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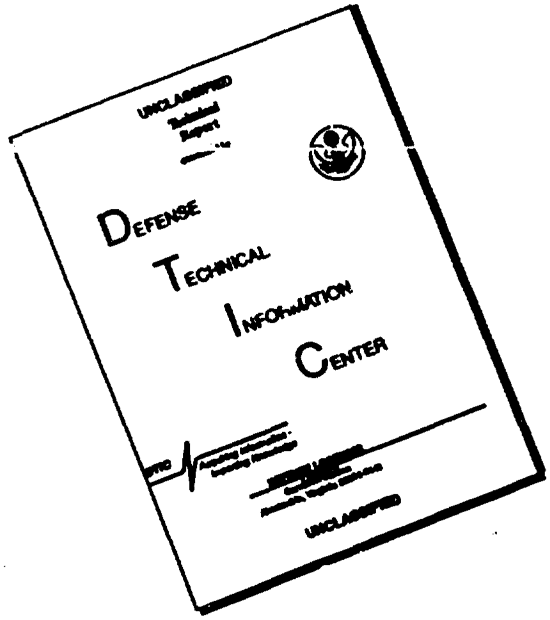

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ENGINE INLET ANTI-ICING SUBSYSTEM SPECIFICATION

COMPETITIVE DATA

SST

BOEING MODEL 2707

SUPERSONIC TRANSPORT
PROGRAM

●

PHASE II-C REPORT
CONTRACT FA-SS-66-5

JUNE 30, 1966

Prepared For
FEDERAL AVIATION AGENCY
Supersonic Transport Development Program

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D6A10117-1

COMPETITIVE DATA

THE BOEING COMPANY
SUPERSONIC TRANSPORT DIVISION

ISSUE NO. 1

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SUBSYSTEM SPECIFICATION

PERFORMANCE/DESIGN AND PRODUCT CONFIRMATION REQUIREMENTS

ENGINE INLET ANTI-ICING SUBSYSTEM SPECIFICATION SUPERSONIC TRANSPORT AIRCRAFT BOEING MODEL 2707

JUNE 30, 1966

D6A10117-1

REVISION RECORD

Revision Date	Pages Revised	Pages Added	Approval

CONTENTS

CONTENTS (Cont.)

ILLUSTRATIONS

TABLES

1.0 SCOPE

1.1 This specification establishes the requirements for performance, design, tests, and qualification for the inlet anti-icing subsystem (hereafter called IAIS), as applied to the prototype B-2707 airplanes. The IAIS is the means by which inlet surfaces are heated to remove or prevent ice formations.

2.0 APPLICABLE DOCUMENTS

2.1 GENERAL. All documents referenced in Par. 2.0 of D6A10107-1, Airframe Subsystem Specification, form a part of this specification to the extent specified herein. In the event of conflict between documents referenced in Par. 2.0 of D6A10107-1 and detailed contents of Pars. 3.0 and 4.0 herein, the detail requirements of Pars. 3.0 and 4.0 shall govern.

2.2 SPECIFIC. In addition to documents referenced in Par. 2.1, the following documents of exact issue shown form a part of this specification to the extent specified herein.

Boeing Documents

Air Vehicle and Ground Support Operation Documents of 733 Vehicle Submittal to FAA

D6-17850	Model Specification
D6A10107-1	Airframe Subsystem
D6A10090-1	Aircraft Integrated Data System
D6A10113-1	Engine Installation Subsystem
D6A10119-1	Electric Power Subsystem
D6A10109-1	Flight Deck Subsystem

3.0 REQUIREMENTS

3.1 PERFORMANCE.

3.1.1 Functional Characteristics. The inlet anti-icing subsystem provides for the control of ice accretion on the selected surfaces to the level required to prevent inlet airflow distortion or damage to the engine in event of ice ingestion and to prevent blockage of the air data sensors.

3.1.1.1 Subsystem Performance Characteristics. The performance characteristics of the inlet anti-icing subsystem shall be as follows:

a. Heat will be provided to the cowl lip (18 inches from the lip), cowl vortex generators, centerbody, and centerbody support struts to maintain a temperature of 35° F or above during all icing conditions specified in FAR 25 down to an ambient temperature of -22° F. The size of runback ice formations shall be limited to prevent engine damage if ingested.

b. Heat will be provided to the inlet air data sensor probes to remove any ice previously formed and to maintain a surface temperature of 35° F during all icing conditions specified in FAR 25 down to an ambient temperature of -40° F.

c. Heating requirements to accomplish the performance of items a and b above at the critical design conditions at 15,000 feet are tabulated in Table I.

d. The subsystem shall be designed to provide increasing anti-icing capabilities with increasing engine power.

e. Control of the subsystem shall be accomplished from the flight deck by a manually operated switch.

Table I. IAIS Heating Requirements

COMPONENT	UNITS OF HEAT	FLIGHT CONDITION		
		CLIMB	HOLDING	DESCENT
Cowl leading edge Centerbody support struts Centerbody forward surface	$\frac{Btu}{min\text{-}ft^2}$	129.0	112.0	45.0
Cowl vortex generator (each)	$\frac{Btu}{min}$	1.8	1.6	0.6
Inlet air data sensor (each)	$\frac{Btu}{min}$	3.6	3.1	1.2

3.1.2 Operability. The allocation of the operability requirements defined below has been accomplished by analysis and experience and may be revised as long as the overall aircraft requirements as specified in the model specification (D6-17850) are satisfied. For definition of terms used, refer to 3.1.2 of D6A10107-1.

