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Survey of Transport Airplane Structural Repairs and Alterations

February 2015

Final Report

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16. Abstract

As part of the reevaluation of widespread fatigue damage (WFD) and the associated notice of proposed rulemaking and reevaluation, the Federal Aviation Administration (FAA) determined that additional research was needed to better understand the WFD risks for repairs, alterations, and modifications (RAM). For this research, the Airworthiness Assurance NDI Validation Center (AANC) at Sandia National Laboratories conducted field and teardown surveys of RAM on transport category airplanes. Field surveys documented 2612 individual RAM on 154 transport airplanes, most of which were in-service airplanes. Field surveys occurred during heavy maintenance visits whenever possible to allow for full access to RAM. Field survey data on RAM pertain to their number, size, location, age, engineering, quality of installation, durability, and other physical aspects. In some instances, the data gathered included the results of repair assessment evaluations conducted by the operators. Summary results from the field survey are discussed. Additionally, AANC conducted in-depth teardown surveys on 22 structures removed from retired airplanes that contained RAM. Field and teardown survey data pertaining to the observed occurrence of fatigue cracking in baseline structures and RAM were documented in two databases that were delivered to the FAA. No multiple site damage or multiple element damage was observed in any RAM surveyed.

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LIST OF SYMBOLS AND ACRONYMS

mg	Mercury
A&P	Airframe and Propulsion
AANC	Airworthiness Assurance NDI Validation Center
AAWG	Airworthiness Assurance Working Group
A/C	Aircraft
AC	Advisory Circular
AD	Airworthiness Directives
A4A	Airlines for America
BHEC	Bolt-hole eddy current
CFR	Code of Federal Regulations
DAH	Design approval holder
DER	Designated engineering representative
DVI	Detailed visual inspection
ET	Eddy current testing
FAA	Federal Aviation Administration
FASTER	Full-Scale Aircraft Structural Test Evaluation and Research
FC	Flight cycles
FH	Flight hours
LR	Large repair
MED	Multiple element damage
MSD	Multiple site damage
NPRM	Notice of proposed rulemaking
OEM	Original equipment manufacturer
RAG	Repair assessment guidelines
RAM	Repairs, Alterations, and Modifications
SB	Service Bulletin
SDR	Service difficulty report
SRM	Structural repair manual
STC	Supplemental Type Certificate
WFD	Widespread fatigue damage

EXECUTIVE SUMMARY

A phenomenon referred to as widespread fatigue damage (WFD) is identified as a severe, degraded condition that threatens continued airworthiness of an airplane. This condition is theoretically inevitable and will be reached at some point in the life of an airplane structure. Multiple site damage (MSD) is a source of WFD characterized by the simultaneous presence of fatigue cracks in similar adjacent structural elements, such as multiple fastener holes in a single rivet line of a lap splice joining two large skin panels. Multiple element damage (MED) is a source of WFD characterized by the simultaneous presence of fatigue cracks in similar adjacent structural elements, such as fuselage frames. A major concern regarding WFD is that cracks are initially so small that they cannot be reliably detected with existing inspection methods. Without intervention, they will continue to grow and will eventually compromise the structural integrity of the airplane before the cracking can be reliably detected. To address this safety concern, the Federal Aviation Administration (FAA) issued a Notice of Proposed Rulemaking (NPRM) on WFD in April 2006. The NPRM on WFD proposed that, for certain transport category airplanes, design approval holders (DAH) must establish a period of time for which it can be demonstrated that the maintenance program is sufficient to preclude WFD in baseline airplane structure, as well as in certain repairs, alterations, and modifications (RAM). Comments to the NPRM suggested that WFD assessments should be focused on baseline structure and that WFD assessments of RAM should be deferred until additional information is gathered. The FAA concurred with the commenters. The final rule requires DAHs to perform WFD assessments of baseline structure to establish a limit of validity of the engineering data that support the structural maintenance program for affected airplanes.

As part of the Widespread Fatigue Damage Rule NPRM reevaluation, the FAA determined that additional research was needed to better understand the WFD risks for RAM. For this research, the Airworthiness Assurance NDI Validation Center (AANC) at Sandia National Laboratories conducted field and teardown surveys of RAM on transport category airplanes. Field surveys documented 2612 individual RAM on 154 transport airplanes, most of which were in-service airplanes. Field surveys occurred during heavy maintenance visits whenever possible to allow for full access to RAM. Field survey data on RAM pertain to their number, size, location, age, engineering, quality of installation, durability, and other physical aspects. In some instances, the data gathered included the results of repair assessment evaluations conducted by the operators. Summary results from the field survey are discussed. Additionally, AANC conducted in-depth teardown surveys on 22 structures containing RAM, which were removed from retired airplanes. Field and teardown survey data pertaining to the observed occurrence of fatigue cracking in baseline structures and RAM were documented in two databases that were delivered to the FAA. No MSD or MED was observed in any RAM surveyed.

1. INTRODUCTION

Structural fatigue has long been recognized as a significant threat to the continued airworthiness of airplanes. This is because even small fatigue cracks can significantly reduce the strength of airplane structure when they occur in multiple locations at the same time in structural elements that contribute significantly to the carrying of flight, ground, or pressurization loads. These elements are referred to as principle structural elements and are essential in maintaining the overall structural integrity of the airplane. Consistent with this fact, the airworthiness standards for certification of new transport category airplanes have addressed fatigue for over 50 years with the intent of preventing catastrophic failures throughout the anticipated operational life of the airplane. These standards have evolved over time as the relevant knowledge-base has increased. For further discussion on the evolution of the fatigue certification standards, see the Damage Tolerance Data for Repairs and Alterations rule [1], along with Advisory Circular (AC) 120-93 [2] and AC 120-104 [3], entitled "Damage Tolerance Inspections for Repairs and Alterations" and "Establishing and Implementing Limit of Validity to Prevent Widespread Fatigue Damage," respectively.

Concern about the continued airworthiness of aging airplanes was brought to the forefront of public attention in 1988, when an 18-foot-long crown section of the fuselage was torn off a B737 during flight. The airplane had been in service for 19 years and had accumulated more than 35,000 flight hours (FH) and more than 89,000 flight cycles (FC). At the time of the accident, it was the second most used airplane in the Boeing 737 fleet, operating beyond its original design service goal of 75,000 FC. Subsequent investigations showed that there were many small cracks growing from adjacent rivet holes in the disbonded lap joint. These cracks were very small and not reliably detectable by the means of inspection used at that time. By themselves, as individual cracks acting alone, they would not have posed a problem. However, because there were so many cracks in adjacent rivet holes, they interacted and caused an unzipping effect along the lap joint just above the window belt.

That accident precipitated actions that led to changes to the airworthiness standards for addressing structural fatigue in existing and future airplanes. Among other things, a phenomenon referred to as widespread fatigue damage (WFD) was defined as a condition that threatens the continued airworthiness of airplanes and is a result of many small cracks that are typically too small initially to be reliably detected with normal inspection methods. Without intervention, these cracks grow rapidly, and eventually compromise the structural integrity of the airplane. WFD is increasingly likely as the airplane ages, and is certain to occur if the airplane is operated long enough without intervention. The Federal Aviation Administration (FAA) has defined WFD as the simultaneous presence of cracks at multiple structural locations that are of such size and density that the structure can no longer maintain residual strength. Sources of WFD are:

- Multiple Site Damage (MSD): A source of WFD characterized by the simultaneous presence of fatigue cracks in the same structural element

- Multiple Element Damage (MED): A source of WFD characterized by the simultaneous presence of fatigue cracks in adjacent structural elements

Both MSD and MED initiate, spread, and can eventually develop into WFD.

Immediately following the Aloha Airlines Flight 243 accident in 1988, Congress passed the Aviation Safety Research Act, which increased the scope of the FAA's mission to include research of structural fatigue degradation and to develop maintenance technologies to counter this threat. Along with expanding that scope, Congress funded FAA research on aging aircraft issues. In response, the FAA began the National Aging Aircraft Research Program in 1989. The initial charter was to conduct research addressing WFD, its effect on structural integrity of airframe structure, and its methods of detection. Research efforts sponsored by the FAA demonstrated the unsafe condition of MSD development. Fuselage structural tests done in the FAA's Full-Scale Aircraft Structural Test Evaluation and Research (FASTER) laboratory, and conducted by other organizations, revealed that MSD significantly reduces the fatigue life by as much as 37% and residual strength by 20% [4]. In addition, research efforts also demonstrated that MSD cannot be effectively managed through inspections. Once MSD develops, the structural integrity rapidly deteriorates.

In addition, the FAA and other national aviation authorities issued regulations and guidance materials to address long-term airworthiness issues in airplane structure that result from aging. The regulations mandated programs developed by industry for existing transport category airplanes, or their equivalent, for new transport category airplanes. Those programs included the Supplemental Structural Inspection Program, the Mandatory Modification Program, the Repair Assessment Program, the Corrosion Prevention and Control Program, and the Aging Airplane Safety Rule (which addresses RAM). AC 91-56B [5] and 120-93 [2] provide further discussion on the Aging Aircraft Program for structures.

In 1998, the FAA amended Title 14 Code of Federal Regulations (CFR) 25.571 (Amendment 25-96) of the aircraft certification requirements for transport category airplanes. Under this amendment, the FAA introduced the term "widespread fatigue damage (WFD)" into 14 CFR 25.571. As part of the certification process, 14 CFR 25.571 requires full-scale fatigue test evidence to demonstrate that WFD will not occur before an airplane reaches its design service goal [6].

In 2004, the FAA provided an update on its Aging Airplane Program [7]. Among other things, the FAA decided to align the compliance dates and actions, where practical, on existing rules and pending proposals that make up the Aging Airplane Program. The WFD notice of proposed rulemaking (NPRM) was identified as one of the pending proposals. The WFD NPRM was published in the Federal Register on April 18, 2006 [8]. The proposal required certain design approval holders to establish operational limits for certain transport category airplanes. The term "initial operational limit" was changed in the final rule to "limit of validity" of the engineering data that support the structural maintenance program. The proposal also required actions to prevent WFD in RAM to these airplanes.

Subsequent to the issuance of the WFD NPRM, the comments and feedback received during the comment period suggested that WFD assessments of repairs and alterations or modifications be deferred until sufficient data were acquired [9]. There was a general agreement among industry stakeholders that there was a low risk of WFD occurring in RAM, and a few of these

stakeholders stated that the FAA should reconsider its decision to remove from the rule the requirements for evaluating certain RAM because there is a technical possibility of a WFD-related accident involving a RAM. Despite this fact, public comments suggested there was insufficient fleet evidence to support a requirement for WFD assessments of RAM. As stated in the WFD final rule, there are no recorded accidents attributed to WFD occurring in properly installed RAM. Additionally, industry stakeholders felt that the costs of including RAM in the rule outweighed the benefits. They further stated that there are limited resources, in terms of manpower, funding, and knowledge, to perform WFD assessments to meet the requirements. Based on this information, the FAA concurred that WFD assessments be focused on baseline structure only and removed most requirements pertaining to WFD evaluations of RAM.

The FAA stated in the WFD final rule that additional data are necessary to further understand the risks posed by RAM for developing WFD. The FAA funded this research to get a better understanding of those risks. This report describes the research tasks performed and the results.

A team composed of personnel from both AANC and FAA (hereafter referred to as the RAM team) met and jointly developed project goals, tasks, and deliverables. The general tasks identified by the team included:

1. Survey existing aviation safety databases for WFD trends
2. Perform field surveys of in-service airplanes
3. Perform teardown inspections of several large RAM
4. Compile field survey and teardown inspection data

Detailed project tasks were performed by the Sandia National Laboratories' Airworthiness Assurance NDI Validation Center (AANC) team, and included conducting a survey of aviation safety databases, a field survey of retired and in-service airplanes, and a teardown survey of retired and salvaged airplanes. Quantitative data were collected for the FAA to use in determining the:

1. range and average number of RAM per surveyed airplane.

2. size of RAM.

3. quality of each repair (1 being the best and 5 the worst).

4. range and average age of RAM in FH and FC (number of FC or FH relative to design service goal or RAM design life).

5. location of RAM on the airplane (relative to major structural elements, load and fatigue sensitivity drivers, and other adjacent repairs).

6. source of data, if available, that substantiated the installation of RAM (e.g., structural repair manual (SRM), Service Bulletin (SB), Designated Engineering Representative, or engineering change order).

7. reason(s) for each RAM installation (e.g., repair versus intentional modification.).

8. occurrence of any damage subsequent to any RAM installation, especially fatigue cracking.

This project began in 2008 with field surveys of retired airplanes. Field surveys of existing RAM on in-service airplanes became a much larger part of the project, becoming the primary activity in 2009 and 2010. An acquisition and teardown survey of select structures was conducted later in the project, culminating in 2011. During that time, a total of 154 transport airplanes were surveyed, with data collected on 2612 individual RAM. Additionally, 22 RAM specimens were collected from 12 retired airplanes and underwent teardown inspections. No MSD/MED was observed and, overall, little fatigue cracking was discovered. Extensive databases of all data collected were delivered to the FAA for field surveys and teardown inspections, and sanitized versions of those databases are included in appendices to this report.

2. SURVEY OF AVIATION SAFETY DATABASES

This project phase was originally conceived to survey and analyze existing aviation safety data sources, including Airworthiness Directives (AD), Service difficulty reports (SDR), and any existing repair records addressing structural fatigue of transport category airplanes to identify significant WFD trends in RAM on specific airplane models. The survey was expected to produce a large volume of useful data. However, the survey efforts revealed extensive inconsistencies in AD and SD reporting practices. As shown in figure 1, most of the information fields in the reports were often left blank, and most of the useful information was written into the comment fields. Thus, the organizational aspect of the reports that would have allowed easy sorting for occurrences of fatigue damage was not available. The number and variety of terms that can be used to describe fatigue damage coupled with the variability of grammar and usage meant that most documents would eventually require individual review, making data analysis and interpretation a much more time-consuming task than the funding and schedule for the project would allow.

Querying these fields for key phrases and indicators proved nearly impossible without significant expenditures for specialized search software development. Data analysis experts at Sandia attempted to use conventional sorting and filtering software to extract information on the occurrence of fatigue crack references in the SDRs, but had little success because of the inconsistent manner in which data were entered into SDRs. After review of more than 400,000 reports issued since 1985 across a broad range of transport category airplanes, AANC concluded that the data could not be interpreted in any meaningful manner. Because no statistically significant information could be derived from the reports, the SDR database survey was terminated and focus on field and teardown surveys was increased.

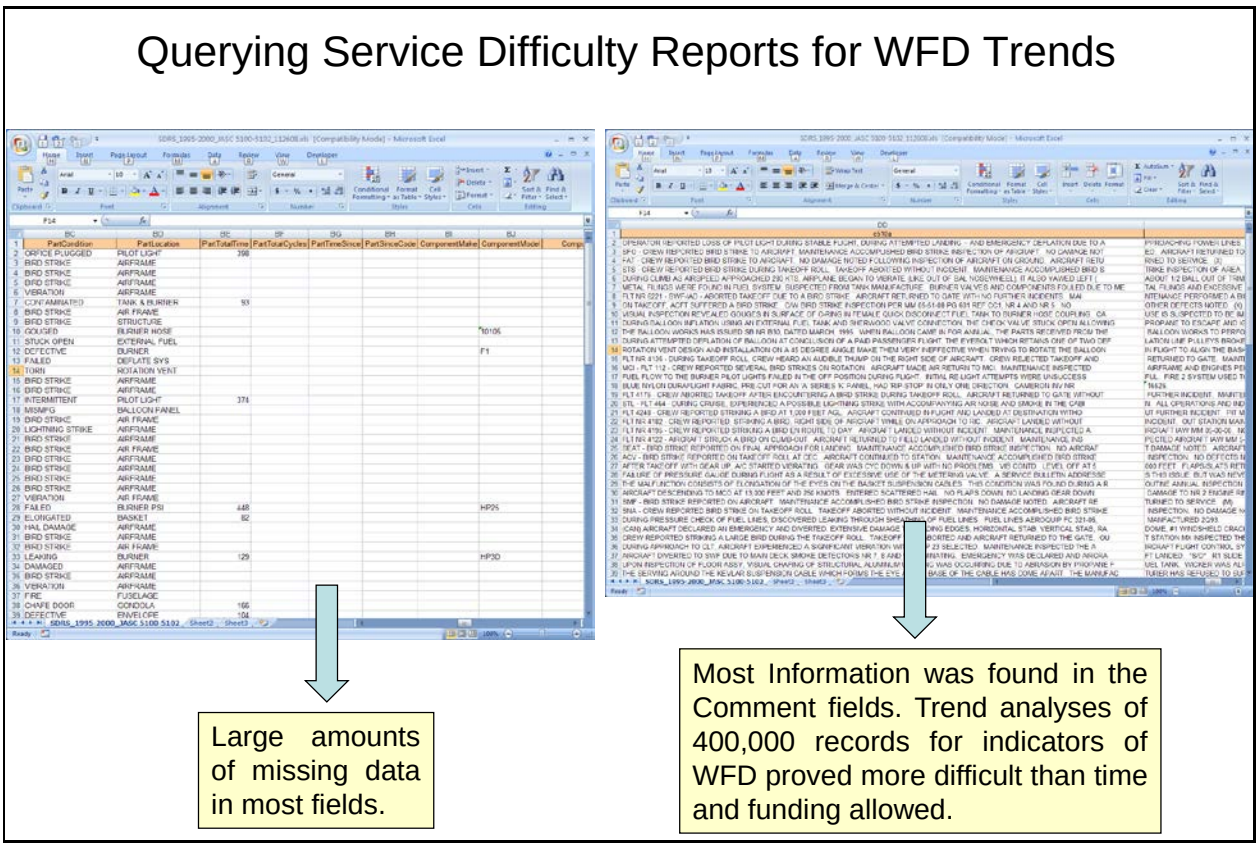


Figure 1. Example of Service Difficulty Reporting Data Analysis Difficulties

3. 1990'S AIRWORTHINESS ASSURANCE WORKING GROUP REPAIR SURVEYS

During the mid-1990's, there was recognition and concern that the large majority of repairs being made on commercial transport airplanes were pressure vessel repairs to the lower fuselage, particularly around door openings. There was concern that repairs to the fuselage could suffer from increased fatigue damage, especially around door openings or in close proximity to a number of other repairs, or if an individual repair was especially large. Therefore, the Airworthiness Assurance Working Group (AAWG) performed a series of field inspections on retired and in-service airplanes, examining the condition of fuselage repairs on 65 airplanes [10]. The AAWG conducted two separate surveys to collect data on the occurrence of fatigue damage or cracking in or around the repairs. In 1992, a fuselage repair survey of stored airplanes was conducted, followed by a repair survey of in-service airplanes in 1994.

The 1992 AAWG Survey included information from airplanes stored at Mojave, California and Amarillo, Texas, and was conducted by five survey teams, each with five engineering representatives from various FAA airplane certification offices, FAA flight standards offices, airplane operators, and airplane manufacturers. Surveys were conducted only on fuselage repairs located below the window belt of airplanes. A total of 356 repairs on 30 airplanes was evaluated over a 3-day period. The scope of 1992 repair surveys included external visual observation of external lower fuselage plating repairs. Inspections were designed to be conducted quickly, with no more than a workstand and light.

The purpose of the 1992 repair surveys was to observe typical repairs firsthand, including numbers, types, proximity, and condition of repairs. Additional purposes were to identify SRM repairs requiring additional attention to ensure continued airworthiness, to observe any repairs that were below SRM standards, and to develop a qualitative opinion of the AAWG's concerns for repairs as a safety issue, if any. The disposition of the 1992 survey findings included documenting the observations in a standard way relative to damage tolerance requirements that could be combined across all original equipment manufacturers (OEM) and making recommendations for further effort as appropriate. The AAWG team procedures included the visual survey and documentation of lower surface fuselage repairs and categorizing those repairs into three groups using engineering judgment and applicable AAWG screening criteria as follows:

- No additional action required (class A)
- Repair requiring supplemental inspection for damage tolerance or additional rework (class B and C)
- Repair not meeting the minimum requirements of a class C repair (remove and replace with class A, B, or C repair prior to return to service)
- Summary of data findings

The 1994 AAWG survey information included the survey of airplanes being operated by airlines and was conducted by OEMs at heavy maintenance locations, including those of the Boeing Company, Airbus®, Douglas, and Lockheed Martin®. A total of 695 repairs on 35 airplanes was surveyed, which included all areas of the airframe. The overall summary of 1994 AAWG survey results was based on AAWG repair criteria with OEM size and proximity limits, including the inspection of 65 airplanes in the quantities for each type or model shown in table 1.

Table 1. Quantity of Each Airplane Type Surveyed by AAWG in 1994

Quantity	Airplane Type
13	727
9	737
7	747
3	DC-8
10	DC-9
4	DC-10
9	A300
2	L-1011
8	F-28

Table 2 shows the overall results of the combined AAWG Repair Surveys of Transport Airplanes. In the combined survey, a total of 1051 repairs was assessed on 65 airplanes with a

distribution of 40% class A and 60% class B/C repairs. There was an average of 16 repairs per airplane. Generally, the repairs were of good quality and appeared to comply with SRM and the size/proximity criteria determined almost all class B/C repairs. No repair or airplane age data were published in the final reports, nor were size or proximity data.

Table 2. Overall Results of Combined AAWG Repair Surveys of Transport Airplanes

		Repair Classification		
Airplane Model	Airplanes Surveyed ('92/'94/Total)	Repairs Requiring No Additional Action (Class A) ('92/'94/Total)	Repairs Requiring Supplemental Inspections (Class B or C) ('92/'94/Total)	Total Repairs Surveyed ('92/'94/Total)
727	6/7/13	39/100/139	66/109/175	105/209/314
737	5/4/9	41/17/58	49/66/115	90/83/173
747	2/5/7	13/37/50	32/130/162	45/167/212
DC 8	0/3/3	0/56/56	0/43/43	0/99/99
DC 9	6/4/10	21/37/58	32/16/48	53/53/106
DC-10	0/4/4	1/12/13	0/21/21	0/33/33
A-300	9/0/9	17/0/17	18/0/18	35/0/35
L-1011	2/0/2	12/0/12	16/0/16	28/0/28
F-28	0/8/8	0/10/10	0/41/41	0/51/51
Total	30/35/65	143/269/412	213/426/639	356/695/1051

In general, the AAWG survey conclusions were that some repairs of good quality may inhibit damage detection during normal maintenance activities and may need supplemental inspection because of size and configuration/proximity considerations. Additionally, the results did not indicate that there had been a sizable number of repairs on structure other than the fuselage. The size distribution of repairs indicated a need for assessments to establish inspection requirements for larger repairs and numbers of smaller repairs in close proximity to each other.

As a result of the AAWG repair survey, the repair assessment guidelines (RAG) were eventually developed and the Repair Assessment Program regulatory requirement was instituted. The RAM team used the 1990's AAWG repair survey as a starting point for the development of the field survey plan on in-service airplanes. Once the field survey was completed and the results were examined, it became more apparent which type of RAM and associated structures should be acquired for teardown inspections.

4. FIELD SURVEY

The purpose of this project phase was to conduct a survey of the RAM that existed in the U.S. domestic Part 121/129 air carrier transport airplane fleet. Data were obtained quantifying their condition with respect to age, location, size, and usage within the fleet. From these data, the magnitude of RAM in the fleet and their fatigue performance were estimated. The FAA used

these estimates as input to determine the risk that RAM may pose for developing WFD. Section 4.1 describes the process that was used to conduct the field survey and the data that were obtained. Quantitative data and pictorial information are presented and discussed.

4.1 FIELD SURVEY PROCESS

The field survey process considered the type of data that were needed to support the FAA's risk assessment, the analysis that was planned for those data, details of how much data was needed, the development of the plan for collecting the data, and the methods actually used for collection. Initial field surveys were performed on retired airplanes. Early results indicated that more useful data could be obtained from in-service airplanes. Thus, the bulk of the field surveys were conducted on active airplanes that were undergoing heavy maintenance at carrier maintenance facilities. The data collected in this survey were from many operators. To maintain the anonymity of the operators, the data were reported in a normalized fashion.

The FAA identified data that were needed for analyzing RAM and for understanding the risks that RAM may pose for developing WFD. To analyze RAM and understand those risks, it was the FAA's objective to estimate the number of RAM in the fleet and determine the fatigue performance of RAM. As a result, the field survey sample plan and teardown inspections plan were developed. The sample plan identified the airplane model age group and number of airplanes per operator to be surveyed. Section 4.1.1 describes the field survey sample plan and its evolution in further detail. Section 5 provides information on the teardown survey, including the process, results, and database.

It should be noted that there is much variability in fleet makeup and maintenance practices among operators. Some operators have new fleets, with one having an average age of 3.2 years. Some have older fleets, with many airplanes in active storage. Some operators perform most of their wide-body heavy maintenance overseas. All of these factors, among others, helped determine which airplanes were actually surveyed. The rationale for selecting particular airplanes is discussed in section 4.1.1 and the factors that influenced which individual airplanes were surveyed are discussed in section 4.1.2.

4.1.1 Development of Field Survey Sampling Plan

Sampling was from retired airplanes from which a subset of those specimens were returned to the AANC laboratory, where they would be disassembled and any structural defects identified and documented. With that in mind, field surveys began at salvage yards with the following results:

- Seven salvage operators were visited between December 2007 and September 2008
- 18 airplanes were surveyed
- Approximately 350 individual RAM were documented
- Maintenance records were obtained for only three airplanes at one salvage operator
- Teardown specimens were obtained from one B737 with maintenance records
- There was often no access to the inside of RAM for full characterization

Initial field surveys were performed on retired airplanes looking for certain types of Supplemental Type Certificates (STC), modified structures, and general repairs. However, it was difficult to obtain full physical access to both sides of many RAM to inspect for MSD/MED cracking. Engineering design data, as well as age and other maintenance records, were also difficult to obtain in the early field surveys on retired airplanes because most airplanes were surveyed based on random availability with a few salvage vendors. Opportunities to survey specific structures of relevance were few and far between.

As the project progressed, it became apparent that sampling only retired airplanes would not provide sufficient maintenance history information to make the project results useful. Thus, it was decided to sample primarily in-service airplanes available during heavy maintenance visits at operator maintenance bases because in-service airplanes have FAA-mandated record-keeping requirements, making it easier to obtain specific maintenance data for individual RAM.

An iterative process was used to develop a sampling plan based on the demographics of the U.S. domestic fleet. A total of 154 airplanes was sampled, 18 of which were retired and 136 of which were active in-service airplanes.

A sampling plan was then developed based on collecting a representative sample of the entire population of the U.S. domestic Part 121/129 air carrier transport category airplane fleet, with a greater than 75,000 pound maximum takeoff weight. At that time, there were approximately 5015 airplanes in this U.S. domestic fleet. One FAA goal was to estimate the number of RAM per FH/FC for the entire population of airplanes in the U.S. domestic fleet. As a result, sampling was partitioned to acquire low-, mid-, and high-age airplanes for each model by considering the availability of RAM maintenance records. If maintenance records were available, only one mid- and two high-age airplane samples were planned. If maintenance records were not available, then one low-age airplane was included in the sample plan. The sampling was also constrained by the following guidelines:

- Include only metal airframe structure susceptible to WFD (appendix 5 of AC 120-104).
- Exclude landing gear, engines or propellers, safe-life parts, hydraulic devices, actuators, cable systems, etc.
- Include only the Parts 121/129 U.S. domestic fleet.
- Include only airplanes greater than 75,000 pounds maximum takeoff weight.
- Quantify the U.S. fleet using the following distribution of 5015 airplanes:
  - The number of operators was reduced to the 13 large, major carriers who have accessible repair/maintenance facilities within the U.S. They include: Air Tran, Alaska, American, Continental, Delta, Federal Express, Frontier, Jet Blue, Northwest, Southwest, United, United Parcel Service, and U.S. Airways.
  - Small operators with only a few airplanes were put into an “Others” group.

- The Airbus A300 and A310 airplanes were merged into a single A300 group.

- The Airbus A318, A319, A320, and A321 airplane series were merged into a single A320 group.

- The DC-9, DC-9-82, DC-9-83, MD-80, MD-82, MD-83, MD-88, MD-90-30, and Boeing 717 airplane series were merged into a single MD-80-90 group.

- The DC-10, MD-10, and MD-11F (stretched DC-10) airplanes were merged into a single DC-10 group.

- The regional jets (Embraer 170, 175, and 190; and Canadair CRJ-900) were moved to the "Opportunity" group because they represented very new airplanes likely to have had few, if any, RAM.

- A "Lowest Priority" group was created, consisting of Boeing 707, Lockheed C-130, and L-1011 airplanes because they were old, low-quantity, and almost out of commercial usage.

Figure 2 shows the relative numbers of each airplane model in the U.S. domestic fleet. The number of airplanes to sample from each model group was based on the relative proportion in the U.S. domestic fleet for that model or model group. The final distribution of the Part 121/129 fleet that was sampled (about 4600 airplanes) is shown in figure 3. It was recognized that certain airplanes, such as freighters, tend to be in service for a long time or are unique. One model kept was the unique B757 freighter. Although the fleet is 15 years old, the freighters will fly for a long time. Another model kept was the B747, which has a double fuselage lobe and flat skin surfaces that are unique and known to crack in those areas. Finally, the MD-11F Freighter, with an average age of 15 years, was kept in the sampling plan because they will be in service for a long time.

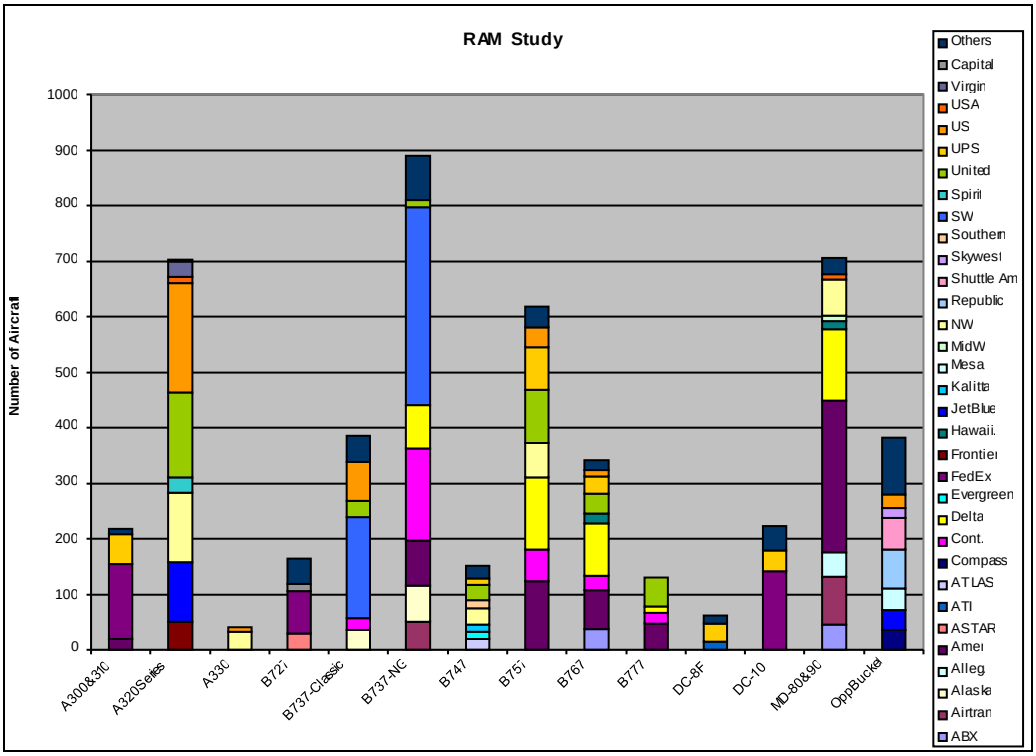


Figure 2. Distribution of the Entire Part 121/129 Fleet

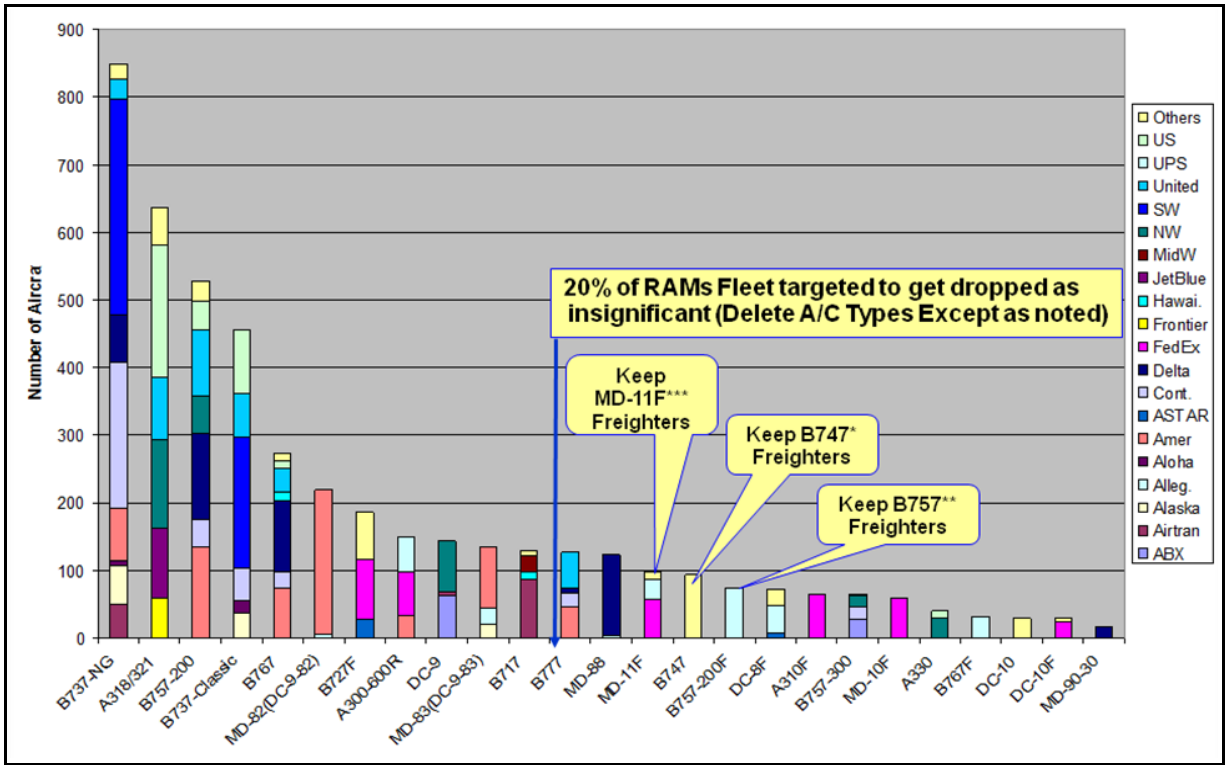


Figure 3. Distribution of the RAM Survey Part 121/129 Fleet

The final RAM sample plan included airplane models B727, B737, B747, B757, B767, DC-9, MD-80, MD-11, A300, and A320. In general, regional jets were dropped because most are below the 75,000 pound maximum takeoff weight limitation in the WFD rule. However, some of the larger regional jet models were placed in the Opportunity group. Ultimately, the total number of airplanes included in the sampling plan was 134. Table 3 shows the final distribution of models in the RAM sample plan, sorted by operator and qualitative age.

Table 3. Final RAM Sample Plan Matrix

Aircraft Type	Airtran	Alaska	American	Delta	FedEx	NW	SW	United	UPS	Total Aircraft
B737-NG		Sample 2 A/C 1 mid, 1 high	Sample 2 A/C 1 mid, 1 high	Sample 10 A/C 2 low, 2 mid, 6 high			Sample 10 A/C 2 low, 2 mid, 6 high	Sample 2 A/C 1 mid, 1 high		26
A318/321						Sample 15 A/C 3 low, 4 mid, 8 high		Sample 3 A/C 1 mid, 2 high		18
B757-200			Sample 4 A/C 1 low, 1 mid, 2 high	Sample 6 A/C 1 low, 2 mid, 3 high		Sample 2 A/C 1 mid, 1 high		Sample 3 A/C 1 mid, 2 high		15
B737-Classic		Sample 2 A/C 1 mid, 1 high					Sample 11 A/C 2 low, 3 mid, 6 high	Sample 4 A/C 2 mid, 2 high		17
B767			Sample 2 A/C 1 mid, 1 high	Sample 5 A/C 1 low, 2 mid, 2 high				Sample 2 A/C 1 mid, 1 high		9
MD-82(DC-9-82)			Sample 8 A/C 1 low, 2 mid, 5 high							8
B727F					Sample 6 A/C 2 mid, 4 high					6
A300-600R			Sample 3 A/C 1 mid, 2 high		Sample 3 A/C 1 mid, 2 high					6

Table 3. Final RAM Sample Plan Matrix (Continued)

Aircraft Type	Airtran	Alaska	American	Delta	FedEx	NW	SW	United	UPS	Total Aircraft
DC-9						Sample 6 A/C 1 low, 1 mid, 4 high				6
MD-83(DC-9-83)		Sample 2 A/C 1 mid, 1 high	Sample 5 A/C 1 low, 1 mid, 3 high							7
B717	Sample 5 A/C 1 low, 2 mid, 2 high									5
MD-11F					Sample 2 A/C 1 mid, 1 high				Sample 2 A/C 1 mid, 1 high	4
B757-200F									Sample 3 A/C 1 mid, 2 high	3
B747-200F						Sample 4 A/C 1 mid, 3 high				4
									TOTAL: 134	

A/C = Aircraft

4.1.2 Field Survey Airplane Operator Participation

A significant amount of communication and coordination was undertaken with the major air carriers to plan field survey trips based on airplane availability during heavy maintenance visits. Specific airplane models within specific age ranges were targeted in the sample plan, although they were not always available. With the cooperative participation by the operators, reasonable substitutions were possible based on relative numbers of relevant airplane models and qualitative ages, so that a representative sample of the entire U.S. domestic fleet was acquired.

Priority was given to gathering comprehensive survey data of all RAM on available airplanes, with the emphasis on surveying at least 134 of the 5015 airplanes in the fleet (2.67%) and collecting at least 2165 RAM. The focus was on the 13 primary operators and their domestic maintenance facilities.

One important goal was to survey airplanes with the maximum likelihood of having associated maintenance records available. An equally important goal was to sample planes during heavy maintenance when airplane interiors were removed and the inner surface of most RAM would be accessible. The general visual inspection process involved initial field surveys of in-service or recently retired transport airplanes from the U.S. domestic fleet, followed by maintenance record reviews for each airplane. However, because of time and cost constraints, the data mining and post-survey data collection activities were minimized to include only available records that could be readily provided by the owner or operator.

When possible, maintenance records were acquired and reviewed prior to the field surveys to obtain the:

- Total FH on airplane.
- Total FC on airplane.
- FH on RAM.
- FC on RAM.
- Date RAM were applied.
- Date airplanes were retired.
- Reason for RAM installation.
- Engineering data source for RAM.

An engineering change order or engineering authorization contained considerably more detailed information than an SRM authorized repair entry in a general maintenance log book. Engineering documents were often easier to obtain than general log book entries from SRM repairs because of FAA record-keeping requirements. Although operators must keep records of all maintenance, the usual practice is to place records from SRM repairs into long-term storage after 1 year.

Most operators were not willing to provide the labor needed to access all maintenance records, particularly those in long term storage. However, they were willing to supply maintenance records when they were readily available, such as with engineering change orders, or if they were available because an electronic record-keeping system was in place. A noteworthy best

practice performed by a major operator uses a tab riveted to each repair with relevant repair information.

4.1.3 Field Survey Data Collection Methods

Using general visual inspection and measurement methods, RAM on each airplane were surveyed and documented in the RAM field survey objectives. Generally, the data for RAM consisted of the size, location, proximity to each other and to other critical structures, Airlines for America (A4A) location codes, age in FC/FH, general condition, causes of occurrence, engineering standard used for design, and any other significant information. Documentation of the RAM included actual measurements, photographs (both inside and outside when possible), materials characterizations, operator records of engineering design approvals, and operator maintenance records (when available). Repairs were also assigned a category (A, B, or C) based on Repair Assessment Program classification criteria. Additionally, a quality rating of 1 to 5 (1 being best and 5 worst) for RAM was assigned by the principle AANC survey staff member. This person was a highly experienced FAA-licensed A&P mechanic with 21 years of heavy structural fabrication maintenance work on transport category airplanes. The general progression of selecting appropriate individual airplanes to survey, obtaining operator permission, and performing the actual survey is detailed as follows:

1. Transport category airplanes were selected for assessment based on a statistical sampling plan of the U.S. domestic transport category fleet that has been on record as of early 2009. Through direct communications with operators, their maintenance dock plans were reviewed for appropriate candidate airplanes because of scheduled maintenance. A significant amount of the time required was for coordinating with the operators to obtain access to their airplanes. Trips were planned to maximize the number of airplanes and operators that could be surveyed. Although the operators generally accommodated the work, unforeseen changes in the maintenance schedules sometimes worked either for or against the field survey.

2. Guidelines and supporting documents were compiled for conducting RAM surveys for the specific airplane model of interest, including SBs, ADs, SRMs, maintenance manuals, and RAG, as they became available.

3. Surveys were performed at operator maintenance bases or salvage yards as airplanes became available. Once travel to a maintenance facility was undertaken, the field survey usually followed a general progression. The overall airplane was sectioned and examined to ensure the entire airplane was surveyed and all RAM included. As each RAM was surveyed, the following information was collected:

    - The installation for each RAM on a subject airplane was classified based on the following criteria:

        - Were the RAM designed and installed per an SRM, designated engineering representative (DER) design, SB, RAG, or engineering best practice?

- Were the RAM in close proximity to other repairs?
- Were the RAM in close proximity to WFD susceptible structure?
- Were the RAM in close proximity to other fatigue critical structure?
- What was the general condition of the RAM as determined by an experienced mechanic?
- If the RAM were repairs, what was the repair category (A, B or C) as determined by the operator?

- The documentation of the RAM consisted of:
  - Photos (with identifying stickers) for later reference (see figure 4).
  - Notations of the location of the RAM on the airplane.
  - Measurements of the RAM sizes, shapes, fastener spacing and sizes, edge distances, and doubler thicknesses.
  - Determinations of the materials used.

