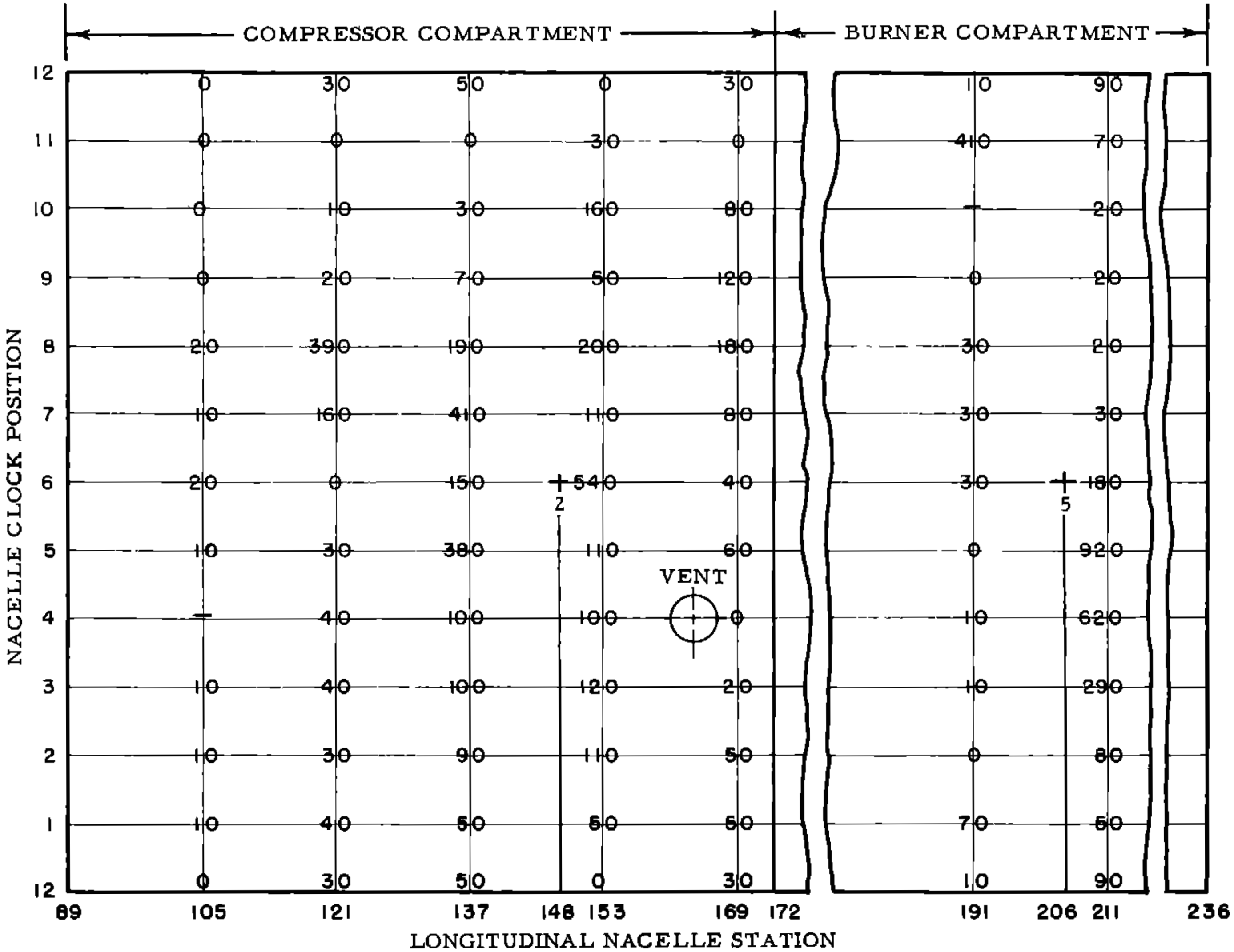
TEST CONDITIONS

EINGINE POWER - 90 PER CENT NRT
TUNNEL SPEED - 165 MPH
TEST FIRE - JP-4 FUEL, 0 3 GPM
RELEASED FOR 10 SEC

NOMENCLATURE

PLUS SIGN INDICATES LOCATION OF FUEL RELEASE PLOTTED VALUES INDICATE MAXIMUM TEMPERATURE RISE (°F) ABOVE AMBIENT READINGS PRIOR TO THE FIRE

FIG 16 EFFECT OF NACELLE FIRE ON AMBIENT TEMPERATURES WITHIN THE NACELLE



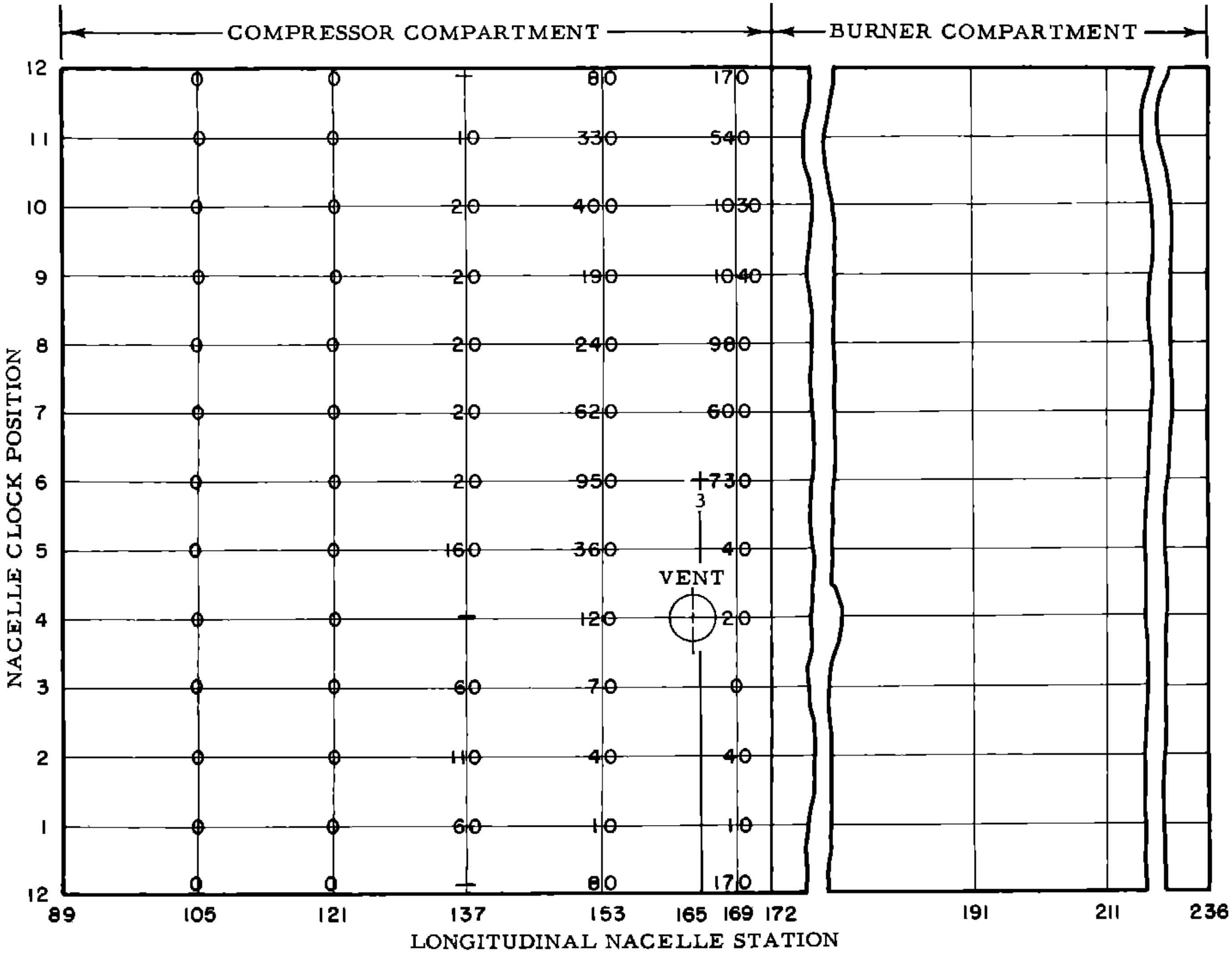
TEST CONDITIONS

ENGINE POWER - 90 PER CENT NRT
TUNNEL SPEED - 165 MPH
TEST FIRE - JP-4 FUEL, 0 3 GPM
RELEASED FOR 10 SEC

NOMENCLATURE

PLUS SIGN INDICATES LOCATION OF FUEL RELEASE PLOTTED VALUES INDICATE MAXIMUM TEMPERATURE RISE (°F) ABOVE AMBIENT READINGS PRIOR TO THE FIRE