3.1.2.1 Reliability. The IAIS shall be designed to achieve the following:

a. The average number of departure delays due to failure of components in the IAIS shall not exceed:

   (1) For B-2707 (G.E.)—14 delays per 100,000 scheduled flights.

   (2) For B-2707 (P&WA)—20 delays per 100,000 scheduled flights.

b. The average number of flight plan deviations due to failure of the IAIS shall not exceed:

   (1) For B-2707 (G.E.)—0.3 deviation per 100,000 flights

   (2) For B-2707 (P&WA)—0.5 deviation per 100,000 flights.

3.1.2.2 Maintainability. The IAIS shall be designed to achieve the following:

a. All scheduled checks and mandatory repairs of line-replaceable units (LRU) shall have a probability of task completion in 20 minutes of 99.7 percent at a transit station.

b. All scheduled checks and mandatory repairs of line-replaceable units shall have a probability of task completion in 1 hour of 99.6 percent at a turnaround station.

c. All scheduled checks and repairs of LRU's to be accomplished at Intermediate Maintenance Service shall have a probability of task completion in 4 hours of 99.85 percent.

d. All scheduled checks and repairs of LRU's to be accomplished at Periodic Maintenance Check shall have a probability of task completion in 16 hours of 99.9 percent.

e. All scheduled checks and repairs of LRU's to be accomplished at an Overhaul Service shall have a probability of task completion in 5 days of 99.95 percent.

3.1.2.2.1 Maintenance and Repair Cycles. The maintenance time check intervals shall be as specified in the model specification (D6-17850).

3.1.2.2.2 Service and Access. The following features shall be provided:

a. Components and assemblies shall be readily accessible to the maintenance technician for the purpose of fault isolation, adjustment, and replacement. Accessibility provisions shall allow for efficient accomplishment of maintenance under the expected climatic conditions to be encountered.

b. Any ducting or other nonoperating components not easily accessible shall have design characteristics that shall preclude necessity of inspection, maintenance, or replacement between basic checks (airframe overhaul).

c. Maintenance shall be accomplished with personnel skill levels used on subsonic aircraft.

3.1.2.3 Useful Life. The IAIS shall have a useful life of 50,000 hours except that the wiring in the engine and inlet area shall have a useful life of 10,000 hours. This assumes that normal maintenance actions are accomplished. The mean time between overhauls of subsystem components shall not be less than 10,000 hours.

3.1.2.4 Environmental. The IAIS shall be capable of withstanding the following conditions:

3.1.2.4.1 Pressures and Temperatures.

a. The environment imposed by the engine, which includes the pressures and temperatures shown in Table II.

b. Temperatures of -50°F to 160°F in the flight deck and to 450°F in other areas where environment is not controlled.

c. Pressures imposed by altitudes equivalent to the following:

(1) -1000 to 73,000 feet in areas that are not pressurized.

(2) -1000 to 15,000 feet with overshoot to 30,000 feet for 5 minutes in the flight deck.

3.1.2.4.2 Ozone. Ozone concentration of 0.2 part per million by volume at the flight deck and 9 parts per million by volume at other locations.

3.1.2.4.3 Vibration. Vibration as specified in Figure 1.

3.1.2.4.4 Sand and Dust. Sand and dust as specified in MIL-STD-210A.

3.1.2.4.5 Humidity. Humidity as specified in MIL-STD-210A.

3.1.2.4.6 Salt Atmosphere. Salt atmosphere containing 0.003 to 15 parts per million by weight of sea salt.

Table II. Environmental Pressures and Temperatures

IDENTIFICATION	SYSTEM OPERATING		SYSTEM NOT OPERATING (STATIC TO SUPER-SONIC CRUISE)	
	NORMAL	MAXIMUM [1]	NORMAL	MAXIMUM [1]
B-2707 (G.E.)				
Bleed port to engine face				
Pressures, psig				
Bleed air	0 to 50	0 to 200	0	0 to 200
Temperatures °F				
Engine case	-50 to 700	-50 to 700	-50 to 1020	-50 to 1100
Bleed air	0 to 700	0 to 700	0 to 800	0 to 1100
Compartment:				
continuous	-30 to 500	-30 to 500	-30 to 610	-30 to 650
intermittent*	-50 to 550	-50 to 550	-50 to 700	-50 to 750
Forward of Engine face				
Pressures, psig				
Bleed air	0 to 35	0 to 100	0	0 to 100
Temperatures °F				
Bleed air				
Compartment:				
continuous	-50 to 200	-50 to 300	-50 to 500	-50 to 550
intermittent*	-50 to 250	-50 to 350	-50 to 550	-50 to 600
B-2707 (P&WA)				
Bleed port to engine face				
Pressures, psig				
Bleed air	0 to 180	0 to 200	0 to 180	0 to 200
Temperatures °F				
Engine case	-50 to 330	-50 to 500	-50 to 650	-50 to 700
Bleed air	0 to 650	0 to 700	0 to 700	0 to 750
Compartment:				
continuous	-30 to 400	-30 to 400	-30 to 400	-30 to 450
intermittent*	-50 to 430	-50 to 450	-50 to 450	-50 to 500
Forward of engine face				
Pressures, psig				
Bleed air	0 to 35	0 to 100	0	0 to 100
Temperatures, °F				
Bleed air	0 to 600	0 to 650	0 to 650	0 to 700
Compartment:				
continuous	-30 to 200	-30 to 300	-50 to 500	-50 to 550
intermittent*	-50 to 250	-50 to 400	-50 to 550	-50 to 600

*Intermittent ≤ 5 minutes.

[1] Expected to occur only with engine or anti-icing subsystem failures.