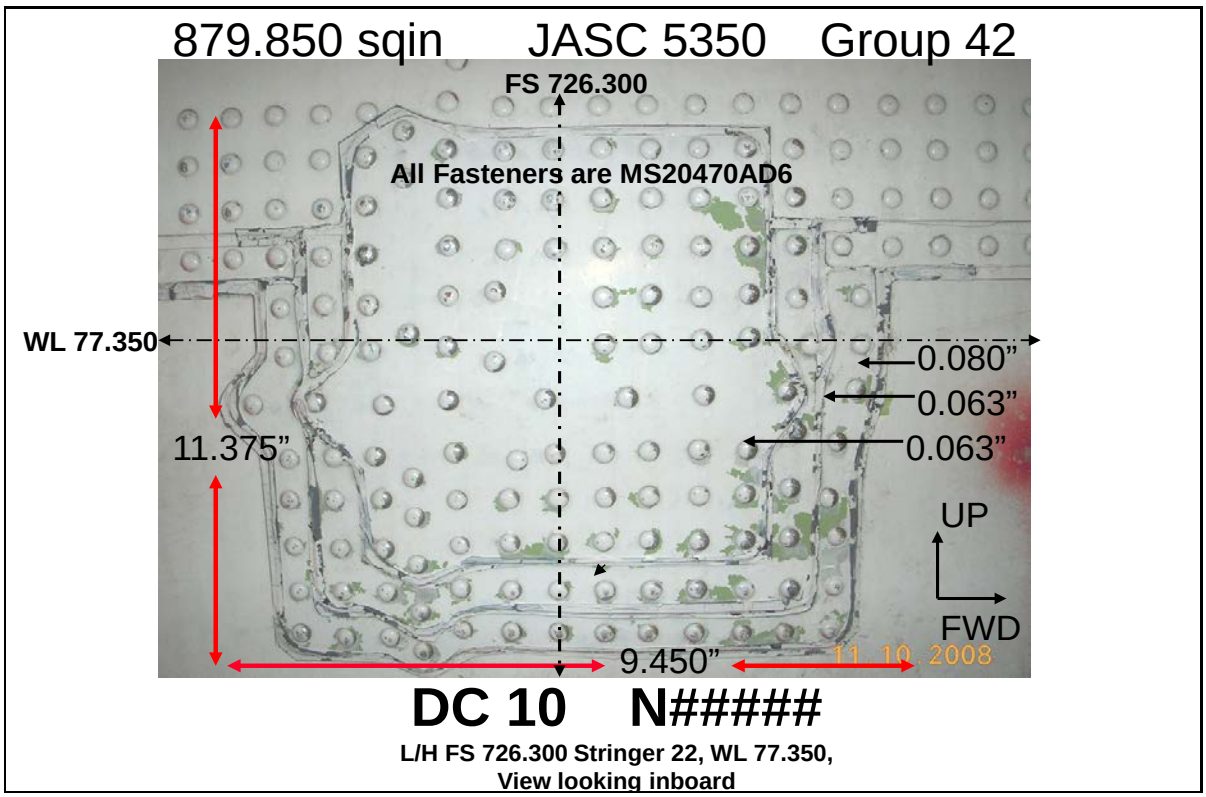


Figure 4. Example of Typical RAM Measurements Taken During Field Surveys

4. All of the measurement data were immediately put in the electronic data collection form via a tablet computer with magnetic stylus and character recognition software. This tablet was carried by the inspector during the field survey. A Microsoft® Excel® spreadsheet data collection form was developed and used so that data could be entered immediately as RAM were surveyed. The objective was to increase the speed of data collection and to prevent errors—especially transcription errors. The spreadsheet data collection form is the basis of the field survey database. Figure 5 shows the AANC inspector with the tablet computer during a field survey.

Figure 5. The AANC Inspector Performing a Field Survey Using a Tablet Computer for Data Input

5. Airplane maintenance logs, usage histories (especially FH/FC since the RAM were installed), and repair design information were obtained as available. In some cases, information was available from the current operator (as discussed previously), the last known owner (such as a leasing company in the case of a retired airplane), the last known operator (such as a Part 121 carrier), or the airplane salvage yards. The availability of airplane information was used to guide the selection of specific airplanes for survey (e.g., if an airplane had undergone the repair assessment process as required by the Aging Airplane Safety Final Rule, the gathering of field survey data was easier to obtain). At the end of each day of field surveys, all photographic documentation was combined into the electronic field survey form and a quality control check was performed to ensure data were accurate and complete.

6. As data were collected and entered into the database at the AANC, a RAM location map was generated for each airplane. These "RAM Location Plot" charts were meant to quickly show the relative sizes and locations of all RAM on each airplane surveyed. Figure 6 shows a sample for reference and appendix A shows the complete collection of the plots for all airplanes surveyed.

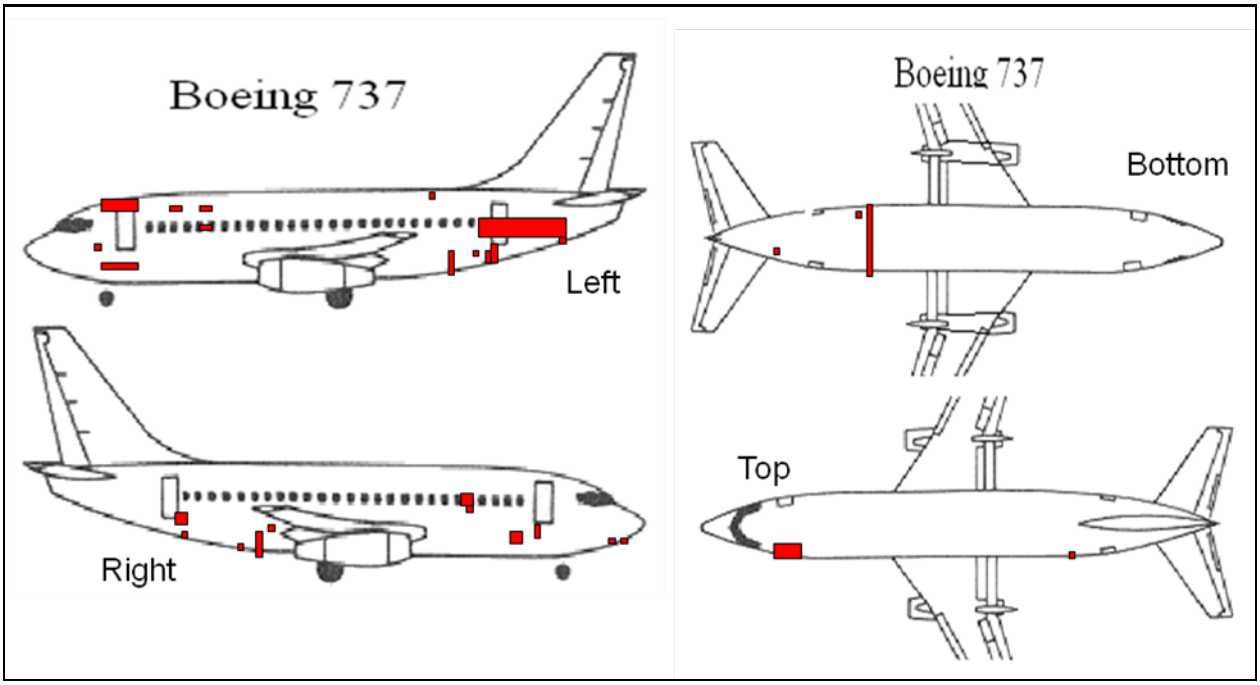


Figure 6. Sample Airplane RAM Location Map

7. A quality rating scale was developed and implemented as part of the field survey process. The objective of implementing such a rating scale was to gather anecdotal data on the quality of RAM installation and current condition. Poor fabrication workmanship can lead to early structural failure [11]. The main questions considered during this portion of the data collection process were if the quality and condition of detailed RAM components retain or surpass the structural integrity of the original and adjacent structure, and if quality-of-repair issues pose a risk leading to a secondary failure concern.

Specific installation issues looked for by the inspector were:

- Correct fastener utilization and proper installation
- Tooling marks deep enough to cause stress risers
- Fretting or riding preload conditions
- Correct hole and cutout preparation
- Correct sealant application
- Existence of compounded workmanship and installation issues
- Deviation from engineering drawings and, if so, the manner of deviation

References used as the basis for the Installation Quality Rating Scale were: AC 43-13, Boeing SRM, carrier maintenance manuals, engineering disposition reports, Manufacturers' SBs, FAA AD, knowledge of best shop practices, and acceptable industry standards. The installation Quality Rating Scale value determinations were assigned, with 1 being best and 5 being worst, as follows:

1. The RAM that received a 1 were fabricated and installed in accordance with the SRM or some other appropriate engineering order, SB, or AD. They exhibited the correct fabrication process and the correct utilization and installation of fasteners and showed evidence of correct area preparation and the correct sealant application. The correct installation methodologies were used.

2. The RAM that received a 2 exhibited discrepant fastener- or workmanship-related issues. Common issues observed were incorrect fastener edge distance, poor execution of fastener installation, oversized or out-of-round holes, poor cutout of the damaged area, or poor filler layer fabrication. The condition of the RAM as observed did not pose an immediate safety issue.

3. The RAM that received a 3 exhibited poor fabrication or installation of the RAM where preloading was indicated, tooling marks were evident, improper fastener installation took place, incorrect hole placement occurred (such as at the chemical-milled step shown in figure 7), or there was poor sealant application or uncured sealant evident. Details listed for scores of 2 may have been present as well. The workmanship or condition did not pose an immediate safety issue, but demonstrated the need for review by a quality assurance inspector or engineer, and possible further reworking.

4. The RAM that received a 4 were outside of engineering specification or tolerance limits, were not installed in accordance with SRM guidance or engineering drawings, and may have exhibited multiple fastener discrepancies, tooling marks, or damage to the surrounding structure. The RAM require removal and engineering re-evaluation for corrections in the near future because of safety concerns.

5. The RAM that received a 5 posed an immediate safety risk and required immediate engineering evaluation. Incorrect material and fasteners were used, unauthorized alteration of primary and secondary structure was observed, or the fabrication work was outside of allowable SRM limits or engineering drawings (such as the grinding of structure and alteration of fasteners shown in figure 8).

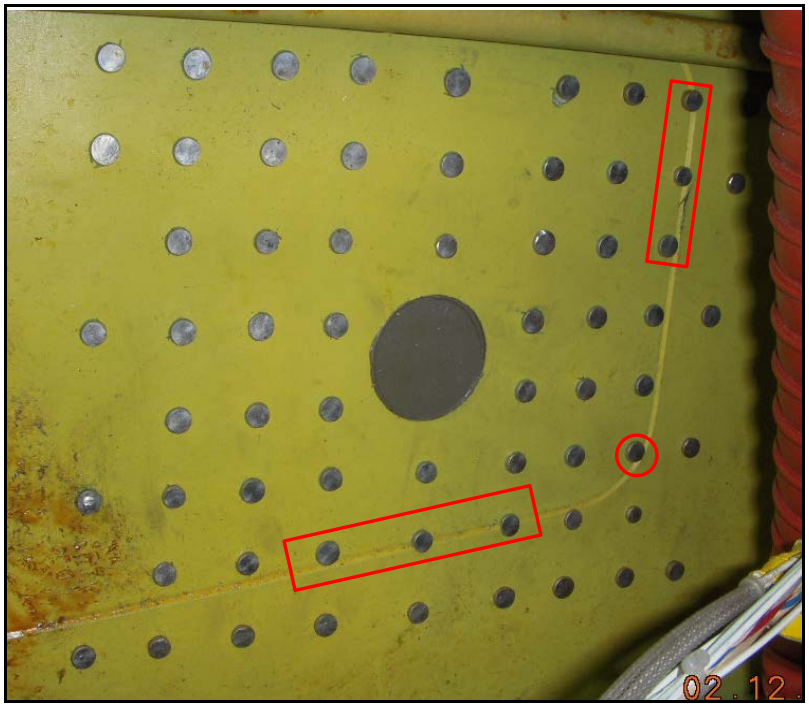


Figure 7. Example of a Poor RAM Installation With Multiple Rivets Installed in a Chemical Milled Edge Step Where Cracking Will Eventually Result (workmanship/condition score of 3)

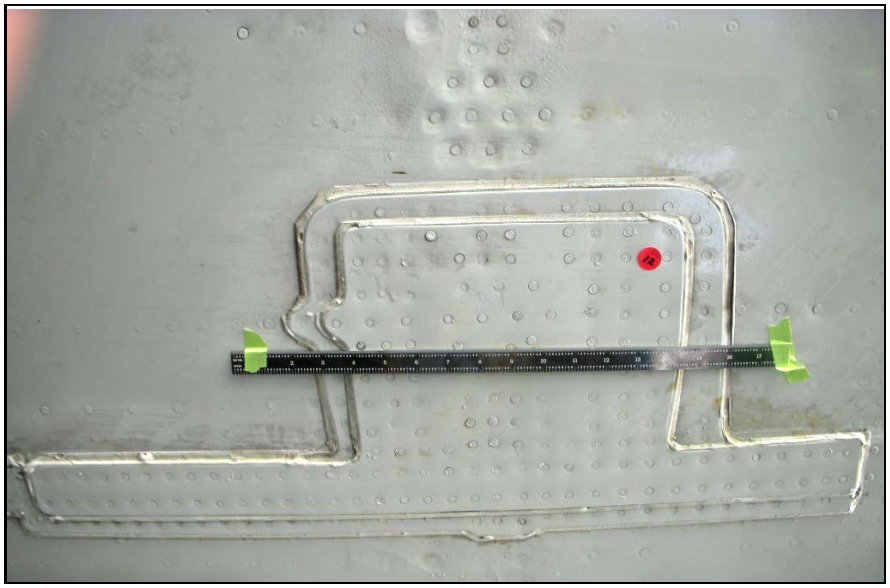


Figure 8. Example of a RAM With Adjacent Fastener Heads Ground Beyond Limits, Requiring Immediate Engineering Evaluation and Repair (workmanship/condition score of 5)

4.2 FIELD SURVEY RESULTS

The overall goal of the project was to collect data that airworthiness engineers at the FAA Transport Airplane Directorate could use to estimate whether RAM posed a risk of developing

WFD. Fatigue and damage tolerance research has provided some measure of the durability of individual repairs, especially when considered relative to size, location, and proximity to other repairs. Thus, the general task was to provide an estimate of the parameters discussed in section 1 for all repairs or altered structures in the U.S. domestic transport fleet. A database of field survey results was developed that contains all of the data collected. The database has three principal components. The first is a large spreadsheet that contains documentation on RAM surveyed; the second shows pictorially where all RAM are located on each airplane (also termed "RAM Location Plots"); and the third is a very large collection of digital pictures taken during the field surveys.

Table 4 shows an overall summary of the models, number of airplanes, and number of RAM included in the field survey results. These summary data are sorted according to airplane models (25), the numbers of airplanes (154) and RAM (2612) sampled, and the numbers of in-service versus retired airplanes (138 versus 16) and RAM (2294 versus 318) sampled. The sampling goals for the number of airplanes (134) and the number of RAM (2165) are compared with actual sample numbers, and the maintenance documentation status for RAM is shown. Although some form of maintenance documentation was available for a large number of RAM, very few actually had FH and FC data that were reasonably available without laborious documentation searches by carrier support personnel.

The following are additional observations regarding the eight Sandia/AANC goals (outlined in section 1):

- The range of RAM per surveyed airplane was between 1 and 342. However, this range is skewed and may not be representative of typical passenger airplanes because one 747 freighter had 342 RAMs. The average number of RAM per surveyed airplane was 16.96 (approximately 17).

- RAM sizes ranged from less than 1 square inch to 14,960 square inches. The average size of all RAM was 303.5 square inches. Fifteen percent of RAM surveyed were greater than 500 square inches.

- The quality of RAM as installed (based on subjective evaluation) was assessed for 715 of 2612 individual RAM during the field survey, and at the end of life for the teardown survey RAM (discussed in section 4.3). Only RAM with access to both sides were evaluated for quality of installation. Of the 715 RAM evaluated, only 12 received a score of 5, indicating the need for immediate maintenance action. The clear majority of RAM (631) received a score of 1 or 2, indicating adequate quality of installation.

- The FH and FC for each airplane ranged from essentially new to older than the design service goal. The average age of airplanes surveyed was 73,192 FH and 33,209 FC.

- The location of RAM on the airplane (relative to major structural elements, load and fatigue sensitivity drivers, and other adjacent repairs) was documented for all 2612 RAM. In most cases, the distance to the nearest sensitive structural element was categorized into bins (0-12 inches, 12-24 inches, etc.).

- The source of the RAM engineering data (e.g., SRM, SB, Designated Engineering Representative, or engineering change order) was documented for approximately half of the RAM in the field survey.

- The root cause of the RAM (e.g., repair versus intentional modification) was also documented for approximately half of the RAM.

- Almost no fatigue cracking was observed in the RAM surveyed, and the few cases in which it was observed involved individual cracks and did not meet the criteria of MSD or MED.

Table 4. Summary of the Models and Airplane Numbers in the RAM Field Survey Results

Airplane Model	Number of Airplanes Surveyed	Number of In-Service Airplanes Surveyed	Number of Retired Airplanes Surveyed	Number of RAM Surveyed	Number of In-Service RAM Surveyed	Number of Retired RAM Surveyed
727	11	4	7	114	75	39
737	38	33	5	668	526	142
747	8	6	2	956	868	88
757	16	16	0	127	127	0
767	12	11	1	49	44	5
777	4	4	0	3	3	0
DC-8F	3	3	0	148	148	0
DC-9	3	2	1	105	61	44
DC-10F	2	2	0	77	77	0
MD-10	2	2	0	58	58	0
MD-11 F	2	2	0	32	32	0
MD-82	6	6	0	50	50	0
MD-83	5	5	0	23	23	0
MD-87	2	2	0	20	20	0
MD-88	4	4	0	45	45	0
MD-90	1	1	0	25	25	0
A300	4	4	0	62	62	0
A300 B4	1	1	0	0	0	0
A310	1	1	0	4	4	0
A319	4	4	0	7	7	0
A320	13	13	0	38	38	0
A330	3	3	0	1	1	0
EMB 170	5	5	0	17	17	0
EMB 175	3	3	0	16	16	0
EMB 190	1	1	0	5	5	0
Total	154	138	16	2612	2294	318

A sampling plan was developed that expanded the scope of a similar sampling project conducted by the AAWG in the 1990s. The current project collected repair and modification data from about twice as many airplanes as in the AAWG survey, and more than four times as many RAM were examined and documented. Except for a few airplanes examined during the early stages of the project, this field survey included the entire fuselage of each airplane. The following are some additional features that make the results particularly useful:

1. All major U.S. Air Carrier (Part 121) operators participated in the survey by volunteering their airplanes for survey. Several smaller Part 121 carriers participated as well.

2. All major OEM airplane models (greater than 75,000 pounds maximum gross takeoff weight) and manufacturers were represented in the sample.

3. Both wide and narrow body airplanes were sampled.

4. The survey team visited a total of 27 maintenance shops during 35 field trips, all within the U.S.

5. The sample was statistically representative of the population because of the large size and diverse sampling plan (see figure 9).

6. The database can be easily sorted and filtered to allow analysis of a wide array of characteristics.

7. The RAM Location Plots are arranged by airplane model for quick reference. Although the registration numbers are not included in this report, the raw data does include them along with the airplane model numbers for quick reference.

8. Additional pictures exist in the files, beyond those linked to the spreadsheet, that allow further investigation of many individual RAM.

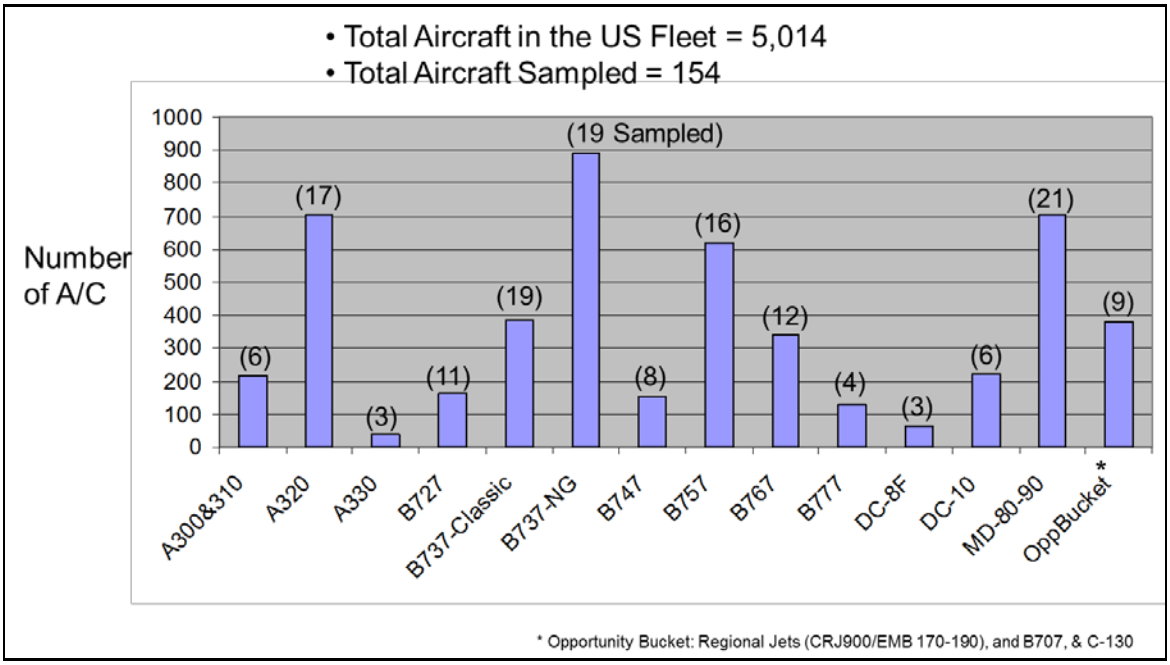


Figure 9. Total Number of Airplanes in the U.S. Fleet by Model and the Total Number of Each Model Sampled During the RAM Field Survey

Other notable observations should be mentioned because they may have a significant influence on the analysis; these include:

- The U.S. domestic fleet has 5014 airplanes, which are an average age of 16 years old.
- Most airplane models have similar rates of RAM accumulation.
- The 747 airplanes surveyed acquire RAM five times faster than other airplanes.
  - Five 747s operated by one air carrier account for 820 RAM in the database.
  - One air carrier operates relatively old 747-200s with many repairs (not a typical usage).
- Type B & C Repairs account for about 50% of all RAM on surveyed airplanes.
- Poor quality RAM (all repairs) totaled only 16 from 715 RAM, with access to both sides in all surveyed airplanes.
- Approximately 15% of all RAM surveyed were considered large repairs (LR), with areas greater than 500 square inches).
- The damage classification was the highest root cause at 31% of surveyed RAM.

4.3 FIELD SURVEY DATABASE

The field survey data collection was done using Microsoft Excel designed by the AANC with dedicated fields and drop-down boxes to make data entry in the field quicker using a tablet computer with magnetic stylus. At the base level of the database is the single-page RAM field survey data acquisition and storage form (figure 10). An airplane information section with base information was propagated to the individual pages for RAM. These unique identifiers allowed rapid aggregation later on. Many categories of information specific to the airplane models, and/or specific structures being surveyed, were available in the dropdown boxes and were tailored to the need. For example, if a rectangular RAM shape was selected from a drop-down box, the form would change to prompt the inspector for length and width measurement data. Alternately, if a circular RAM shape was selected, the inspector would be prompted for diameter measurement data. During the actual survey, the inspector would strive to obtain data on, and complete, as many fields of the form as possible. If ancillary data were later obtained, they would be entered as soon as possible. Real-time data entry coupled with the subsequent addition of maintenance record information, embedded pictures, and links to other documents made data collection and merging rapid and efficient (figure 11). Approximately 8000 pictures were obtained during the field surveys. In most cases, they were taken by AANC field survey personnel, but, in one case, they were provided by an operator who had recently completed a full Repair Assessment Program of all its airplanes. The AANC staff found the additional pictures often added a sense of three-dimensionality or location information to the photos, which are included as part of the field survey data collection form. A total of 80 categories (columns) of information were included in the database spreadsheet, but not all categories apply to each set of RAM. For example, RAM location information might be included as the body station and stringer location on the fuselage, which would preclude it from being listed at a wing station location.

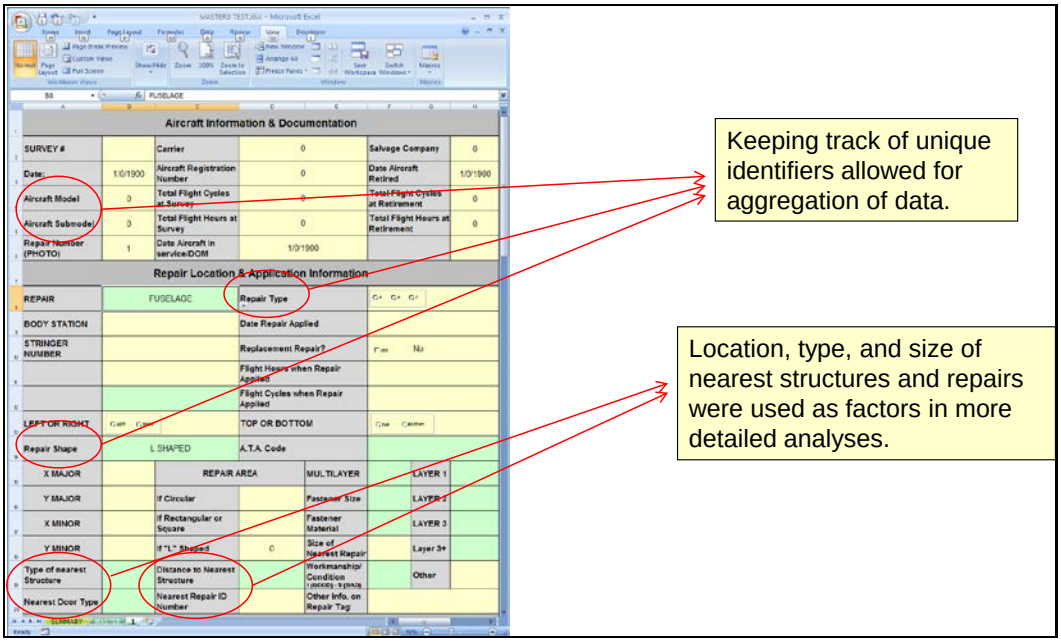


Figure 10. Examples of the Unique RAM Field Survey Data Fields That Made Merging and Analysis More Complete and Straightforward

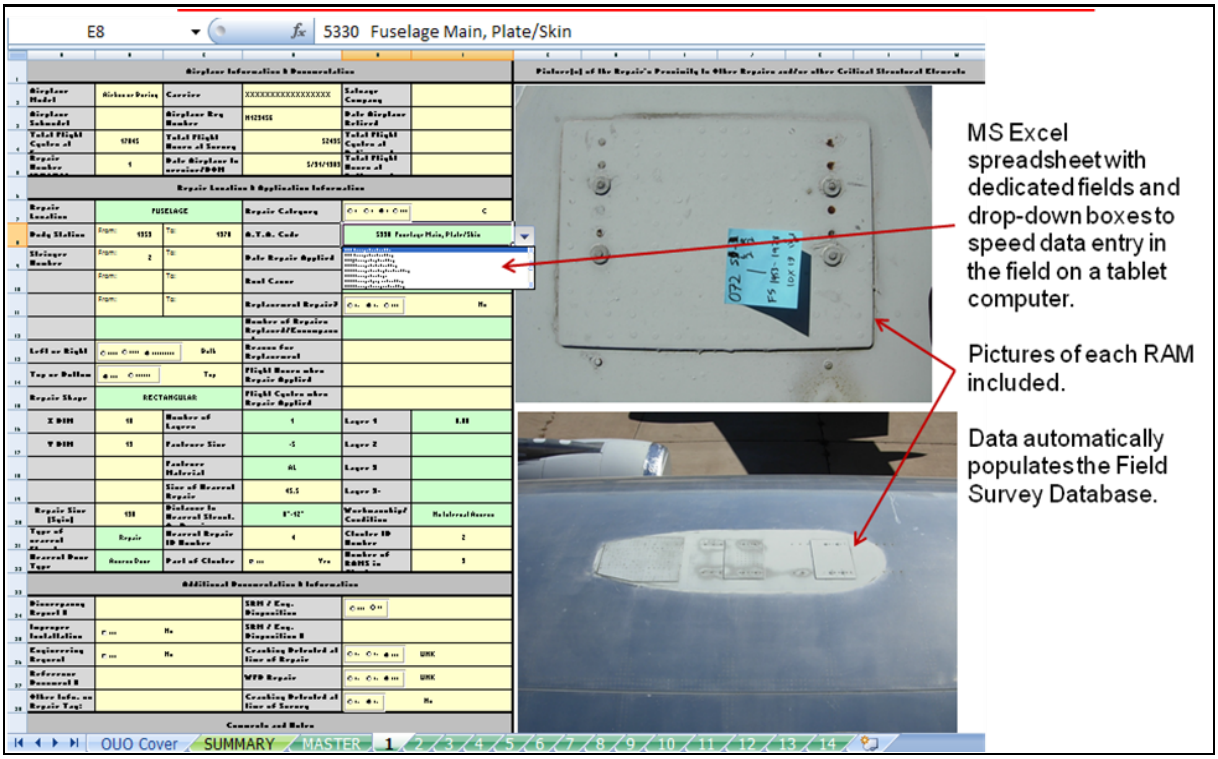


Figure 11. Example of a Completed RAM Field Survey Data Acquisition and Storage Form

Data from the single-page field collection sheet were electronically transferred and merged into a cumulative spreadsheet after each field trip (figure 12). This method prevented transcription errors, although data entry errors could propagate if not caught and corrected during the actual field survey. One unified set of headings was used throughout the entire field survey process.

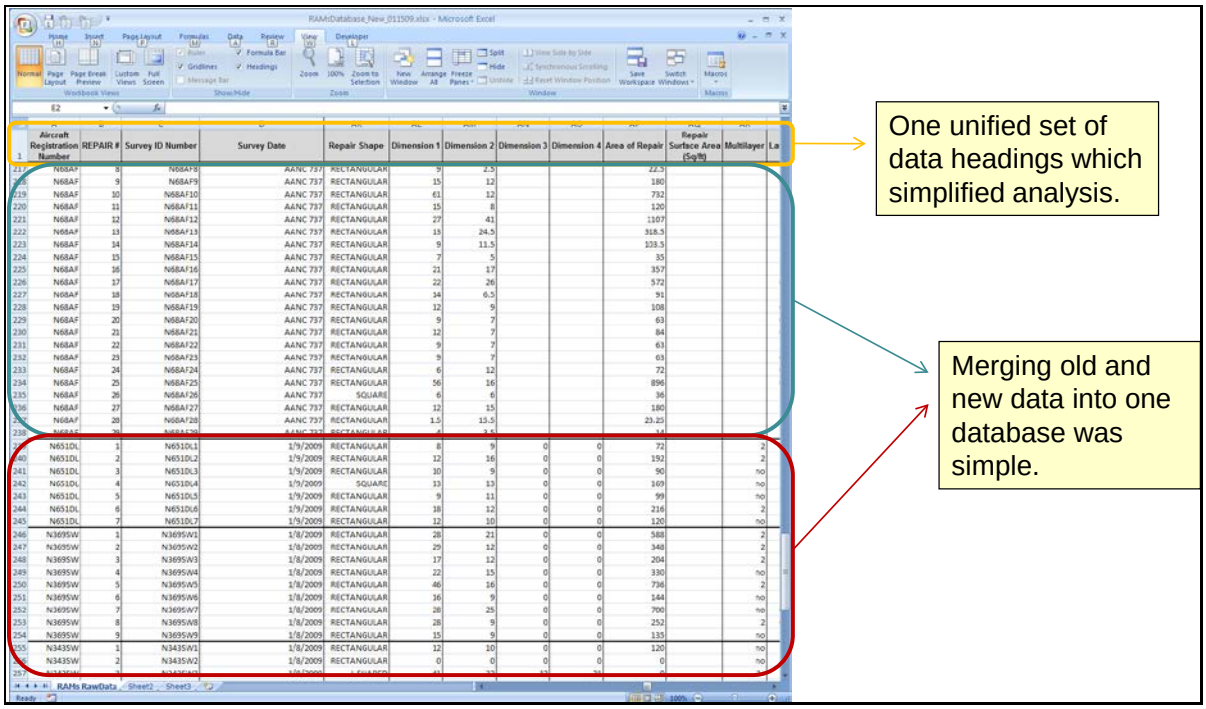


Figure 12. Integrating New and Old RAM Field Survey Data Was Simple With Microsoft Excel

Once data were merged into the full database spreadsheet, they were easily transferred or converted to many formats for further analysis. In the example shown in figure 13, data are being compiled from the field data acquisition and storage form into the spreadsheet database and exported into commercially available statistical software for analysis. This is just one example of the high degree of flexibility obtained from using simple commercial off-the-shelf research tools.

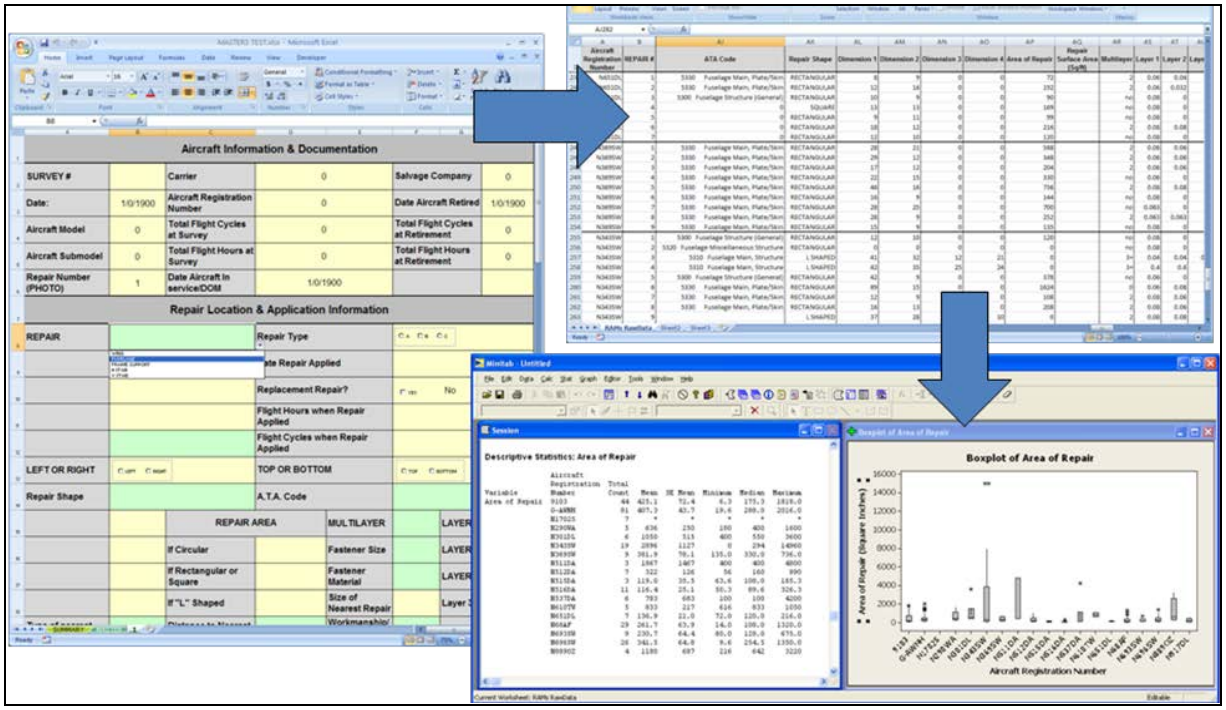


Figure 13. Field Survey Database Information Exported to Statistical Software for Analysis

Whereas the data can be analyzed in the Microsoft Excel application or exported to other analysis software, the AANC also developed a simple tool for performing some initial analysis and gathering "snapshots" based on some initial high-level concerns. The analysis tool results for the entire RAM Field Survey Database are shown in figure 14. The tool was developed to allow for queries based on the carrier, the airplane model, and the airplane submodel. It provided relevant summations and averages of data, such as the average number of RAM per airplane, that were meant to support achieving the AANC RAM objectives listed in section 1. The "carrier" category allows sorts for all airplanes, in-service airplanes, salvage airplanes, and for each individual participating carrier; only one carrier category can be selected at a time. The "model" category allows sorts for all major airplane models included in the field survey (i.e., Boeing, Airbus, and Embraer). The "submodel" category is linked to the model category in that only appropriate submodels are available as a sort option for any given model. For instance, only -100, -200, and -400 sub models are available when the 747 model is selected. A detailed discussion of how each value was calculated and general observations on the eight Sandia/AANC RAM field survey objective results are included in the following paragraphs.

Choose Carrier:	**All Airplanes**
Choose Model:	**All**
Choose Submodel:	**All**

Summary Statistics	
Total Number of Airplanes	154
Total Number of RAMS	2612
Average Age at Survey (Months)	301.30
Average Number of Flight Hours	73,191.84
Average Number of Flight Cycles	33,209.13
Average Flight Hours per Cycle	3.00
Average Number RAMS per Airplane	16.96
Average Size RAM (Sqin)	303.46
Number of RAMS with Dates	555
Average Age of RAMS at Survey (Months)	61.78

Nearest Structure Distribution	
Repair	479
Door	819
Window	158
Major Joint or Splice	634
Gear Mounts or Hard Points	70
Cutout in Structure	54
Control Surface Attachment	21
Vertical or Horizontal Tail Attachments	31
Blank	384

Repair Category Distribution	
UNK	699
A	513
B	1367
C	71

Workmanship/Condition Distribution	
No Internal Access	1873
1	419
2	212
3	62
4	10
5	12

Root Cause Distribution	
Unknown	1315
Damage	808
Structural Modification	171
Antenna Modification	112
Corrosion	67
Airworthiness Directive	23
Lightninig Strike	18

Repair Location Distribution	
FUSELAGE	1569
WING	161
PRESSURIZED DOOR	85
FRAME SUPPORT	398
Press Bulkhead AFT	45
Press Bulkhead FWD	25
H STAB	7
Blank	347

Replacement Repair Distribution	
Yes	106
No	603
UNK	1941

Reason For Replacement	
ADDITIONAL DAMAGE	8
Antenna Modification	9
Category "B" to "A"	5
EA R&R EXISTING REPAIR	7
FURTHER CRACKING	13
INCORRECT INSTALLATION	5
NO DOCUMENTATION	3
Not per FAA approved repair data	7
RAP	2
Replacement of Temp Repair	9
Other	8
UNK	1962
NA	603

Repair Area (Sqin) Distribution	
A (0-100)	1101
B (100-500)	1095
C (500-1,000)	183
D (1,000-2,000)	86
E (2,000-10,000)	55
F (>10,000)	2
Blank	128

Figure 14. RAM Field Survey Database Summary Statistics Calculated With the Analysis Tool

The "summary statistics" field includes a count of the number of airplanes, number of individual RAM, and number of RAM for which a date of installation record was obtained. The summary statistics field also contains calculated values for the average age of all airplanes, the average number of FH and FC of all airplanes, the average FH per FC of all airplanes, the average number of RAM per airplane for all airplanes, the average size of RAM for all airplanes, and the average age of the RAM in months for all airplanes. The averages are calculated based on the selected airplane categories with data taken at the time of the field survey.

The "nearest structure distribution" field was set up to provide information on fatigue critical structure nearest to various RAM. The fatigue critical structures specifically identified as important were: other repairs, doors, windows, other cutouts in the principle structure, major fuselage joints or splices, gear mounting or hard points, control surface attachments, and vertical or horizontal stabilizer attachments. If the field was left blank during the survey, that was also noted. As an example, the information in figure 14 showed that, for all carriers on all models and submodels, there were 479 RAM for which the nearest fatigue critical structure was another repair.

The "repair category distribution" field is a count of the number of category A, B, or C repairs, or unknown category repairs occurring in the database, given the carrier, model, and submodel selected. Category A repairs require no additional action and are permanent. Category B repairs may require supplemental inspection for damage tolerance or rework, but are considered

permanent. Category C repairs require supplemental inspection and are considered temporary only. If this field was left blank, it was because either the data were not available or there was a modification, but not a repair.

The "workmanship/condition distribution" field was based on an assessment of the quality of the installation for the individual RAM and how well it was holding up over time. A numerical rating scale was used with 1 being best and 5 being worst, as discussed in section 4.1.4.

The "root cause distribution" field includes a count of the number of RAM that fell into one of the seven types of common situations causing structural work. The broadest description was "damage," which included any kind of structural deficiencies that did not fall into any other description. It was usually an unplanned maintenance event resulting in a repair to some structural element. "Structural modification" was an optional maintenance action installed for some reason other than safety of flight (such as the installation of blended winglets). The selection of "antenna modification" indicated that some change to principle structure was required. The selection of "corrosion" indicated that fatigue cracking was not exhibited. The AD was a required safety of flight structural repair or modification. The selection of "lightning strike" indicated that some repair was required.

The "repair location distribution" field includes a count of the number of RAM that occurred on or in each of the listed structures. The listed structures include fuselage skin, wing skin or support frames, pressurized door, frame support, aft or forward pressurized bulkheads, or horizontal stabilizers. This field was left empty on the field survey data collection form if the RAM did not occur in one of these listed structures.

The "replacement repair distribution" field includes a count of the number of RAM that were known to be either a replacement on an existing repair, or not. If there was no definitive information, this field was left blank on the field survey data collection form.

The "reason for replacement" field was associated with the replacement repair distribution field and provided further accounting of the reasons that repairs were replaced. Those reasons included additional damage, antenna modification, repair category "B" upgrade to "A" category, engineering assessment of an existing repair requiring further repair or replacement, further fatigue cracking, incorrect installation, no maintenance action documentation, design not in accordance with FAA-approved data, a Repair Assessment Program action, replacement of a temporary repair, or some other unspecified cause.

The "repair area distribution" field includes a count of the number of RAM in each of five size ranges, where area of the RAM is expressed in square inches. The five size ranges are (0-100), (100-500), (500-1000), (1000-2000), (2000-10,000), and (>10,000) square inches.

4.4 RAM LOCATION PLOTS

Plots showing the approximate location of each RAM for which data were collected are provided as quick visual references. The aim of the plots is to highlight in a general sense where RAM most commonly occur on each model of airplane by marking their location with RAM location plots on an airplane diagram (figure 7). It is well known that the most common areas for repairs

tend to be around fuselage doors because of the amount of activity at those doorways. One question that can be answered is whether or not other areas represent RAM hot spots. Appendix A shows RAM Location Plots for all airplanes in the field survey. Because of proprietary data restrictions, the registration number of each airplane is removed. The set of RAM Location Plots with individual airplane registration numbers was delivered to the FAA as part of the official use only data package. In some cases, the RAM location plots from surveys conducted early in the project might be expanded to show the relative size of RAM, whereas in others, a standard-sized RAM location plot chart was used to indicate the approximate location of a particular RAM. It is easy to conclude from examining the collection of plots that the high-damage areas of most transport airplanes are still centered on door and hatch openings in the fuselage. Certain models may have other specific areas that preferentially accumulate RAM and the example provided is the lap joint of 737 classic airplanes; however, these appear to be well known and adequately managed RAM that do not show any tendency towards increased occurrence of fatigue damage.

5. TEARDOWN SURVEY

5.1 TEARDOWN PROCESS

The objective of this project phase was to collect, teardown, and inspect aged specimens from transport airplanes with RAM to baseline principle structural elements. The inspections were focused on the detection of WFD at fastener holes. Specimens were collected mostly from U.S. sites where retired transport category airplanes undergo decommissioning, component disassembly or removal for resale, and recycling of the scrap metal. One was collected from an airline maintenance shop. There are several airplane salvage yards across the country that conduct this type of business, along with long-term storage of unneeded airplanes. The ready availability of so many retired transport airplanes provided ample opportunity to select structures of interest, especially later in the project. Early in the project, during field surveys of retired airplanes at salvage yards, several teardown specimens were acquired and placed in storage at the AANC hangar using the guidance discussed below. Later in the project, field survey data were also used to guide the selection of structures to collect for teardown and inspection. In particular, there was an emphasis on collecting large-area RAM.

The following general steps were initially planned to accomplish this phase of the project. However, once the field survey task was moved to the highest priority, some of the assumptions and planned procedures for this later task were modified to incorporate, and adjust to, the findings from the field survey.

1. Review the results of prior AAWG repair survey activities (see the Airworthiness Assurance Working Group Final Report dated 12/12/96 and titled "Continued Airworthiness of Structural Repairs" [11]), aviation safety database surveys, and ADs or SBs to identify candidate RAM structures for teardown survey. High-priority major alterations for consideration included cargo door installations. Select the transport category airplane models for assessment through a survey of airplane salvage yards for availability. This was modified in early 2009 to include all airplanes on the FAA airplane sample plan target list.

2. Compile guidelines for conducting teardown surveys, including specimen-specific engineering documents, SBs, ADs, SRMs, maintenance manuals, and RAG as they become available.

3. Obtain airplane maintenance logs, usage histories, and engineering design information if available. The information may, in some cases, be available from airplane salvage yards, the STC owner, the last known airplane operator, or the last known owner. Use the available maintenance and engineering history to provide direction in selecting specific airplanes (i.e., if maintenance and engineering histories are not readily available for an individual airplane, do not select it even though it meets other selection criteria).