FIG 17 EFFECT OF NACELLE FIRE ON AMBIENT TEMPERATURES WITHIN THE NACELLE



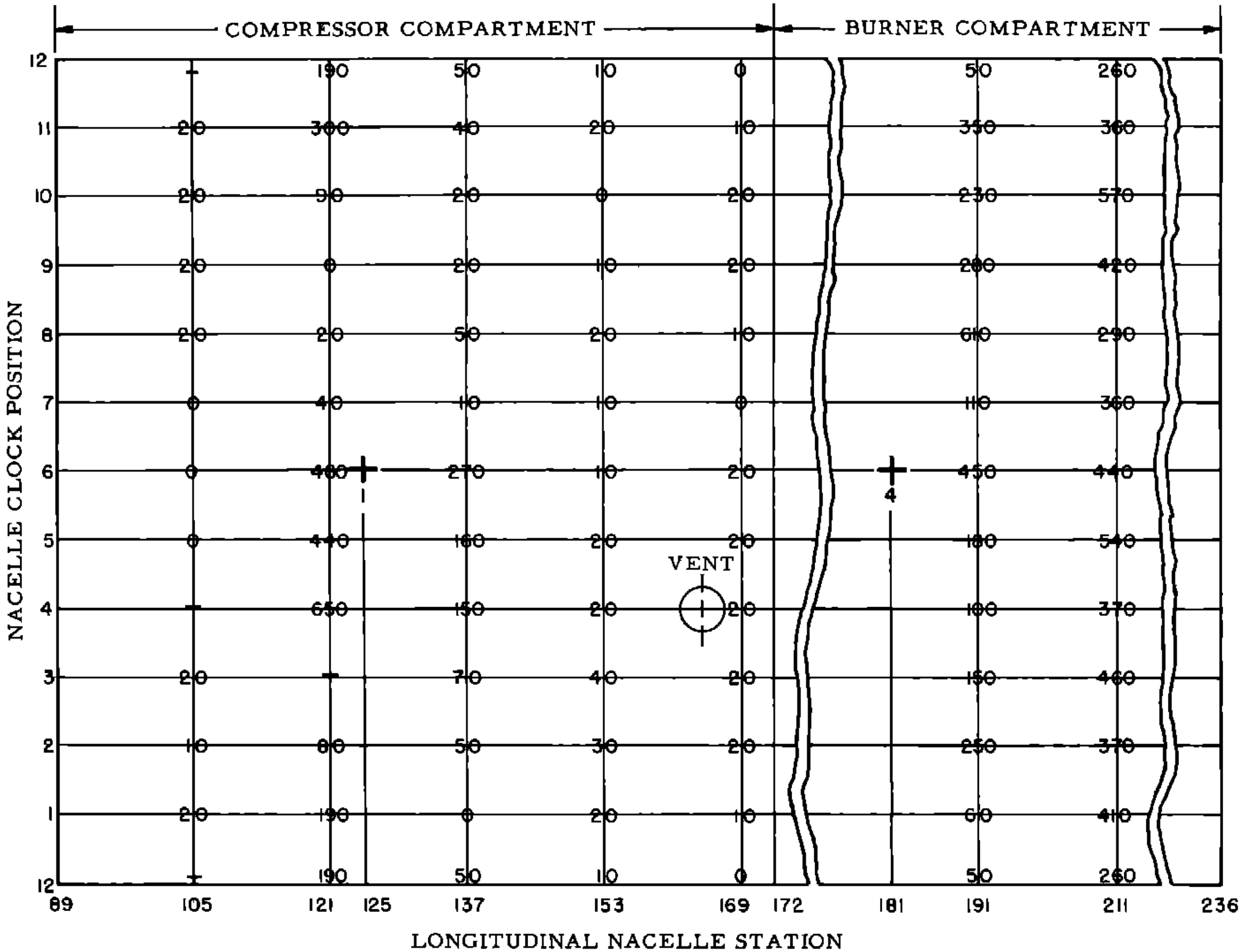
TEST CONDITIONS

ENG POWER - 90 PER CENT NRT
TUNNEL SPEED - 165 MPH
TEST FIRE - JP-4 FUEL, 0 3 GPM
RELEASED FOR 10 SEC

NOMENCLATURE

PLUS SIGN INDICATES LOCATION OF FUEL RELEASE PLOTTED VALUES INDICATE MAXIMUM TEMPERATURE RISE (°F) ABOVE AMBIENT READINGS PRIOR TO THE FIRE