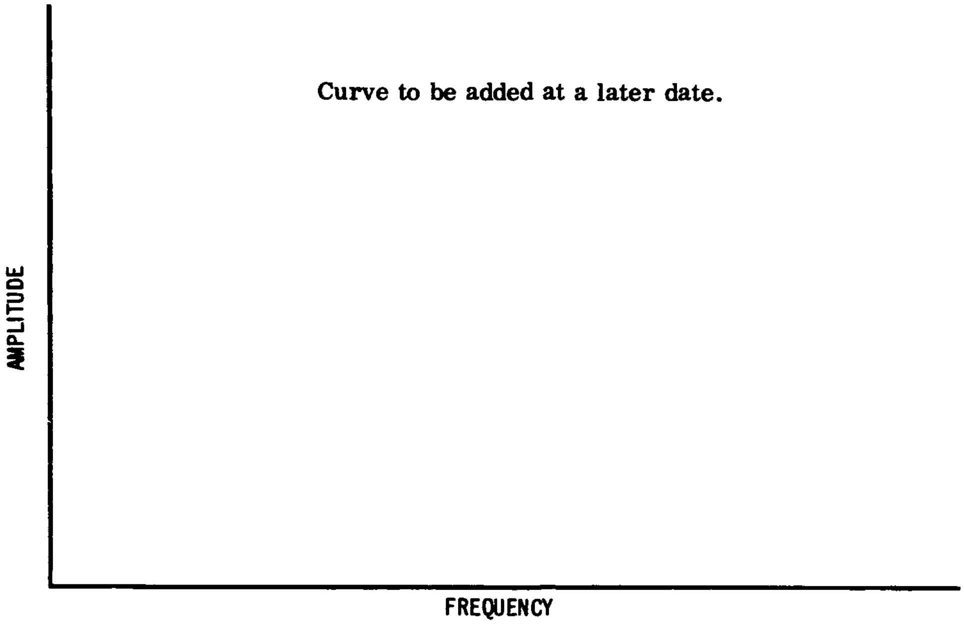


Figure 1. Vibration Environment

3.1.2.4.7 Explosive Atmosphere. Explosive atmosphere consisting of a Jet-A-kerosene-and-air mixture.

3.1.2.5 Human Performance. Instruments and controls shall be provided in the flight deck to enable the crew to operate and control the IAIS. Lights and/or other indicators shall provide maximum information with minimum dependence on or manipulation of controls by operators to indicate system failures or improper operation. (Refer to D610109-1, Flight Deck Subsystem Specification.)

3.1.2.6 Safety.

3.1.2.6.1 Flight Safety. Design consideration shall be given to optimize subsystem safety through application of redundancy, fail-safe techniques, and component derating. Failure of any one component within the subsystem shall not induce failure of other components in the subsystem. A separate service and control shall be provided for each engine to ensure that a single failure will not affect more than one engine.

3.1.2.6.2 Ground Safety. Par. 3.1.2.6.1 applies.

3.1.2.6.3 Personnel Safety. Operation of the subsystem on the ground shall not endanger personnel working on or near the engines. No component failures shall produce conditions which would endanger personnel using normal maintenance safety provisions.

3.2 SUBSYSTEM DEFINITION.

3.2.1 Interface Requirements.

3.2.1.1 Schematic Arrangement. The interface schematic arrangement for the IAIS shall be as shown below:

a. B-2707 (G.E.)—Fig. 2.

b. B-2707 (P&WA)—Fig. 3.

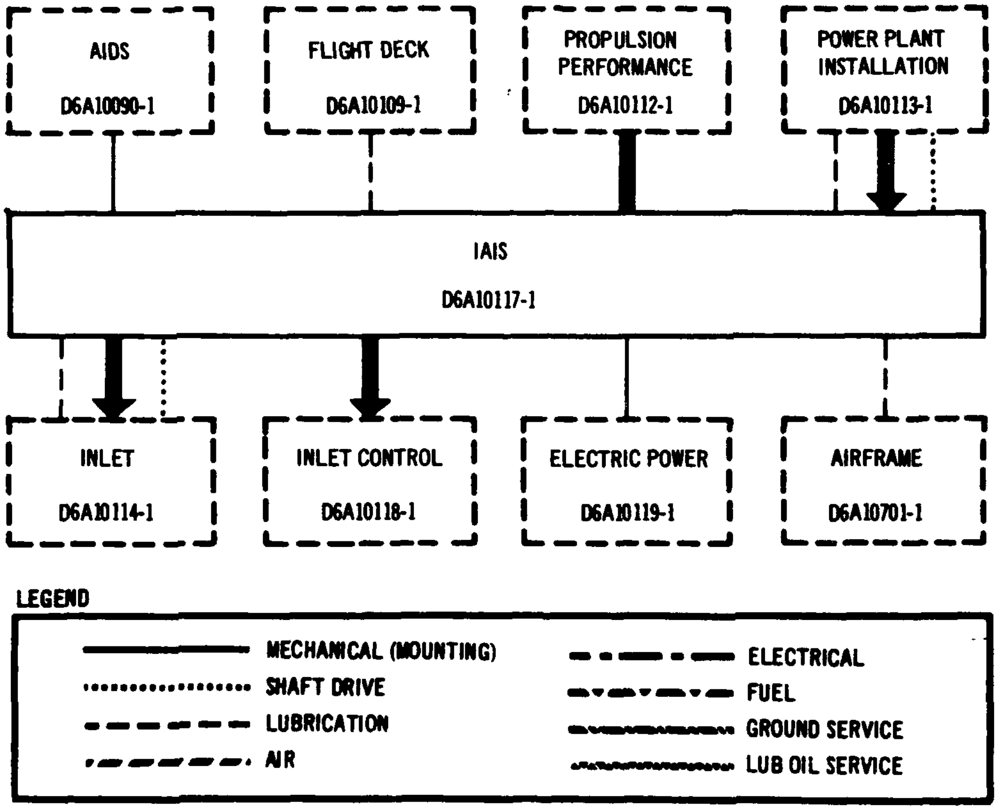


Figure 2. Interface Schematic Diagram—B-2707 (G.E.)