4. Travel to airplane salvage operations within the U.S. and conduct initial data gathering of the structures of interest on the airplane to include, at a minimum gathering, the following information:

   a. Classification of RAM installation for RAM on a subject airplane:

      i. Are the RAM designed and installed per an SRM, DER design, SB, RAG, or engineering best practice?

      ii. Are the RAM in close proximity to other alterations?

      iii. Are the RAM in close proximity to a WFD-susceptible structure?

      iv. Are the RAM in close proximity to other fatigue critical structure?

      v. What is the general condition of the RAM?

   b. Documentation of the RAM:

      i. Photographs/simple engineering drawings

      ii. Notations of the location of the RAM on the airplane

      iii. For each specimen, document the same information acquired for RAM in the field survey portion of this project

5. While at the airplane salvage operation, conduct a field survey of the structures of interest, including both a detailed visual survey from both sides (inside and outside the airplane), if accessible, and other NDI, as appropriate, for cracks, corrosion, disbonds, etc. Use survey procedures based on the OEM's recommended standard practice/other directed survey requirements (SBs and ADs).

6. Ship the structure back to the AANC hangar in Albuquerque, NM, and begin the teardown survey process. If possible, to ensure that damage is not imparted to the RAM structure during the removal process (or documentation of such damage in the case that it

occurred), AANC personnel should be present during the removal and preparation for shipment of each specimen acquired.

a. Teardown survey is defined as destructive evaluations to characterize the condition and state of damage through disassembly, and direct observation and measurement of any damage found.

b. The extent of fatigue cracking, corrosion, faying surface fretting fatigue, structural disbanding, and any other damage found should be quantified.

c. Reconstruction of crack growth histories on selected cracks using standard fractographic methods, including striation counting, may be performed.

7. Depending on survey results, subcomponent testing may be conducted on selected portions of removed structures. Subcomponent tests include fatigue or residual strength testing. Such information can be useful in obtaining data for calibration and validation of prediction methodologies.

With the shift in project focus to performing field surveys of in-service airplanes, teardown specimen acquisition was postponed. However, consideration was given to later collection of additional teardown specimens and a plan was developed. Instead of developing a list of structures for collection by review of existing databases as originally intended, the RAM team identified specific structures of interest to target for acquisition, based on feedback from the field surveys, expert knowledge of several senior FAA engineers, and the availability of known fleets that were being retired at the time. The list that was developed included, but was not limited to:

- Passenger-to-freight STC door conversion surround frame (e.g., from the B747 and A300)
- Upper-deck floor beams and flat skin areas (specific to the B747)
- Aft pressure bulkheads and fuselage lap joint replacement modifications (e.g., B737)
- Large area repairs on fuselage structures (e.g., MD-80, B737, B757, and A320)
- Clusters of several small repairs in close proximity to each other on fuselage structures (e.g., MD-80, B737, B757, and A320)

Once the in-service airplane field surveys were completed and preliminary data analysis performed, the data showed that there were in excess of an estimated 50,000 large area (greater than 500 in.^{2}) repairs or modifications flying in the domestic commercial fleet. The RAM of this size or larger were thought to have the highest probability of containing MSD or MED associated with the RAM. To make the most conservative probabilistic statement possible concerning the potential for WFD occurrence in the U.S. domestic fleet, additional large area specimens (greater than 500 in.^{2}) were needed. Thus, specimen collection efforts were focused on collecting RAM greater than 500 in.^{2} in size, in addition to the criteria already listed. As

initial teardown work on the previously acquired specimens began, 13 additional LR specimens were acquired. Over the life of the project, 22 different specimens from 12 airplanes were acquired and underwent teardown inspection. One requirement for acquisition was that associated maintenance records detailing age, engineering authorization, and structural installation details could be obtained along with the structure. The specimens covered a range of locations on airplanes and included a variety of principle structural elements. Many were large area repairs to fuselage pressure vessels, which were consistent with the statistical requirements. The concept of a fracture-critical equivalent structure proposed by Safarian [12] was used to define 35 equivalent structures from the original 22 specimens. A fracture-critical equivalent structure was defined as a contiguous unit of structure that would provide a two-bay fracture growth opportunity that could lead to catastrophic structural failure. For example, a lap joint that was more than six frame bays long would provide three fracture-critical equivalent structures. Within the framework of binomial probability distributions, 35 specimens will provide estimates that quantify the probability of failure with confidence intervals. In this case, the probability was less than 2 percent ($P < 0.02$) of WFD occurring in RAM of the domestic fleet, with a 50% confidence interval. To state it another way, there is a probability of $p = 0.98$ that WFD will not occur in the domestic fleet of transport category RAM if it does not occur in any specimen in a random sample of 35 specimens.

Specimens were identified using various means, including availability of models and structures, as well as through full maintenance records. The AANC staff traveled to the salvage company and performed a preliminary inspection. After a specimen was identified as appropriate for teardown inspection, it was usually necessary to purchase the piece. Cut-lines were generally drawn by AANC personnel on the subject airplane or in detailed photos of the airplane. Because of contracting delays, the pieces were often removed by salvage company personnel at a later date and shipped to the AANC. Shipments to the AANC were either handled directly by the salvage company or through a commercial trucking logistics company. Specimens were generally prepared for shipment by the salvage companies with the intent of protecting them from further damage during shipping. In general, the specimens arrived in a condition comparable to when they were removed from the airplane. Any damage that was caused in shipping was generally evident and was not attributed to in-service fatigue causes. Shipping damage was usually in the form of surface scratches, minor dents, or bent structures on the ends or edges of a piece. Because specimens were always secured to pallets or other shipping platforms, it is unlikely that fatigue cracking initiated or progressed during shipping. On receipt at the AANC, a photo documentation process was started with pictures of the as-shipped specimens. Photography of each specimen was continued throughout the subsequent disassembly process until the specimen had been fully disassembled and inspected. Results were recorded in a spreadsheet-based database that included specimen age, structural details, engineering data, and inspection results.

A teardown and inspection protocol was followed, which was developed to find fatigue cracking at fastener holes and other fatigue critical structures. The general approach was to clean and inspect (general visual) structures and determine the most appropriate method for disassembly. Disassembly began with the removal of any ancillary components or structures (e.g., insulation, electrical standoffs), followed by paint striping if necessary. Teardown then proceeded to fastener removal (figure 15); as it progressed, the outer skin layers were carefully peeled off.

The inner layers were then removed and the support structure was disassembled. All components were inspected using detailed visual inspection (DVI); followed by performing bolt-hole eddy current (BHEC) was then performed on all open fastener holes.

Figure 15. Drilling Rivets to Remove Each Layer of a Lap Joint Modification

The teardown inspection protocol for fuselage structure consisted of the following general steps:

1. Perform DVI of the entire structure and document significant defect indications on an electronic teardown inspection data acquisition sheet.

2. Drill and remove fasteners in external skin. Perform BHEC inspection of each open fastener hole and document significant defect indications on an electronic teardown inspection data acquisition sheet.

3. Remove the outer skin panels and each successive skin panel layer. Clean, perform DVI and eddy current testing (ET) around the panel edges and between fastener holes. Perform BHEC of each open fastener hole and document significant defect indications on an electronic teardown inspection data acquisition sheet.

4. After removing the skin from the substructure, clean, perform DVI and ET around edges and between fastener holes as appropriate, and perform BHEC of each open fastener hole. Document significant defect indications on an electronic teardown inspection data acquisition sheet.

5. Disassemble the support structure, including frames and stringers. Clean, perform DVI and ET around edges and between fastener holes as appropriate, and perform BHEC of each open fastener hole of all frames and stringers. Document significant defect indications on an electronic teardown inspection data acquisition sheet.

6. If attach clips are considered fatigue critical baseline structure for 14 CFR Part 26.43, clean, perform DVI and ET around edges and between fastener holes as appropriate, and perform BHEC of each open fastener hole in WFD-susceptible structure. Document significant defect indications on an electronic teardown inspection data acquisition sheet.

The teardown inspection protocol for cargo door modifications consisted of the following general steps, and was also used for the heavy wing structure specimen:

1. Perform DVI of entire structure and document significant defect indications on an electronic teardown inspection data acquisition sheet.

2. Remove all attached hardware such as hinges, locking mechanisms, and scuff plates. Clean, perform DVI and ET on each piece of hardware if it is considered a WFD-susceptible structure, and document significant defect indications on an electronic teardown inspection data acquisition sheet.

3. Drill and remove fasteners in internal skin. Clean, perform DVI of newly opened areas, and BHEC-inspect each open fastener hole in removed skin. Document significant defect indications on an electronic teardown inspection data acquisition sheet.

4. Drill and remove fasteners in external skin. Clean, perform DVI of newly opened areas, and BHEC-inspect each open fastener hole in removed skin. Document significant defect indications on an electronic teardown inspection data acquisition sheet.

5. Remove all skin from the substructure and clean, perform DVI and ET around edges and between fastener holes as appropriate, and perform BHEC of each open fastener hole. Document significant defect indications on an electronic teardown inspection data acquisition sheet.

6. Disassemble support structure, including floor beam stubs, attach and secondary support structures, frames, and stringers. Clean, perform DVI and ET around edges and between fastener holes as appropriate, and perform BHEC of each open fastener hole of all frames and stringers. Document significant defect indications on an electronic teardown inspection data acquisition sheet.

The most sensitive method for finding fatigue cracking in fastener holes is the BHEC method shown in figure 16. The basic setup for this type of inspection calibrates on an electrical discharge machining notch length of 0.020 inch; actual crack-length detection can be slightly less. Although the original protocol called for performing BHEC at each step along the disassembly process, it was evident early in the project that doing the inspections on single layers of material was easier and quicker. Inspection of single layers (rather than stacked layers) is also

more sensitive for crack detection because the edge effect from stacks of layers that can mask crack signals is removed. Thus, the protocols were adjusted to wait until layers and structures were completely disassembled before performing the BHEC.

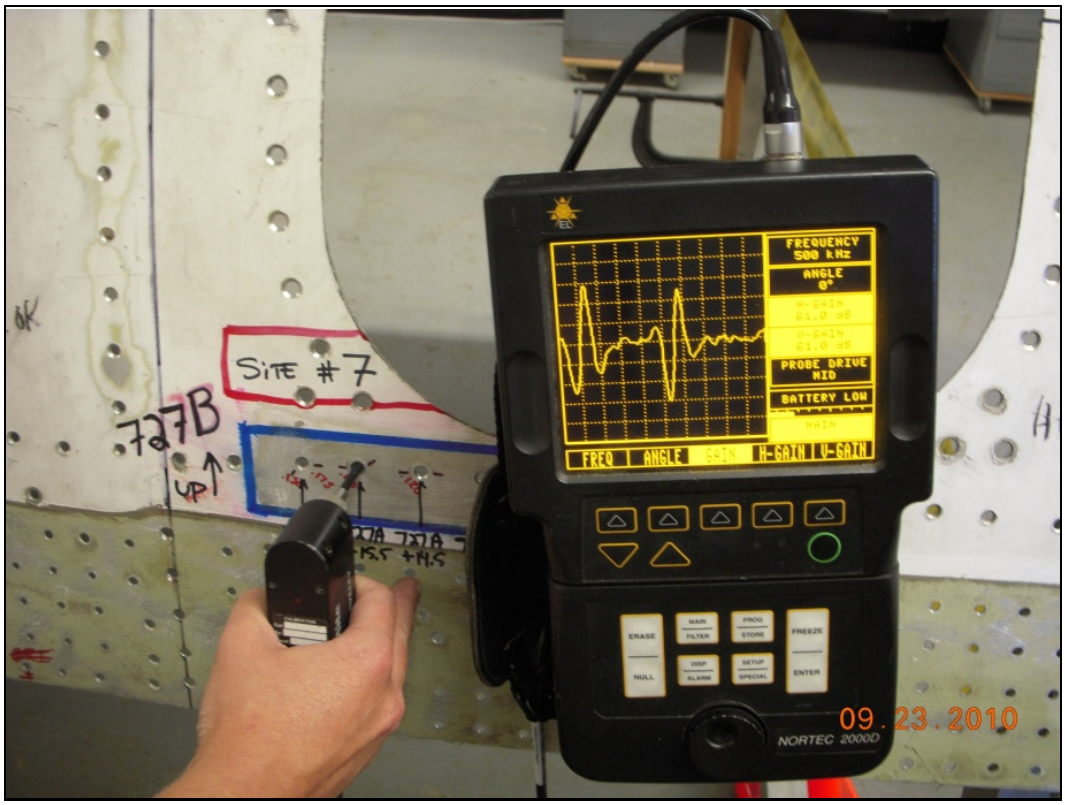


Figure 16. The ET Inspection of Fastener Holes Showing Crack Detection

The process was intended to occur as an iterative, phased approach. That is, surveys and disassembly occurred layer by layer, with appropriate surveys after each stage of disassembly. Any defects identified underwent appropriate characterization, which included measuring the length of the crack. The detailed work plan called for the characterization of each fatigue crack, up to and including destructive fractographic analysis. The purpose of this step was to gather additional details that could help determine how the defect was formed and how long it had been propagating in the structure. However, as the teardowns proceeded, it became evident that there was no need for expensive fractographic analysis. The few cracks that were found were either in very old structures that were beyond the design service goal, or were clearly caused by issues such as improperly installed fasteners or interference from hitting other structures.

5.2 TEARDOWN RESULTS

The summary of accomplishments in completing this task of the project included:

- Acquiring 22 different teardown specimens along with the maintenance records pertaining to each of the 38 RAM on the structures.

- Acquiring the teardown structures from 12 different airplanes across many different models and operators.

- Acquiring teardown structures from both passenger and freighter airplanes.

- Performing complete teardown and detailed inspection of the 35 equivalent structures obtained from the 22 specimens.

- Using teardown protocols that included complete layer separation and substructure disassembly.

- Performing BHEC of all open fastener holes (approximately 20,000 holes).

- Performing DVI on approximately 123,985 in.^{2} (861 ft^2) of fuselage skin, stringer, and frame.

- Characterizing the length of the few fatigue cracks found (figure 17).

- Collecting extensive photo documentation of the teardown process and results for each specimen and developing an electronic database.

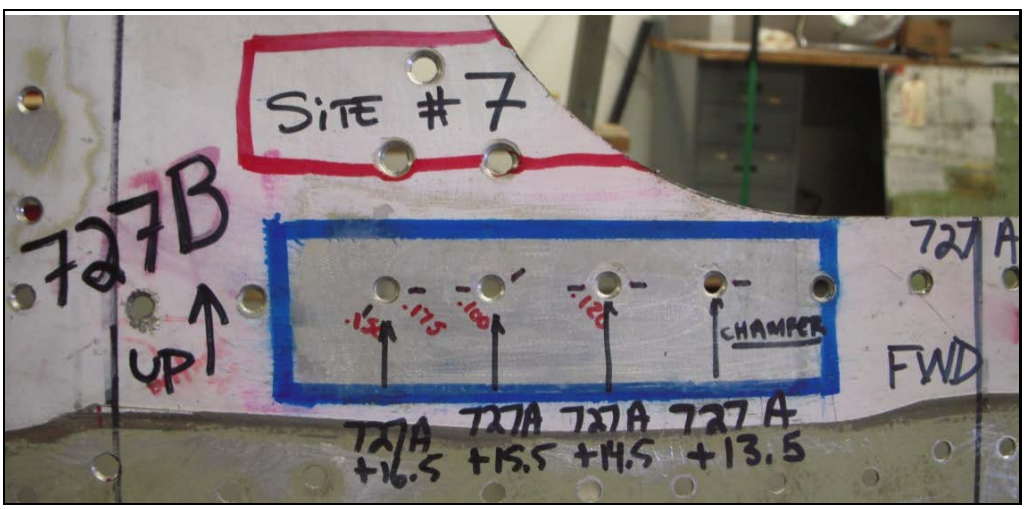


Figure 17. Fatigue Crack Length Characterization of RAM Teardown Finding

The summary data shown in table 5 include the airplane model, a descriptive name and location of each structure on the airplane, the age of the RAM, and the inspection results for the baseline and repaired or modified structure for each teardown specimen. The data show very little age-related fatigue cracking. Two occurrences of fatigue cracking that might be considered MSD were found, but both occurred in the baseline structure that was nearing the design service goal in age and was known to be susceptible to fatigue crack formation at those locations. Otherwise, the cracks that were found were individual isolated events that did not have the characteristics that indicate WFD.

Table 5. Teardown Specimen Summary of Airplane Structure, Age, and Inspection Results

Item #	Airplane Model	Component Description	Approximate Location	RAM Age in Flight Hours/Cycles	NDI Results Baseline Structure	NDI Results RAM Structure
1	B737-200	Lap Joint Window Belt Replacement Doubler RH	BS 727-907, Str 9R-15R	9827/22202	4 cracks in 2 holes & 1 cracked clip	2 tie clips w/ 3 cracks
1-1	B737-200	Lap Joint Window Belt Replacement Doubler RH - Original Structure	BS 727-907, Str 9R-15R	50255/73383	20 cracks in 11 holes	NA
2	B737-200	Lap Joint Window Belt Replacement Doubler LH	BS 727-907, Str 9L-15L	9827/22202	No indications	No indications
3	B737-200	Lap Joint Replacement Doubler Stringer 4 LH	BS 540-907, Str 4L	9827/22202	No indications	No indications
4	B737-200	Lap Joint Replacement Doubler Stringer 4 RH	BS 540-907, Str 4R	9827/22202	No indications	No indications
5	DC-10-30F	STC Conversion Cargo Door Passenger to Freighter	BS 575-840, Str 5L-31L	29,557/7180	No indications	No indications
6	B727-200	STC Conversion Cargo Door Passenger to Freighter	BS 450-700, Str 1-20L	9660/5401	No indications	2 cracks lower door frame
LR1	B747-200	Fuselage Skin Aft Lower Lap Repair LH	BS 1700-1840, Str 38L-42L	25181/3777	No indications	No indications
LR2	B747-200	Fuselage Skin, Aft Pressure Bulkhead Web + T-chord RH	BS 2360, Str 1-22R	12576/1961	No indications	No indications
LR3	B757-200	Fuselage Side of Body Skin with 3 RAMs LH	BS 560-680, Str 12L-17L	19302/8294	No indications	No indications
LR4	A300-B4-203	Wing Spar to Fuselage SB53-265 Repair, Hole "I" FR47 LH	FR 47 LH, Lower Aft Wing Spar at Fuselage	15821/10031	3 prior known cracks	Hole #s 44 & 187 cracked
LR5	A300-B4-203	Lap Joint Repair Doubler Below Window Belt RH	FR 34-41, Str 18R	8735/6766	No indications	No indications
LR6	A300-B4-203	Lap Joint Repair Doubler at Floor Line RH	FR 36-44, Str 28R	34248/24605	No indications	No indications
LR7	A300-B4-203	Fuselage Skin Doubler Gross Wt. Increase Mods LH & RH	FR 54-56, Str 31-43 L&R	8735/6766	No indications	No indications
LR8	B737-200	Fuselage Skin Side of Body Combines 4 Repairs LH	BS 727-727B, Str 15L-19L	4672 FC	1 site w/ 12 cracks in 7 holes	No indications
LR9	B737-200	Fuselage Skin Aft Lower at Potable Water Port LH	BS 927-987, Str 20L-27L	20374 FC	No indications	No indications
LR10	B737-200	Fuselage Skin Center Lower Aft Repair Doubler	BS 834-899, Str 25L-25R	16182 FC	No indications	No indications
LR11	B757-200	Fuselage Skin Fwd Cab Repair, 4-way Splice LH	BS 300-325, Str 16L-20L	12628/5321	No indications	No indications
LR12	B757-200	Fuselage Skin Fwd Repair Below Window Belt Lap Joint LH	BS 590-630, Str 14L-19L	31122/13188	No indications	No indications
LR13	DC-9-30	Fuselage Skin Repair Aft of Wing Under Fairing RH	BS 770-798, Str 15R-20R	1877 FH	No indications	No indications
LR14	A320-200	Fuselage Skin Aft of L3 Cabin Door 2 Repairs in Specimen LH	FR 69-70, Str 16L-25L	27905 FC	1 crack at door corner	No indications
LR15	A320-200	Fuselage Skin Fwd at Avionics Access Door & Static Ports RH	FR 18-24, Str 33R-37R	12350/5997	No indications	No indications
LR16	B757-200	Fuselage Skin Center Aft Lower Belly at Antenna Mount	BS 715-740, Str 28L-28R	16984/6929	No indications	No indications

Specimens 1, 2, 3, 4, LR8, LR9, and LR10 came from the same retired passenger B737 and were obtained early in the overall project. The first four were lap joint modifications in accordance with Boeing SBs, and the other three were repairs to lower aft fuselage structure (discussed later in this section). As was often the case in this project, maintenance records were highly variable in the degree to which they fully documented all aspects that were of interest. Operators had their own overall records management schemes that were approved under their operating certificates, and often the particular information being sought was in other files that were not in-hand from these retired airplanes. In the case of this B737, extensive engineering documents were readily available detailing the repair work. However, the organization that operated the airplane during the repair period did not include the airplane FH and flight times on the engineering documents for many of these RAM—only the date of the work was recorded. Data from other recorded maintenance activities included both the dates and the FH and FC. A plot of the age of the airplane in FH and FC versus the date was constructed (figure 18) and the age of RAM was estimated from the date the repairs occurred.

DAYS	FLT HRS	FLT CYLS		CYLS/DAY
0	1	1	NEW	
5739	33459	35509		6.187141
6020	35051	39058		12.62989
7007	40428	51181		12.28267
7171	41258	53009		11.14634
7778	44400	60171		11.79901
8158	45980	63764		9.455263
8426	47304	66701		10.95896
9119	50255	73383	RETIRED	9.642136

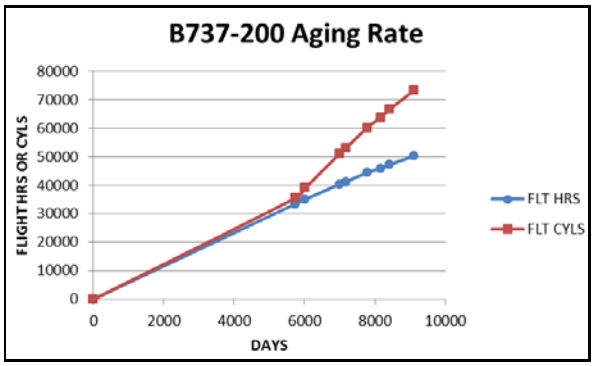


Figure 18. Maintenance Event Data (left) Used to Plot Age vs. Date (right) and to Estimate the Age of Teardown Specimens

Specimen 1 was a fuselage lap joint modification on a B737 right side window belt coupled with an impact repair at the edge of the modification doubler. Figure 19 shows that two holes suffered fatigue cracking in the repaired area and that one unrelated cracked shear tie was found a significant distance away.

Figure 19. Teardown Specimen 1

Specimen 1-1 was the base structure around the windows associated with specimen 1 that suffered anticipated age-related multisite fatigue damage in holes around window cutouts, as shown in figure 20.

Figure 20. Teardown Specimen 1-1

Specimen 2 was a fuselage lap joint modification on a B737 left-side window belt coupled with an AD repair to a window corner.

Specimen 3 was a fuselage lap joint modification on a B737 left-side crown skin.

Specimen 4 was a fuselage lap joint modification on a B737 right-side crown skin.

Specimen 5 was a cargo door frame structure installed on a DC-10 that had been converted from a passenger airplane to a freighter. The STC conversion was performed by a European repair station.

Specimen 6 was a cargo door frame structure installed on a B727 that had been converted from a passenger airplane to a freighter. The STC conversion was performed by a U.S. repair station.

Two cracks at fastener holes with thread marks were found in a lower door frame structure (see figure 21).

Figure 21. Teardown Specimen 6

Specimen LR1 was a fuselage lap joint corrosion repair to the lower aft fuselage of a B747.

Specimen LR2 was a combination of RAM on the aft pressure bulkhead t-chord and web of a B747 and the fuselage skin that was cut to provide access to the bulkhead. The aft pressure bulkhead web was repaired for gouges and tooling marks at the t-chord edge.

Specimen LR3 was a fuselage repair on a B757 for gouging on the side of the body due to jetway impact.

Specimen LR4 was a wing repair on an A300 for cracking in the lower skin below the spar cap. Three known prior cracks were confirmed as not growing, and two widely separated cracks were found in the repair doubler skin (see figure 22).

Figure 22. Teardown Specimen LR4

Specimen LR5 was a lap joint repair on an A300 for corrosion at the bonded lap joint and stringers.

Specimen LR6 was a lap joint modification on an A300 in accordance with an Airbus SB.

Specimen LR7 was a fuselage modification on an A300 to increase the maximum gross weight as part of a conversion from passenger to freighter configuration. The STC conversion was accomplished by a U.S. repair station.

Specimen LR8 was a fuselage repair on a B737 that collected four previous small repairs in close proximity into one LR. Fatigue cracking was found in seven adjacent holes along the floor beam next to the repair doubler (see figure 23).

Figure 23. Teardown Specimen LR8

Specimen LR9 was a fuselage repair on a B737 that cut out corrosion and incorporated a previous small repair on the aft belly.

Specimen LR10 was a fuselage frame repair on a B737 that required a large skin doubler on the aft belly.

Specimen LR11 was a fuselage skin repair on a B757 forward cabin necessitated by impact with a jetway.

Specimen LR12 was a fuselage skin repair on a B757 necessitated by gouging on the side of body due to jetway impact.

Specimen LR13 was a fuselage skin repair on a DC 9 necessitated by heat damage aft of the right wing.

Specimen LR14 was a fuselage skin repair on an A320 necessitated by denting aft of the left rear cabin door. A large crack in the lower door frame was found (see figure 24).

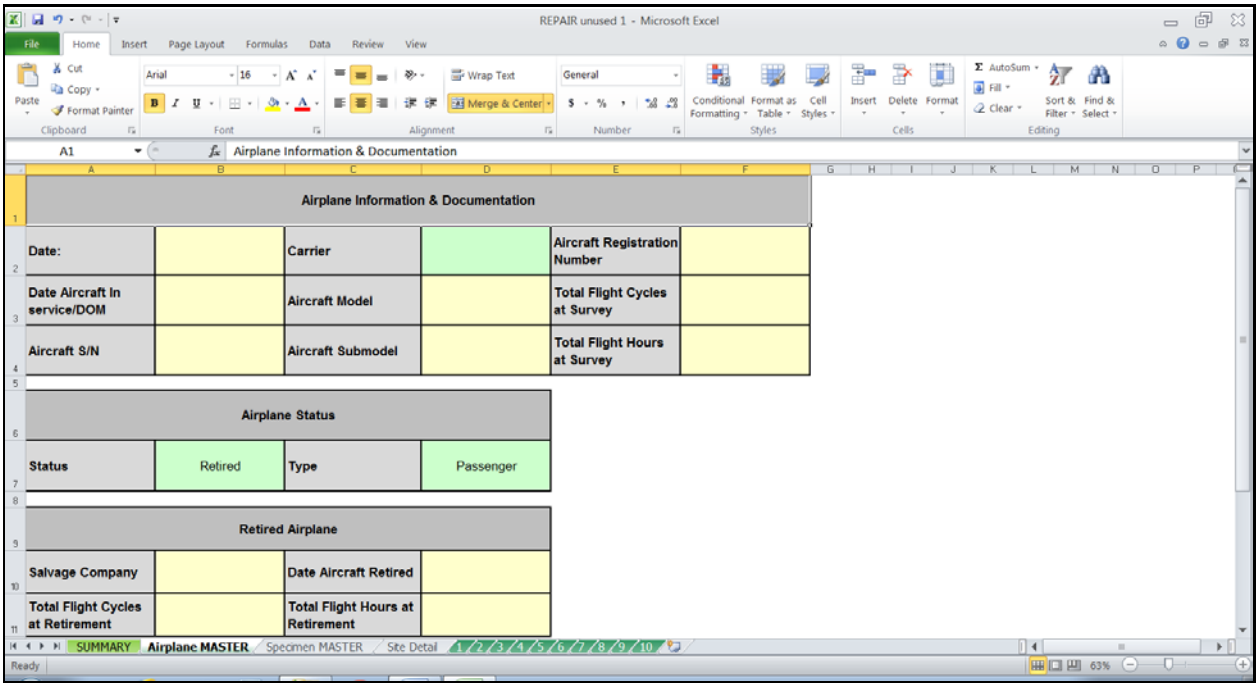
Figure 24. Teardown Specimen LR14

Specimen LR15 was a fuselage skin repair on an A320 necessitated by impact with a tow tug on the forward lower cabin.

Specimen LR16 was a fuselage antenna modification on a B757 lower aft belly that also suffered from corrosion and tooling damage.

5.3 TEARDOWN DATABASE

The intent of the teardown survey was to provide the same general data for each specimen as the field surveys, with additional information acquired by performing the detailed inspections and subsequent defect characterization. The field survey electronic data acquisition and storage form was adapted for use on teardown specimens and RAM (figures 25-27). Thus, 23 Microsoft Excel spreadsheets were generated and serve as the teardown database deliverable. One additional spreadsheet was generated for specimen 1 because of damage found in the original structure between two RAM. Each spreadsheet was modified to incorporate the inspection data, including the inspection method used and the inspection results. Additional attention was given to documenting the maintenance drivers and records for each specimen, especially the engineering documents. The reason for RAM was detailed in the comments section of the Individual RAM sheets. Relevant pictures were included of the structures before, during, and after teardown. Pictures of any damage found are included as well. The data were not aggregated into a single large column-ordered database because of the relatively small number of specimens and the large amount of data per RAM compared to the field survey. Also, the desire to perform more in-depth reviews of each specimen and the inspection results by the FAA precludes the need for an aggregation.

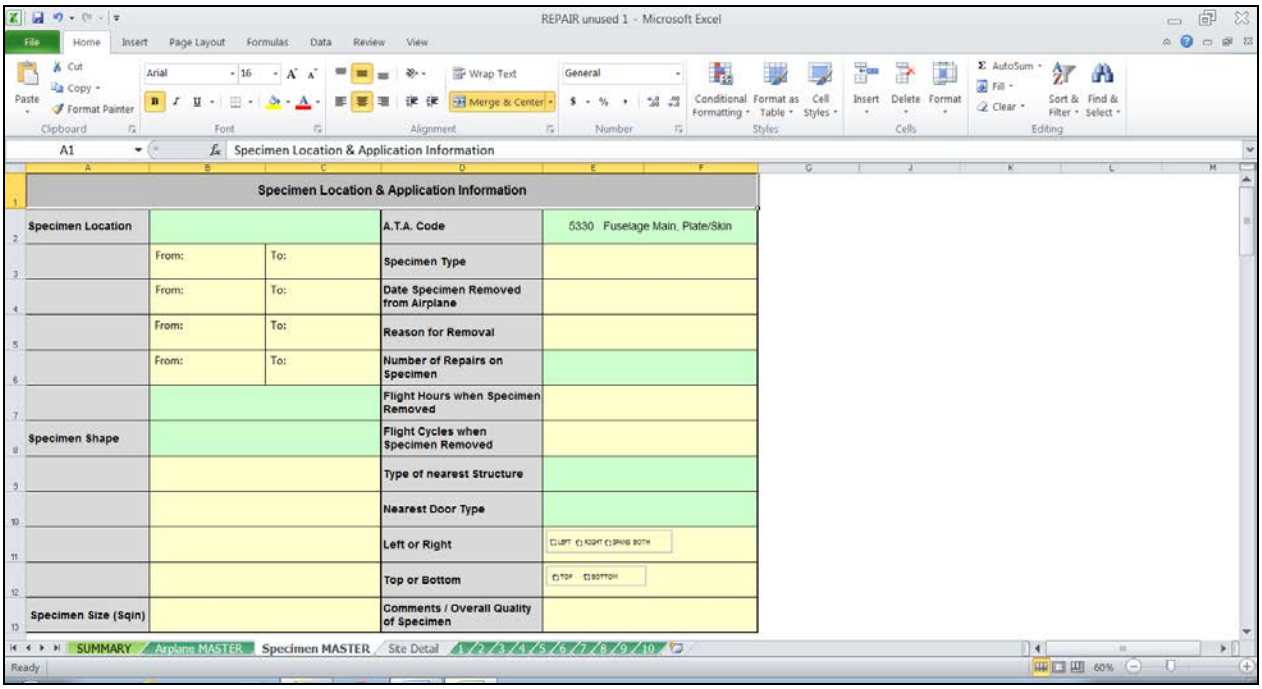


Airplane Information & Documentation					
Date:		Carrier		Aircraft Registration Number	
Date Aircraft In service/DOM		Aircraft Model		Total Flight Cycles at Survey	
Aircraft S/N		Aircraft Submodel		Total Flight Hours at Survey	

Airplane Status			
Status	Retired	Type	Passenger

Retired Airplane			
Salvage Company		Date Aircraft Retired	
Total Flight Cycles at Retirement		Total Flight Hours at Retirement	

Figure 25. Airplane Master Page of the Teardown Database Spreadsheet



Specimen Location & Application Information				
Specimen Location			A.T.A. Code	5330 Fuselage Main, Plate/Skin
	From:	To:	Specimen Type	
	From:	To:	Date Specimen Removed from Airplane	
	From:	To:	Reason for Removal	
	From:	To:	Number of Repairs on Specimen	
			Flight Hours when Specimen Removed	
Specimen Shape			Flight Cycles when Specimen Removed	
			Type of nearest Structure	
			Nearest Door Type	
			Left or Right	
			Top or Bottom	
Specimen Size (Sqin)			Comments / Overall Quality of Specimen	

Figure 26. Specimen Master Page of the Teardown Database Spreadsheet

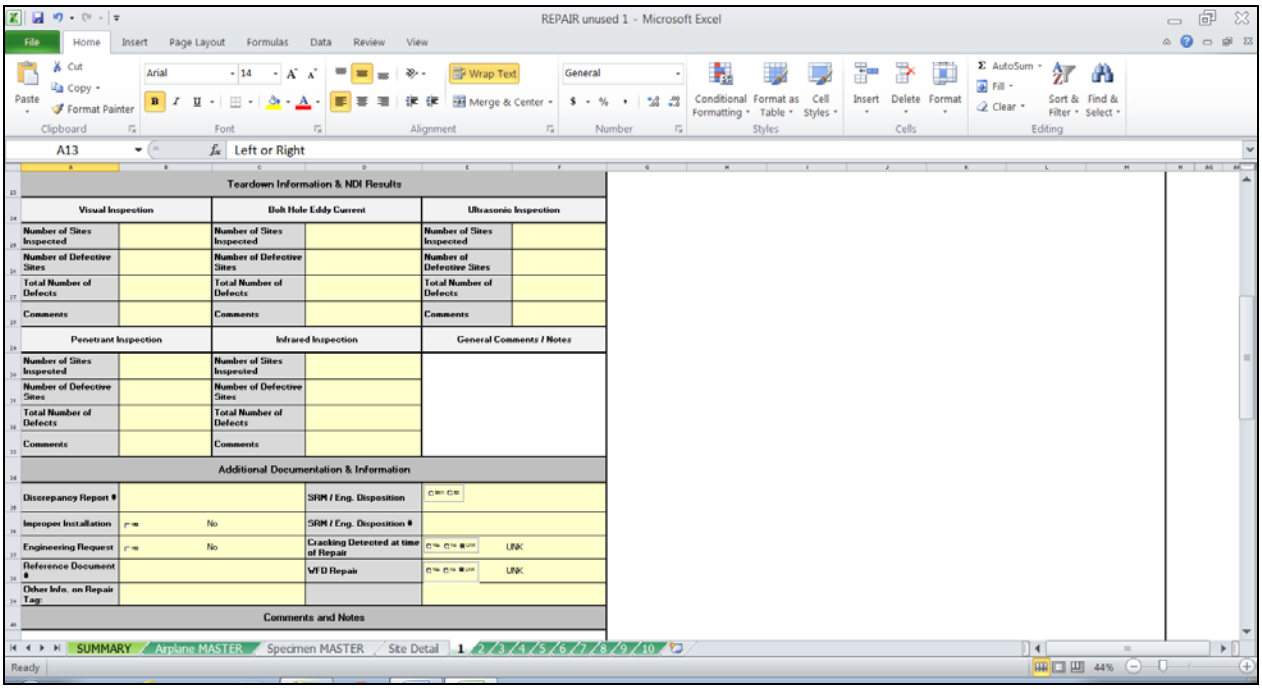


Figure 27. Inspection and Documentation Sections of an Individual RAM Page of the Teardown Database Spreadsheet

A nonproprietary form of the electronic database deliverable for this project task can be found in appendix B. It provides airplane model and age data along with individual RAM data and a diagram of the RAM location on each airplane. Proprietary information pertaining to operators or owners of the airplanes has been removed.

6. CONCLUSIONS

A relatively large number of individual repairs, alterations, and modifications (RAM) were documented and inspected for the occurrence of fatigue cracking in a field survey of transport airplanes. Of the 2612 individual RAM surveyed on 154 airplanes from 2008 to 2010, none showed evidence of cracking that could lead to widespread fatigue damage (WFD). In fact, investigation revealed very little fatigue cracking that could be clearly associated with the presence of RAM. It was determined that the dataset was a representative sample of the U.S. domestic transport fleet of 5015 airplanes. From the sample data, estimates of the population characteristics of RAM in the U.S. domestic fleet were made. The most important RAM characteristics were the number per airplane, the size, the age, the general location and makeup of each RAM, and the age of the airplanes on which they occurred. Thus, data are available for the Federal Aviation Administration to determine whether RAM pose a risk of developing WFD and whether further rulemaking is necessary to address those risks.

Additionally, a sample of airplane structures containing RAM was collected and underwent complete teardown and detailed inspection for fatigue cracking. Large area RAM (greater than 500 in.^{2}) were preferentially sampled. Twenty two specimens from 12 airplanes were carefully disassembled into individual structural components with all fasteners removed. Detailed visual

and eddy current testing inspection was performed on each component and each fastener hole, respectively. Some minor fatigue cracking was found and documented. However, no multiple site damage/multiple element damage was found in any specimens. For statistical analysis purposes, the 22 individual teardown specimens were considered as 35 fatigue critical equivalent structures based on two-bay size criteria. Because no multiple site damage/multiple element damage was found in any of the teardown equivalent structures, it can be inferred that the binomial probability of no WFD occurring in the U.S. domestic fleet is 98%, with 50% confidence bound on the probability estimate.

The following are some additional data and observations from this study:

1. Most observed RAM appear to be properly installed based on a qualitative rating.

2. The Aging Airplane Safety Final Rule provides some degree of mitigation of risk of RAM developing WFD because it requires a damage tolerance evaluation of repairs and alterations/modifications that affect fatigue critical structure. The evaluation may result in damage tolerance inspections or other maintenance actions of those repairs or alterations/modifications.

3. The few existing deficiencies that were observed (<1% of RAM) appear to be individual workmanship issues.

7. REFERENCES

1. Schneider, G. "Damage Tolerance Data for Repairs and Alterations," *Federal Register*, Vol. 72, No. 238, 2007, p. 70486.

2. AC 120-93, "Damage Tolerance Inspections for Repairs and Alterations," November 20, 2007.

3. AC 120-104, "Establishing and Implementing Limit of Validity to Prevent Widespread Fatigue Damage," January 10, 2011.

4. Bakuckas, J., "Full-Scale Testing of Fuselage Structure Containing Multiple Cracks," DOT/FAA/AR-01/46, July 2002.

5. AC 91-56 B, "Continuing Stuctural Integrity Program for Airplanes," March 7, 2008.

6. AC 25.571D, "Damage Tolerance and Fatigue Evaluation of Structure," January 13, 2011.

7. Giordano, M., "Fuel Tank Safety Compliance Extension (Final Rule) and Aging Airplane Program Update (Request for Comments)," *Federal Register*, Vol. 69, No. 146, July 30, 2004, pp. 45936-95942.

8. Sippel, W., "Aging Airplanes Program: Widespread Fatigue Damage," *Federal Register*, Vol. 71, No. 74, 2006, pp. 19928-19951.

9. Sippel, W., "Aging Airplanes Program: Widespread Fatigue Damage," *Federal Register*, Vol. 75, No. 219, 2010, pp. 69746-69789.

10. Airworthiness Assurance Working Group (AAWG) A Final Report of the AAWG *Continued Airworthiness of Structural Repairs, Task 2—Structural Repairs*, 1996.

11. Sobeck, F., "Aging Airplane Safety," *Federal Register*, Vol. 70, No. 21, 2005, pp. 5518-5534.

12. Safarian, P., Personal Communication on Characteristics and Rationale for Defining Fatigue Critical Equivalent Structures, 2010.