FIG. 18 EFFECT OF NACELLE FIRE ON AMBIENT TEMPERATURES WITHIN THE NACELLE



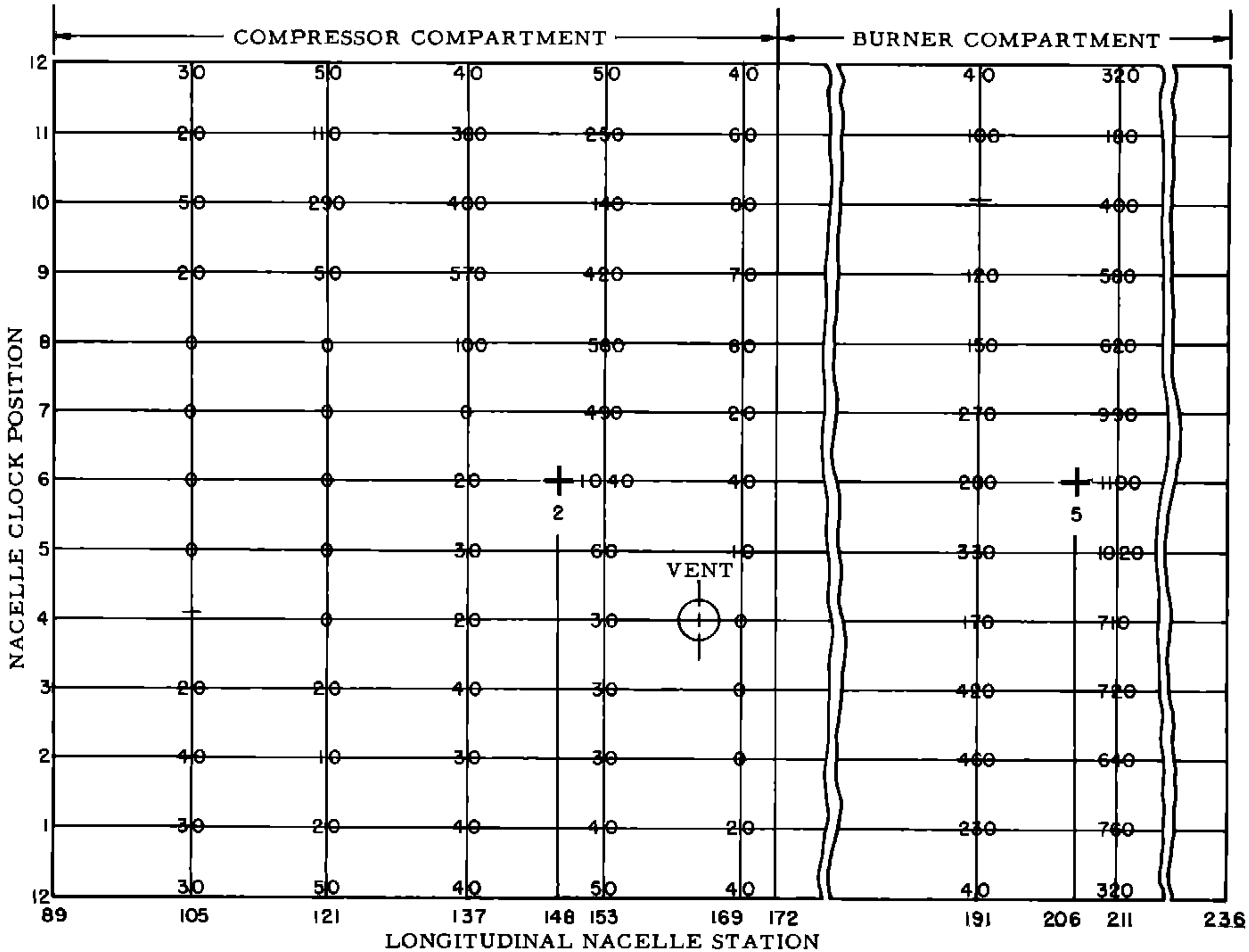
TEST CONDITIONS

ENGINE POWER - IDLE
TUNNEL SPEED - 0
TEST FIRE - JP-4 FUEL, 0 3 GPM RELEASED FOR 10 SEC

NOMENCLATURE

PLUS SIGN INDICATES LOCATION OF FUEL RELEASE PLOTTED VALUES INDICATE MAXIMUM TEMPERATURE RISE (°F) ABOVE AMBIENT READINGS PRIOR TO THE FIRE

FIG 19 EFFECT OF NACELLE FIRE ON AMBIENT TEMPERATURES WITHIN THE NACELLE



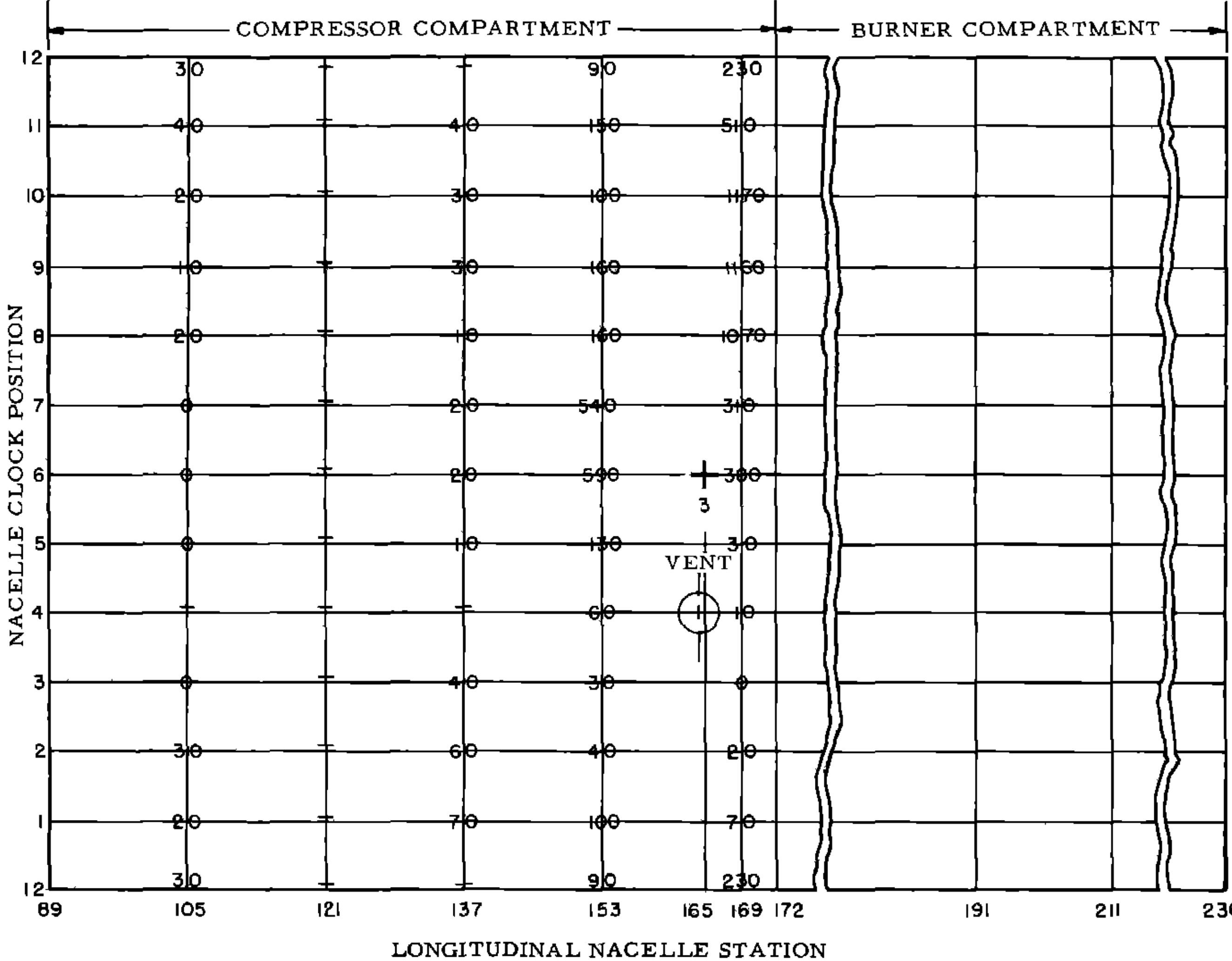
TEST CONDITIONS

ENGINE POWER - IDLE
TUNNEL SPEED - 0
TEST FIRE - JP-4 FUEL, 0 3 GPM
RELEASED FOR 10 SEC

NOMENCLATURE

PLUS SIGN INDICATES LOCATION OF FUEL RELEASE PLOTTED VALUES INDICATE MAXIMUM TEMPERATURE RISE (°F) ABOVE AMBIENT READINGS PRIOR TO THE FIRE