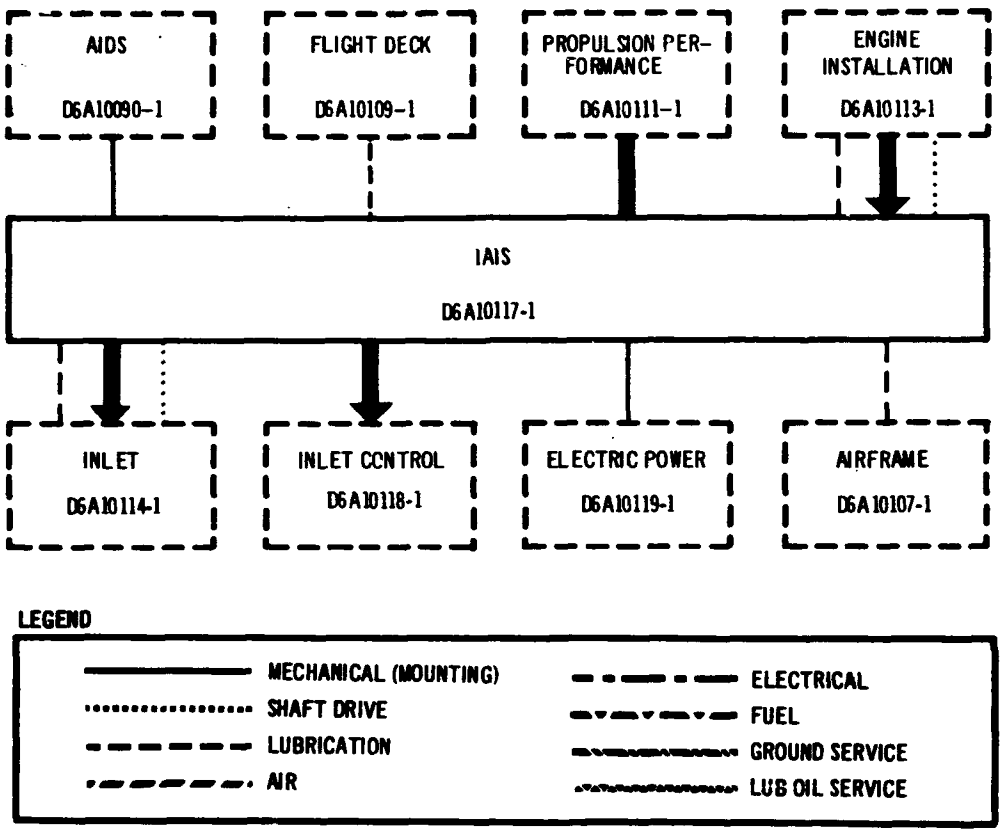


Figure 3. Interface Schematic Diagram—B-2707 (P&WA)

3.2.1.2 Detailed Interface Definition (DIF). Bleed airflow requirements for the IAIS shall remain within the limits mutually resolved with the power plant installation and propulsion performance subsystems. Engine compressor bleed air shall be supplied which has a minimum temperature of 500°F and a minimum pressure of 100 psia at the following conditions:

a. Maximum unaugmented thrust.

b. All static and flight conditions.

c. All altitudes from 0 to 22,000 feet.

d. All ambient air temperatures from -40° to +50°F.

3.2.1.2.1 DIF for B-2707 (G.E.). The IAIS shall be supplied from the engine anti-icing system with the engine compressor bleed airflows shown in Fig. 4. The downstream pressure drop characteristics of the IAIS are represented by

$$W = 3.78\ C_D A \sqrt{\frac{P \Delta P}{T}}$$

where

- W = anti-icing airflow, lb/min/ft inlet leading edge circumference
- $C_D A$ = 8.1 sq. in.
- T = Bleed air temperature, °R
- P - Downstream (exhaust) pressure in psia
- ΔP = Anti-icing air pressure at entrance to IAIS minus the exhaust pressure, all in psia.

3.2.1.2.2 DIF for B-2707 (P&WA). The IAIS shall be supplied with engine compressor bleed air which satisfies the requirements of Fig. 5.

3.2.2 Component Identification. To be added in revision.

3.3 DESIGN AND CONSTRUCTION.

3.3.1 Subsystem Design Features. The IAIS consists of those components required to supply, distribute, and control the flow of hot air to selected surfaces on the four supersonic inlets. Each inlet shall be a separate and identical section of the subsystem as shown in Fig. 6. The hot air is obtained from engine compressor bleed.

3.3.1.1 Protected Surfaces. The following surfaces shall be anti-iced:

a. Cowl—leading edge and inside surface of cowl lip, air data sensor probes, and vortex generators.

b. Centerbody—forward surface of inlet centerbody, leading edge of centerbody support struts, and air data sensor probes.

(1) For B-2707 (G.E.)—The engine manufacturer is responsible for the design and substantiation of the engine anti-icing subsystem for the protection of the engine inlet guide vanes and bearing support struts. The method of system integration is shown as a part of this specification.

(2) For B-2707 (P&WA)—The engine does not require an anti-icing system.