APPENDIX A—REPAIRS, ALTERATIONS, AND MODIFICATIONS RAM LOCATION PLOT CHARTS OF FIELD-SURVEYED AIRPLANES (NON-PROPRIETARY)

Table A-1. Page Location for Each Airplane Type in Appendix A

Airplane Type	Page Number (in appendix A)
A-300	A-2, A-90, A-98, A-131, A-135
A-320	A-20, A-22, A-28, A-44, A-45, A-46, A-48, A-51, A-71, A-76, A-89, A-107, A-110, A-115, A-123, A-124, A-125
A-330	A-100, A-101, A-102
B-727	A-10, A-12, A-13, A-14, A-47, A-52, A-53, A-56, A-58, A-59, A-103, A-128
B-737	A-5, A-6, A-7, A-14, A-15, A-16, A-17, A-18, A-21, A-24, A-25, A-27, A-29, A-31, A-35, A-39, A-60, A-62, A-66, A-68, A-70, A-73, A-75, A-82, A-83, A-91, A-92, A-93, A-97, A-99, A-108, A-113, A-114, A-118, A-126, A-133, A-136, A-137
B-747	A-4, A-134
B-757	A-8, A-36, A-40, A-57, A-61, A-64, A-67, A-69, A-72, A-77, A-78, A-79, A-80, A-81, A-87, A-111, A-112, A-132
B-767	A-9, A-11, A-23, A-26, A-32, A-65, A-74, A-120, A-121, A-122, A-138, A-139, A-140
B-777	A-84, A-86, A-95, A-96
DC-8	A-85, A-88, A-104, A-106
DC-9	A-3, A-37, A-38, A-41, A-42, A-43, A-49, A-50, A-54, A-55, A-63, A-94, A-105, A-109, A-116, A-117, A-119, A-127, A-129, A-130
DC-10	A-30, A-33, A-34,