FIG. 20 EFFECT OF NACELLE FIRE ON AMBIENT TEMPERATURES WITHIN THE NACELLE



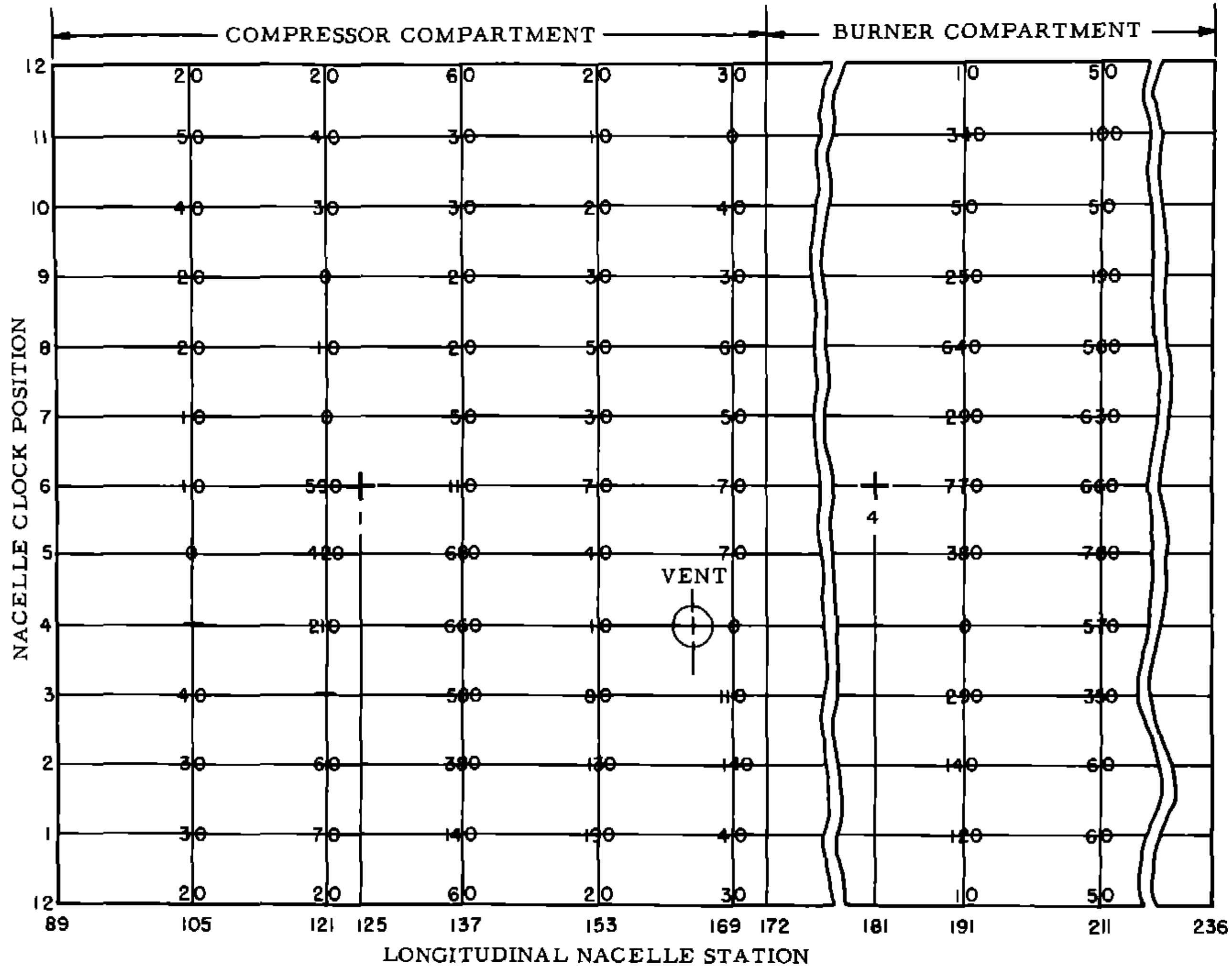
TEST CONDITIONS

ENGINE POWER - IDLE
TUNNEL SPEED - 0
TEST FIRE - JP-4 FUEL, 0 3 GPM RELEASED FOR 10 SEC

NOMENCLATURE

PLUS SIGN INDICATES LOCATION OF FUEL RELEASE   PLOTTED VALUES INDICATE MAXIMUM TEMPERATURE RISE (°F) ABOVE AMBIENT READINGS PRIOR TO THE FIRE

FIG. 21 EFFECT OF NACELLE FIRE ON AMBIENT TEMPERATURES WITHIN THE NACELLE



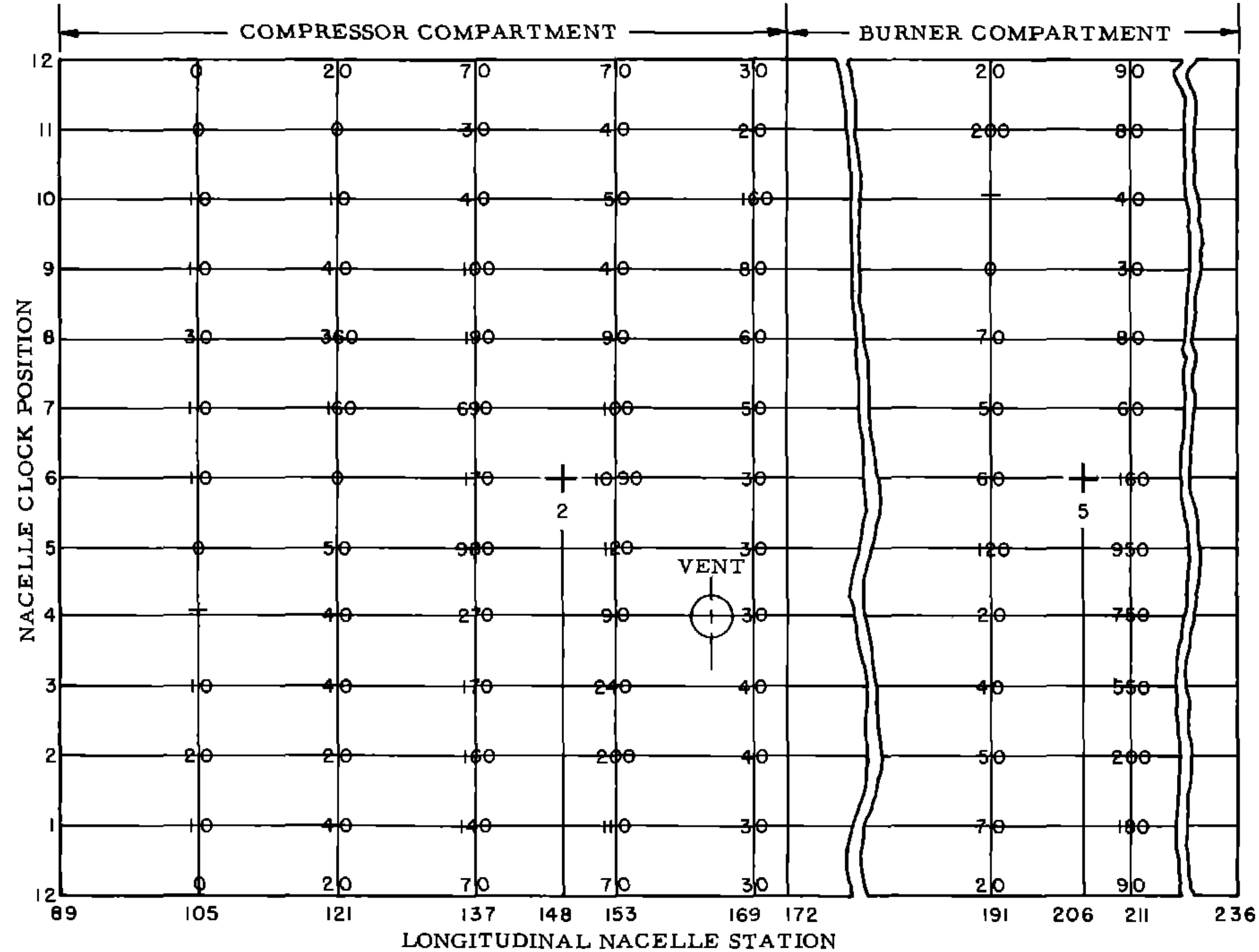
TEST CONDITIONS

ENGINE POWER - MRT (MAX RATED THRUST)
TUNNEL SPEED - 165 MPH
TEST FIRE - JP-4 FUEL, 0 3 GPM
RELEASED FOR 10 SEC

NOMENCLATURE

PLUS SIGN INDICATES LOCATION OF FUEL RELEASE PLOTTED VALUES INDICATE MAXIMUM TEMPERATURE RISE (°F) ABOVE AMBIENT READINGS PRIOR TO THE FIRE