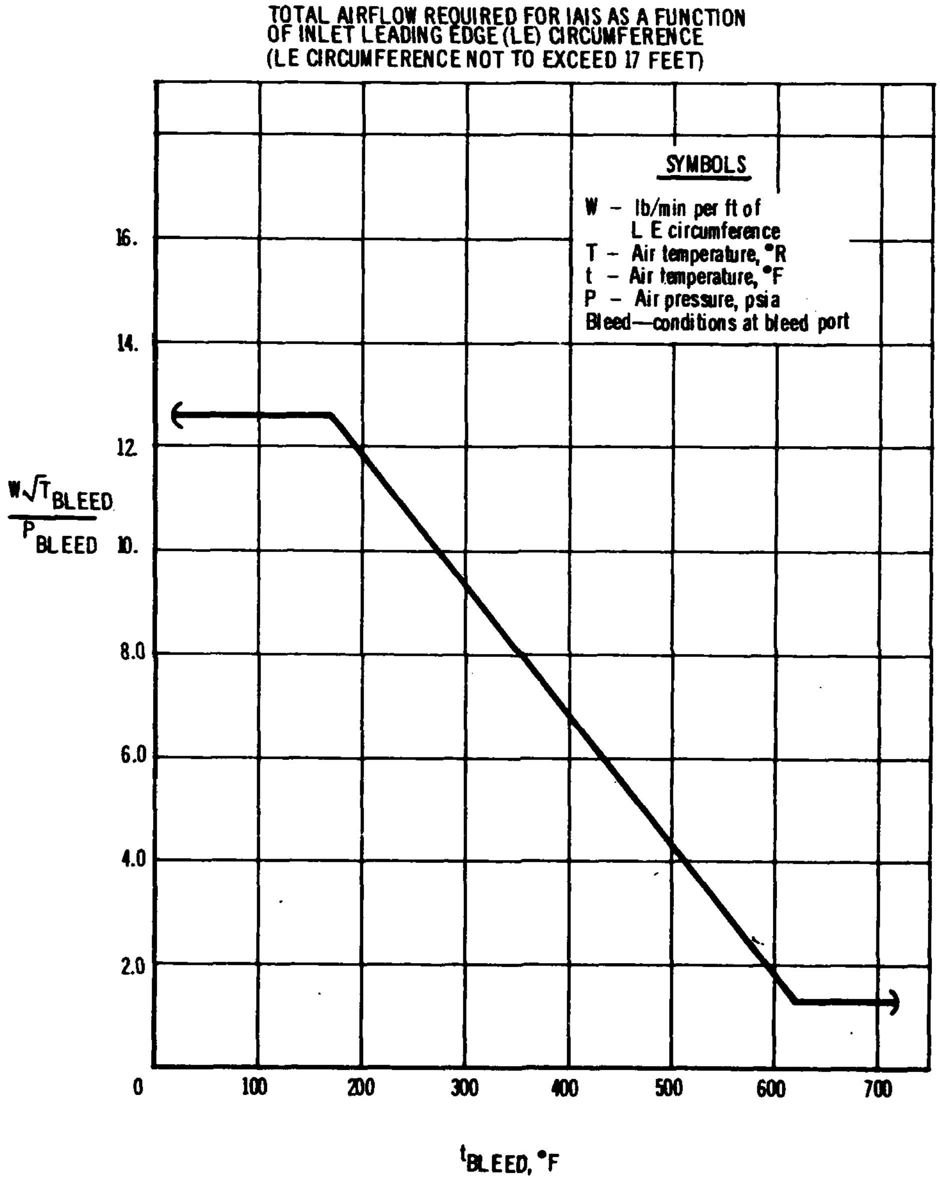


Figure 4. IAIS Total Airflow Requirements for B-2707 (G.E.)