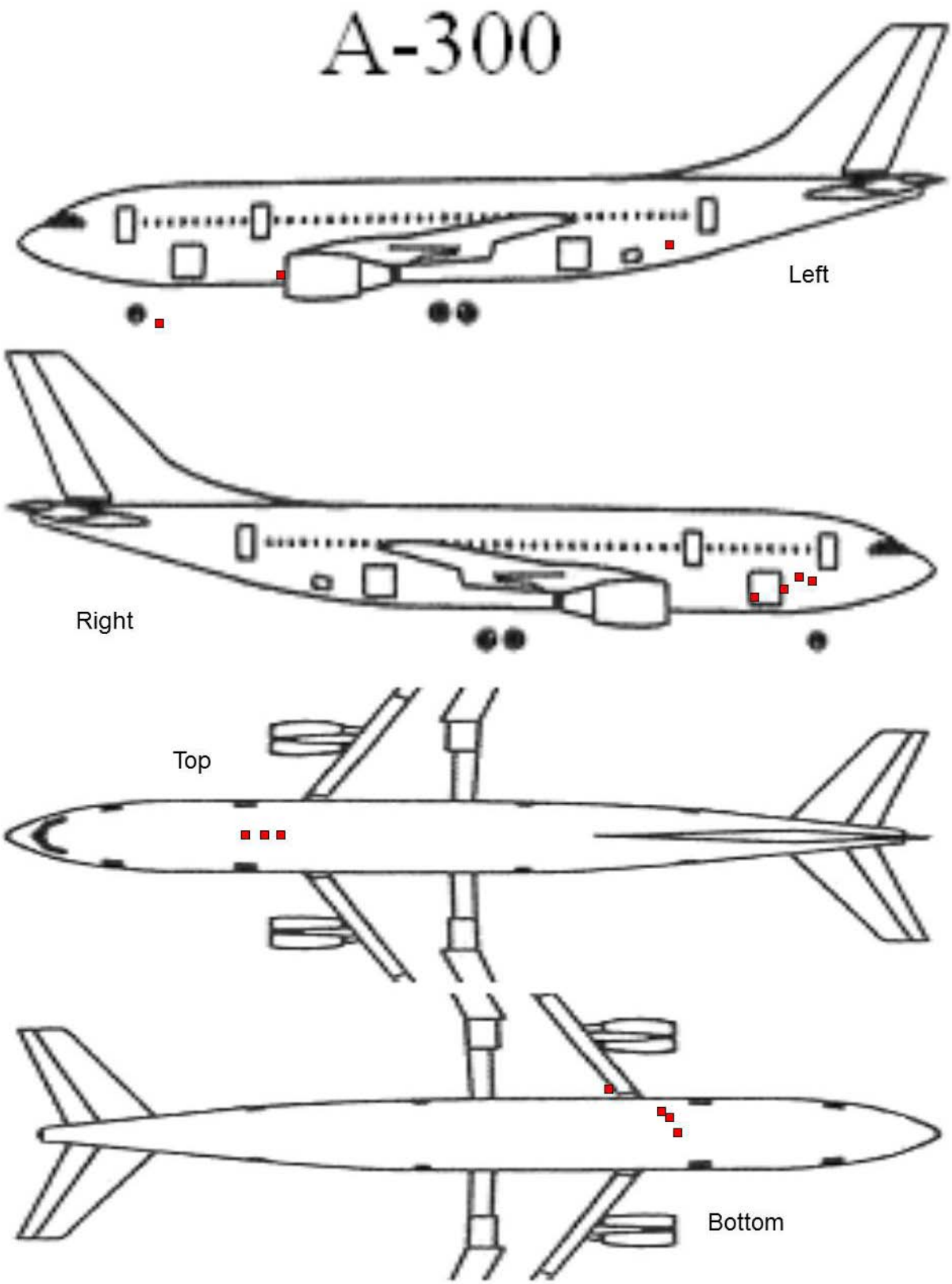


Figure A-1. RAM Location Plot Chart, A-300

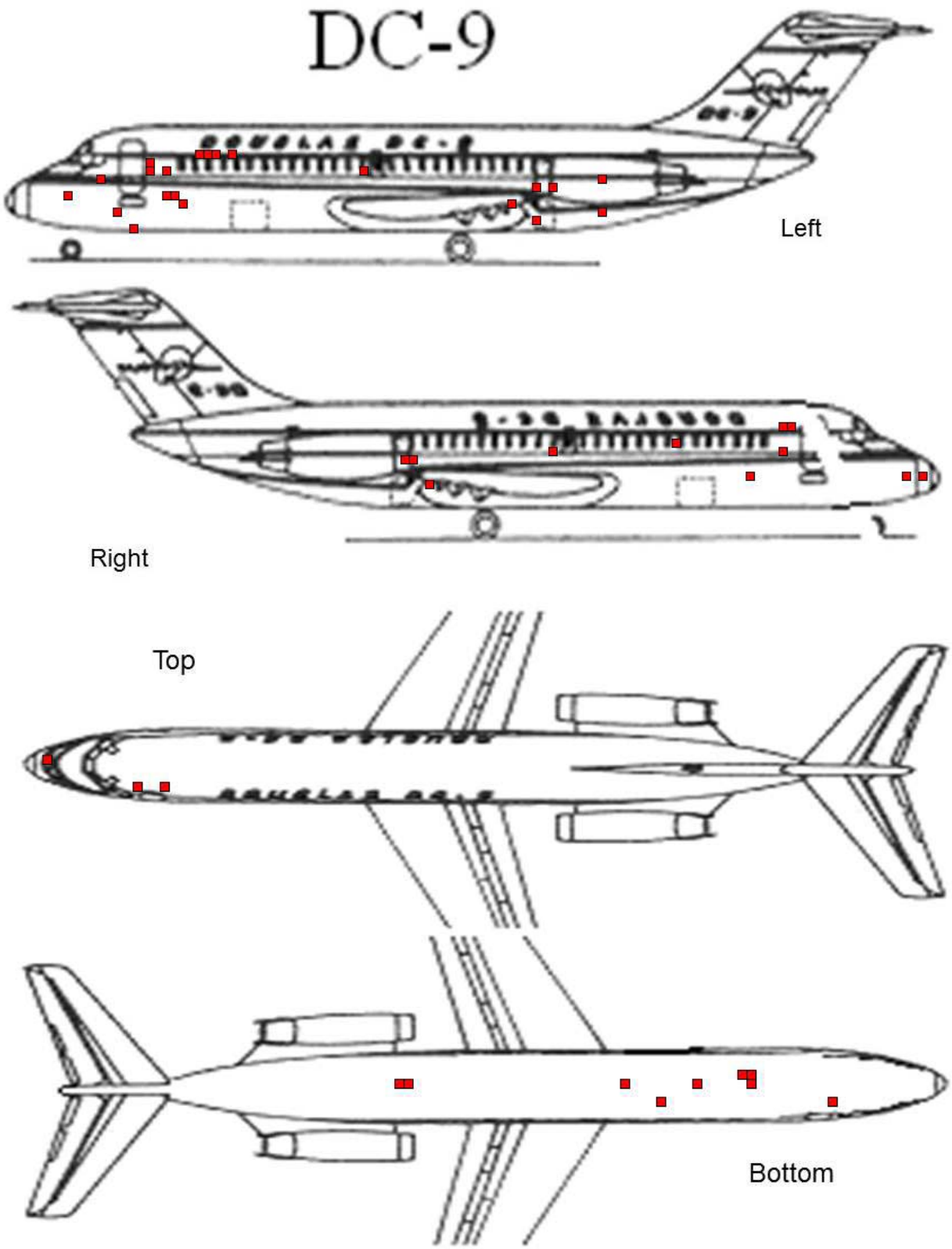


Figure A-2. RAM Location Plot Chart, DC-9

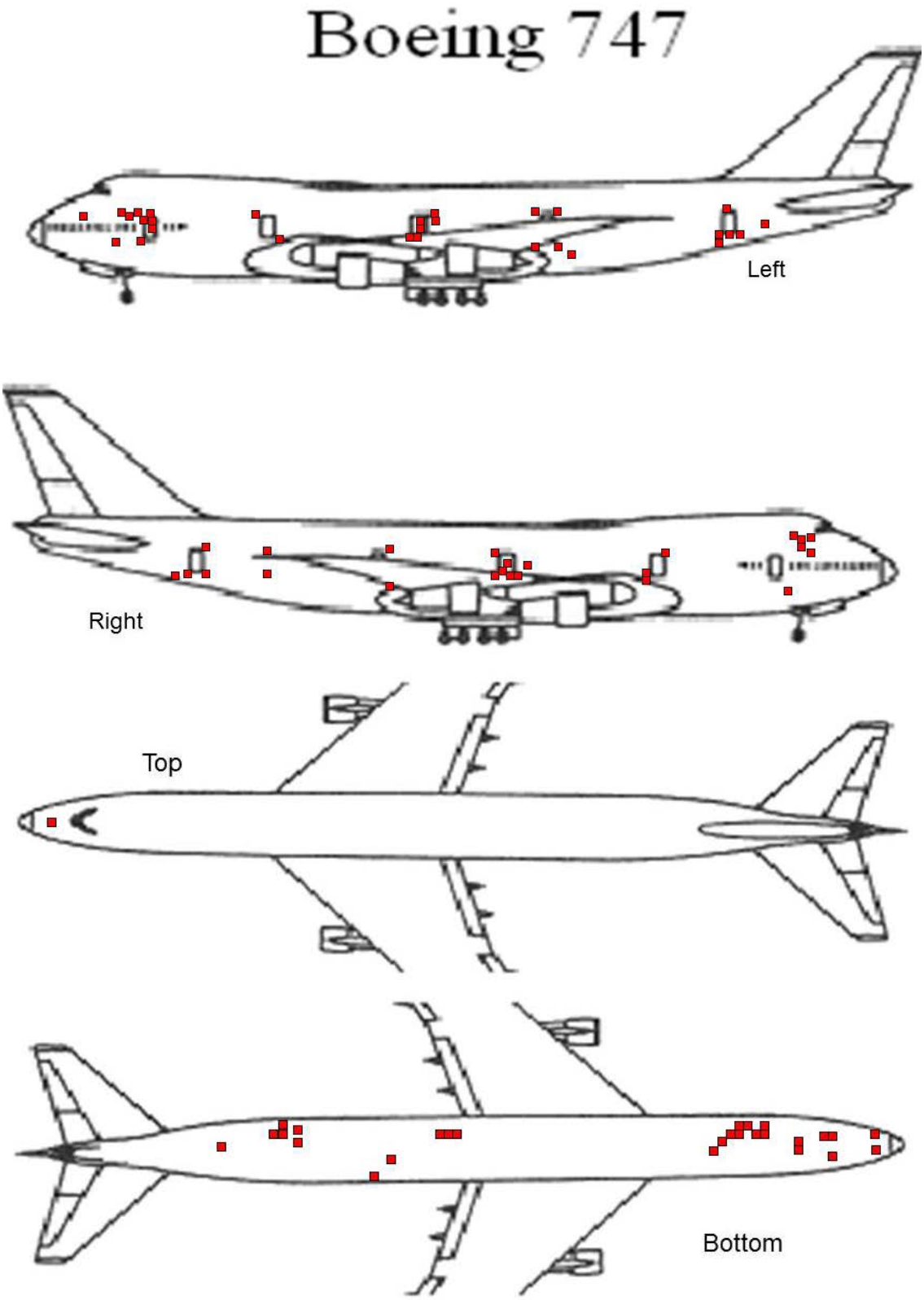


Figure A-3. RAM Location Plot Chart, Boeing 747

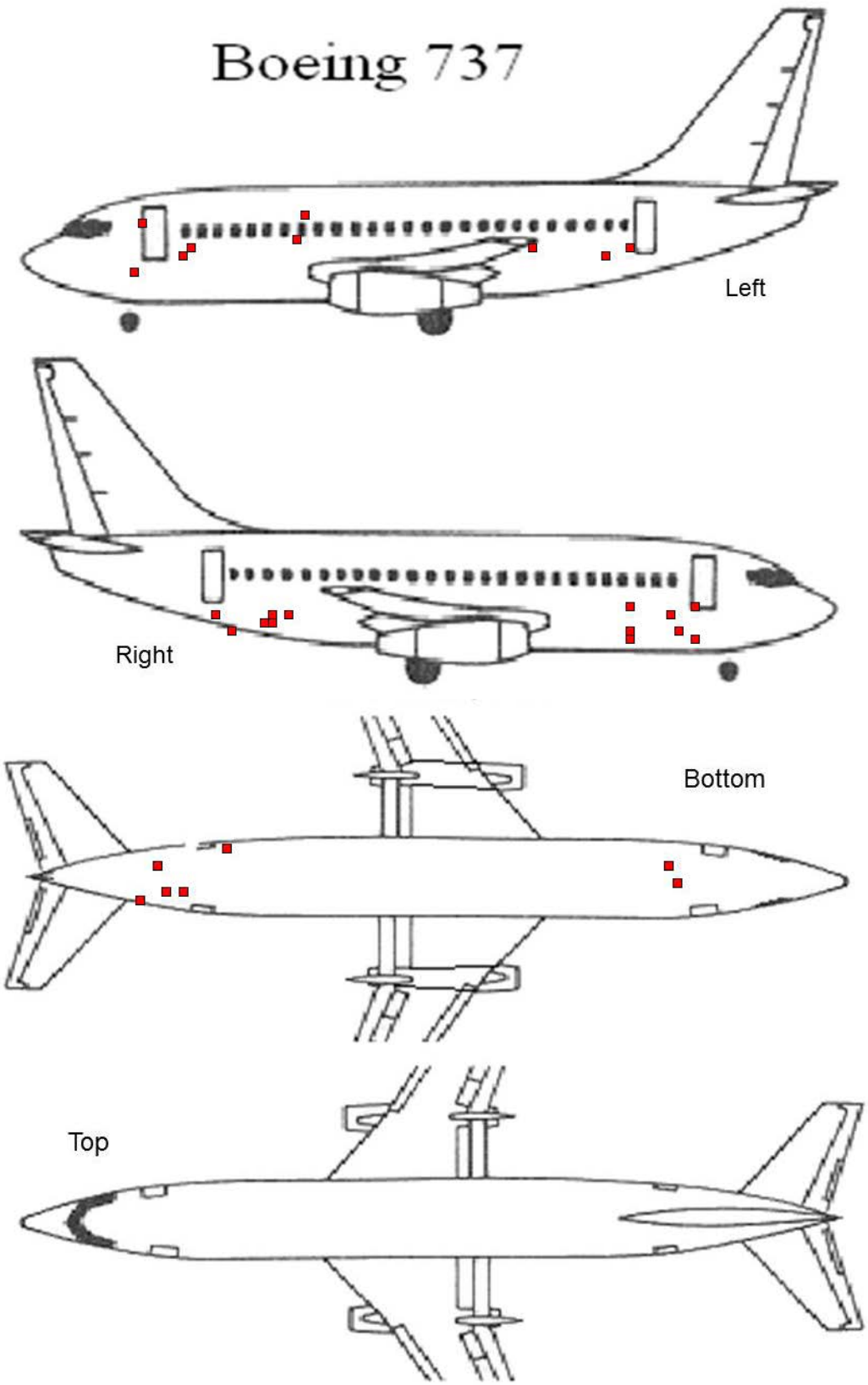


Figure A-4. RAM Location Plot Chart, Boeing 737

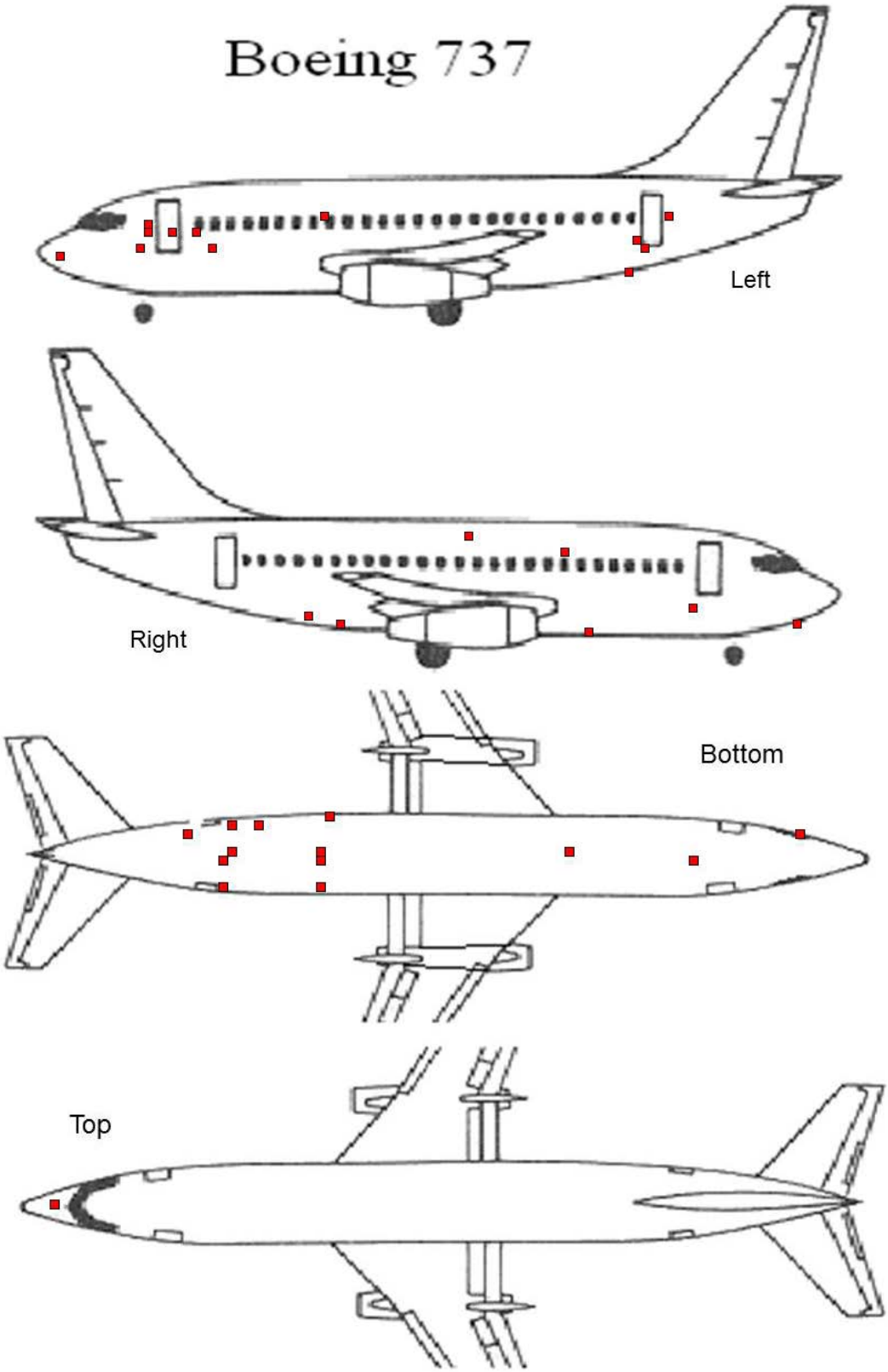


Figure A-5. RAM Location Plot Chart, Boeing 737

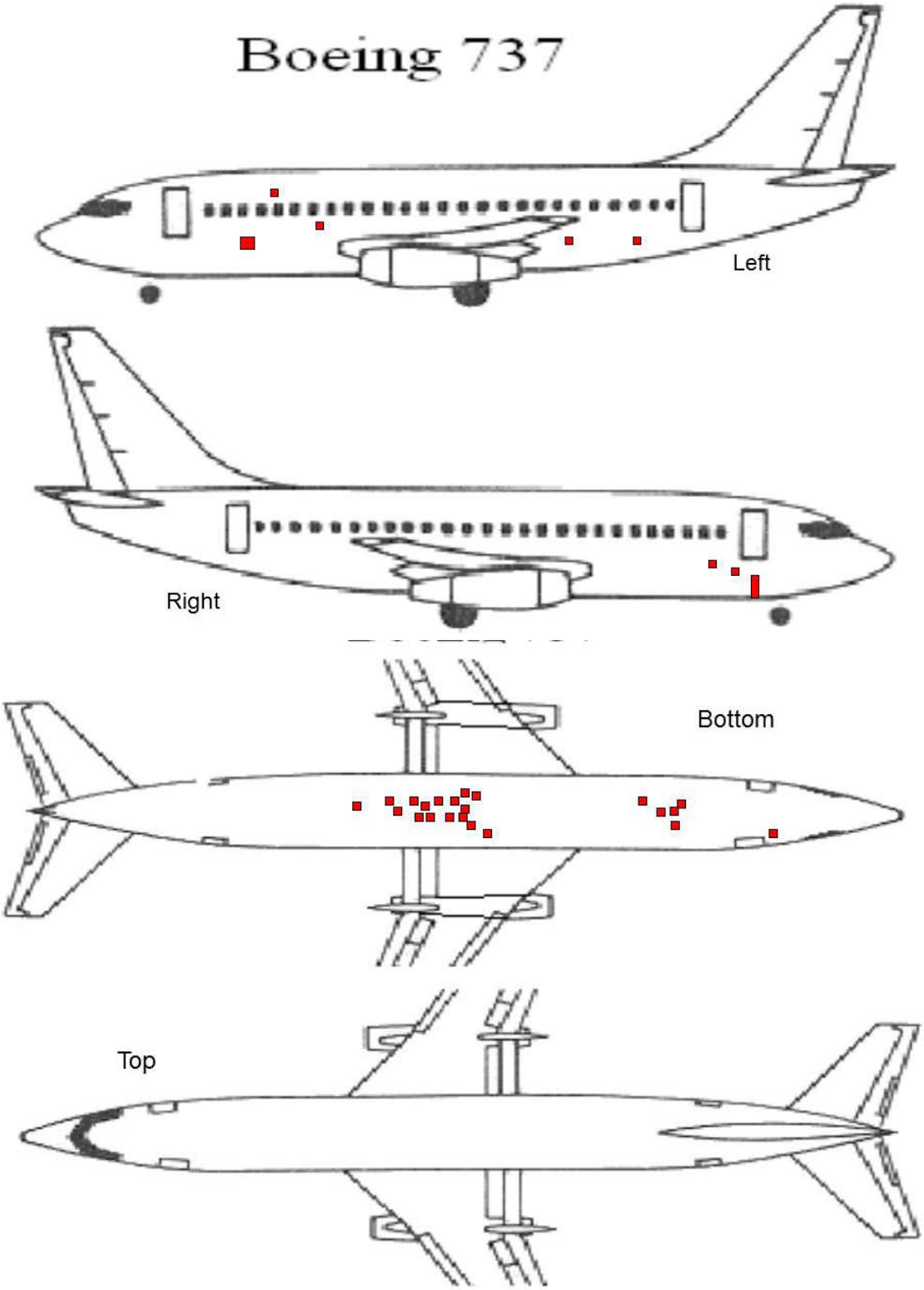


Figure A-6. RAM Location Plot Chart, Boeing 737

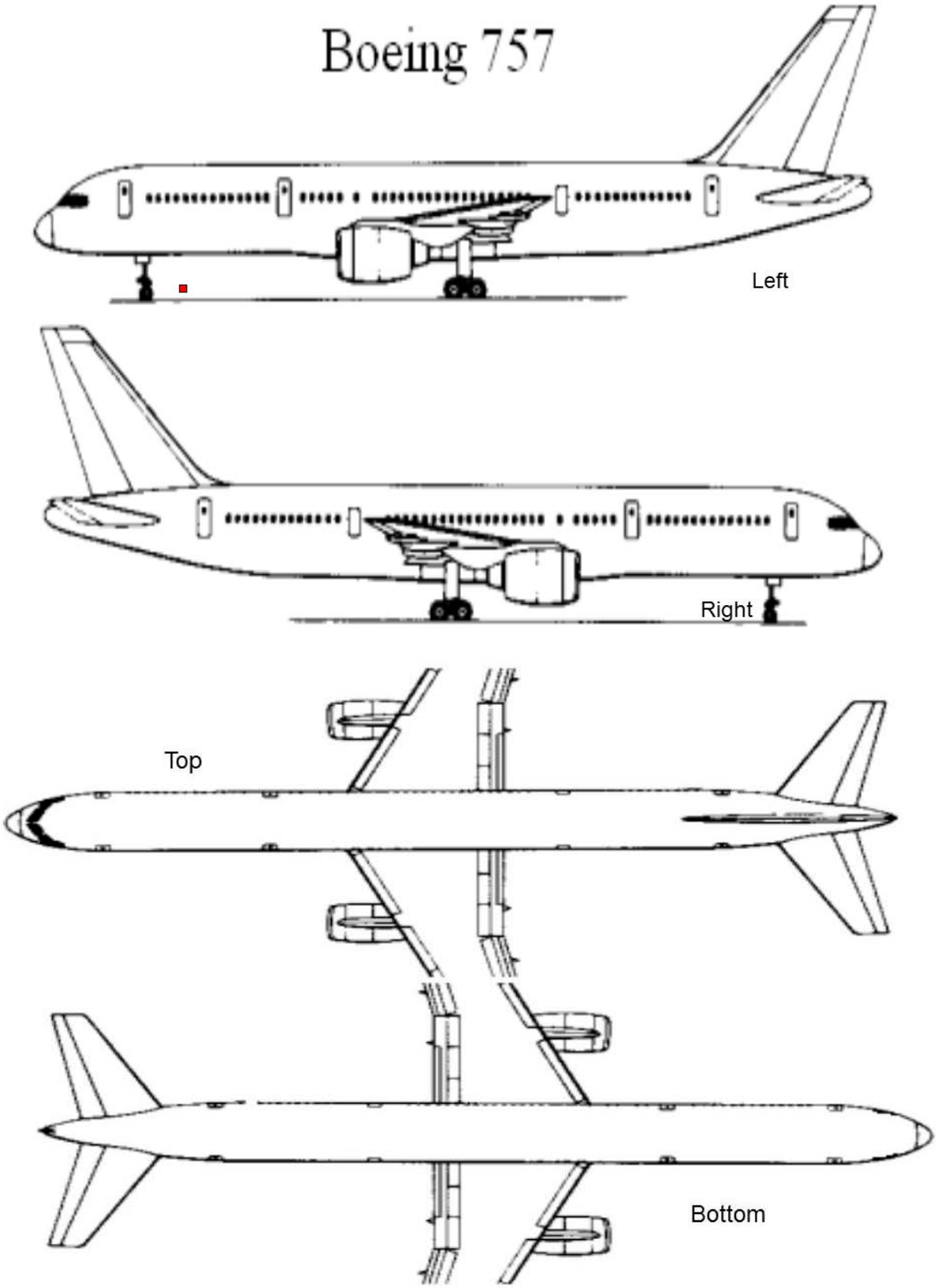


Figure A-7. RAM Location Plot Chart, Boeing 757

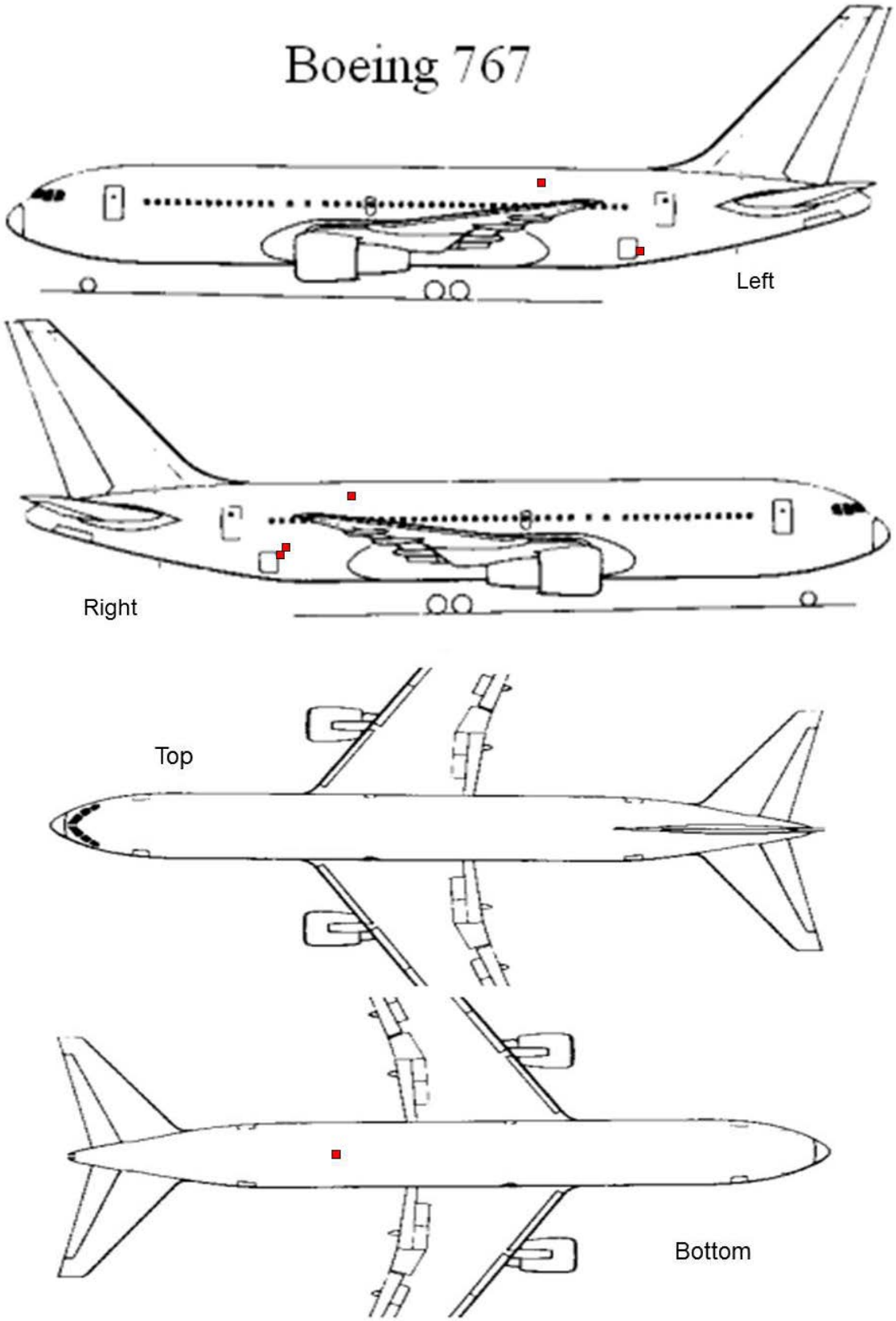


Figure A-8. RAM Location Plot Chart, Boeing 767

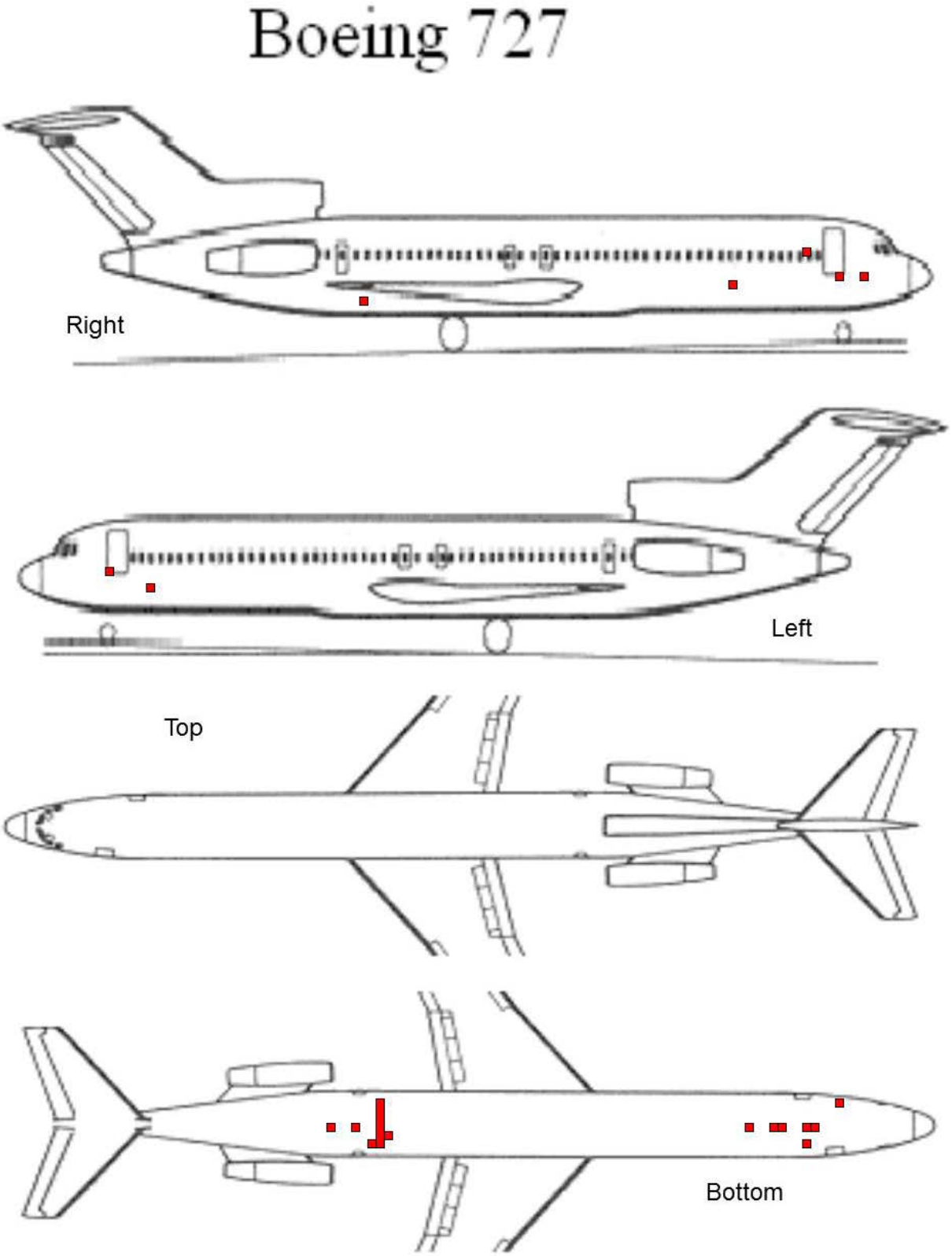


Figure A-9. RAM Location Plot Chart, Boeing 727

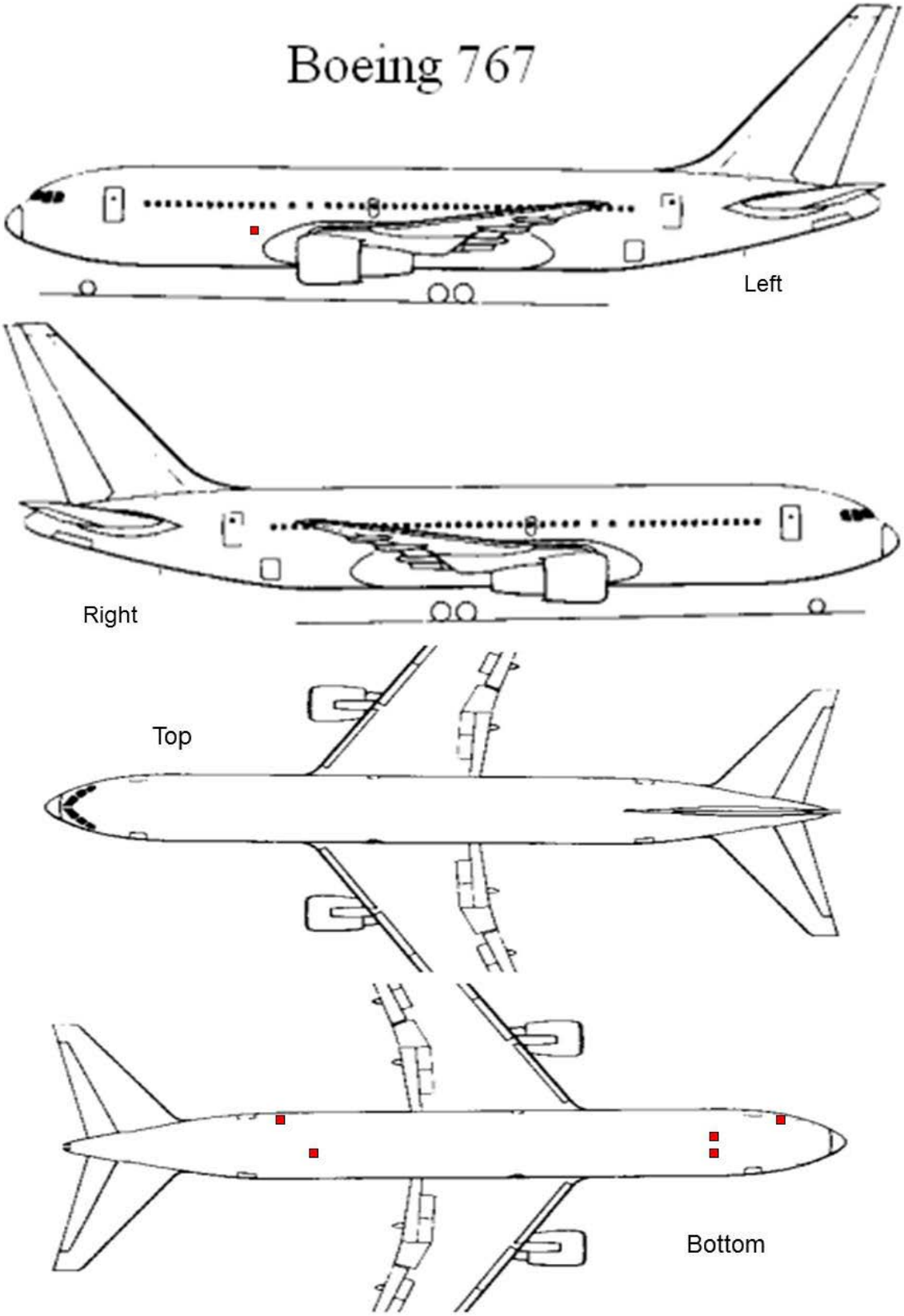


Figure A-10. RAM Location Plot Chart, Boeing 767

Boeing 727

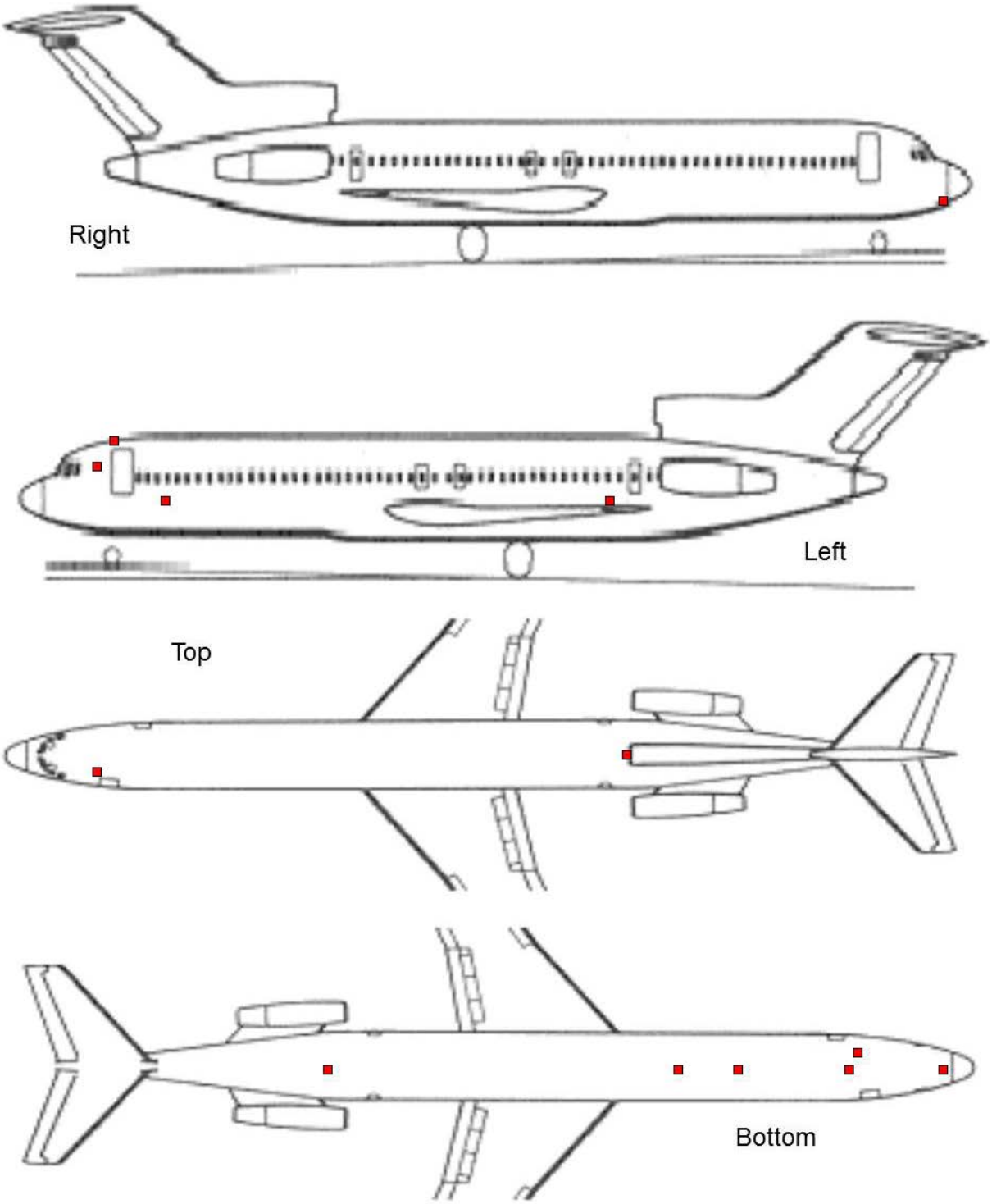


Figure A-11. RAM Location Plot Chart, Boeing 727

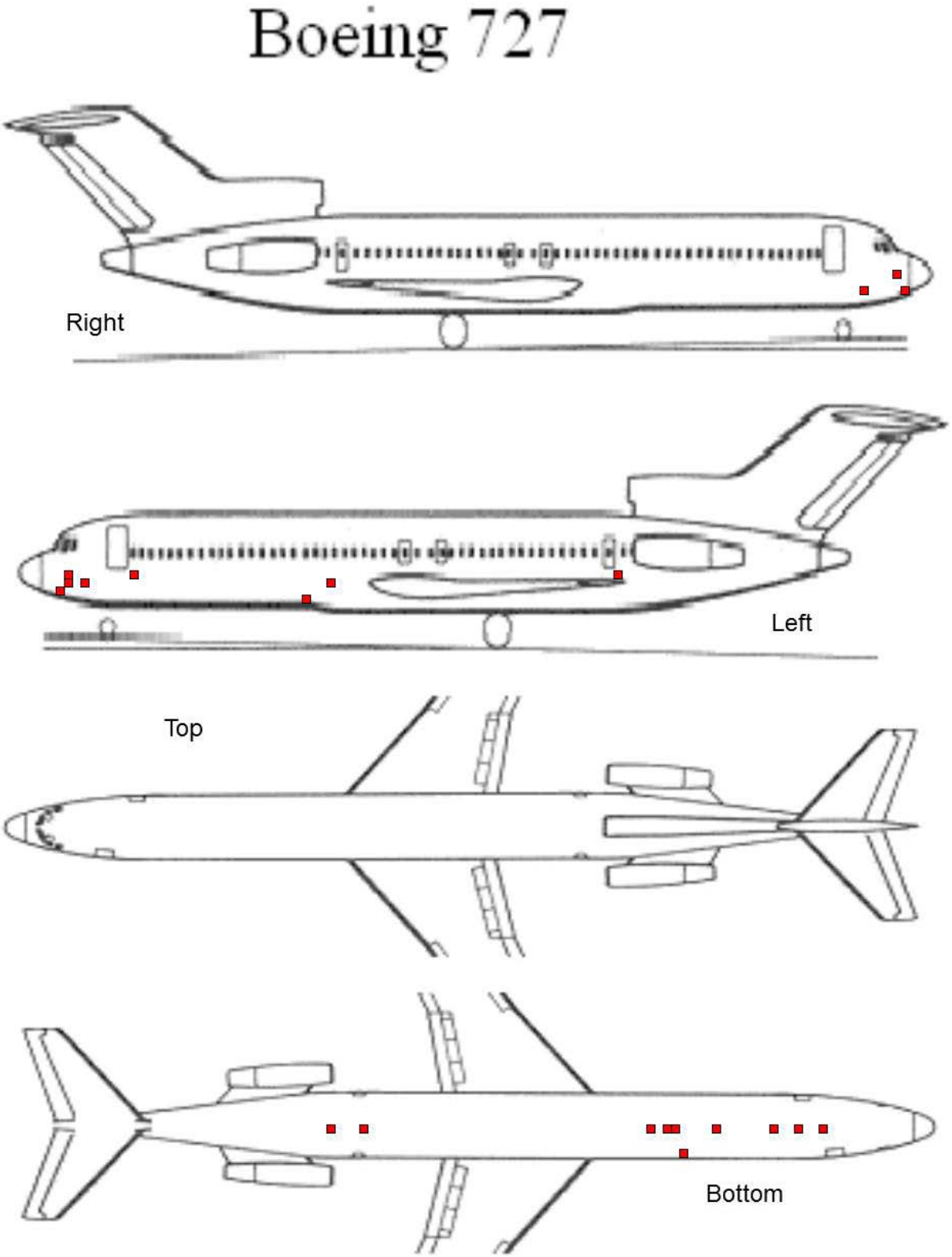


Figure A-12. RAM Location Plot Chart, Boeing 727

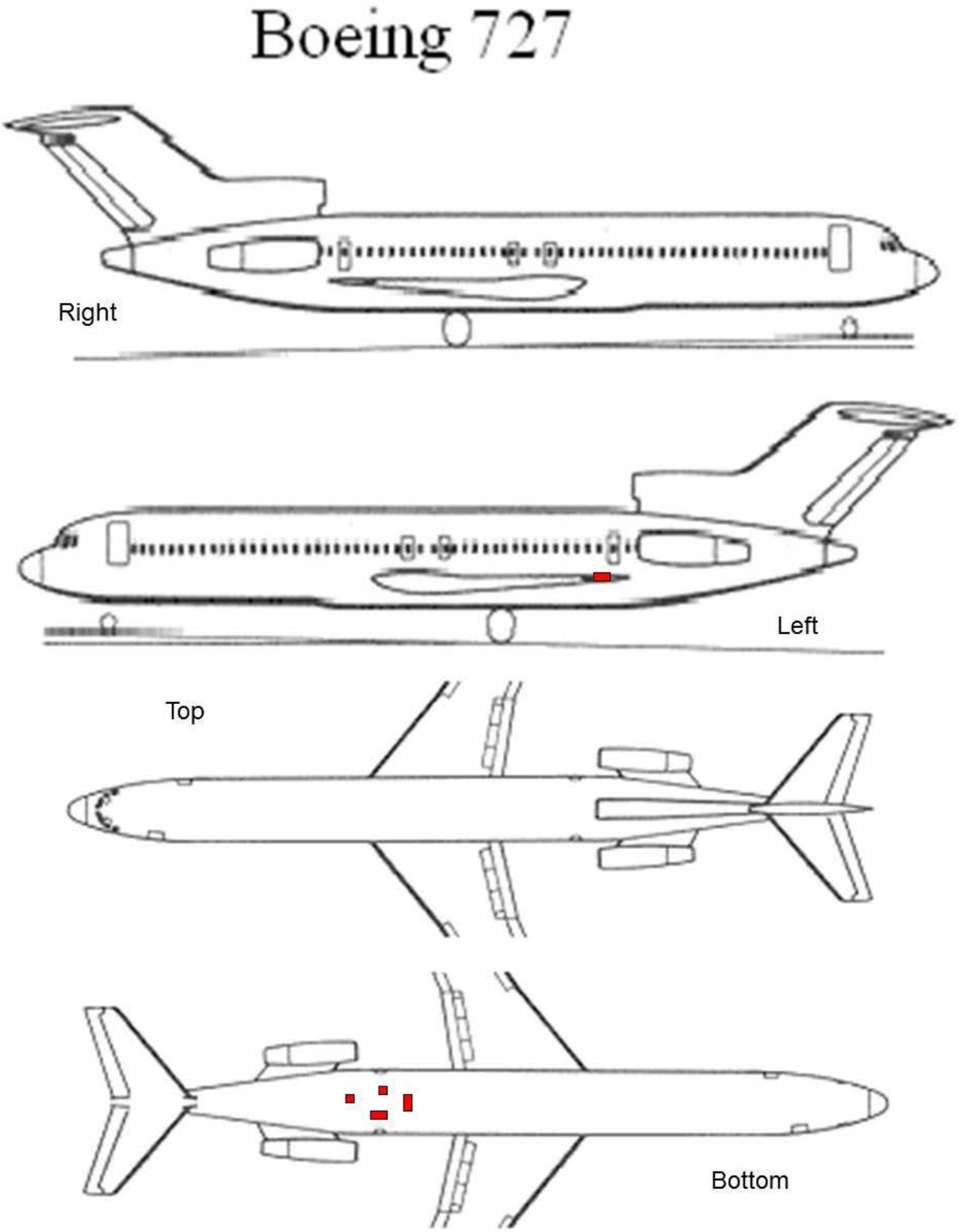


Figure A-13. RAM Location Plot Chart, Boeing 727

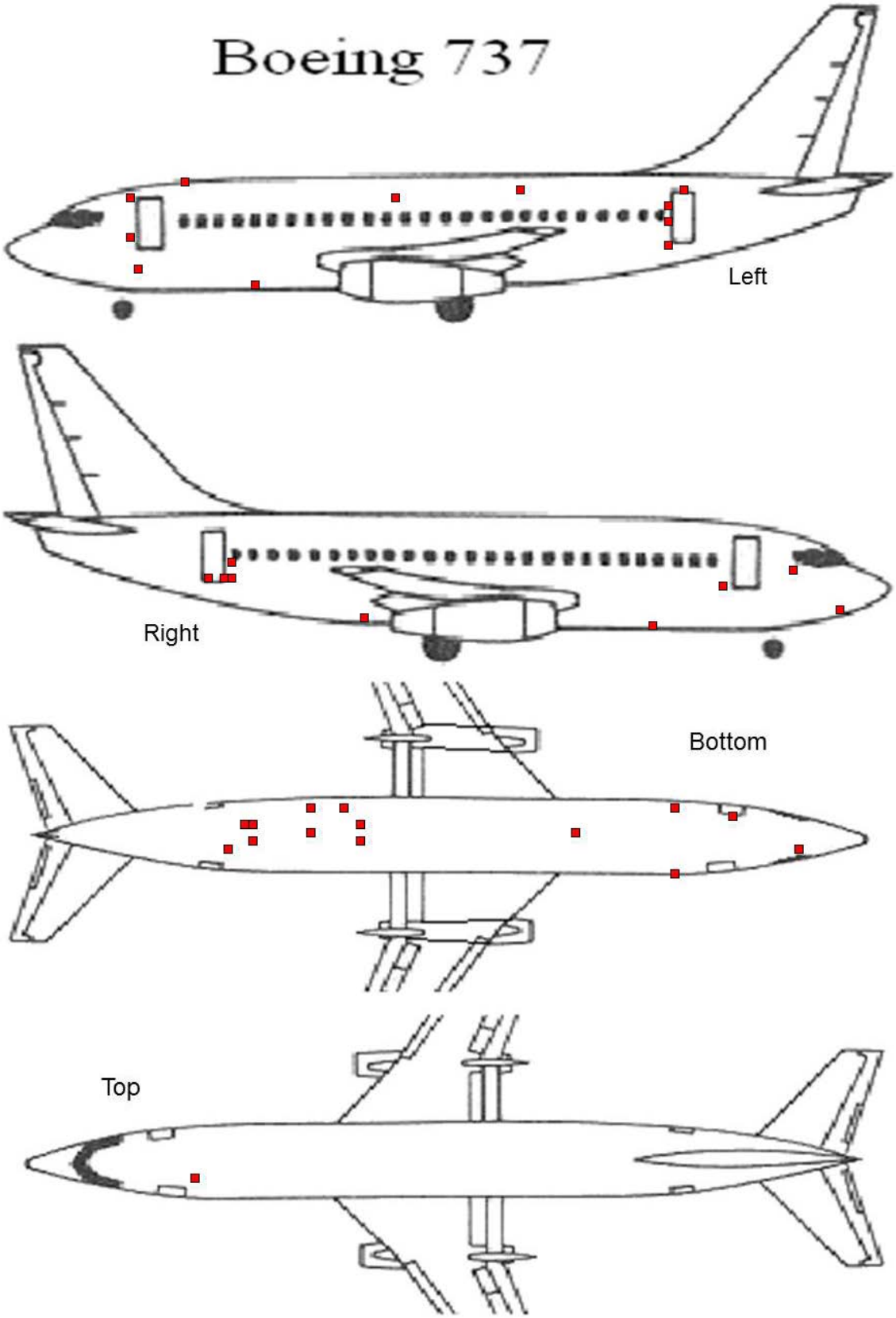


Figure A-14. RAM Location Plot Chart, Boeing 737

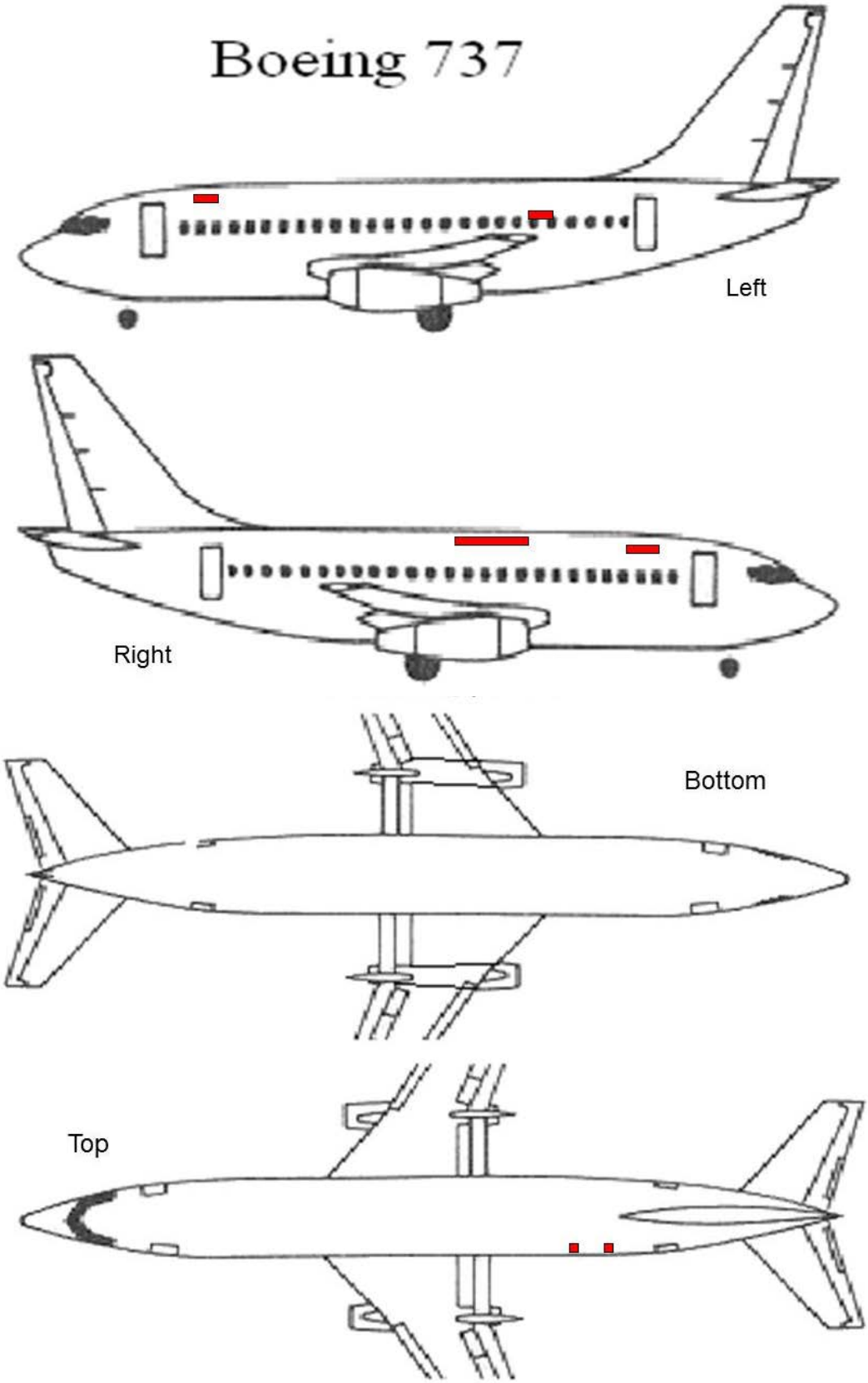