FIG. 22 EFFECT OF NACELLE FIRE ON AMBIENT TEMPERATURES WITHIN THE NACELL¯



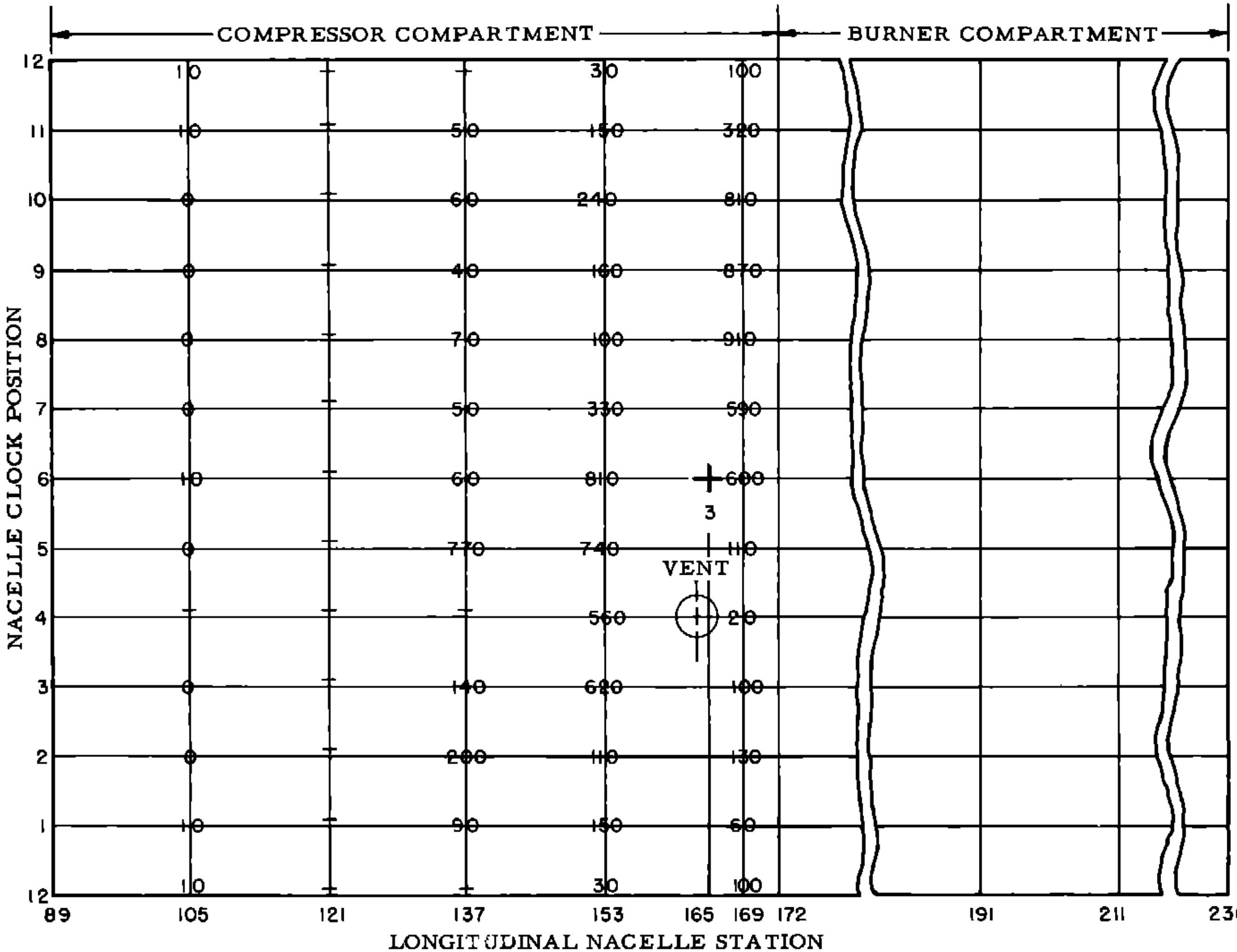
TEST CONDITIONS

EINGINE POWER - MRT (MAX RATED THRUST)
TUNNEL SPEED - 165 MPH
TEST FIRE - JP-4 FUEL, 0 3 GPM
RELEASED FOR 10 SEC

NOMENCLATURE

PLUS SIGN INDICATES LOCATION OF FUEL RELEASE PLOTTED VALUES INDICATE MAXIMUM TEMPERATURE RISE (°F) ABOVE AMBIENT READINGS PRIOR TO THE FIRE