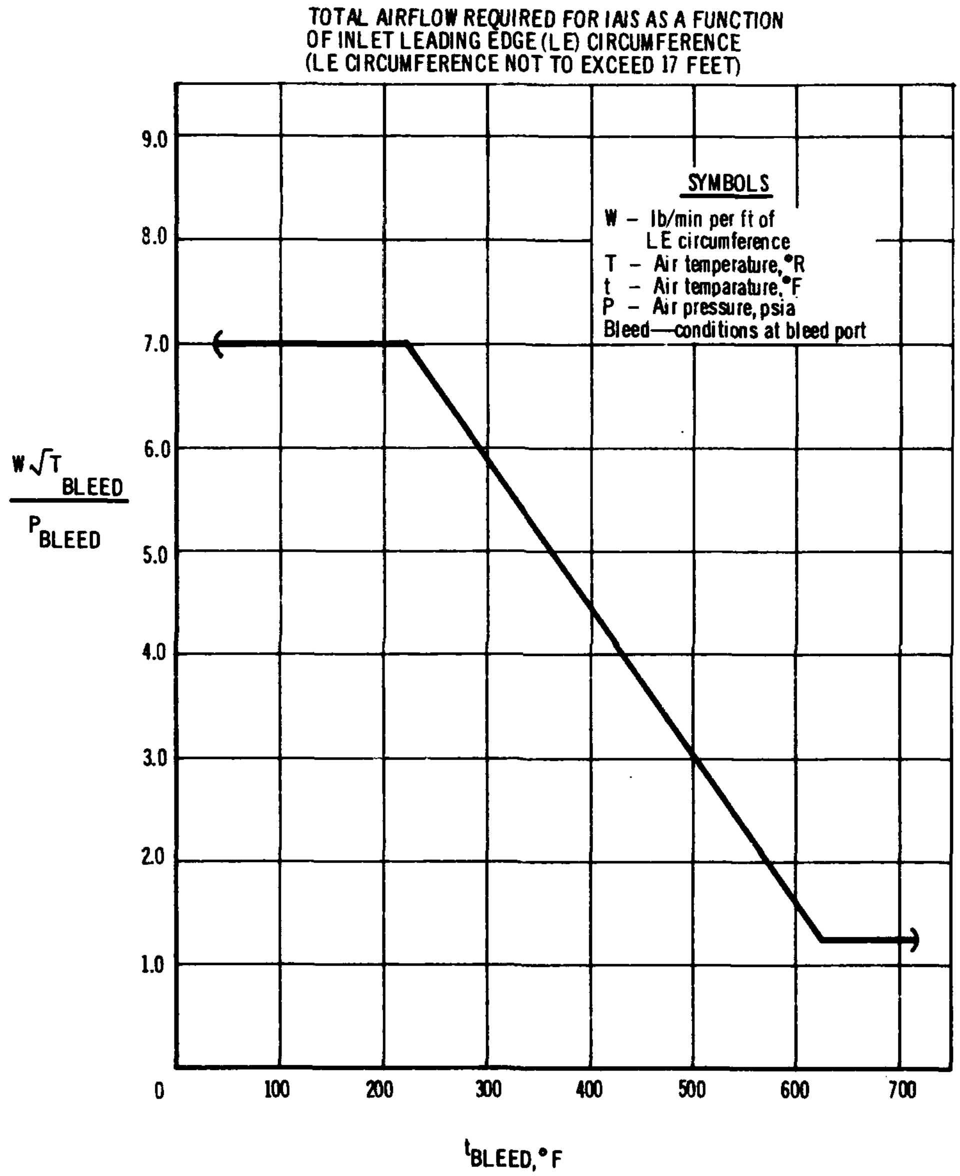
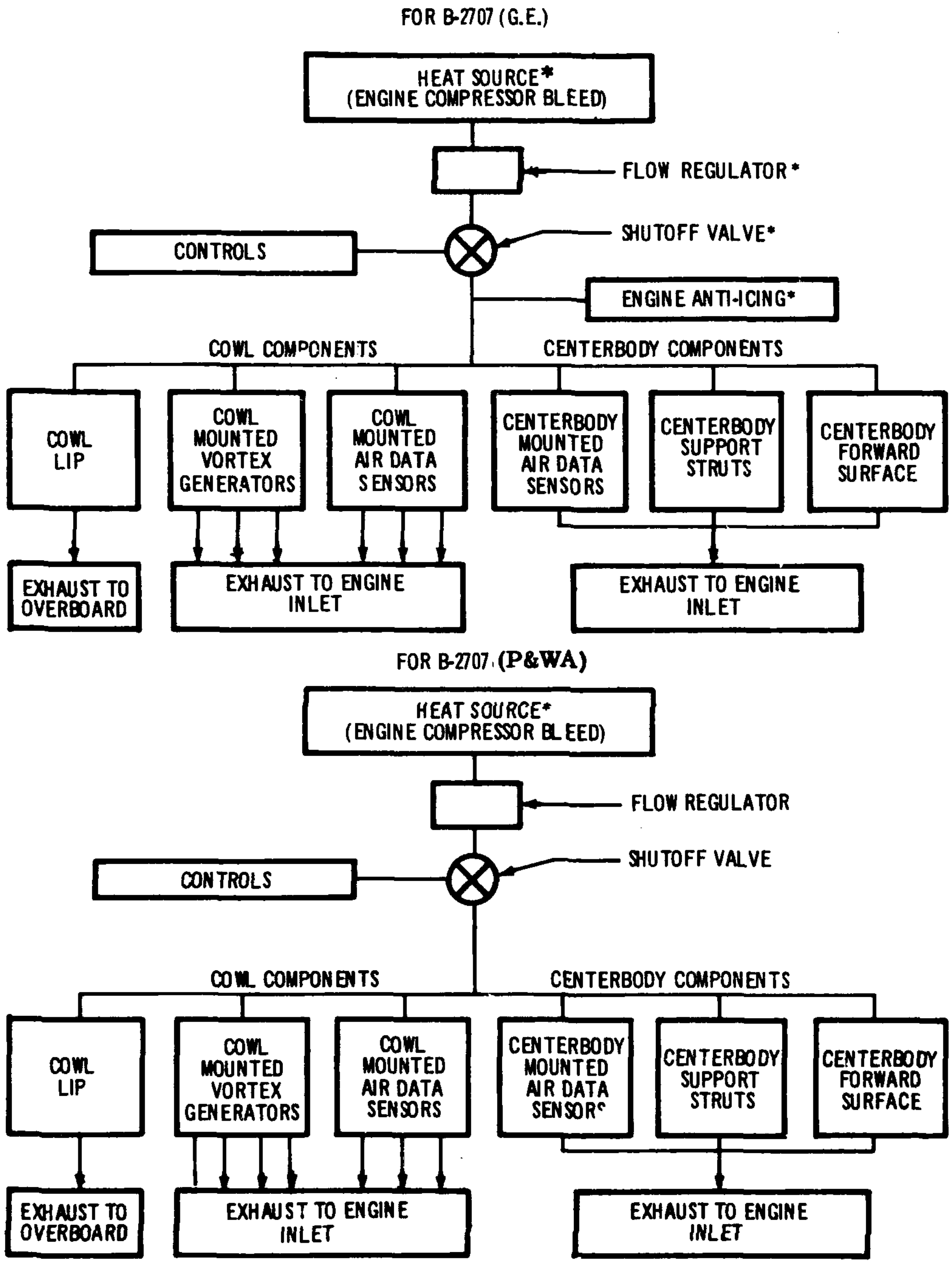


Figure 5. IAIS Total Airflow Requirements for B-2707 (P&WA)



* PROVIDED BY ENGINE MANUFACTURER.