Figure A-15. RAM Location Plot Chart, Boeing 737

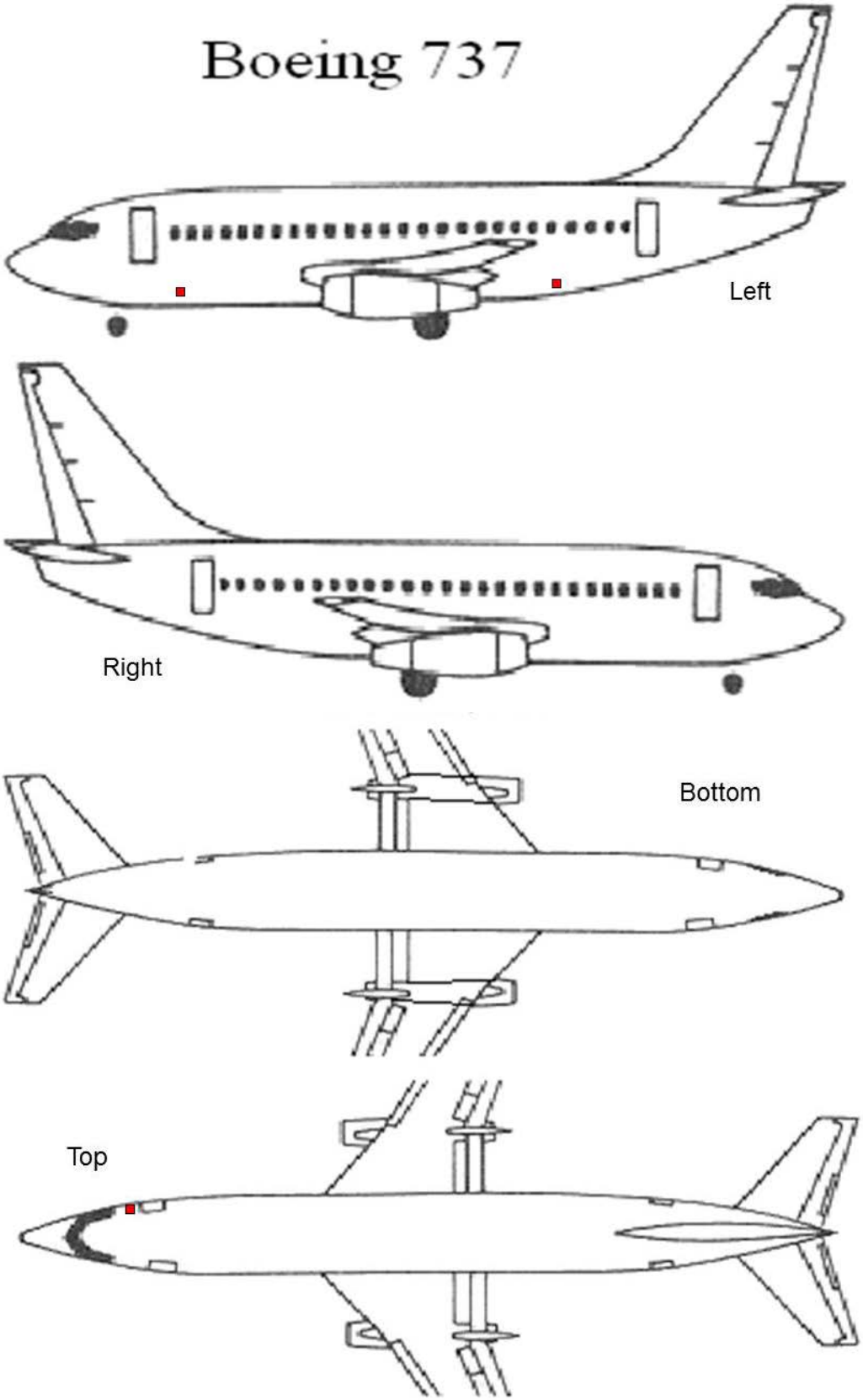


Figure A-16. RAM Location Plot Chart, Boeing 737

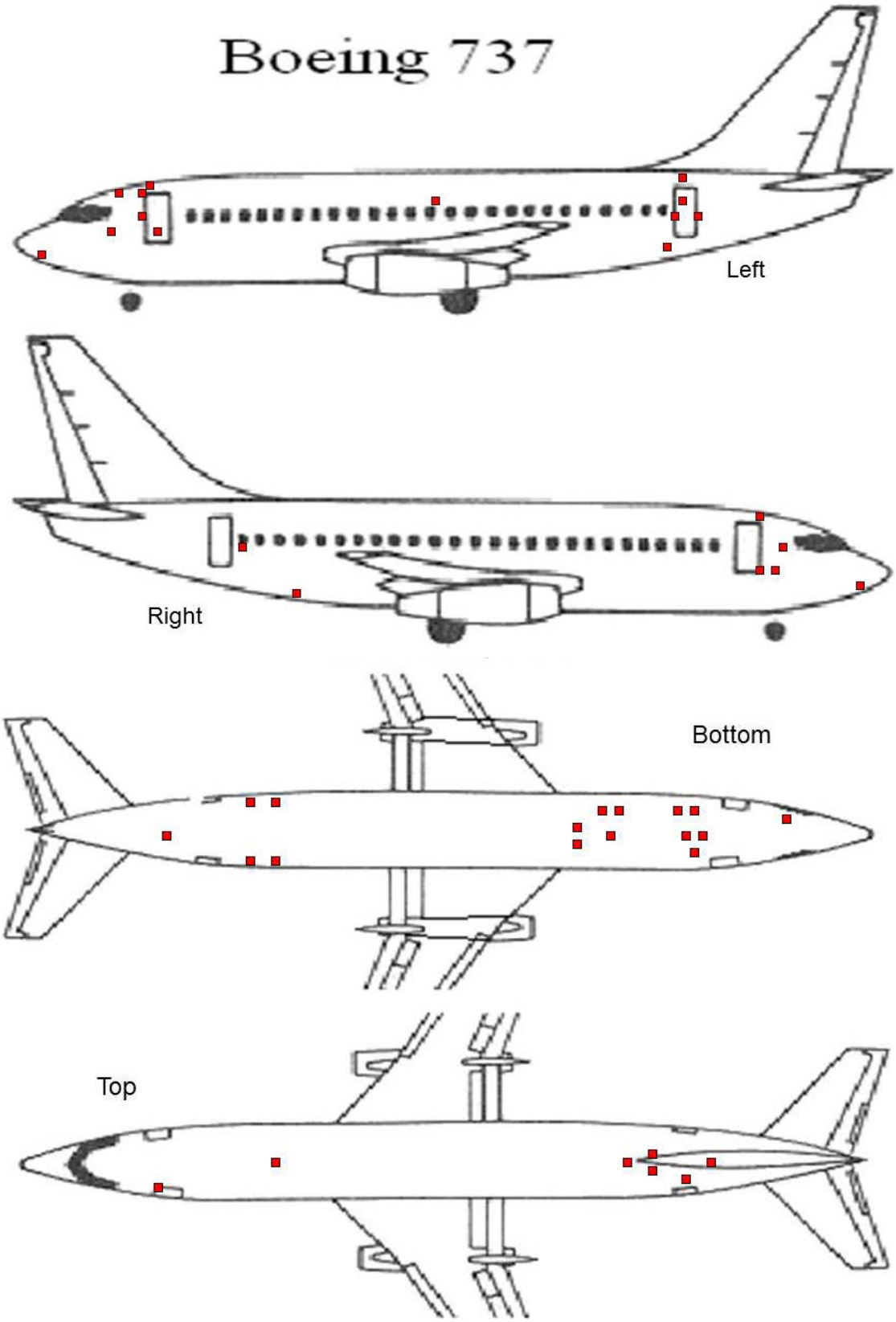


Figure A-17. RAM Location Plot Chart, Boeing 737

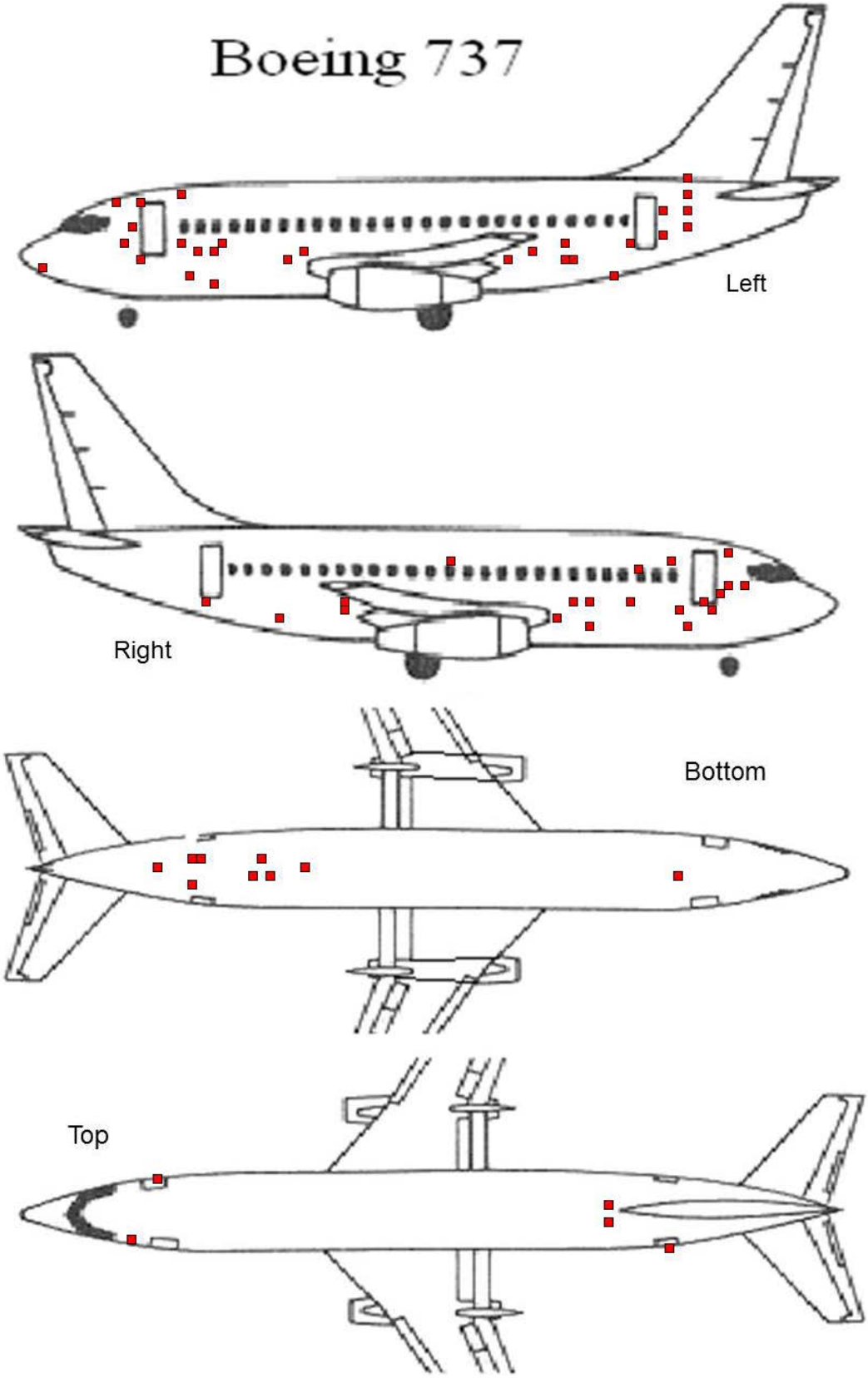


Figure A-18. RAM Location Plot Chart, Boeing 737

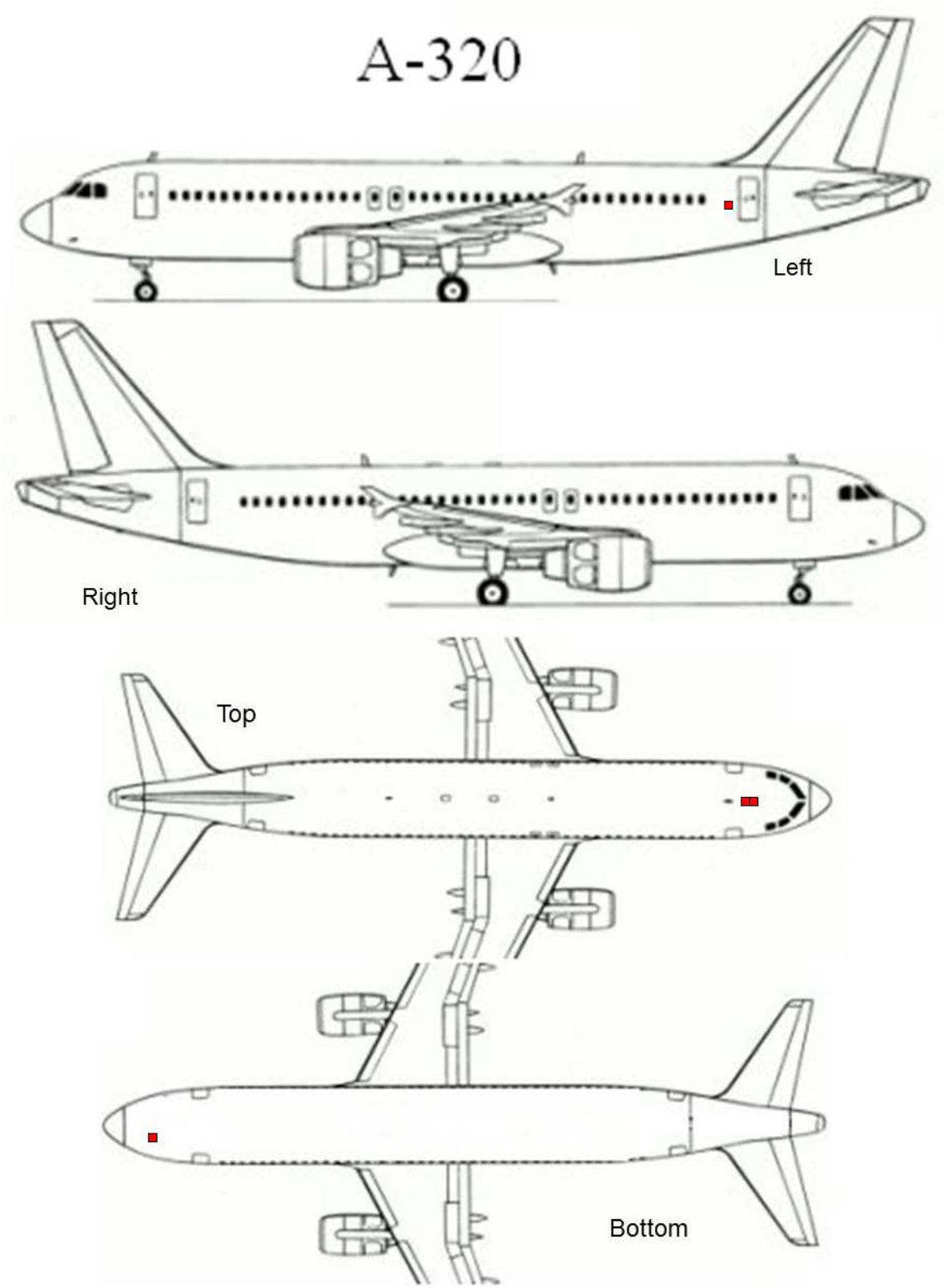


Figure A-19. RAM Location Plot Chart, A-320

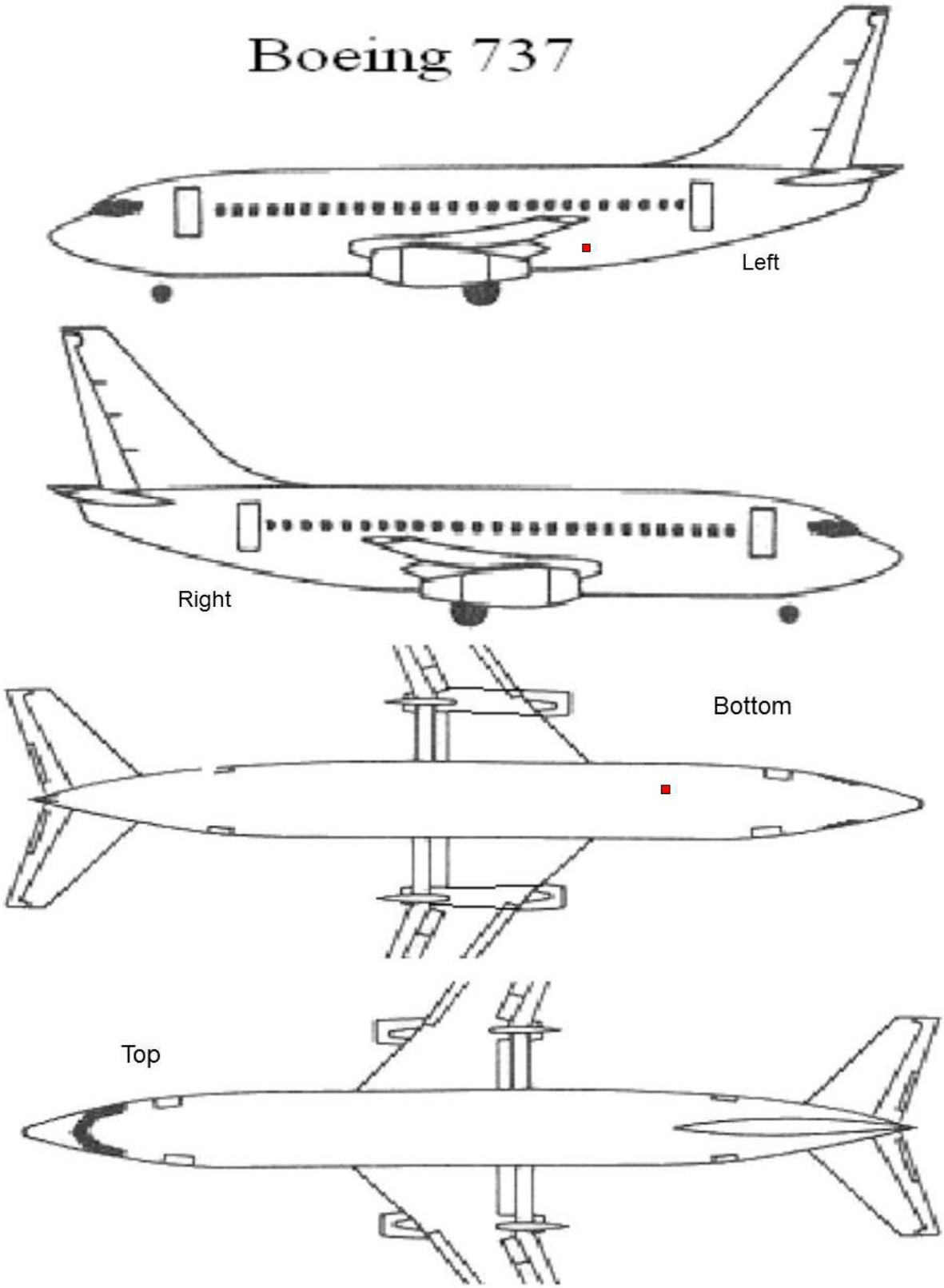


Figure A-20. RAM Location Plot Chart, Boeing 737

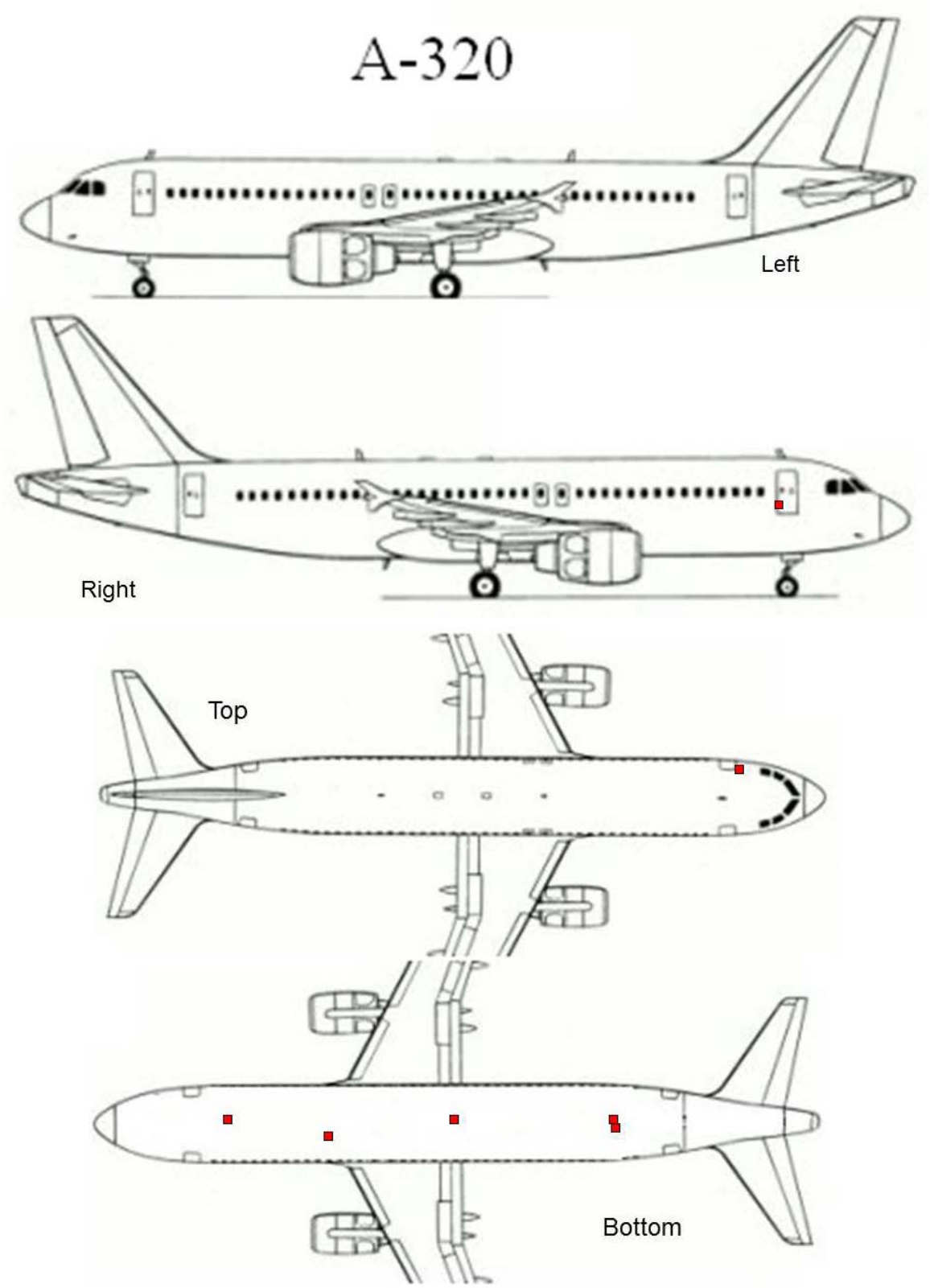


Figure A-21. RAM Location Plot Chart, A-320

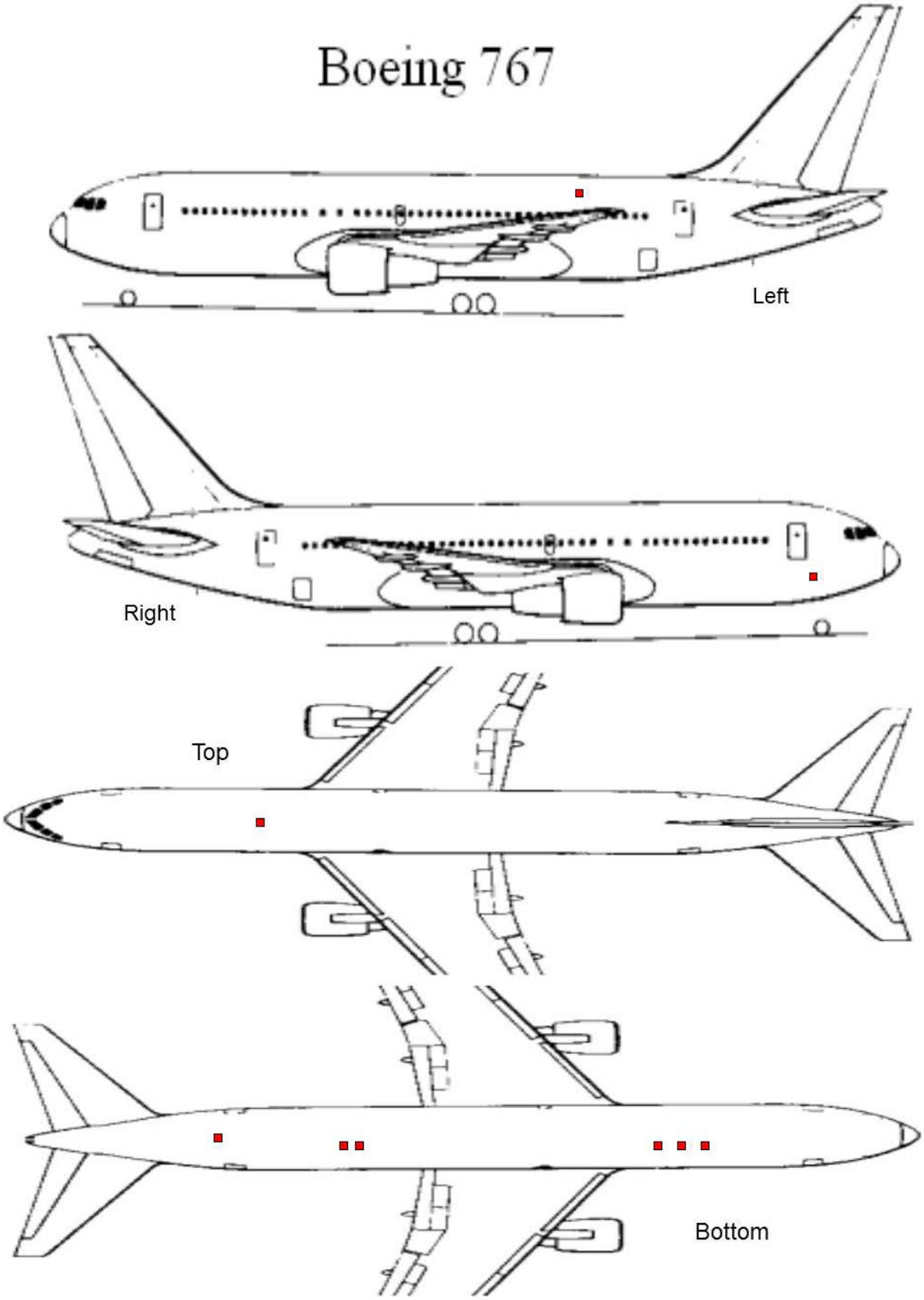


Figure A-22. RAM Location Plot Chart, Boeing 767

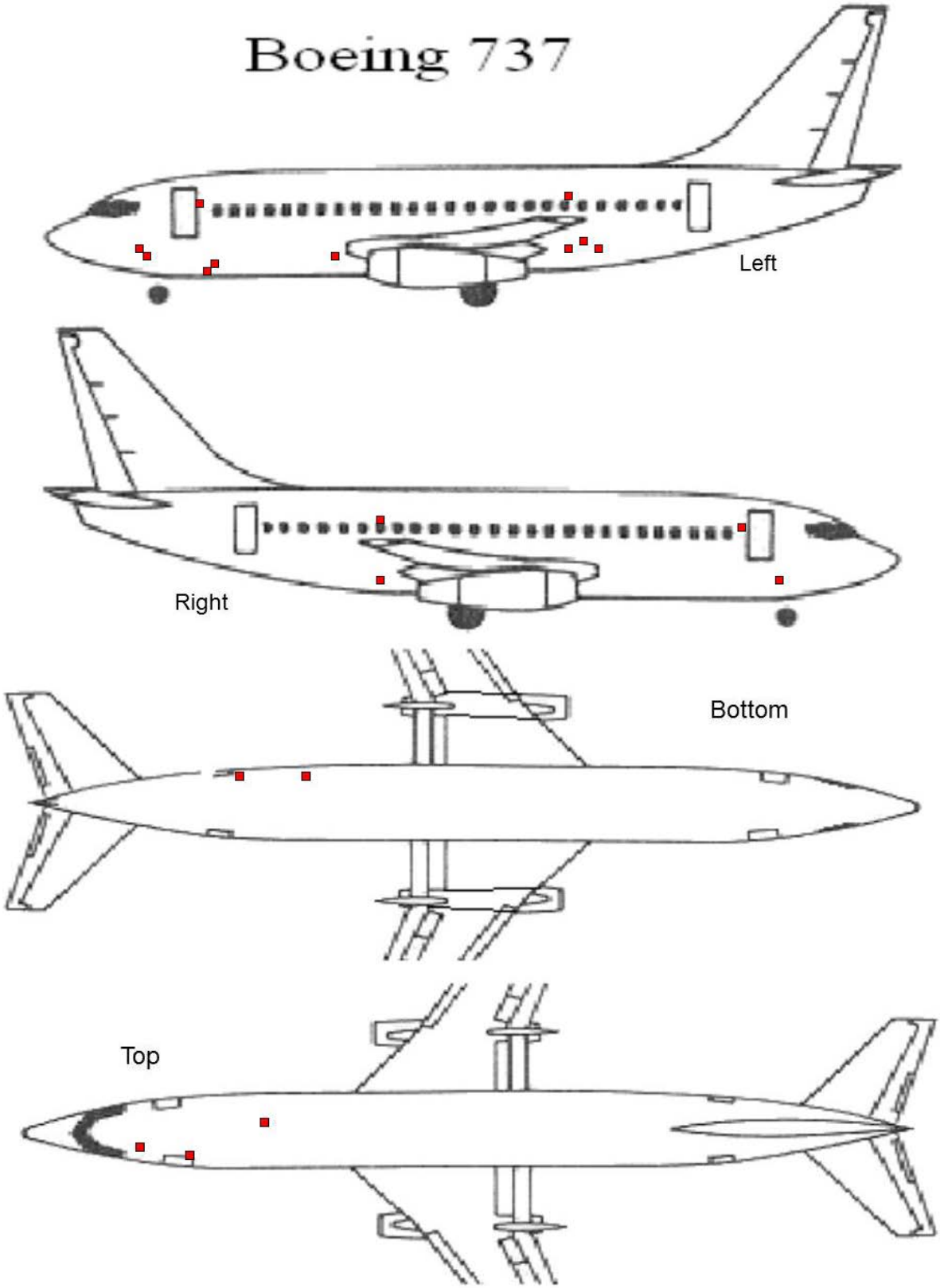


Figure A-23. RAM Location Plot Chart, Boeing 737

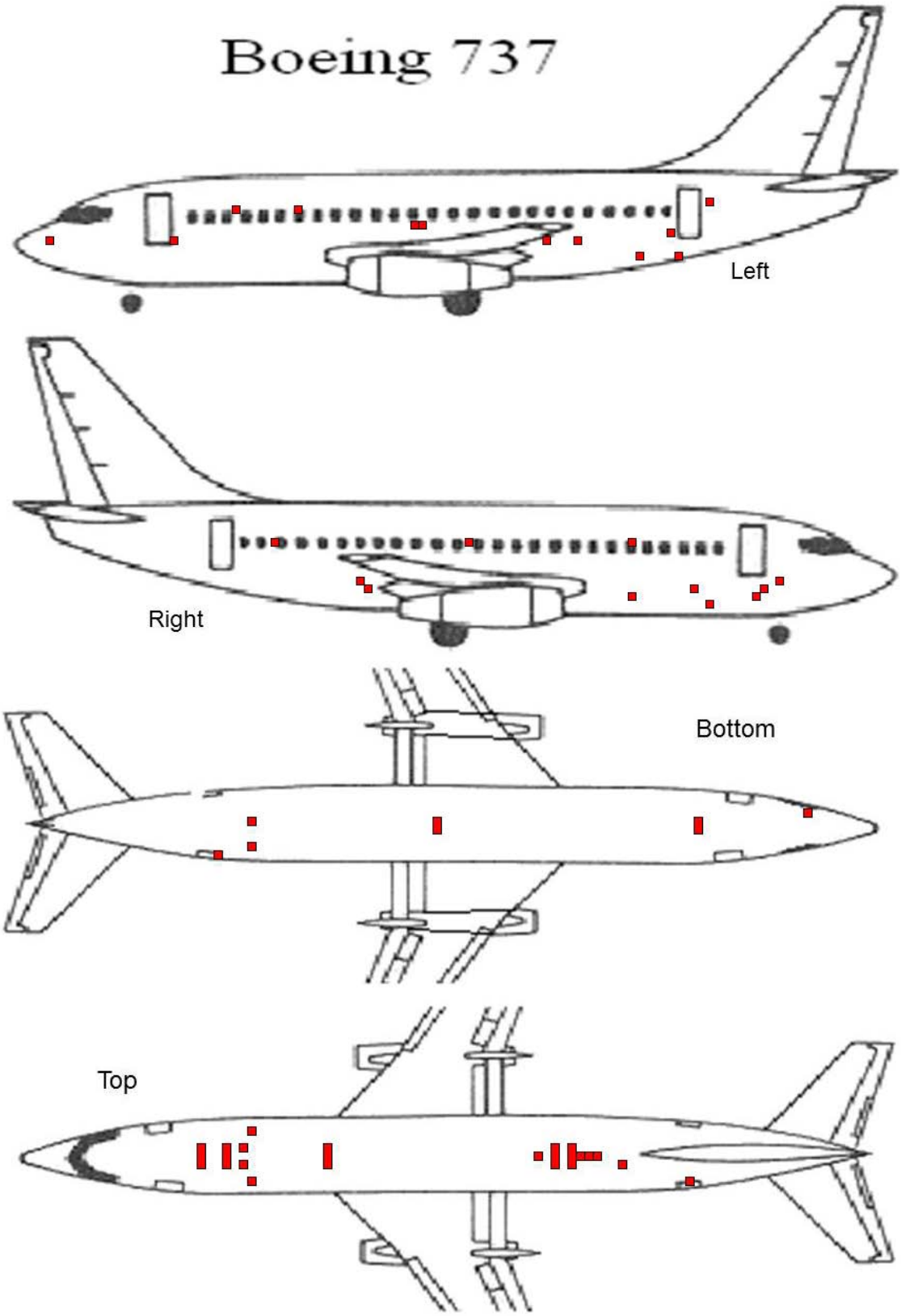


Figure A-24. RAM Location Plot Chart, Boeing 737

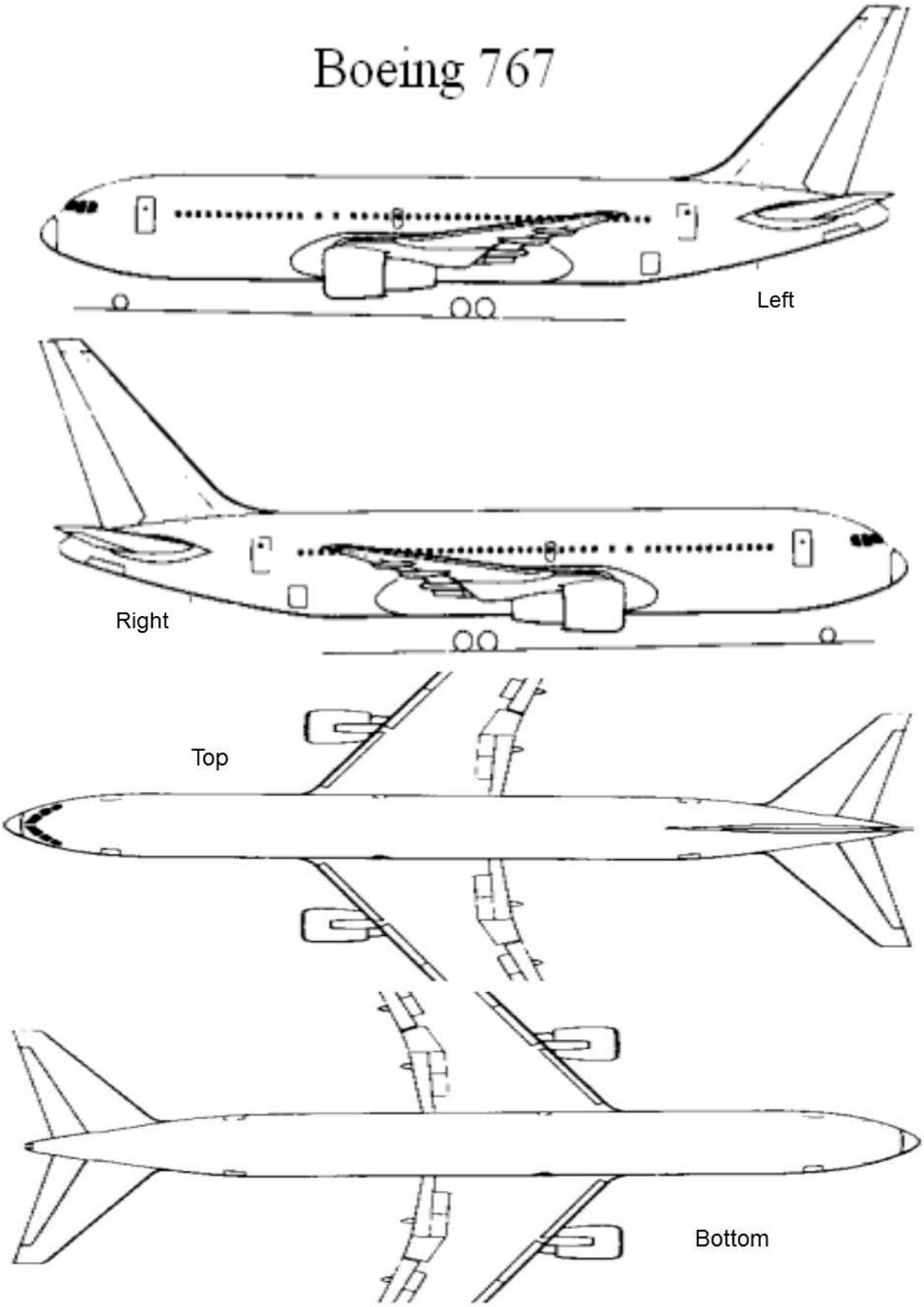


Figure A-25. RAM Location Plot Chart, Boeing 767

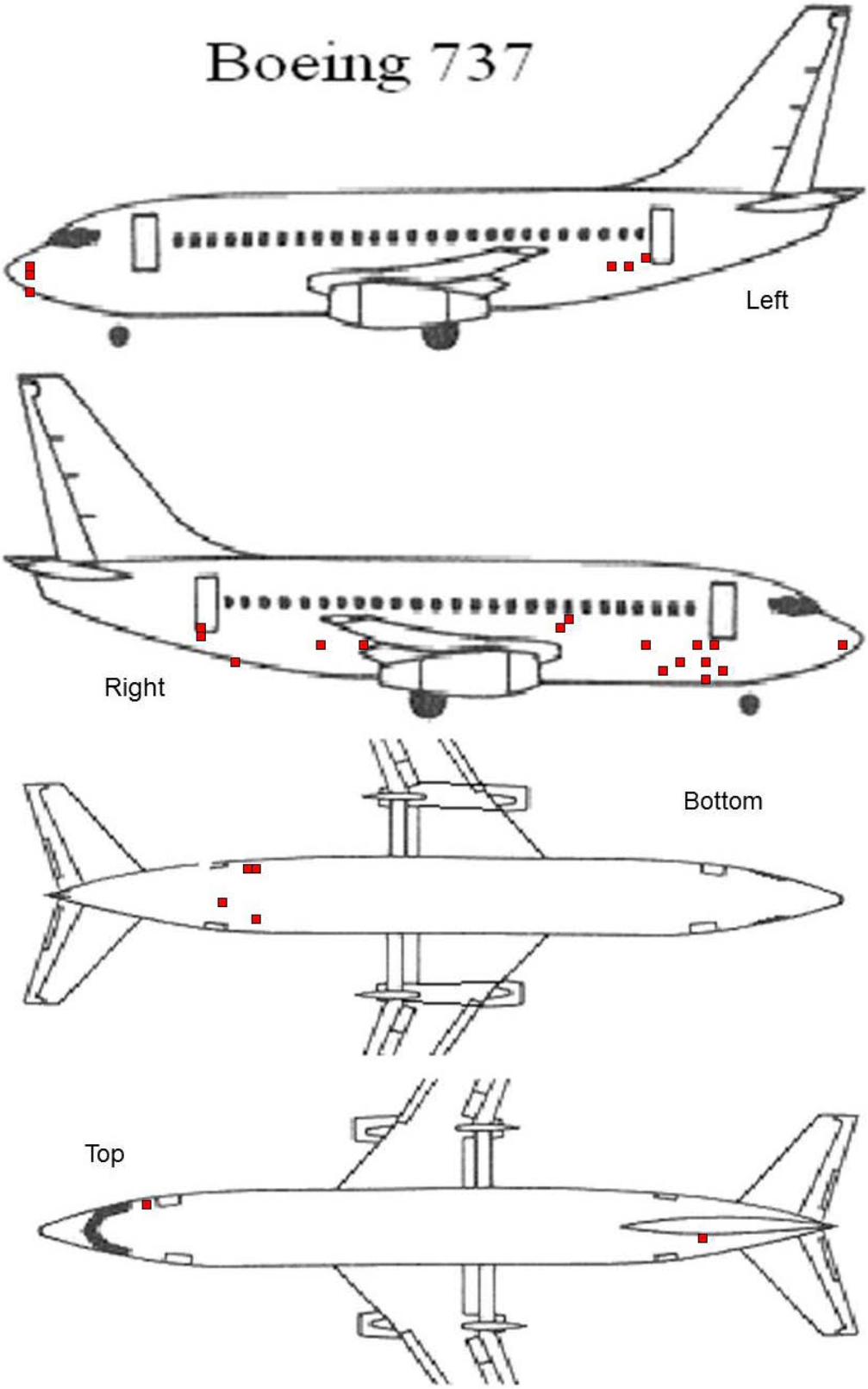


Figure A-26. RAM Location Plot Chart, Boeing 737

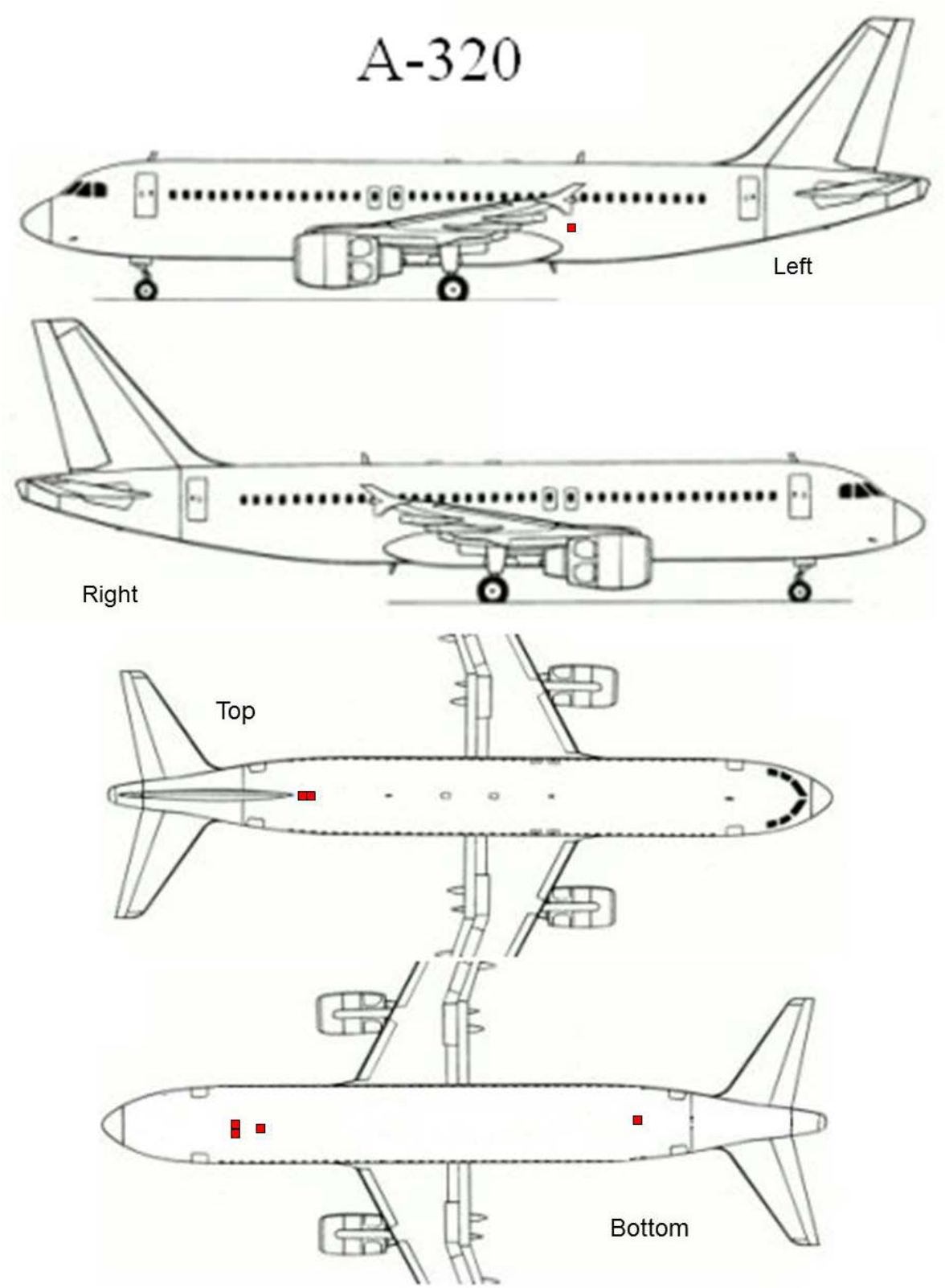


Figure A-27. RAM Location Plot Chart, A-320

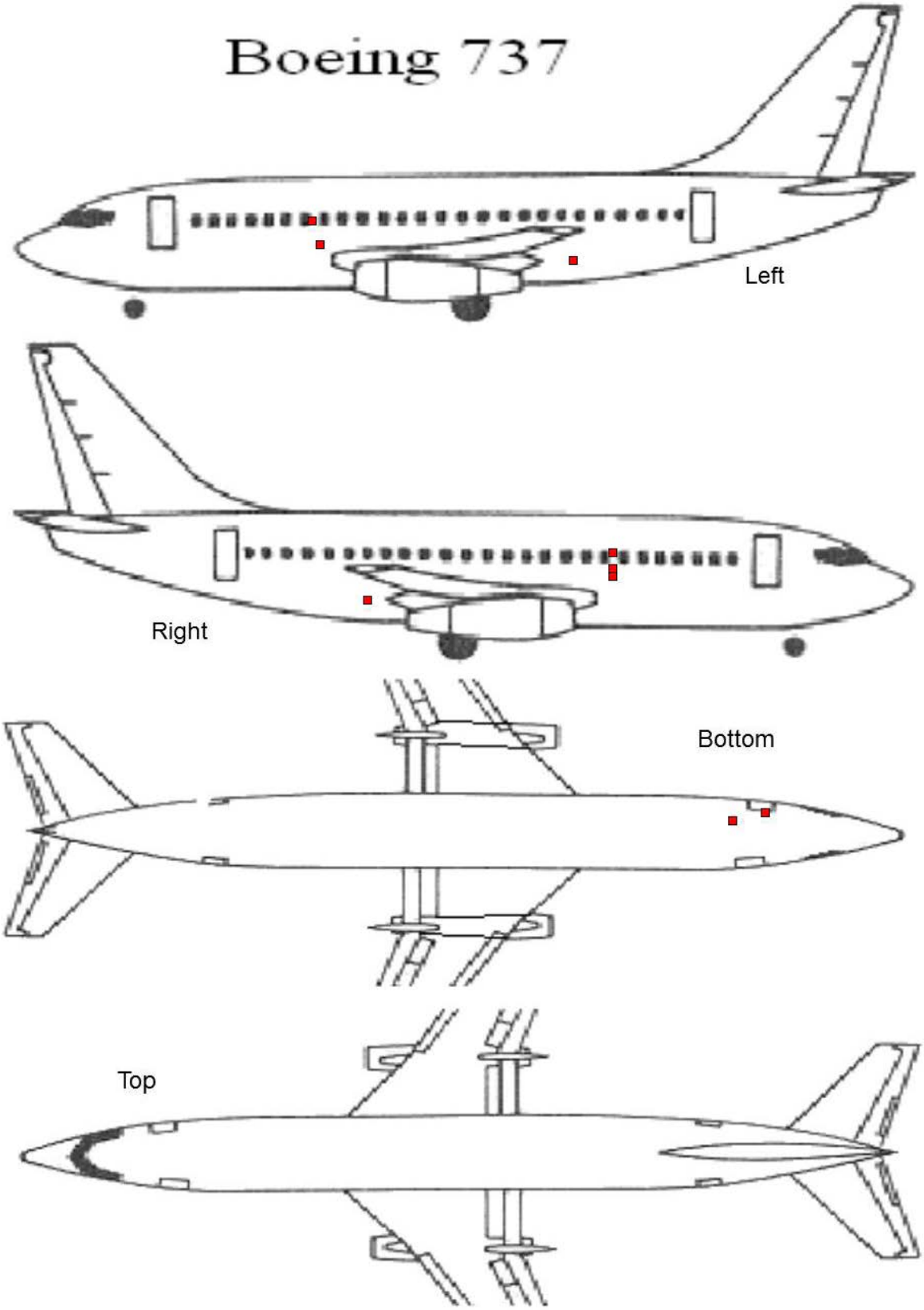


Figure A-28. RAM Location Plot Chart, Boeing 737

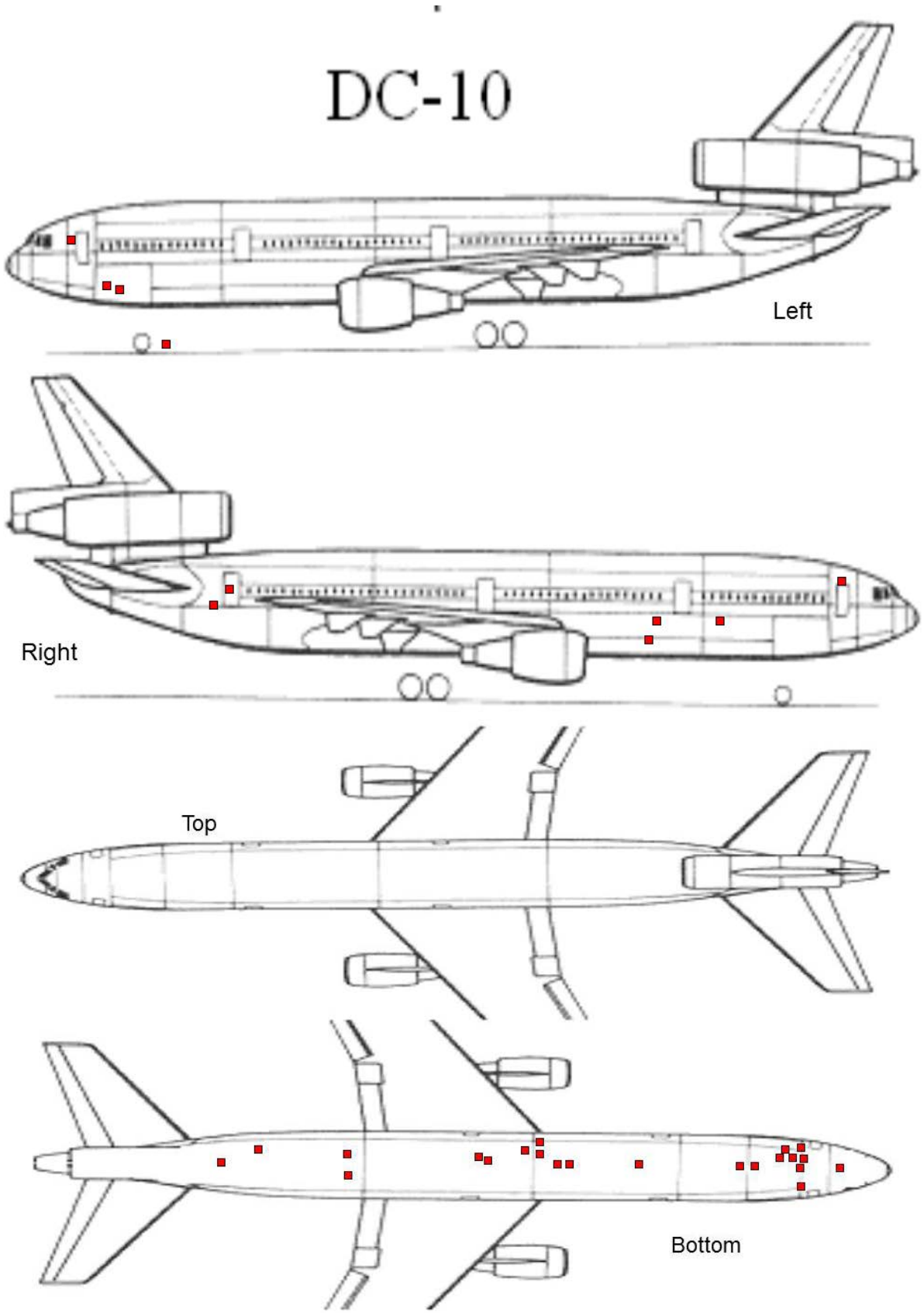