FIG. 23 EFFECT OF NACELLE FIRE ON AMBIENT TEMPERATURES WITHIN THE NACELLE



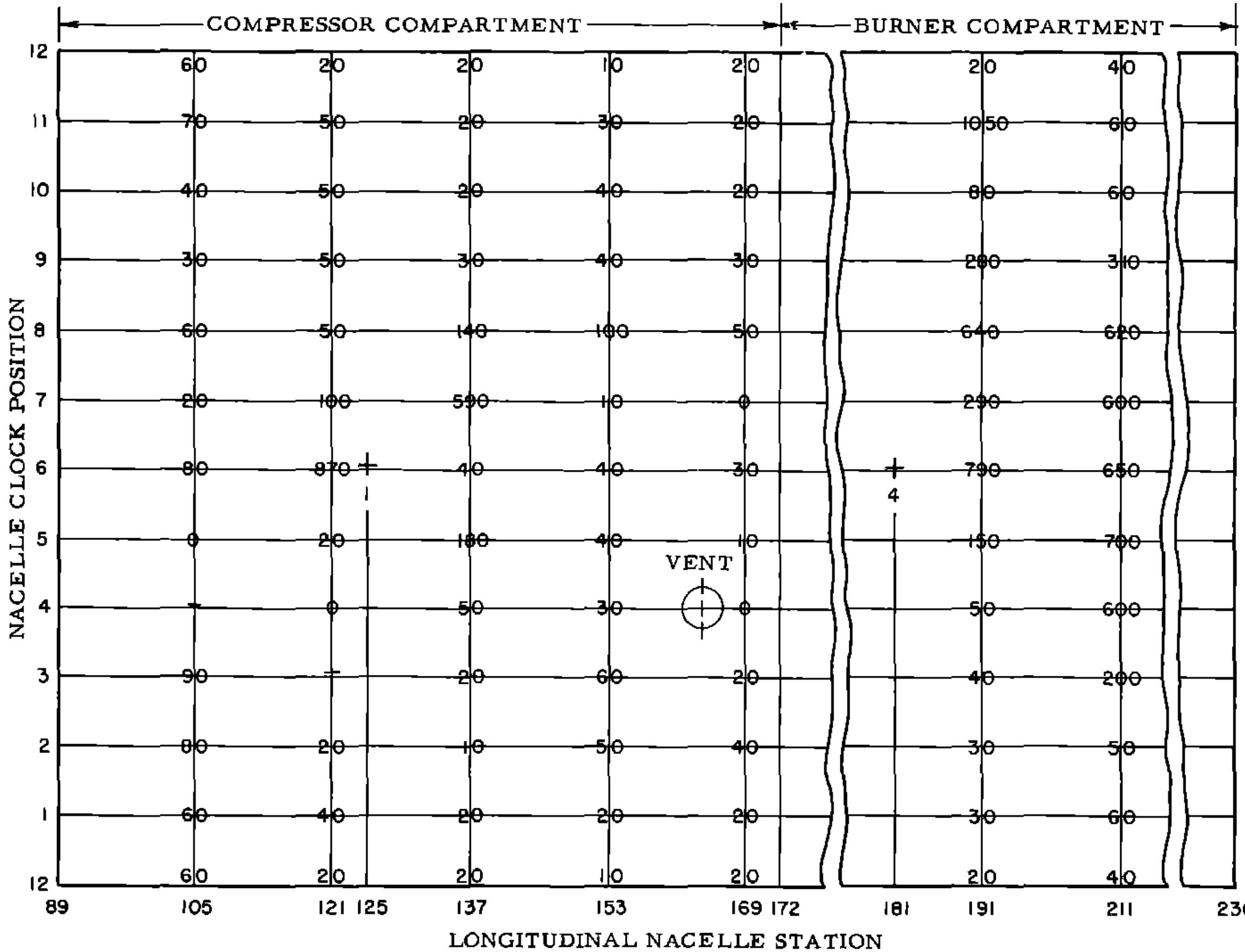
TEST CONDITIONS

ENGINE POWER - MRT (MAX RATED THRUST)
TUNNEL SPEED - 165 MPH
TEST FIRE - JP-4 FUEL, 0 3 GPM
RELEASED FOR 10 SEC

NOMENCLATURE

PLUS SIGN INDICATES LOCATION OF FUEL RELEASE PLOTTED VALUES INDICATE MAXIMUM TEMPERATURE RISE (°F) ABOVE AMBIENT READINGS PRIOR TO THE FIRE

FIG. 24 EFFECT OF NACELLE FIRE ON AMBIENT TEMPERATURES WITHIN THE NACELLE



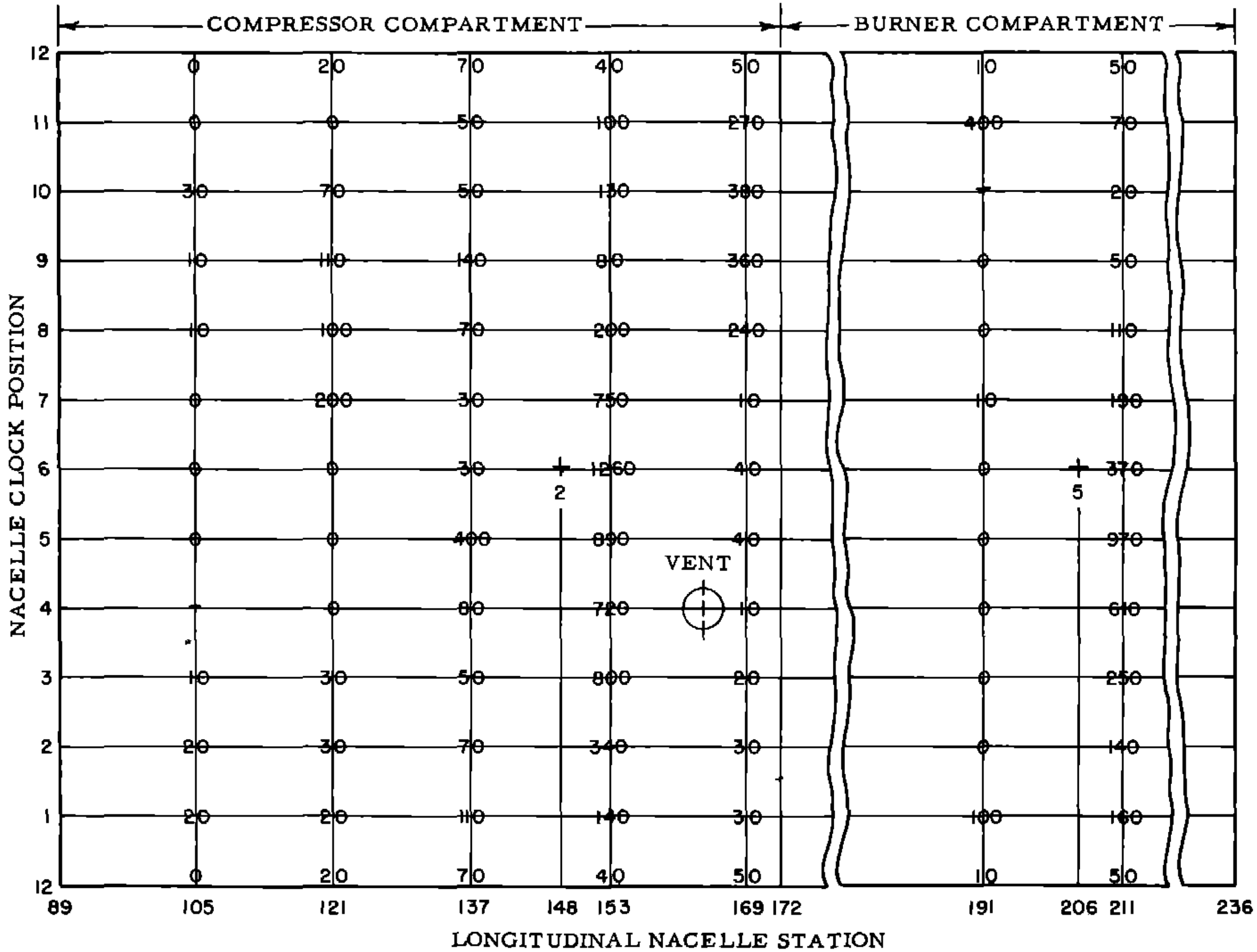
TEST CONDITIONS

ENGINE POWER - MRT WITH ANTI-ICING AIRFLOW
TUNNEL SPEED - 165 MPH
TEST FIRE - JP-4 FUEL, 0 3 GPM RELEASED FOR 10 SEC

NOMENCLATURE

PLUS SIGN INDICATES LOCATION OF FUEL RELEASE PLOTTED VALUES INDICATE MAXIMUM TEMPERATURE RISE (°F) ABOVE AMBIENT READINGS PRIOR TO THE FIRE