Figure 6. IAIS Design Features

3.3.1.2 Air Supply and Distribution. The anti-icing air shall be directed forward in a supply manifold from the bleed-air source through the regulator and shutoff valves to distribution ducts for cowl and centerbody anti-icing.

a. For B-2707 (G.E.)—The distribution duct for engine anti-icing protection manifolds from the supply duct aft of the engine face and continues to the engine manufacturer-supplied components.

b. For B-2707 (G.E.) and (P&WA)—The distribution duct for anti-icing to the cowl components shall pass forward near the top of the nacelle to the cowl-mounted air data sensor probes and to circumferential distribution ducts which supply the cowl-mounted vortex generators and the cowl lip inside surface and leading edge.

3.3.1.3 Anti-Icing Air Exhaust. The spent anti-icing air shall be exhausted from the various components as follows:

a. Cowl lip—to the outside of the nacelle at the forward end of the cowl lip.

b. Cowl-mounted air data sensor probes and vortex generators—to the inlet from the individual components.

c. Centerbody components from a manifold to the inlet through the centerbody boundary layer bleed holes.

3.3.1.4 Air Supply Components. All air supply components (ducts, valves, regulators) shall be designed and installed to conform to the following:

a. No single failure of an air supply component shall result in overheating of any engine or inlet structure or other component that would result in damage to the engine.

b. Stainless steel or titanium shall be used for all supply air ducts.

c. Air supply components shall be designed to minimize local high-velocity airflows and have minimum leakage.

d. Flow-regulating devices shall have a minimum area position so that regulator failure will not result in complete loss of anti-icing capabilities.

e. The shutoff valve shall be designed to fail in the closed position.

f. The capabilities of dispatch and continuation of the normal flight plan with a shutoff valve failed open shall be design objectives.

g. Proof Pressure—Components shall withstand without permanent deformation the greater of either.

(1) 1.5 times the maximum normal operating pressure at the associated temperature for the maximum stress pressure-temperature combination.

(2) 1.1 times the pressure at the associated temperature for the maximum stress pressure-temperature combination to which the component could be exposed in the event of failure of an upstream pressure regulating device.

h. Burst Pressure—Components shall withstand without rupture the greater of either

(1) 2.5 times the maximum normal operating pressure at the associated temperature for the maximum stress pressure-temperature combination.

(2) 1.5 times the pressure at the associated temperature for the maximum stress pressure-temperature combination to which the component could be exposed in the event of failure of an upstream pressure regulating device.

3.3.1.5 Controls. Subsystem design shall conform to the following:

a. Anti-icing airflow shall be controlled by a 115-volt ac 400-cps electrically actuated shutoff valve and a temperature-actuated regulator valve.

b. A separate control circuit shall be provided for each engine.

c. Means shall be provided in the flight deck to indicate system operation when an anti-icing air shutoff valve is open.

3.3.1.6 Weight. To be added.

3.3.2 Selection of Specification. Refer to Par. 3.3.2 of D6A10107-1.

3.3.3 Materials, Parts, and Processes. Refer to Par. 3.3.3 of D6A10107-1.

3.3.4 Standard and Commercial Parts. Refer to Par. 3.3.4 of D6A10107-1.

3.3.5 Moisture and Fungus Resistance. Refer to Par. 3.3.5 of D6A10107-1

3.3.6 Corrosion of Metal Parts. Refer to Par. 3.3.6 of D6A10107-1.

3.3.7 Interchangeability and Replacement. Refer to Par. 3.3.7 of D6A10107-1.

3.3.8 Workmanship. Refer to Par. 3.3.8 of D6A10107-1.

3.3.9 Electromagnetic Interference. Refer to Par. 3.3.9 of D6A10107-1.

3.3.10 Identification and Marking. Refer to Par. 3.3.10 of D6A10107-1.

3.3.11 Storage. Refer to Par. 3.3.11 of D6A10107-1.

4.0 QUALITY ASSURANCE

4.1 ENGINEERING TEST AND EVALUATION. The following tests shall be conducted to support the design and development of this subsystem.

4.1.1 Icing Tunnel Tests. Tests shall be conducted in an icing tunnel to establish and demonstrate subsystem performance. (See Pars. 3.1.1 and 3.1.1.1.)

4.1.2 Engine Tests. Dry-air tests shall be conducted on a ground-test-mounted engine to demonstrate and verify subsystem performance and safety of operation. Surface temperature and anti-icing airflow temperatures and pressures shall be measured at various engine power settings. (See Pars. 3.1.1.1, 3.1.2.2.1, 3.3.1, 3.3.1.1, 3.3.1.2, and 3.3.1.3.)

4.2 PRELIMINARY QUALIFICATION TESTS. Not applicable.

4.3 FORMAL QUALIFICATION.

4.3.1 Inspection. Subsystem components shall be inspected before and after installation in the airplane to ensure conformity with the applicable requirements of Pars. 3.1.2.2.2, 3.1.2.5, 3.1.2.6.2, 3.2.1.1, 3.2.1.2, 3.3.1, 3.3.1.2, 3.3.1.3, 3.3.1.4, and 3.3.1.5.