Figure A-29. RAM Location Plot Chart, DC-10

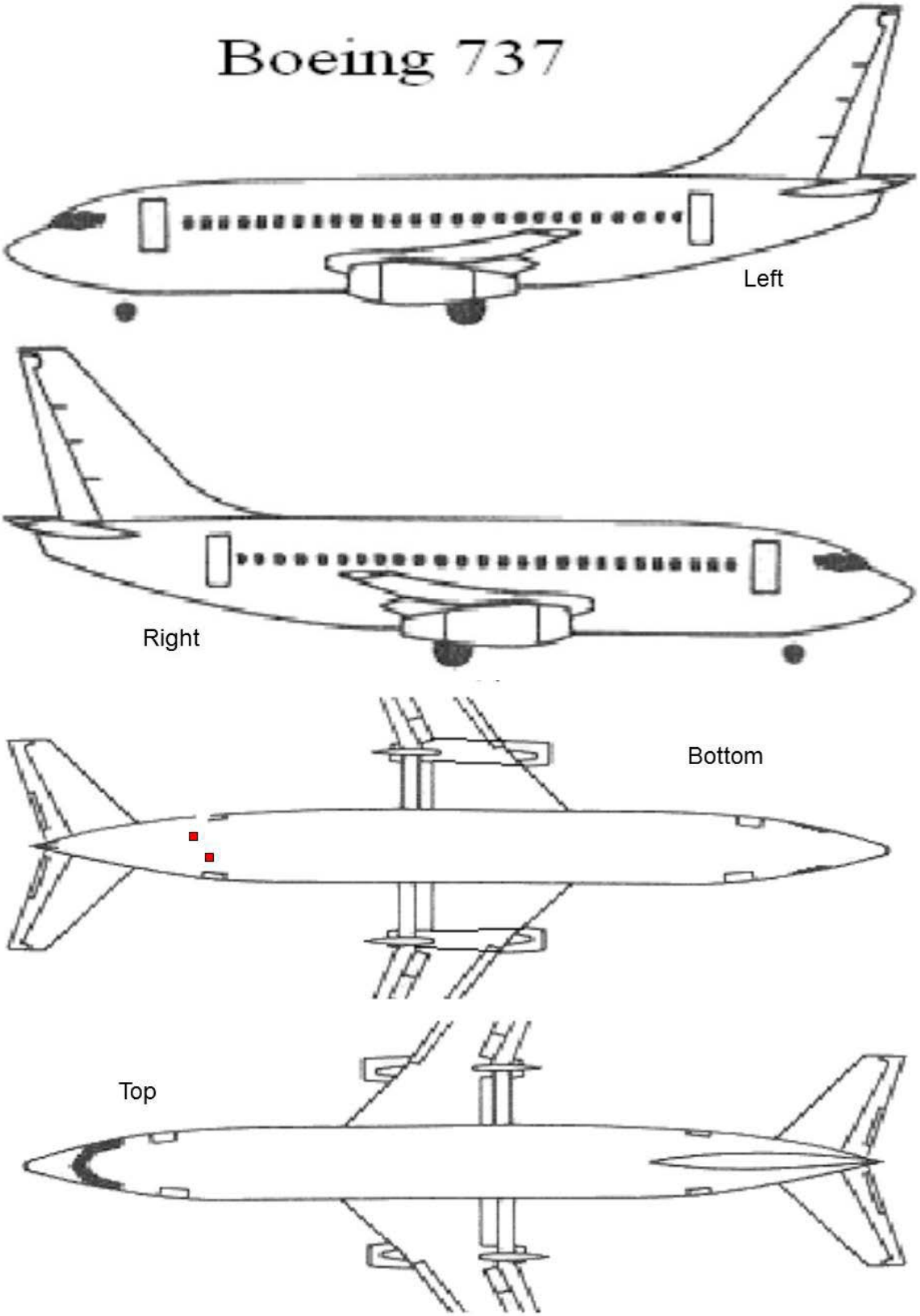


Figure A-30. RAM Location Plot Chart, Boeing 737

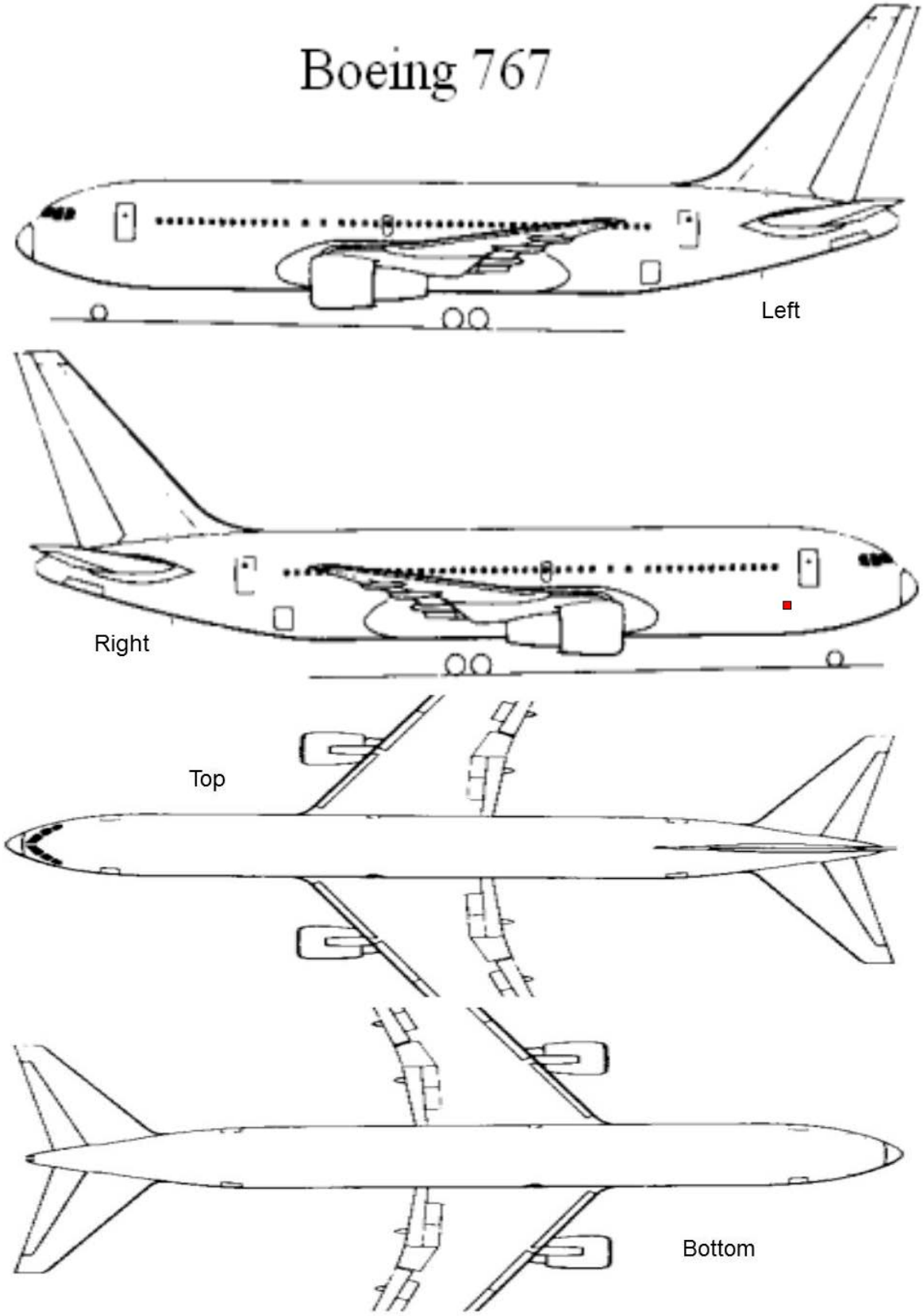


Figure A-31. RAM Location Plot Chart, Boeing 767

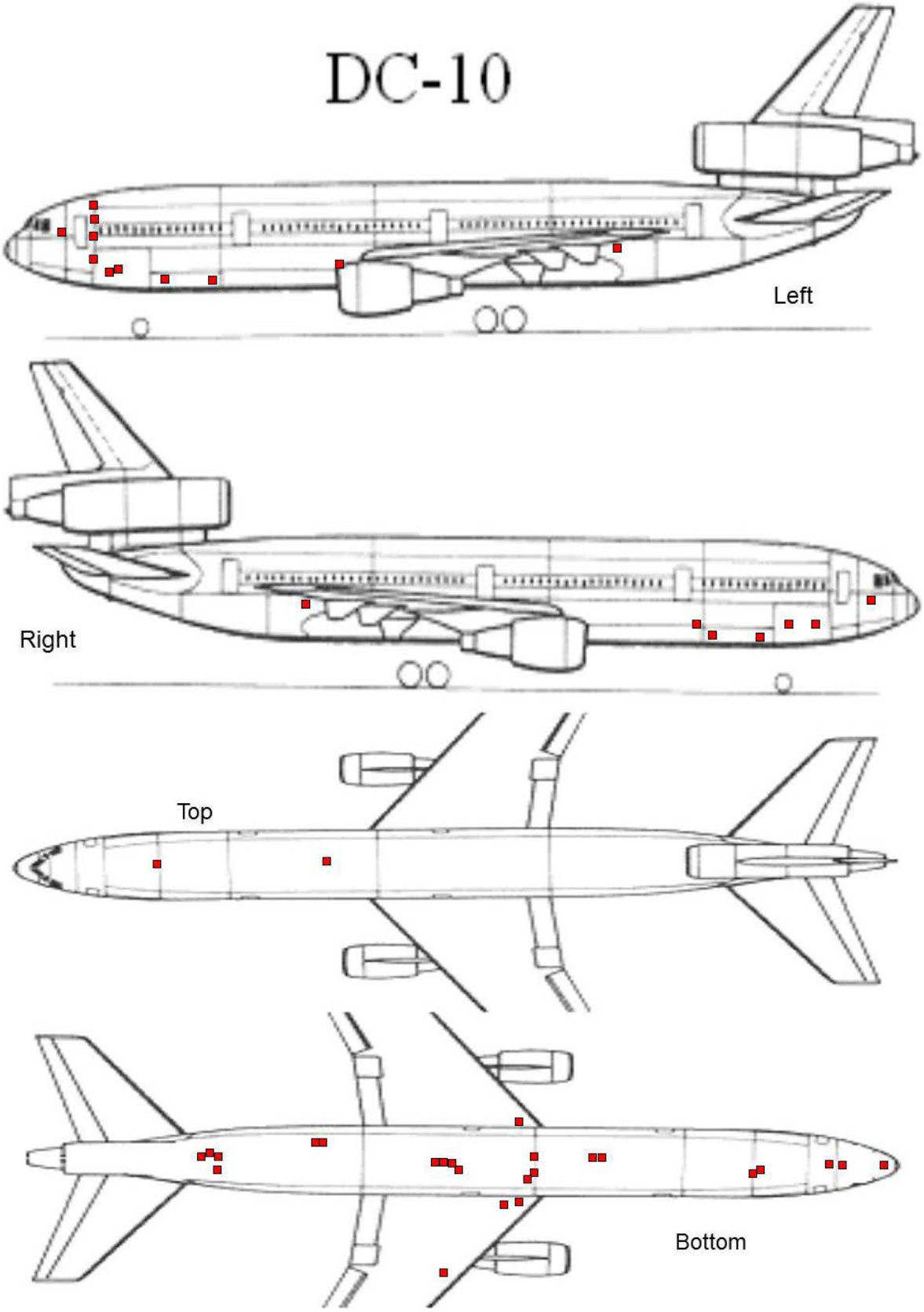


Figure A-32. RAM Location Plot Chart, DC-10

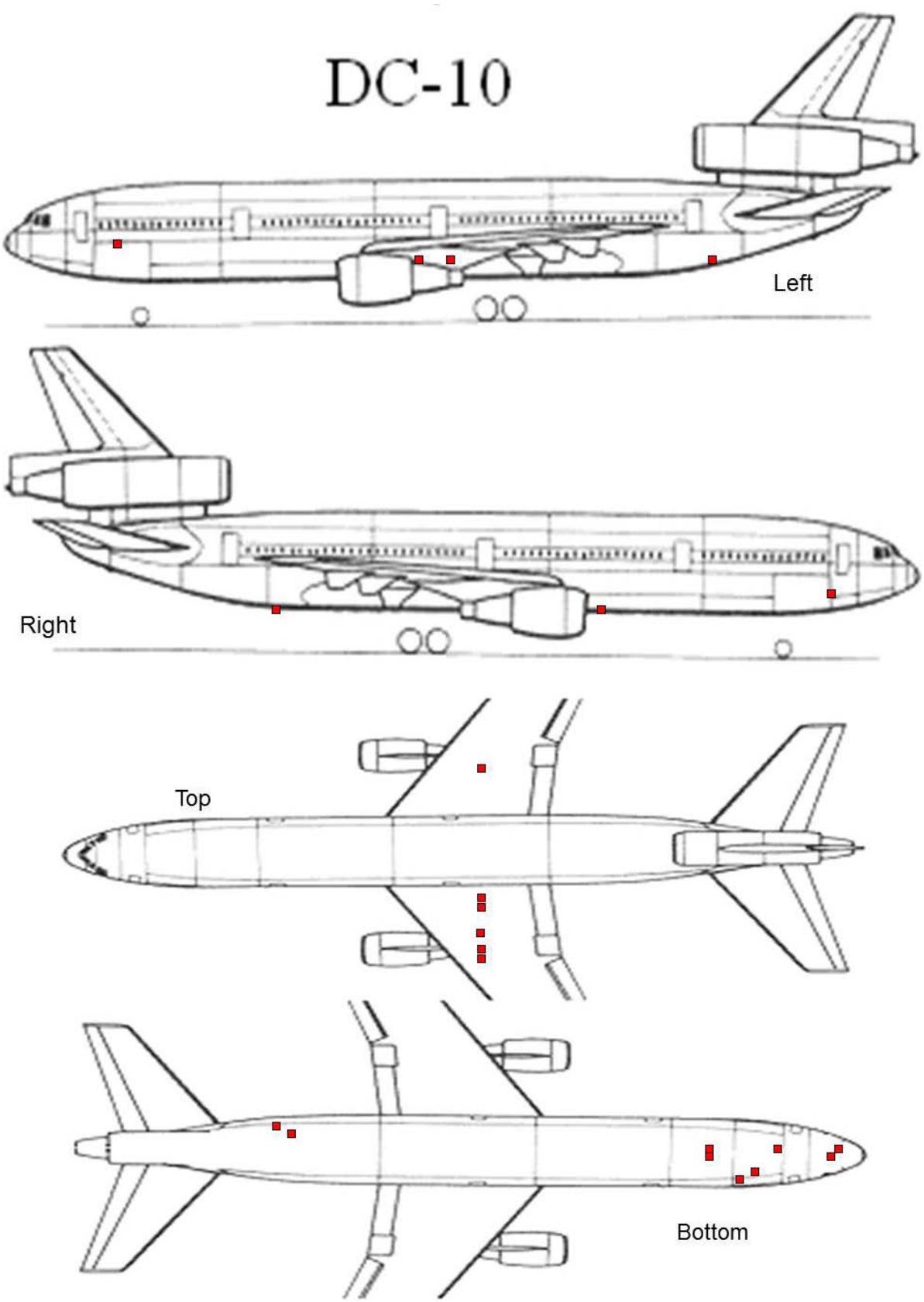


Figure A-33. RAM Location Plot Chart, DC-10

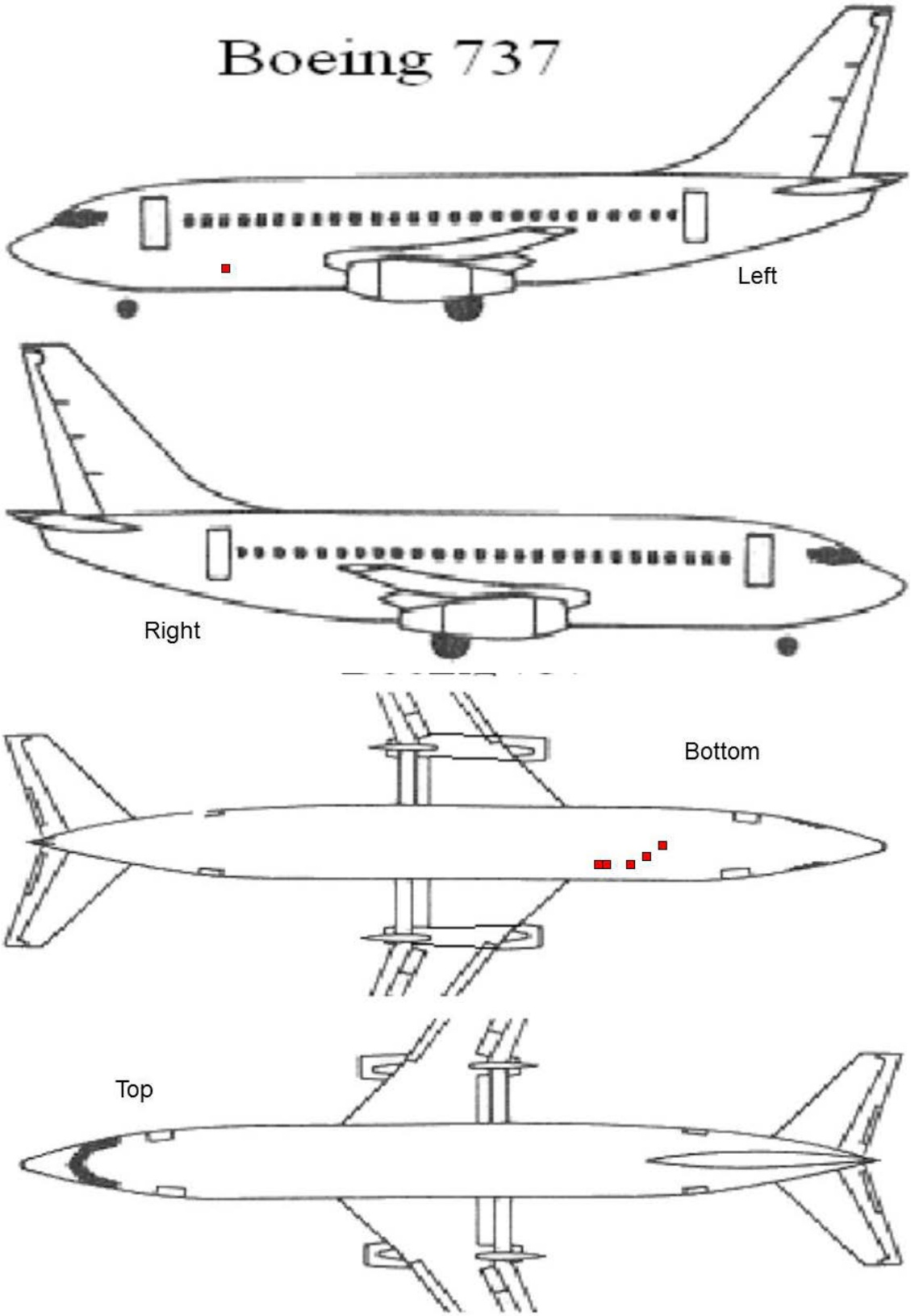


Figure A-34. RAM Location Plot Chart, Boeing 737

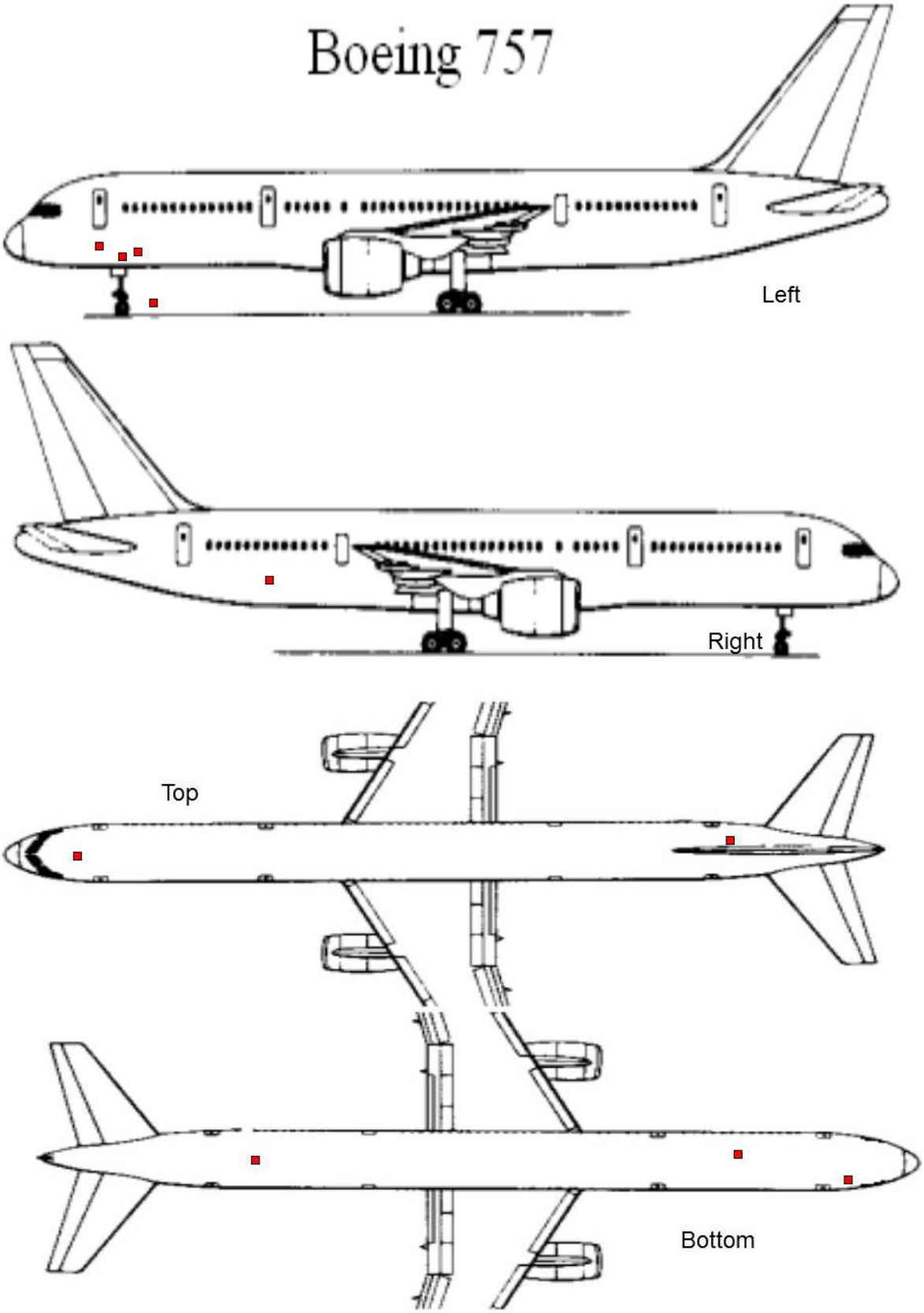


Figure A-35. RAM Location Plot Chart, Boeing 757

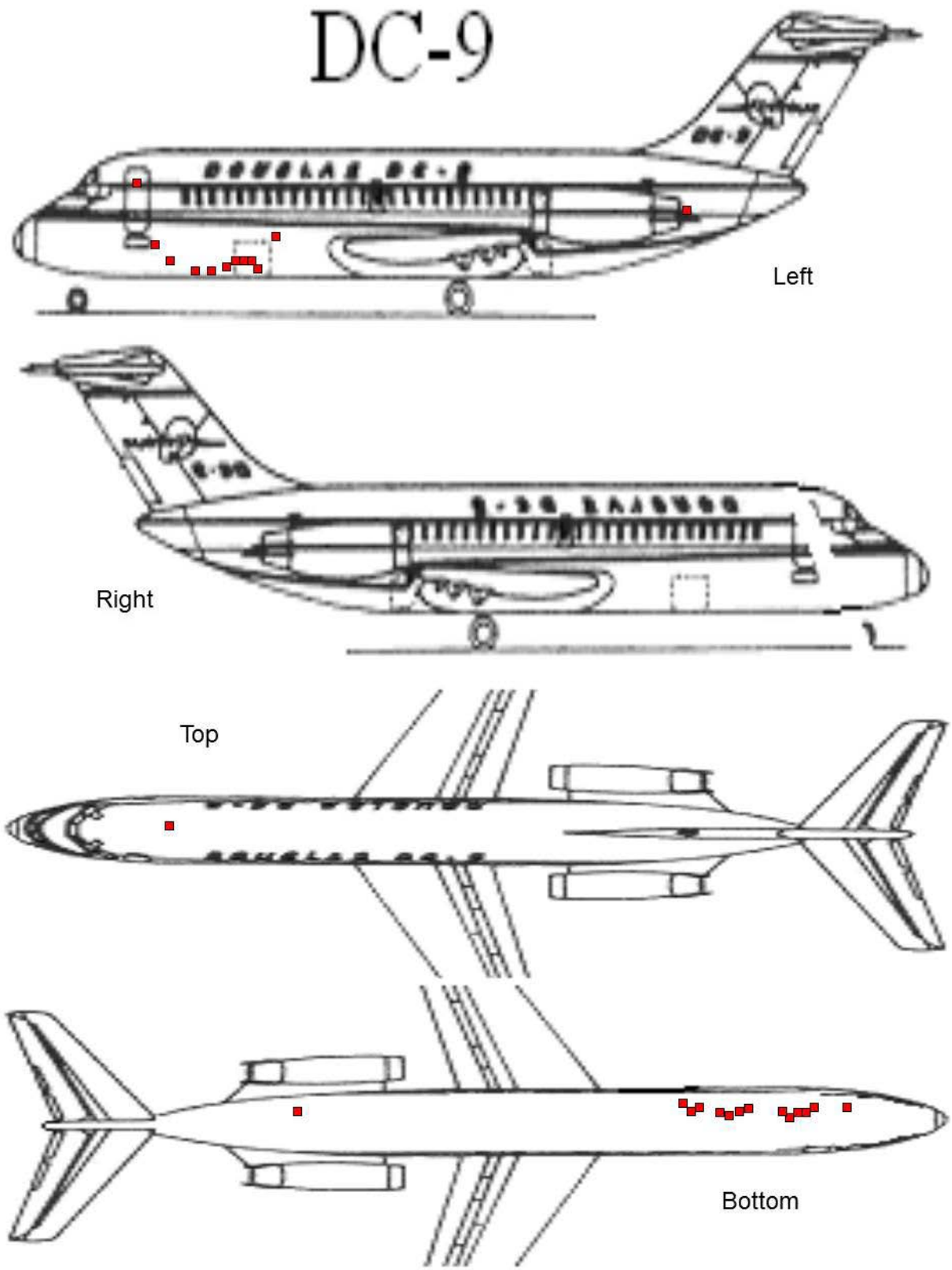


Figure A-36. RAM Location Plot Chart, DC-9

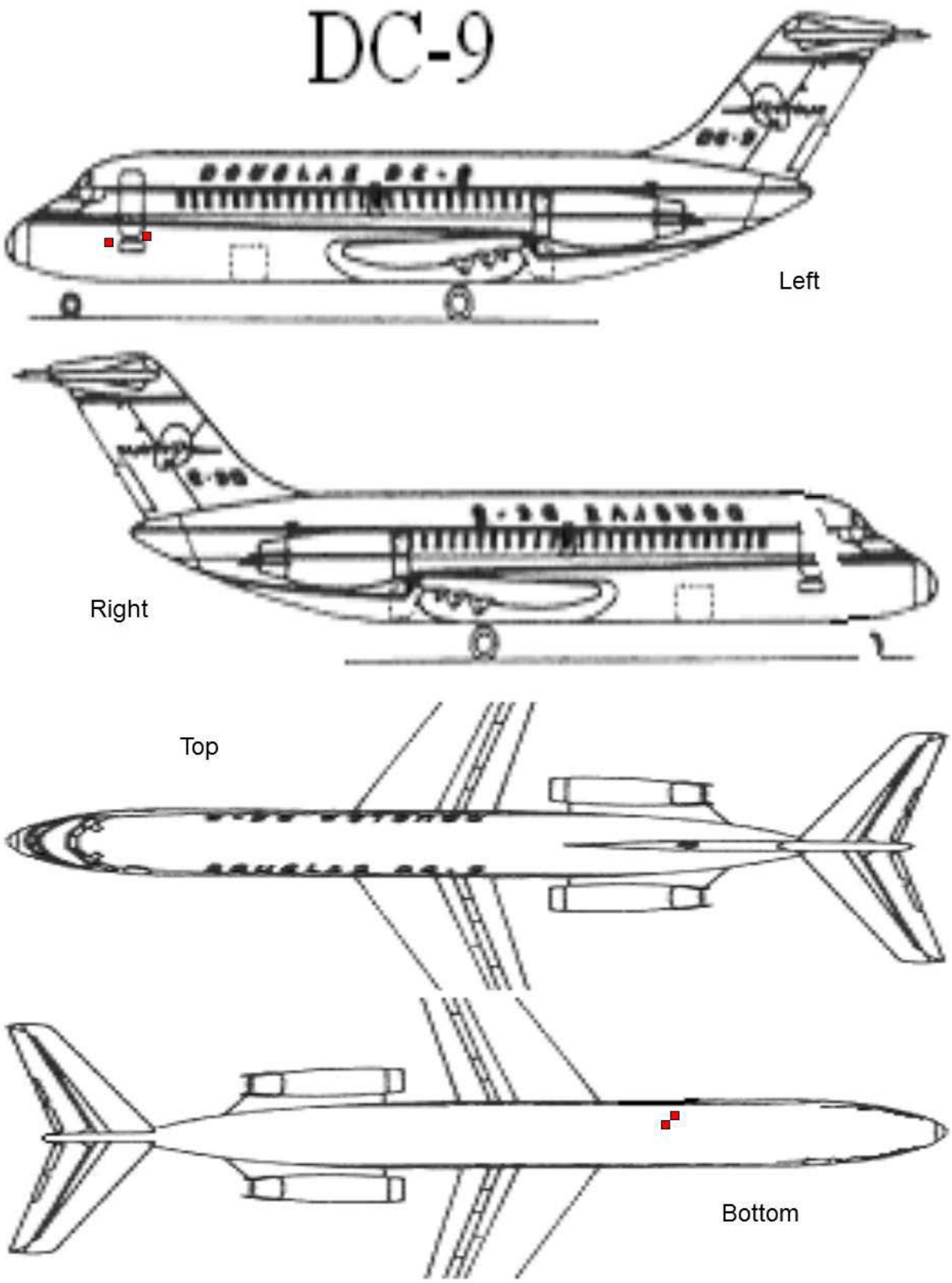


Figure A-37. RAM Location Plot Chart, DC-9

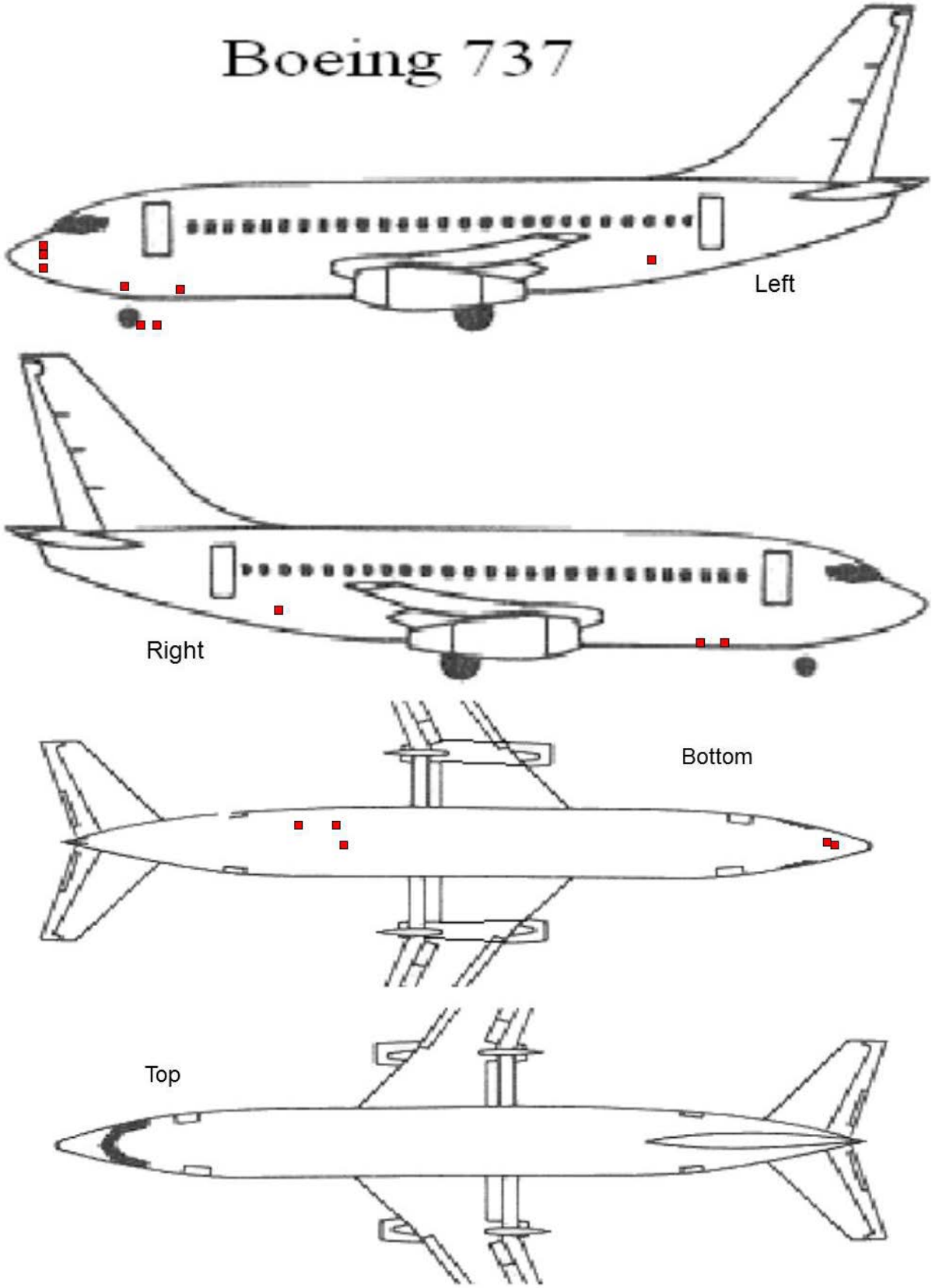


Figure A-38. RAM Location Plot Chart, Boeing 737

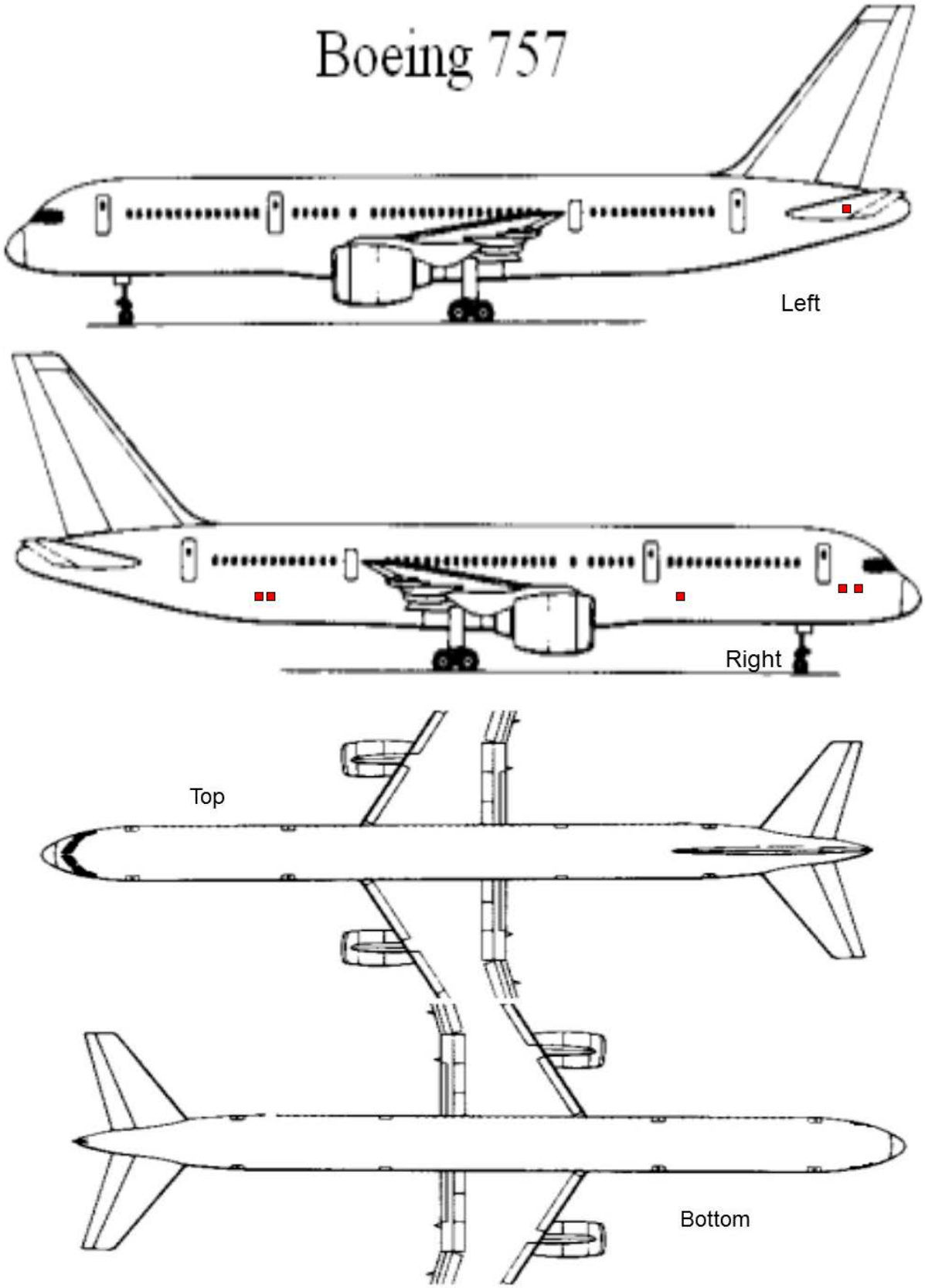


Figure A-39. RAM Location Plot Chart, Boeing 757

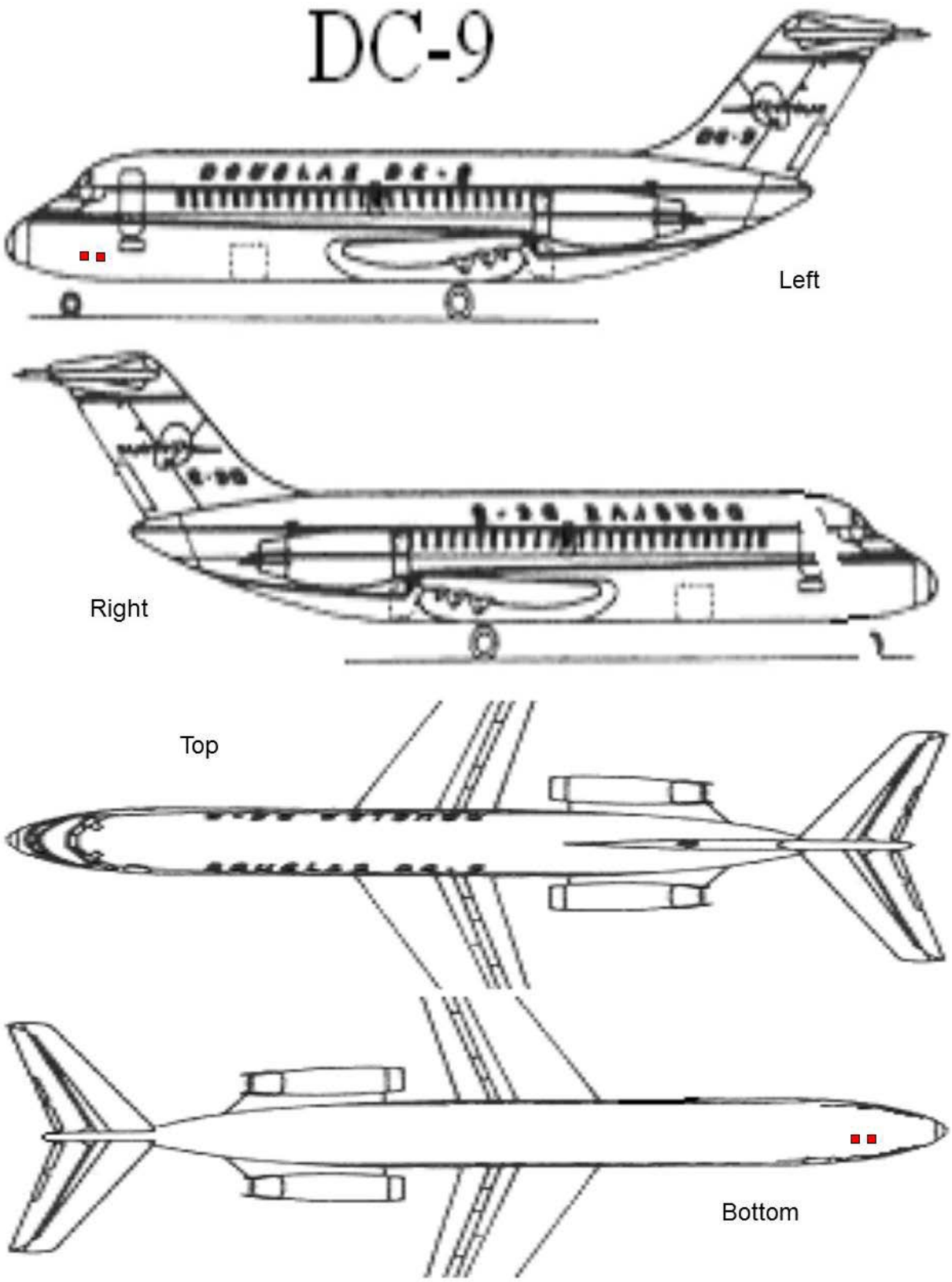


Figure A-40. RAM Location Plot Chart, DC-9

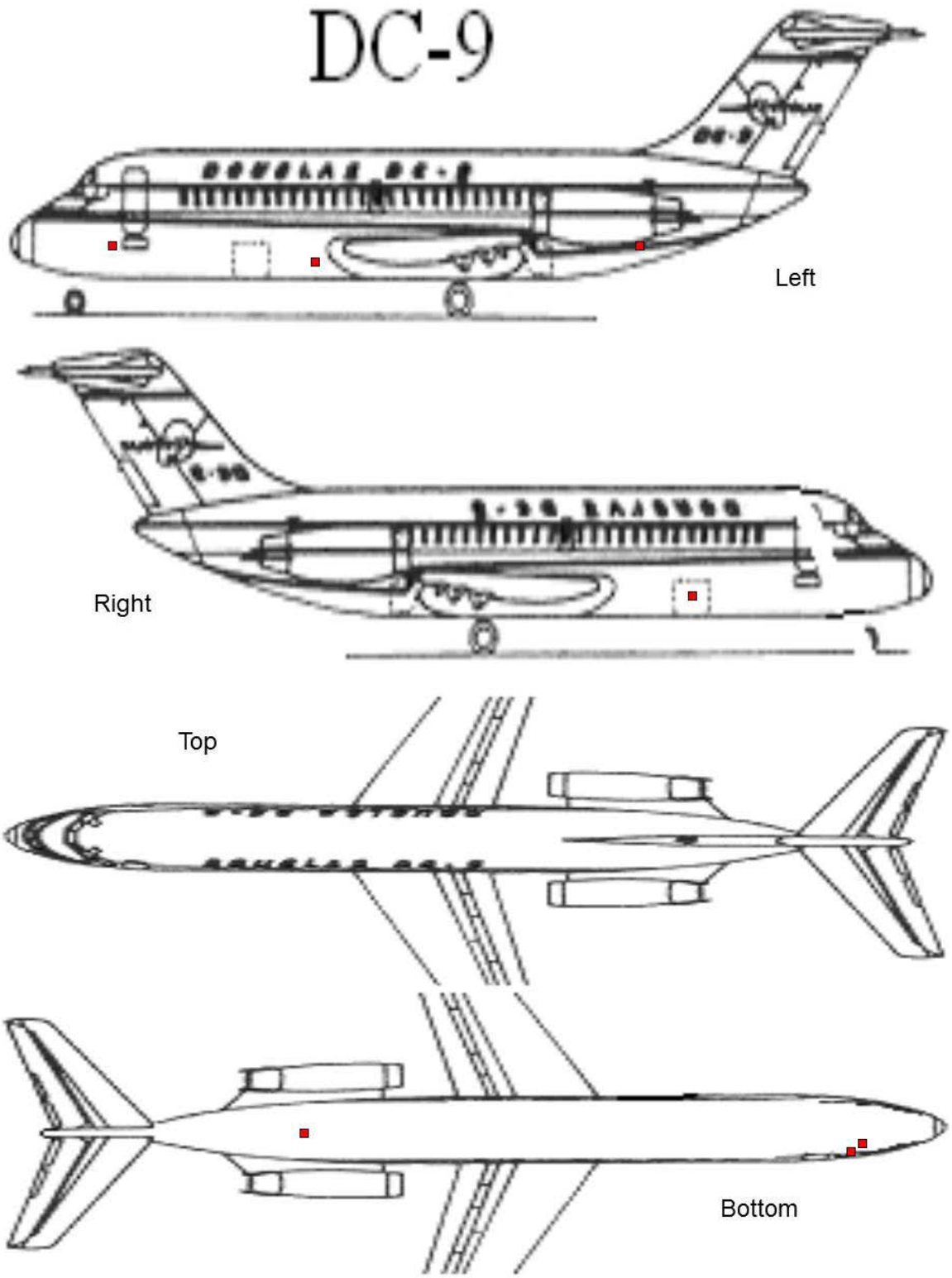


Figure A-41. RAM Location Plot Chart, DC-9

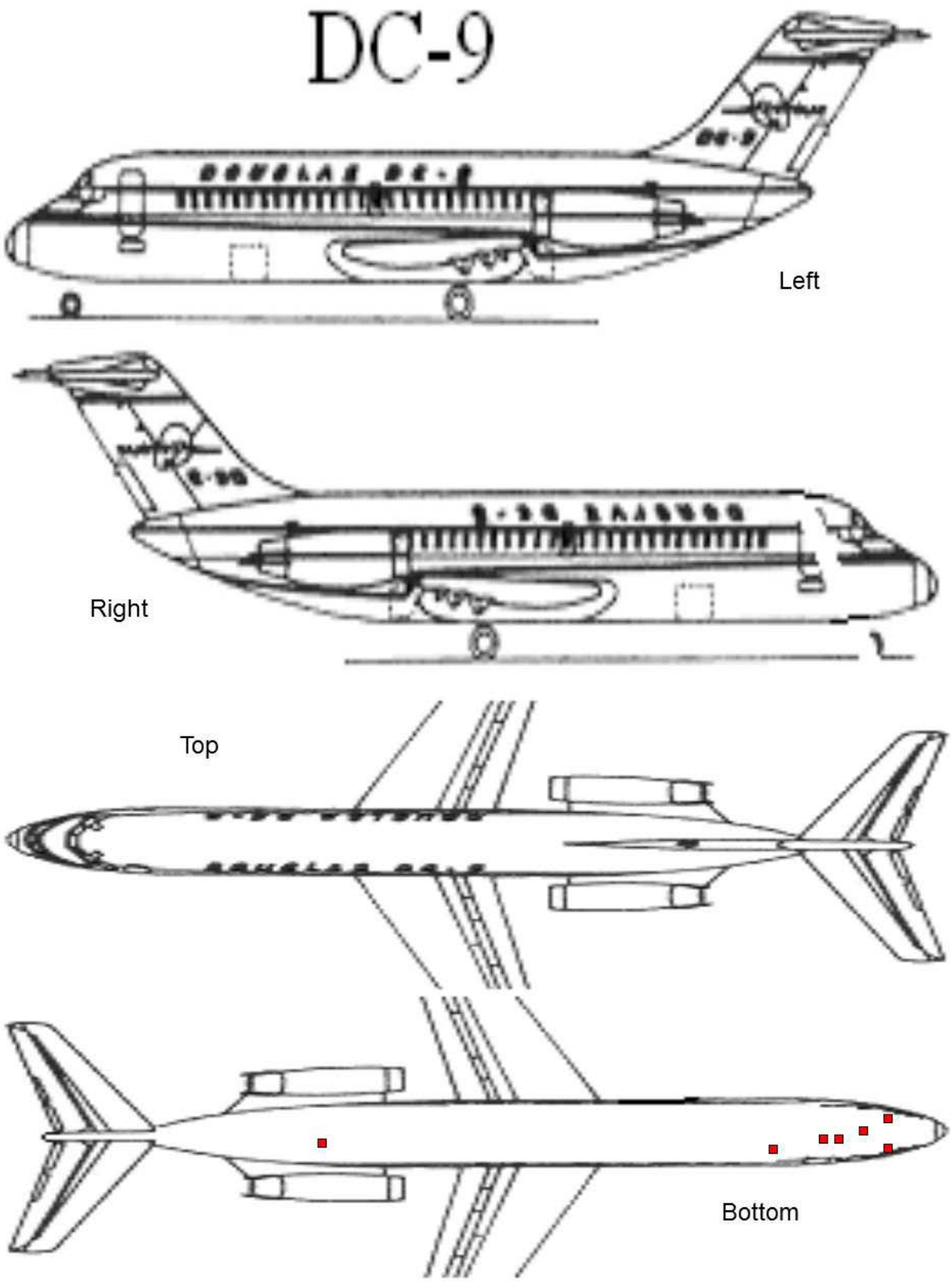


Figure A-42. RAM Location Plot Chart, DC-9

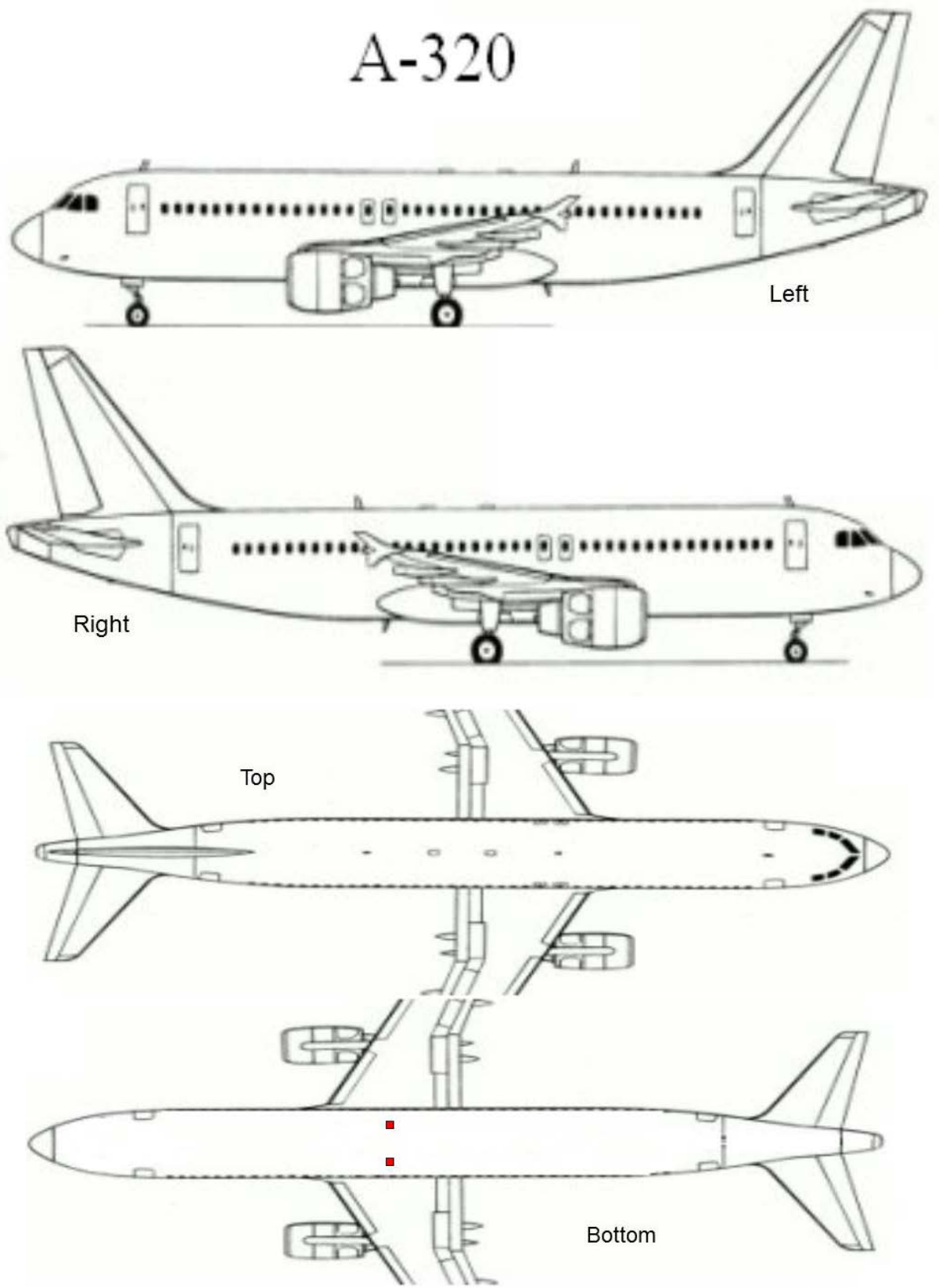


Figure A-43. RAM Location Plot Chart, A-320

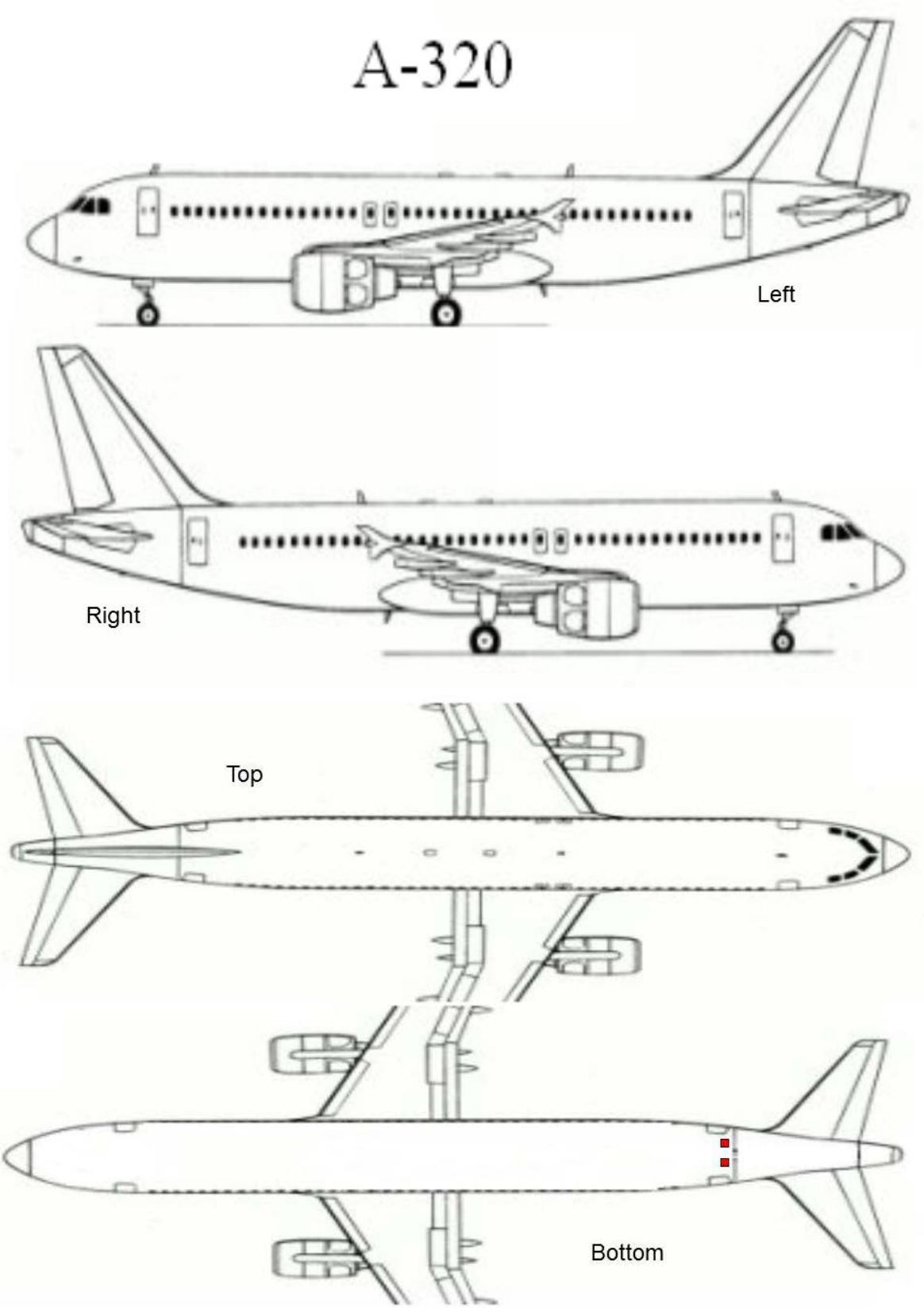