FIG 25 EFFECT OF NACELLE FIRE ON AMBIENT TEMPERATURES WITHIN THE NACELLE



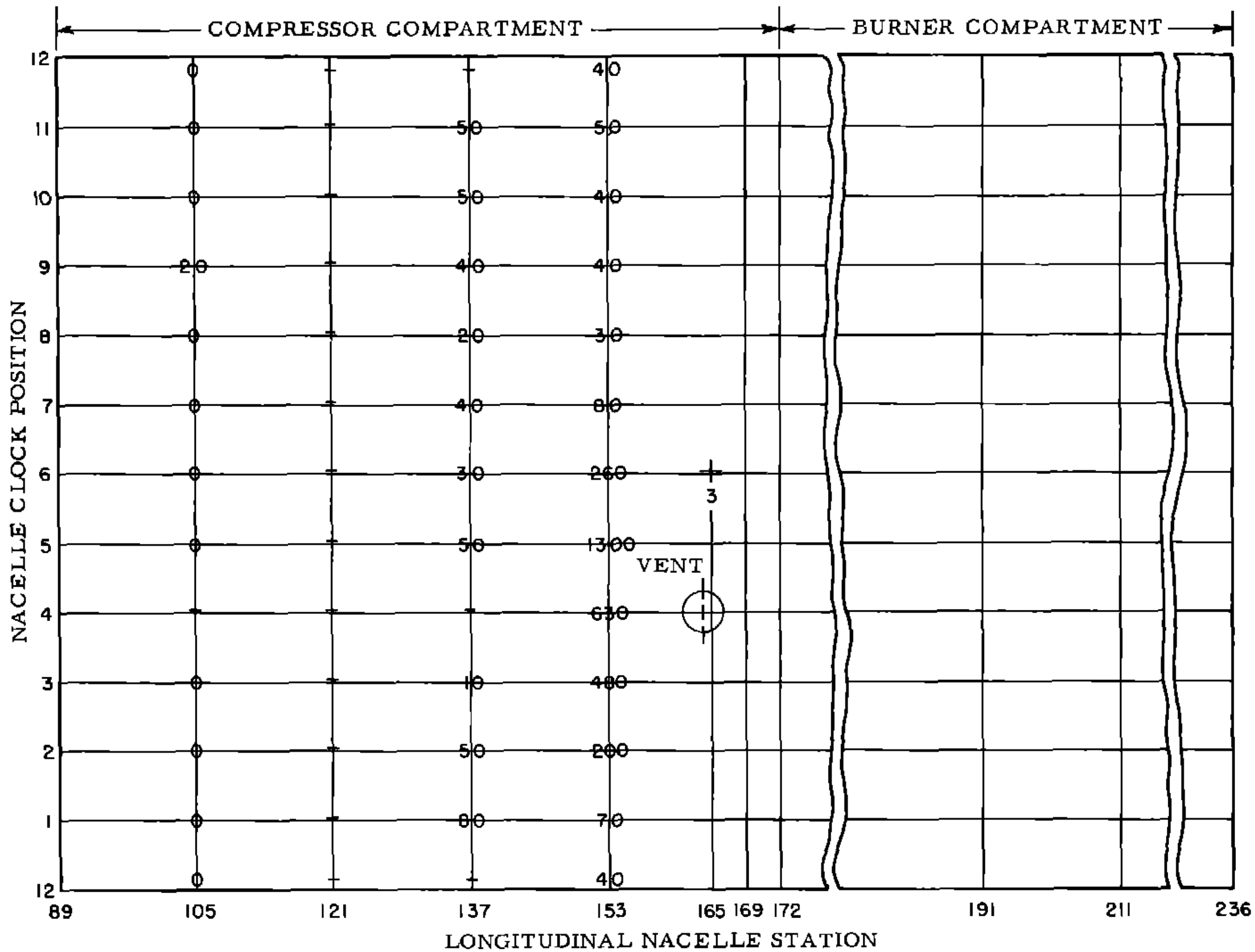
TEST CONDITIONS

ENGINE POWER - MRT WITH ANTI-ICING AIRFLOW
TUNNEL SPEED - 165 MPH
TEST FIRE - JP-4 FUEL, 0 3 GPM RELEASED FOR 10 SEC

NOMENCLATURE

PLUS SIGN INDICATES LOCATION OF FUEL RELEASE PLOTTED VALUES INDICATE MAXIMUM TEMPERATURE RISE (°F) ABOVE AMBIENT READINGS PRIOR TO THE FIRE

FIG 26 EFFECT OF NACELLE FIRE ON AMBIENT TEMPERATURES WITHIN THE NACELLE



TEST CONDITIONS

ENGINE POWER - MRT WITH ANTI-ICING AIRFLOW
TUNNEL SPEED - 165 MPH
TEST FIRE - JP-4 FUEL, 0 3 GPM RELEASED FOR 10 SEC

NOMENCLATURE

PLUS SIGN INDICATES LOCATION OF FUEL RELEASE PLOTTED VALUES INDICATE MAXIMUM TEMPERATURE RISE (°F) ABOVE AMBIENT READINGS PRIOR TO THE FIRE