4.3.2 Analyses. Analyses shall be conducted as follows:

a. To establish performance over the entire envelope of the FAR 25 icing conditions in all applicable flight conditions. (See Pars. 3.1.1, 3.1.1.1, 3.2.1.2, 3.2.1.2.1, 3.2.1.2.2, and 3.3.1.1)

b. To establish airflow characteristics, including detailed pressure drop analysis of subsystem and supply components to verify compliance with the requirements of Pars. 3.2.1.2, 3.2.1.2.1, 3.2.1.2.2, 3.3.1.2, 3.3.1.3, 3.3.1.4, and 3.3.1.5.

c. To establish verification of the following paragraphs: 3.1.2.2, 3.1.2.2.1, 3.1.2.2.2, 3.1.2.3, 3.1.2.4.1, 3.1.2.4.2, 3.1.2.4.3, 3.1.2.4.4, 3.1.2.4.5, 3.1.2.4.6, 3.1.2.4.7, 3.3.1.6, 3.3.2, 3.3.3, 3.3.4, 3.3.5, 3.3.6, 3.3.7, 3.3.8, 3.3.9, 3.3.10, and 3.3.11.

Data from subsystem tests, tests conducted by component suppliers and from tests and performance on in-service commercial jets, may be used in the analyses.

4.3.3 Demonstration. System operation shall be demonstrated in the tests described in Pars. 4.1 and 4.3.4.

4.3.4 Tests.

4.3.4.1 Airplane Tests. Dry-air ground and flight tests shall be conducted to verify and demonstrate system performance. Heated surface temperatures shall be measured at various power settings and flight conditions. (See Pars. 3.1.1.1, 3.1.2.6.1, 3.3.1, 3.3.1.1, 3.3.1.2, and 3.3.1.3.)

4.3.4.2 Natural Icing Flight Tests. Natural icing flight tests shall be conducted to demonstrate system capabilities. Heated surface temperatures shall be measured and the extent of ice formations on unheated surfaces shall be evaluated. (See Pars. 3.1.1, 3.1.1.1, and 3.3.1.)

4.4 RELIABILITY TESTS. Tests specifically designed to verify the reliability of the subsystem will not be conducted. The results of tests conducted under Pars. 4.1.2, 4.3.2, 4.3.4.1, and 4.3.4.2 shall be used in the analyses of the reliability and confidence levels of the subsystem.

4.5 CROSS-REFERENCE INDEX. The paragraphs in Section 4.0 which give the means of verification for each paragraph of Section 3.0 are identified in the Verification Cross-Reference Index (Table III).

Table III Verification Cross-Reference Index

TITLE	REQUIREMENTS PARAGRAPH NO.	VERIFICATION PARAGRAPH NO.
Functional Characteristics	3.1.1	4.1.1, 4.3.2, 4.3.4.1, 4.3.4.2
Subsystem Performance	3.1.1.1	4.1.1, 4.1.2, 4.3.2, 4.3.4.1
Reliability	3.1.2.1	4.4
Maintainability	3.1.2.2	4.3.2
Maintenance and Repair Cycle	3.1.2.2.1	4.3.2
Service and Access	3.1.2.2.2	4.3.2
Useful Life	3.1.2.3	4.3.2
Pressures and Temperatures	3.1.2.4.1	4.3.2
Ozone	3.1.2.4.2	4.3.2
Vibration	3.1.2.4.3	4.3.2
Sand and Dust	3.1.2.4.4	4.3.2
Humidity	3.1.2.4.5	4.3.2
Salt Atmosphere	3.1.2.4.6	4.3.2
Flight Safety	3.1.2.6.1	4.1.2, 4.3.2, 4.3.4.1
Ground Safety	3.1.2.6.2	4.1.2, 4.3.2, 4.3.4.1
Personnel Safety	3.1.2.6.3	4.3.1
Schematic Arrangement	3.2.1.1	4.3.1
Detailed Interface Definition (DIF)	3.2.1.2	4.3.1, 4.3.2
DIF—B-2707 (G.E.)	3.2.1.2.1	4.3.2

Table III (Cont.)

TITLE	REQUIREMENTS PARAGRAPH NO.	VERIFICATION PARAGRAPH NO.
DIF—B-2707 (P&WA)	3.2.1.2.2	4.3.2
Subsystem Design Features	3.3.1	4.1.2, 4.3.1, 4.3.4.2
Protected Surfaces	3.3.1.1	4.1.2, 4.3.4.1
Air Supply and Distribution	3.3.1.2	4.1.2, 4.3.1, 4.3.2
Anti-Icing Air Exhaust	3.3.1.3	4.1.2, 4.3.1, 4.3.2
Air Supply Components	3.3.1.4	4.3.1, 4.3.2
Controls	3.3.1.5	4.3.1, 4.3.2
Weight	3.3.1.6	4.3.2
Selection of Specification	3.3.2	4.3.2
Materials, Parts, and Process	3.3.3	4.3.2
Standard and Commercial Parts	3.3.4	4.3.2
Moisture and Fungus Resistance	3.3.5	4.3.2
Corrosion of Metal Parts	3.3.6	4.3.2
Interchangeability and Replacement	3.3.7	4.3.2
Workmanship	3.3.8	4.3.2
Electromagnetic Interference	3.3.9	4.3.2
Identification and Marking	3.3.10	4.3.2
Storage	3.3.11	4.3.2

D6A10117-1

5.0 ADDITIONAL DATA

Not applicable.

SUPPLEMENT I

This supplement describes the requirements and their verification for the production airplanes that are different from those of the prototype airplanes. The following paragraph numbers refer to corresponding numbers in the subsystem specification.

4.0 QUALITY ASSURANCE PROVISIONS

The IAIS for the production airplane shall be certified to the applicable FAR standards. A design analysis based on the tests and analyses of Pars. 4.1 and 4.3 shall be used to show compliance with FAR 25.1419, .1093, and .1309.