FIG. 27 EFFECT OF NACELLE FIRE ON AMBIENT TEMPERATURES WITHIN THE NACELLE

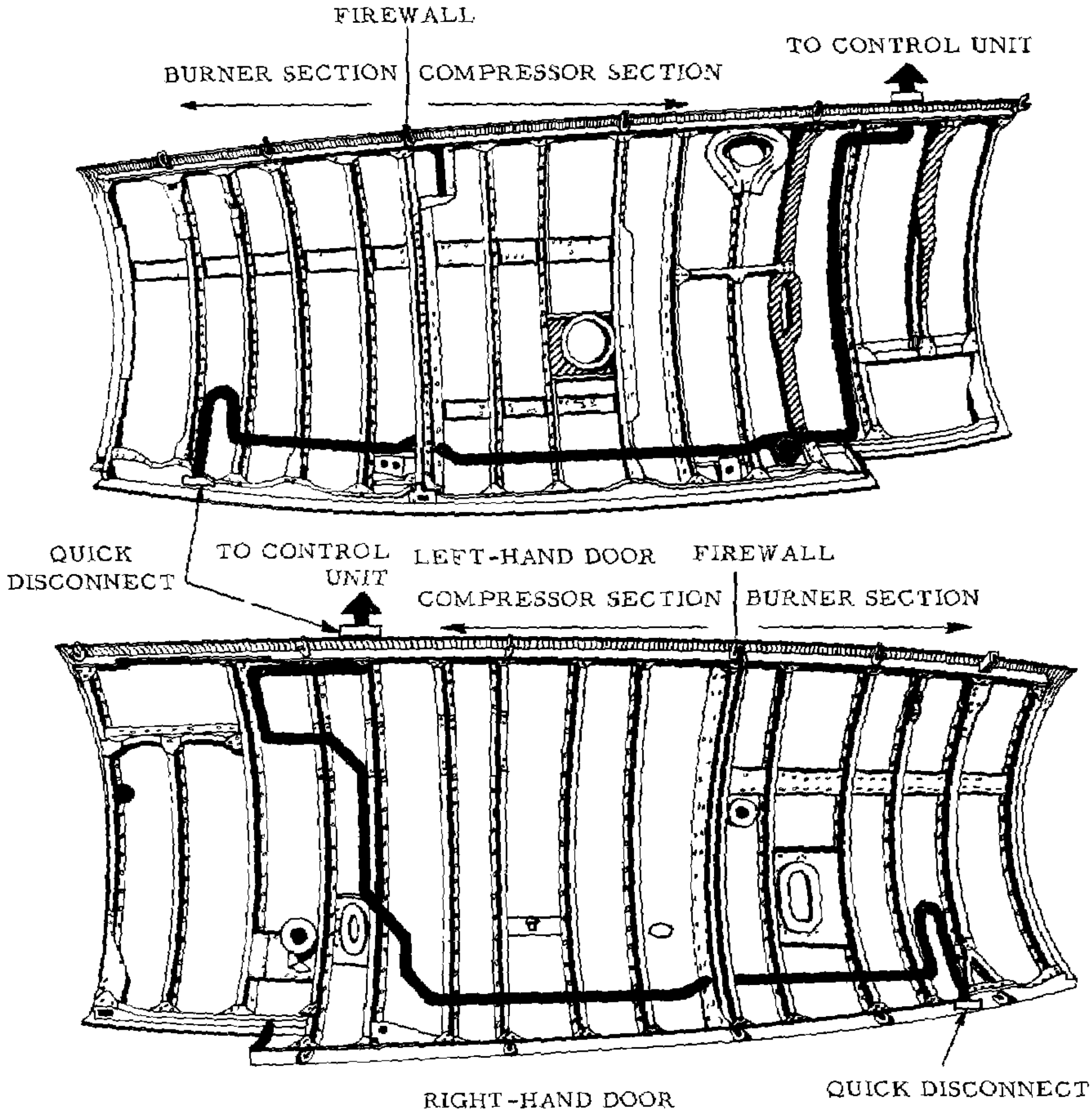


FIG 28 INTERMEDIATE ROUTING OF KIDDE CONTINUOUS-TYPE DETECTOR ELEMENT MOUNTED ON THE DOOR

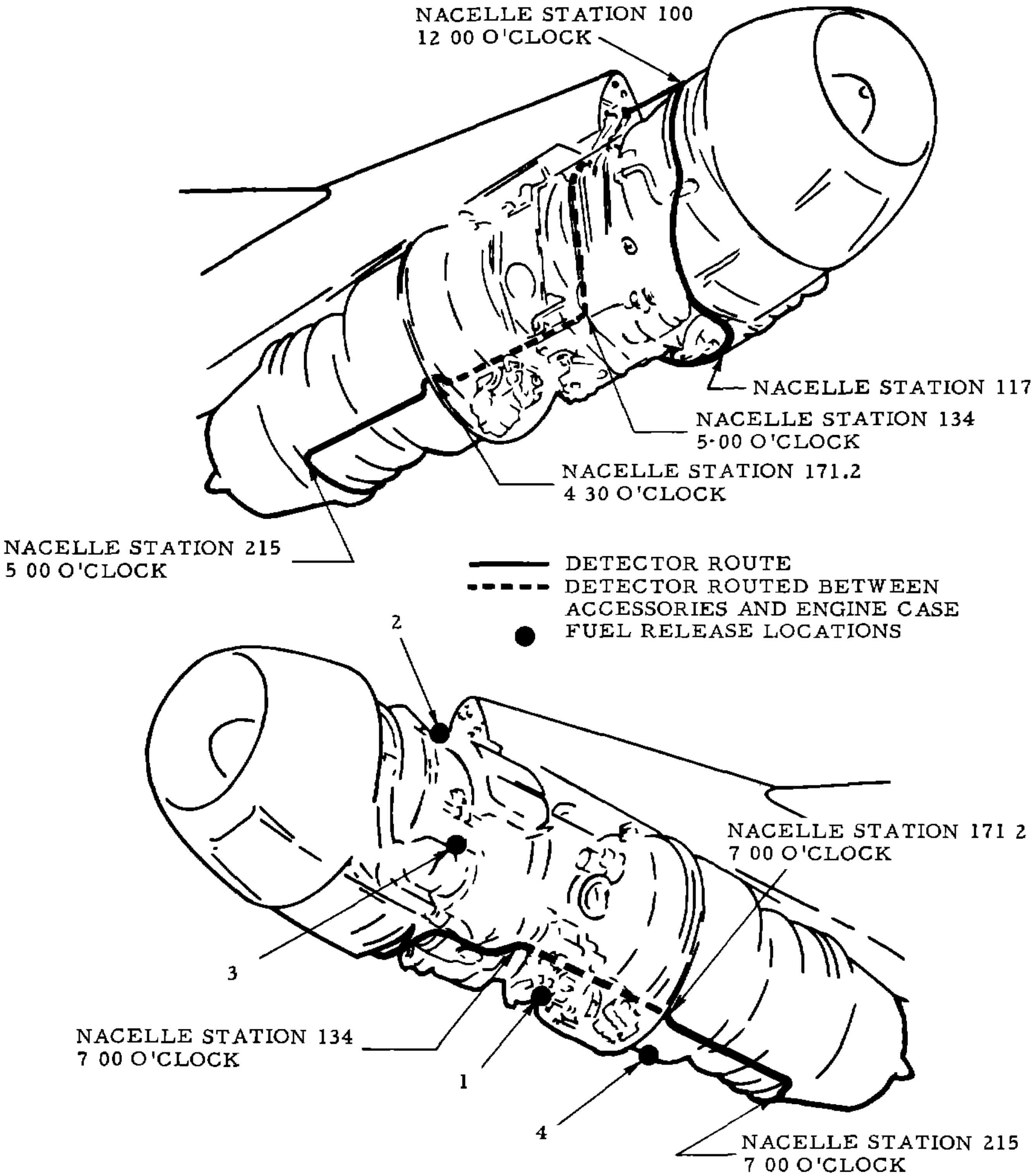


FIG. 29 FIRST INTERMEDIATE ROUTING OF CONTINUOUS-TYPE DETECTOR MOUNTED ON THE ENGINE USING FENWAL DETECTOR

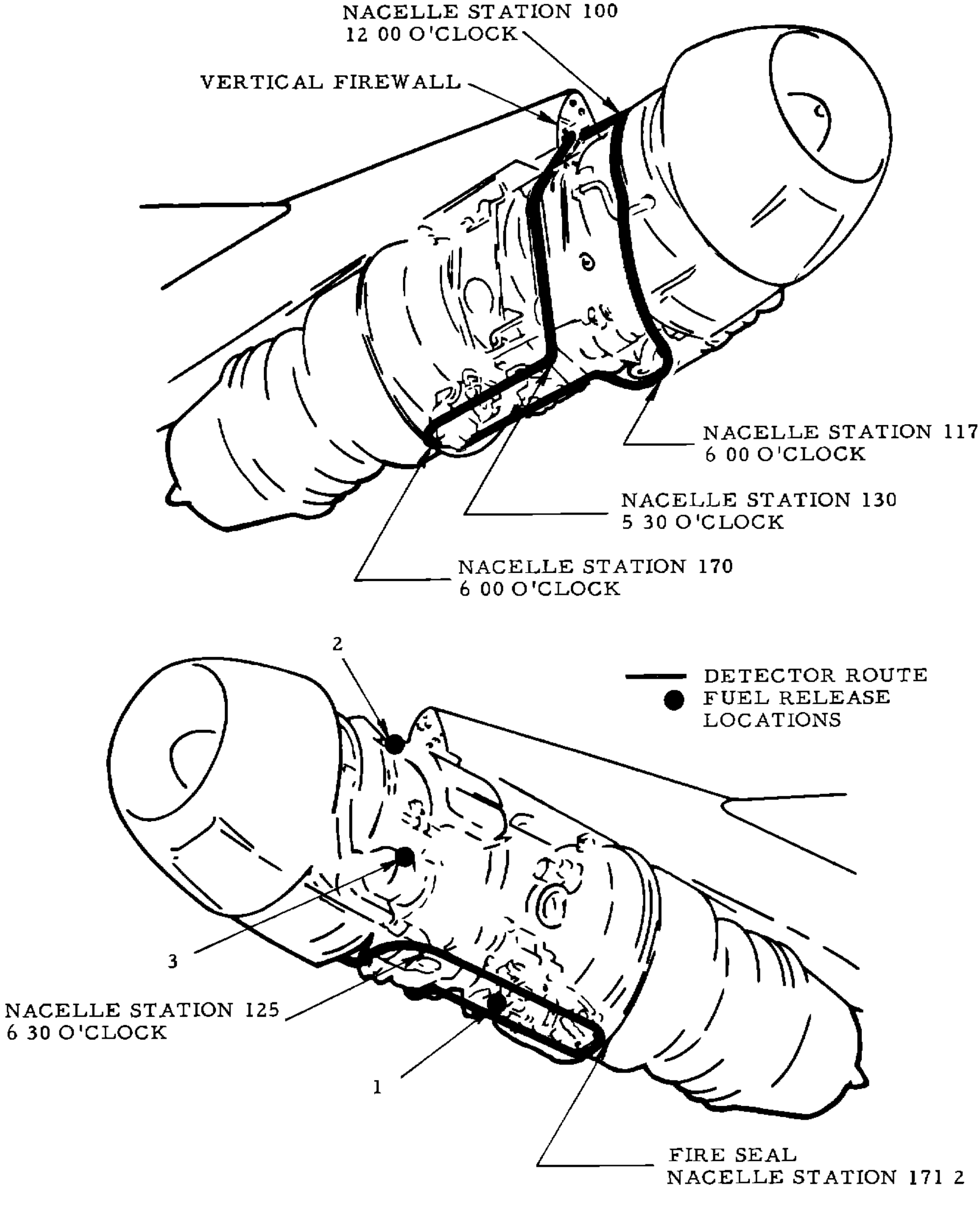


FIG 30 SECOND INTERMEDIATE ROUTING OF CONTINUOUS-TYPE DETECTOR MOUNTED ON THE ENGINE USING EDISON DETECTOR