Figure A-44. RAM Location Plot Chart, A-320

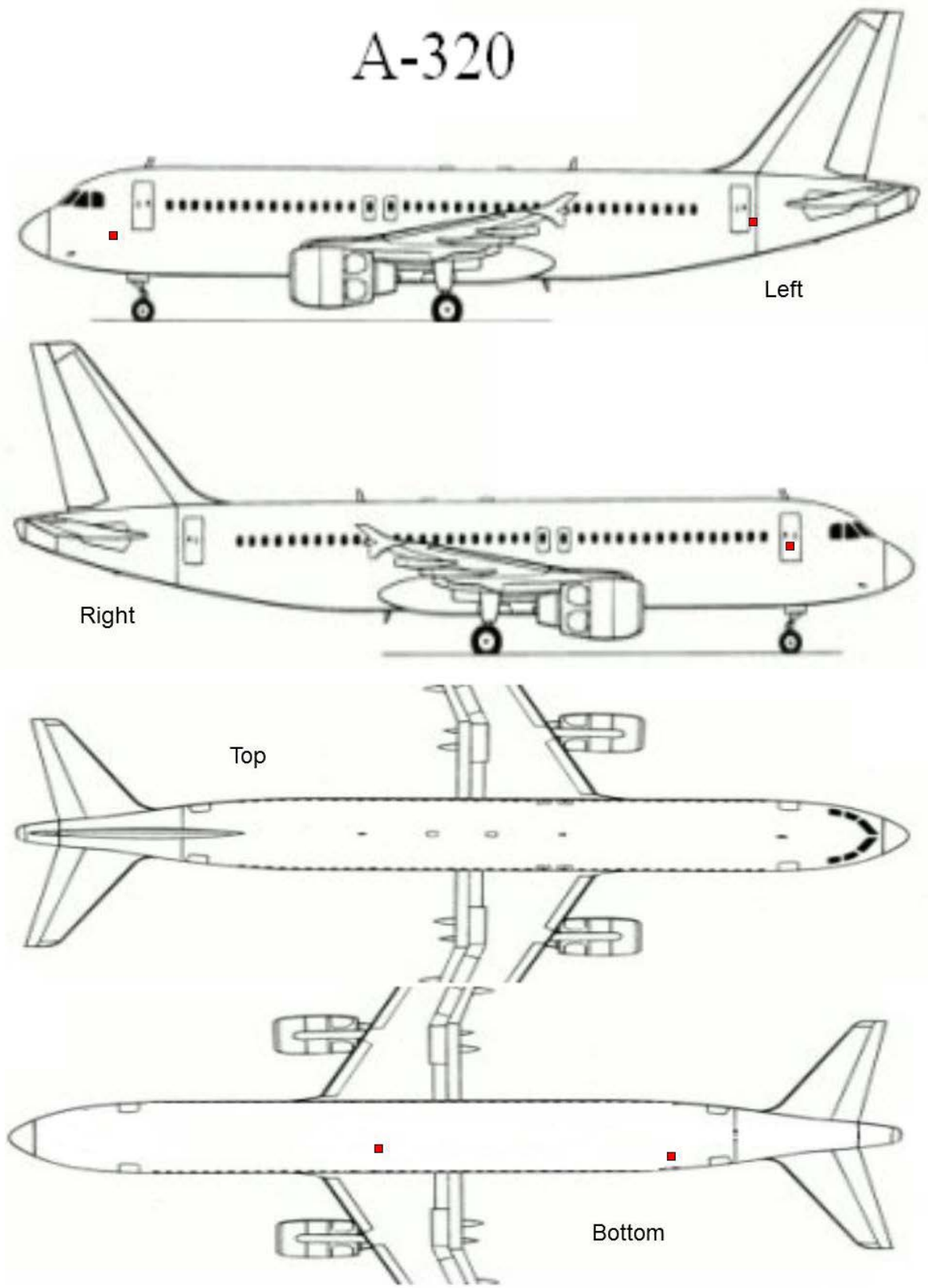


Figure A-45. RAM Location Plot Chart, A-320

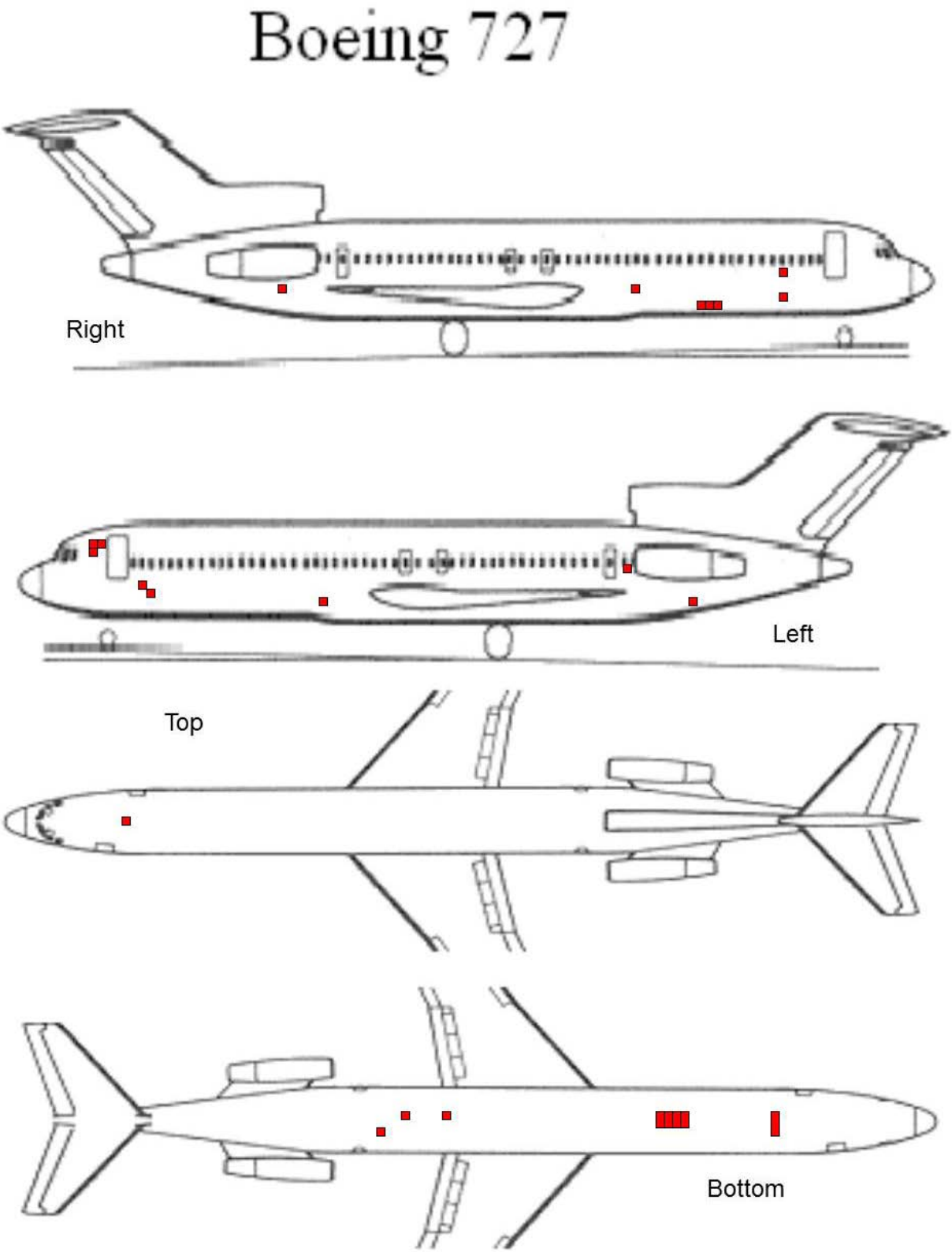


Figure A-46. RAM Location Plot Chart, Boeing 727

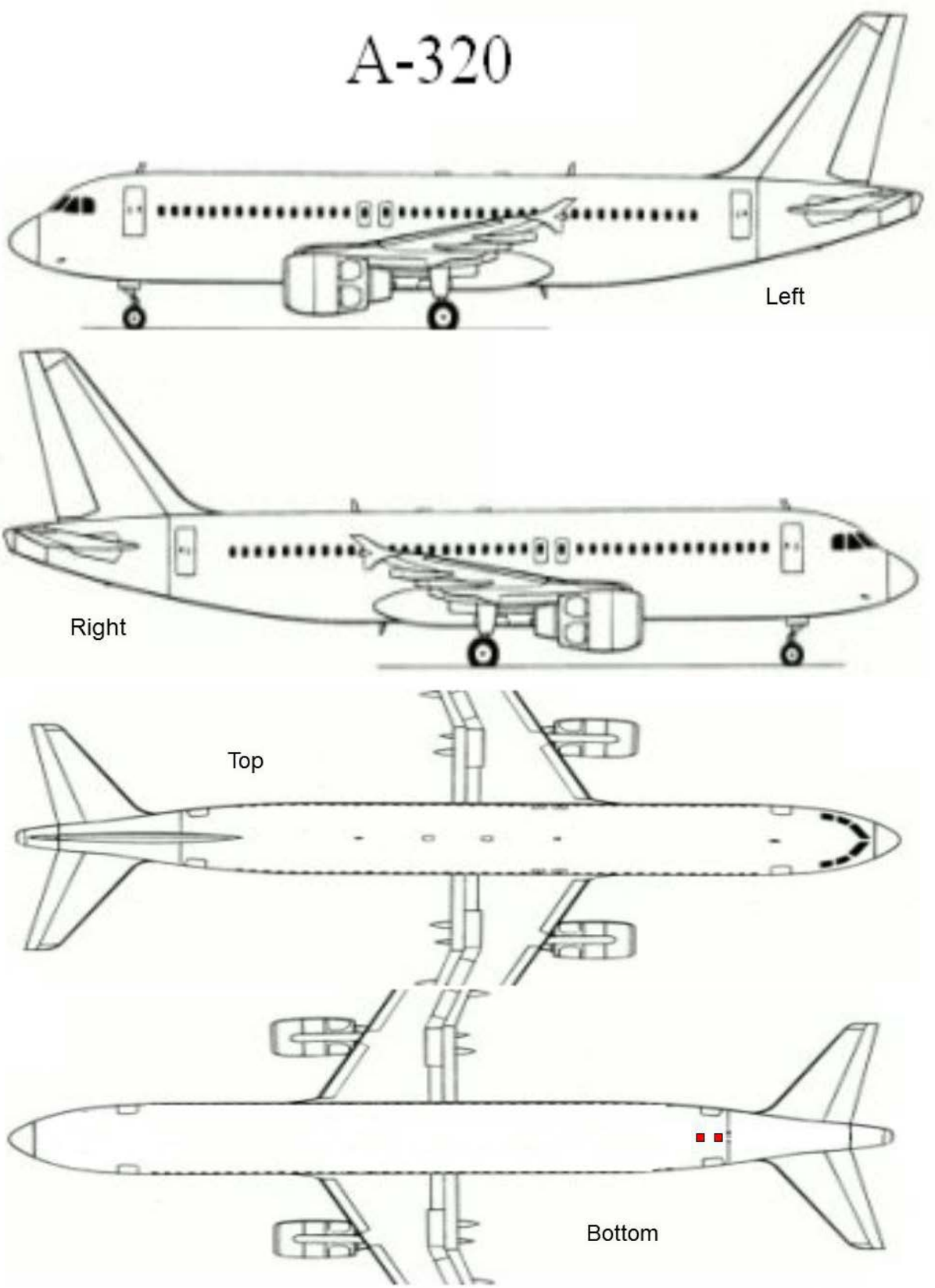


Figure A-47. RAM Location Plot Chart, A-320

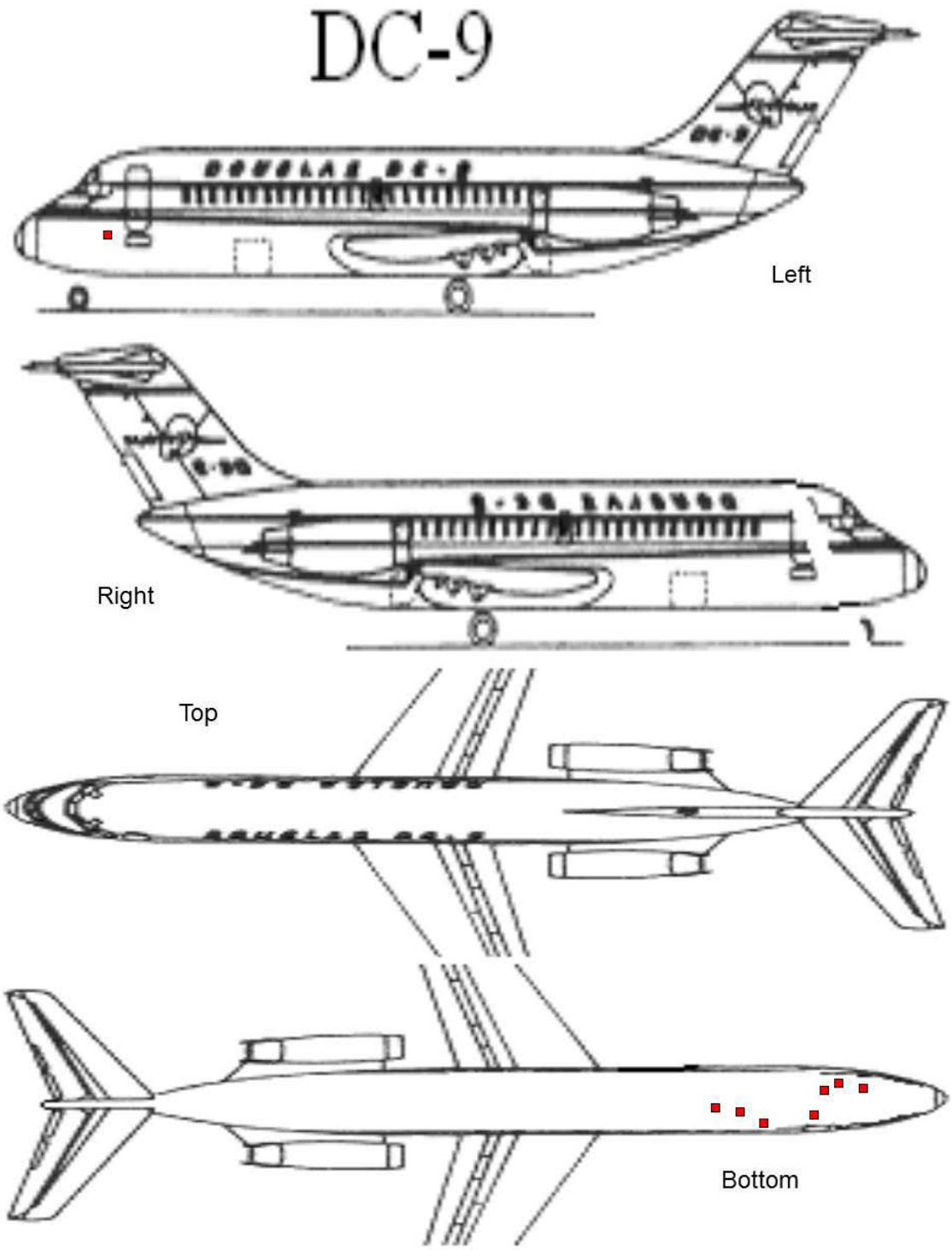


Figure A-48. RAM Location Plot Chart, DC-9

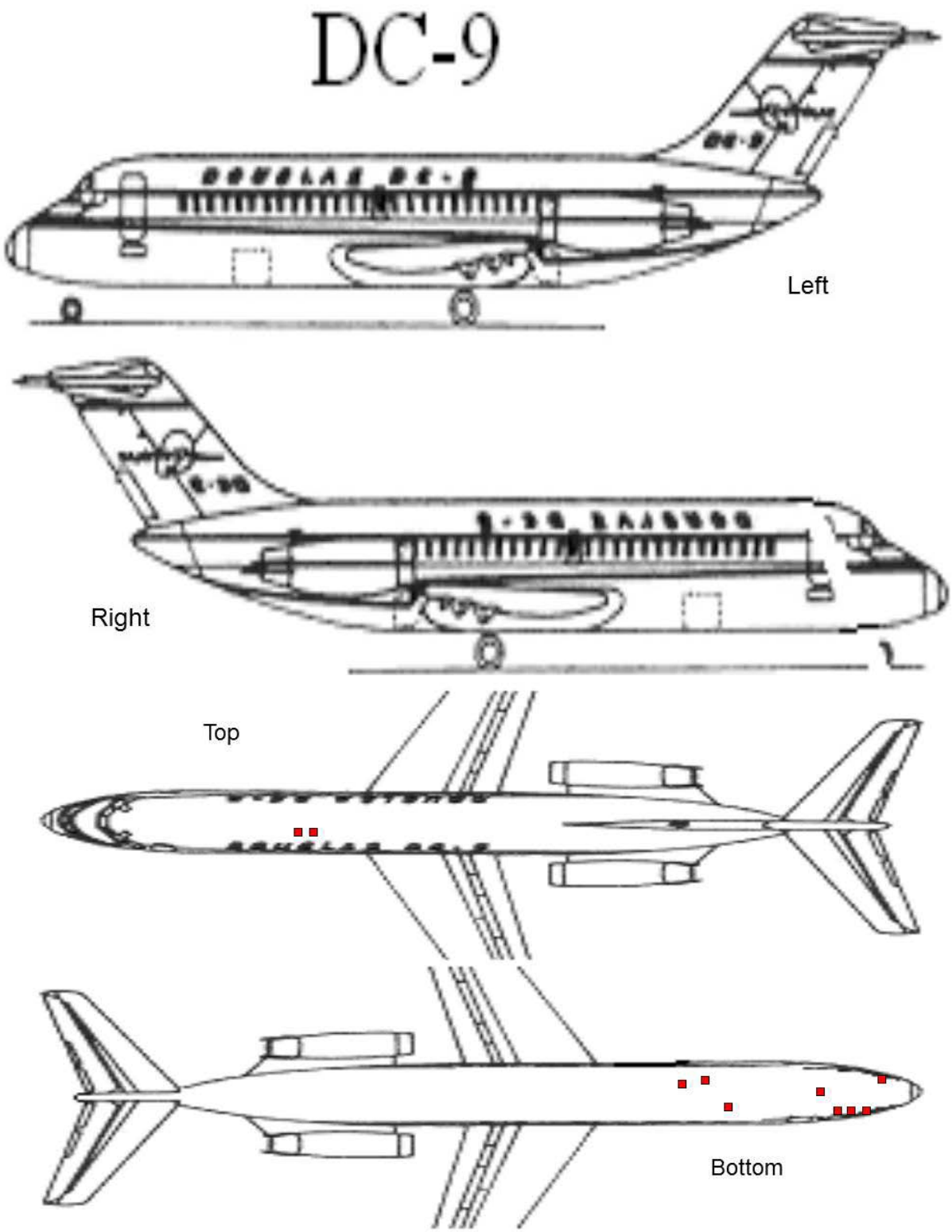


Figure A-49. RAM Location Plot Chart, DC-9

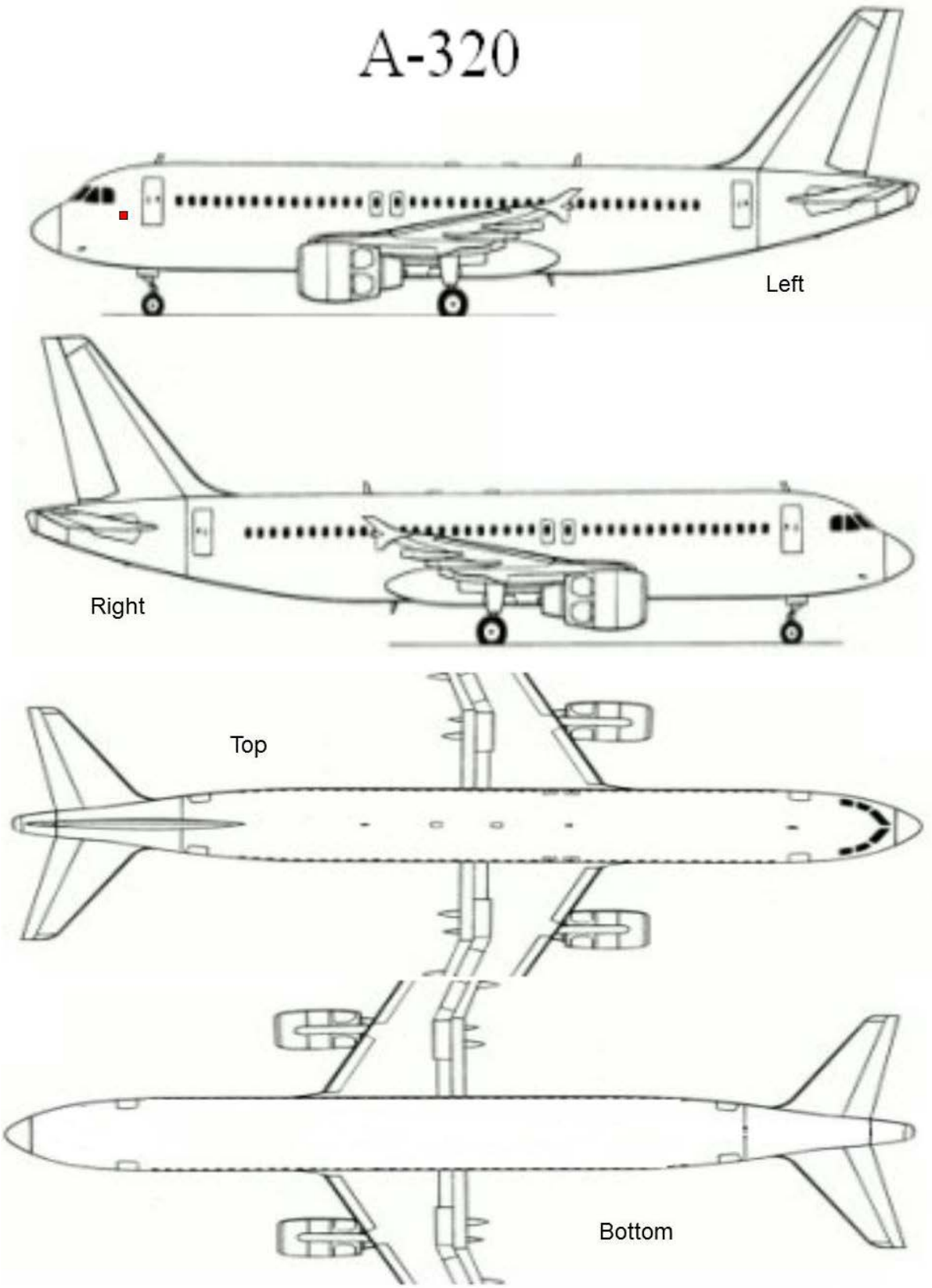


Figure A-50. RAM Location Plot Chart, A-320

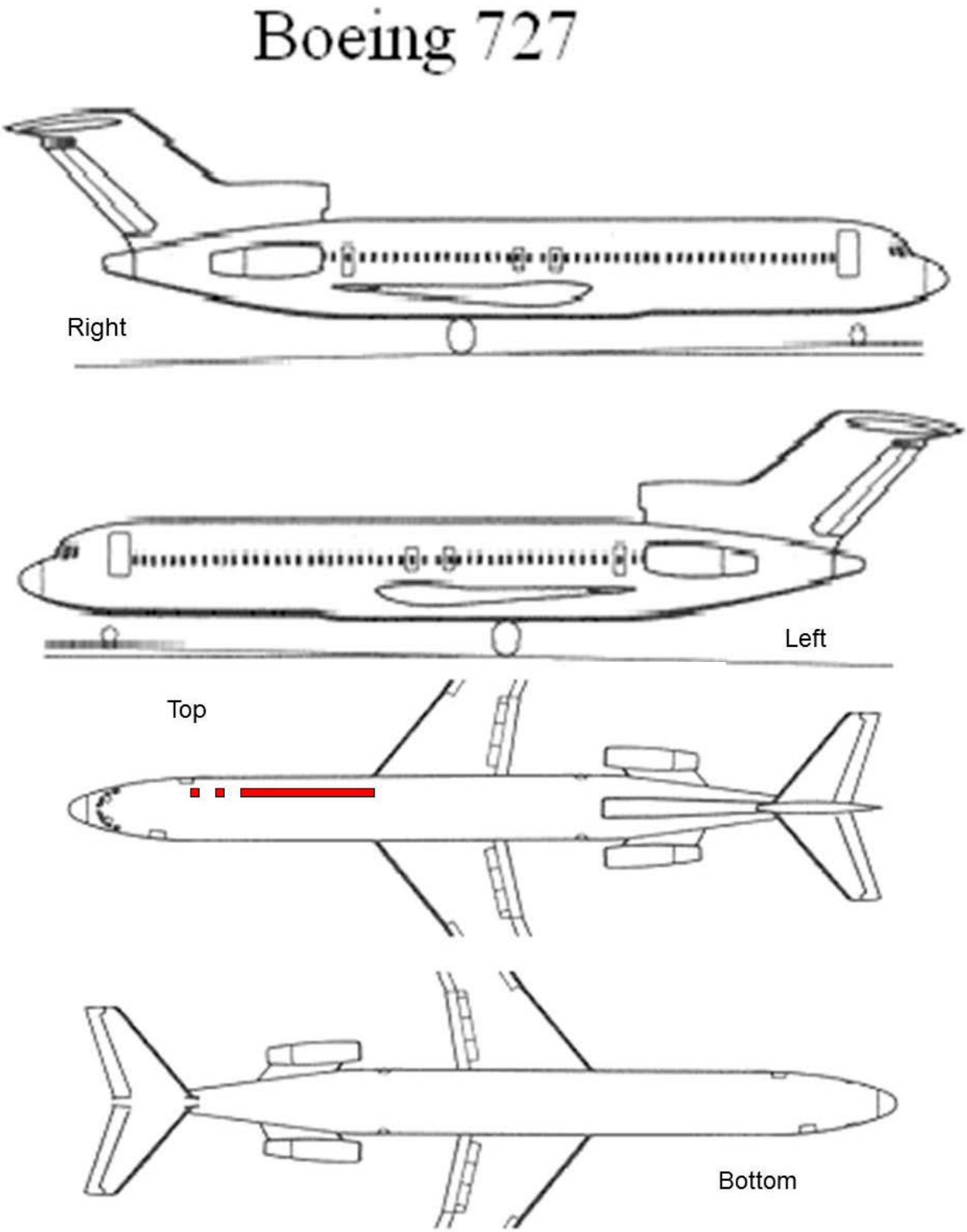


Figure A-51. RAM Location Plot Chart, Boeing 727

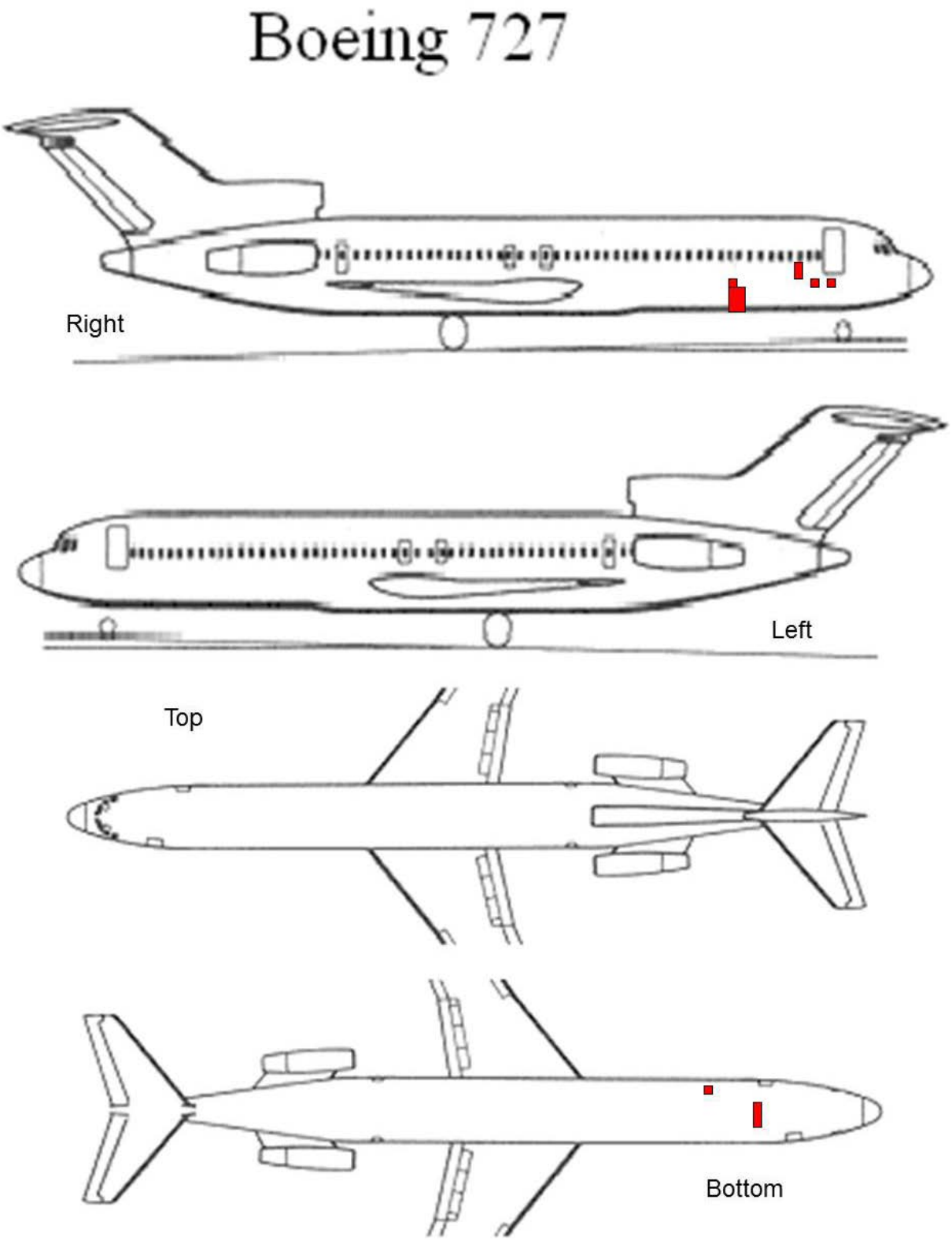


Figure A-52. RAM Location Plot Chart, Boeing 727

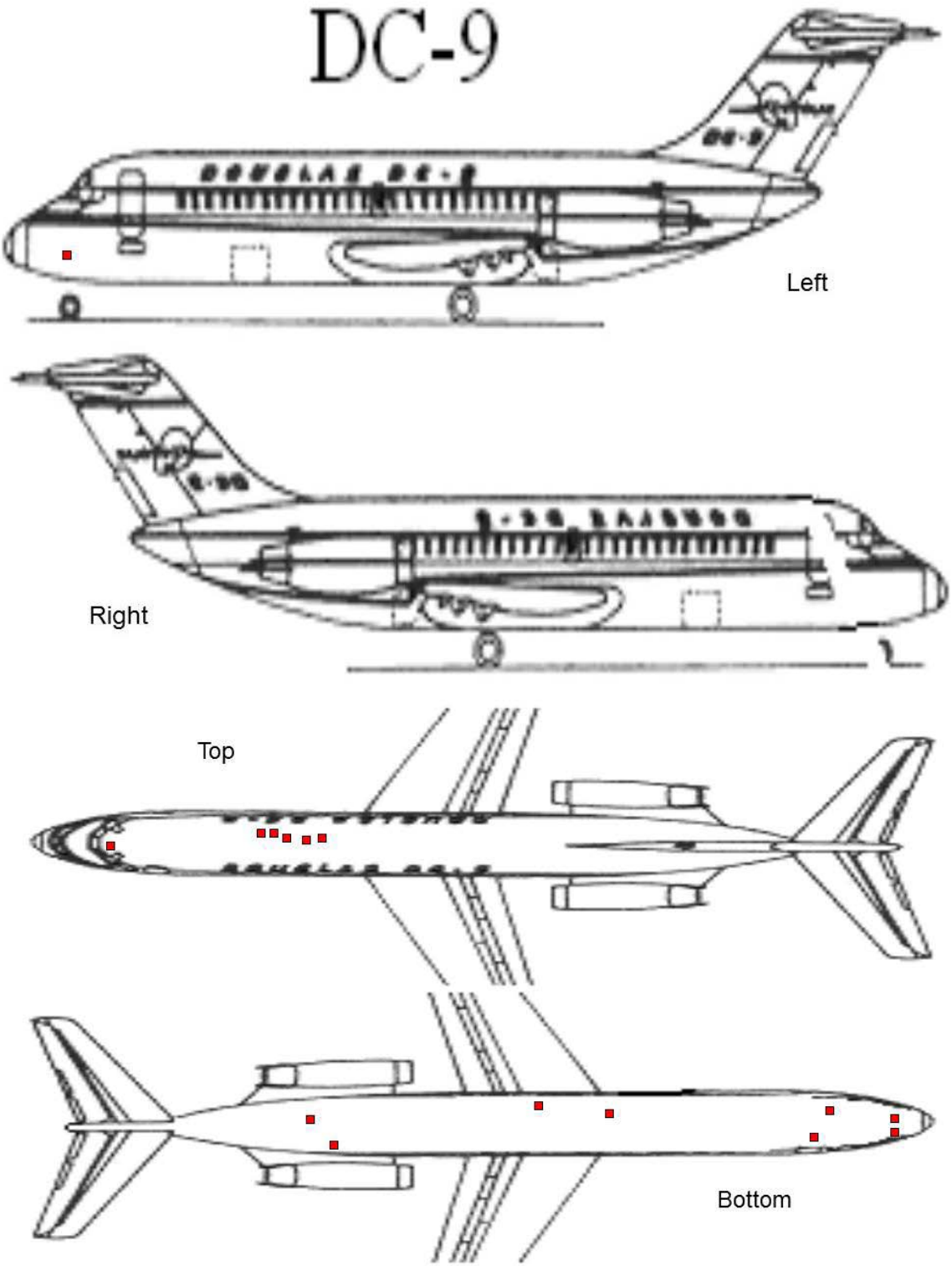


Figure A-53. RAM Location Plot Chart, DC-9

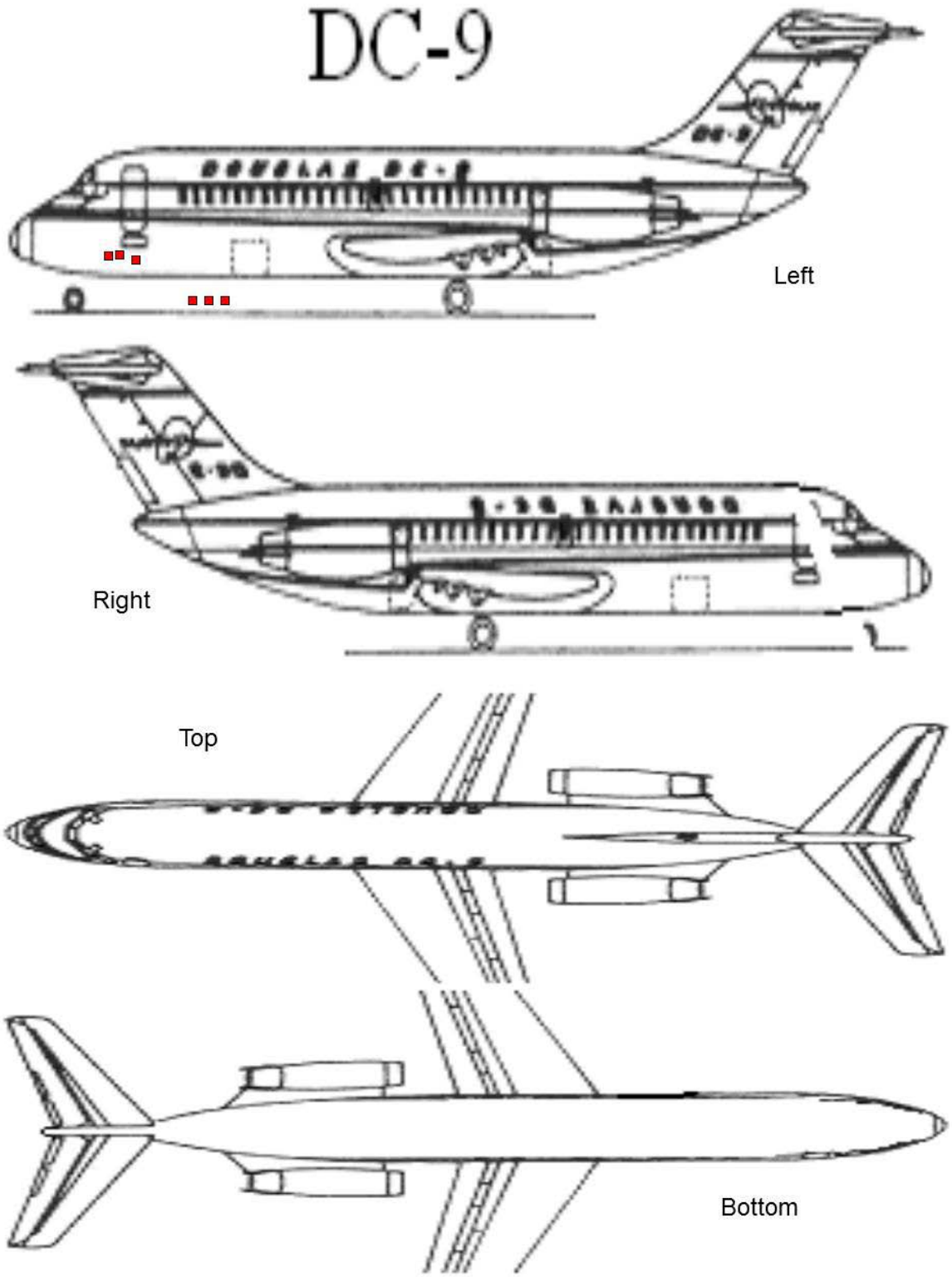


Figure A-54. RAM Location Plot Chart, DC-9

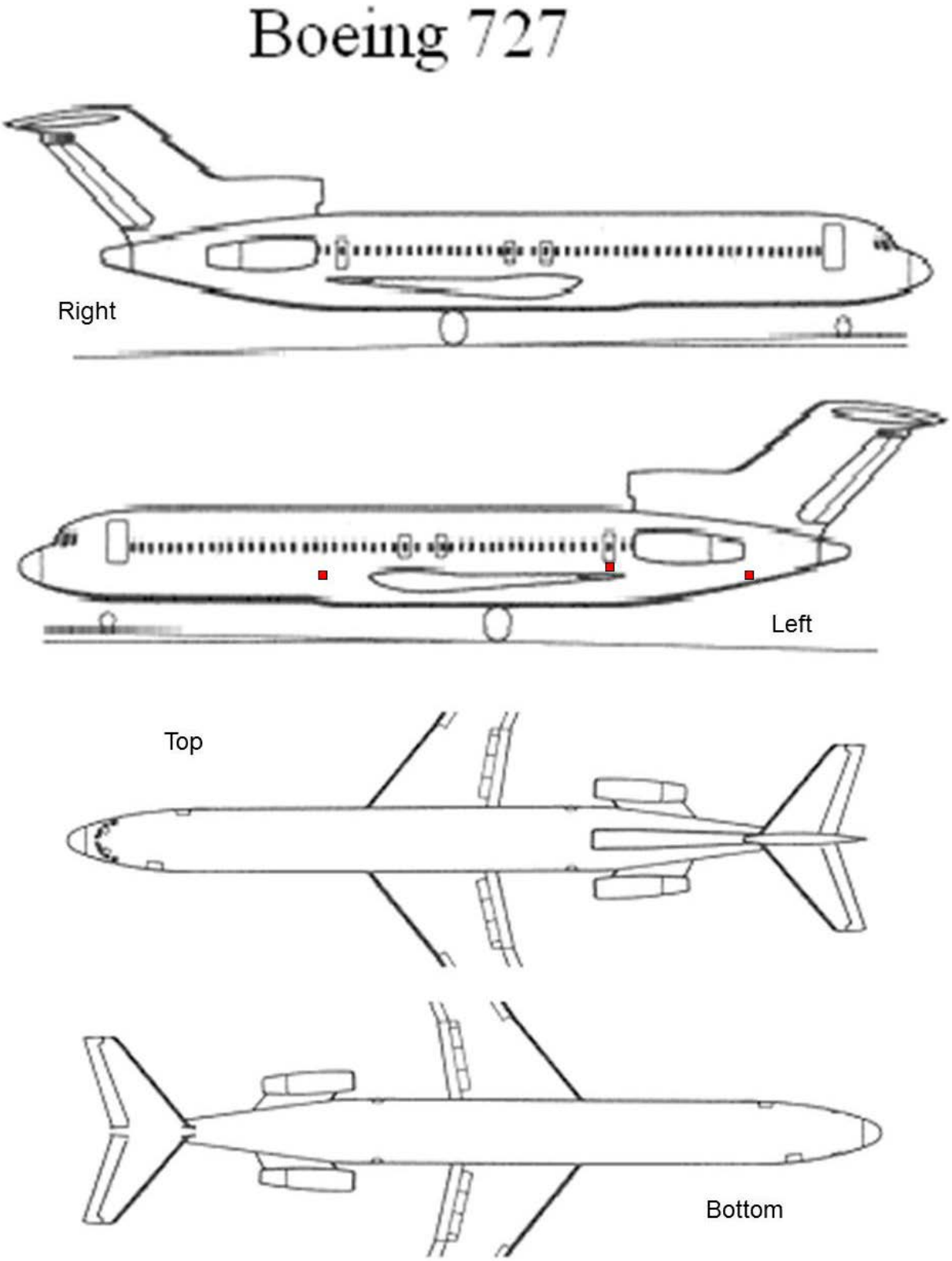


Figure A-55. RAM Location Plot Chart, Boeing 727

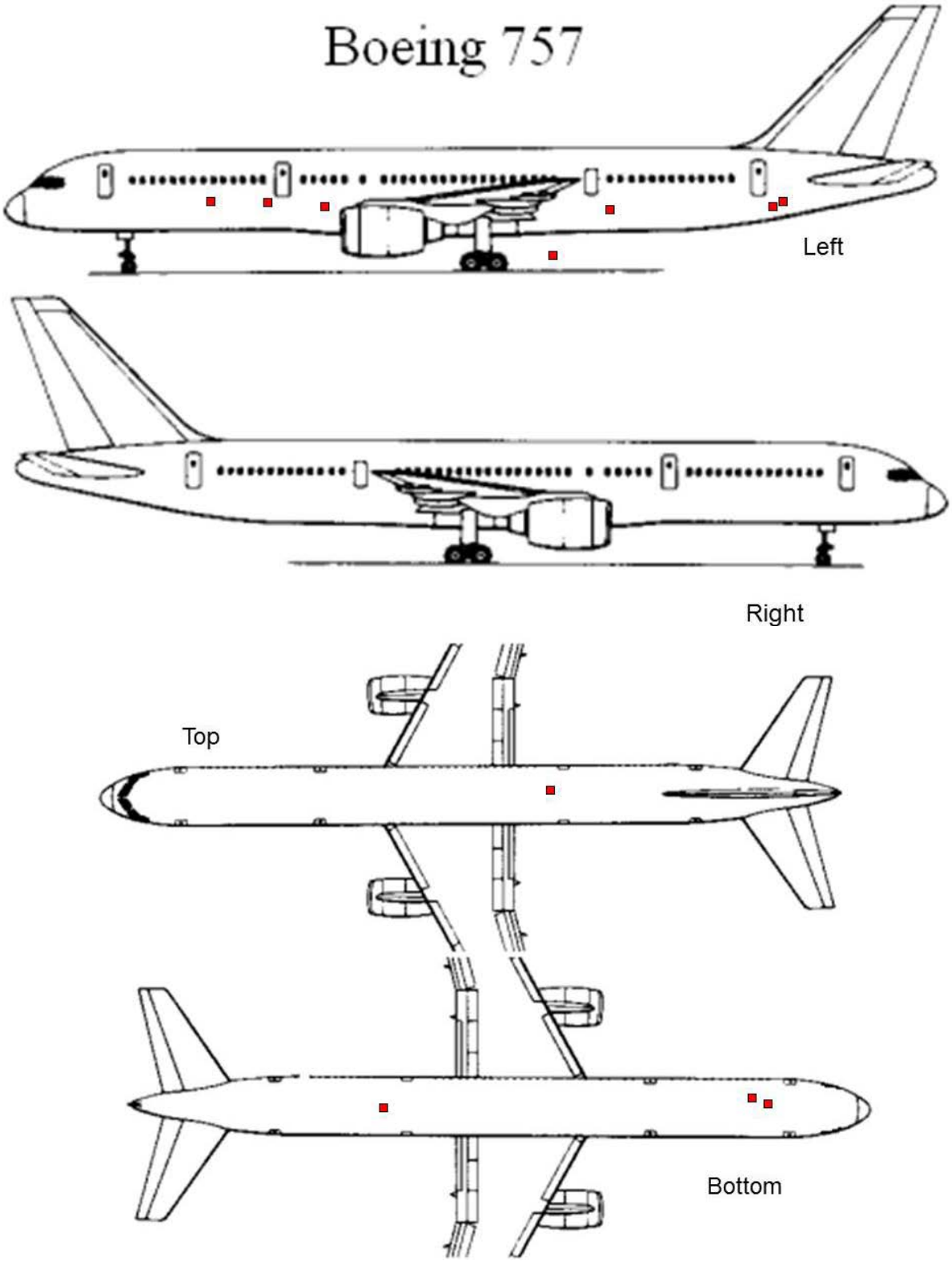


Figure A-56. RAM Location Plot Chart, Boeing 757

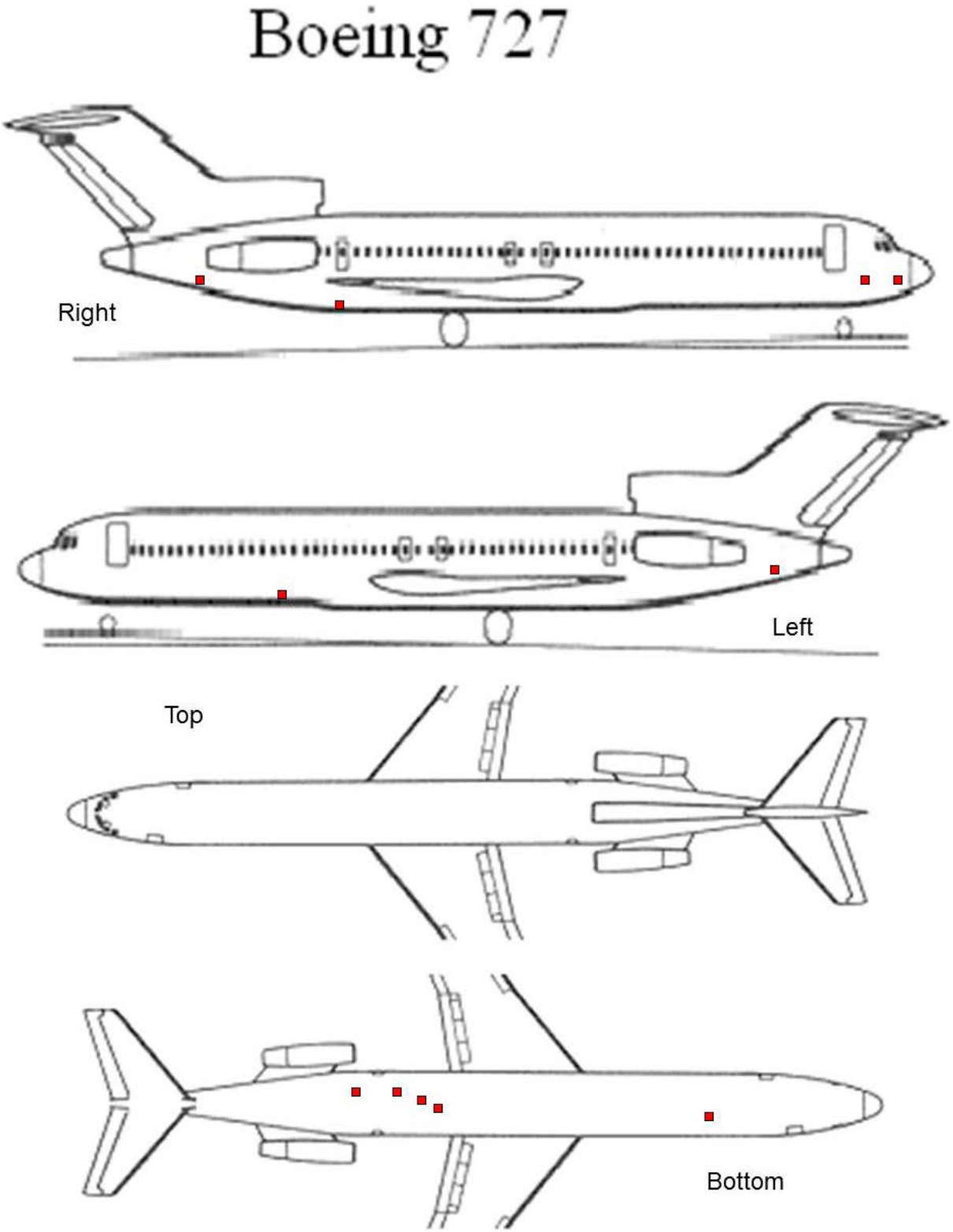


Figure A-57. RAM Location Plot Chart, Boeing 727

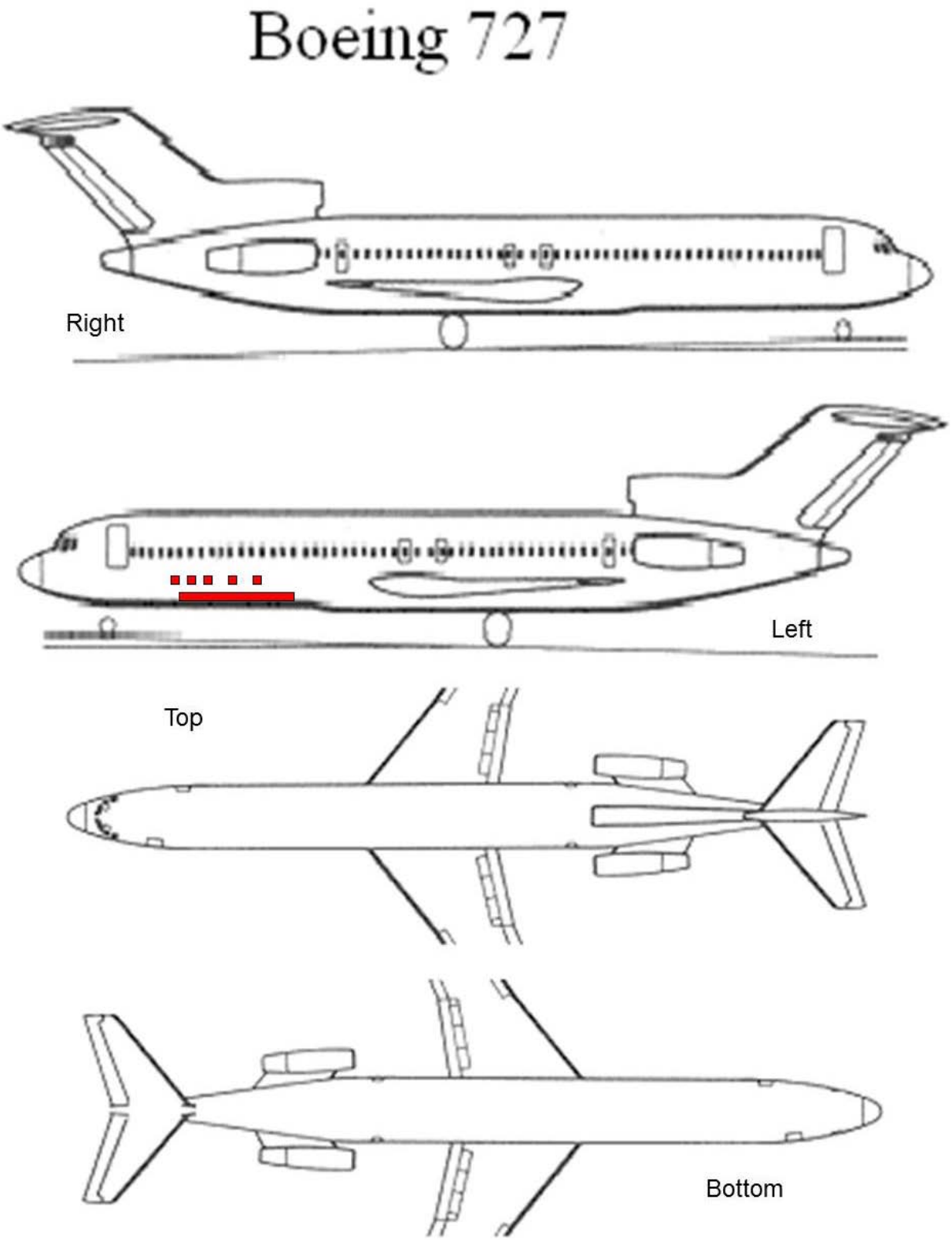


Figure A-58. RAM Location Plot Chart, Boeing 727

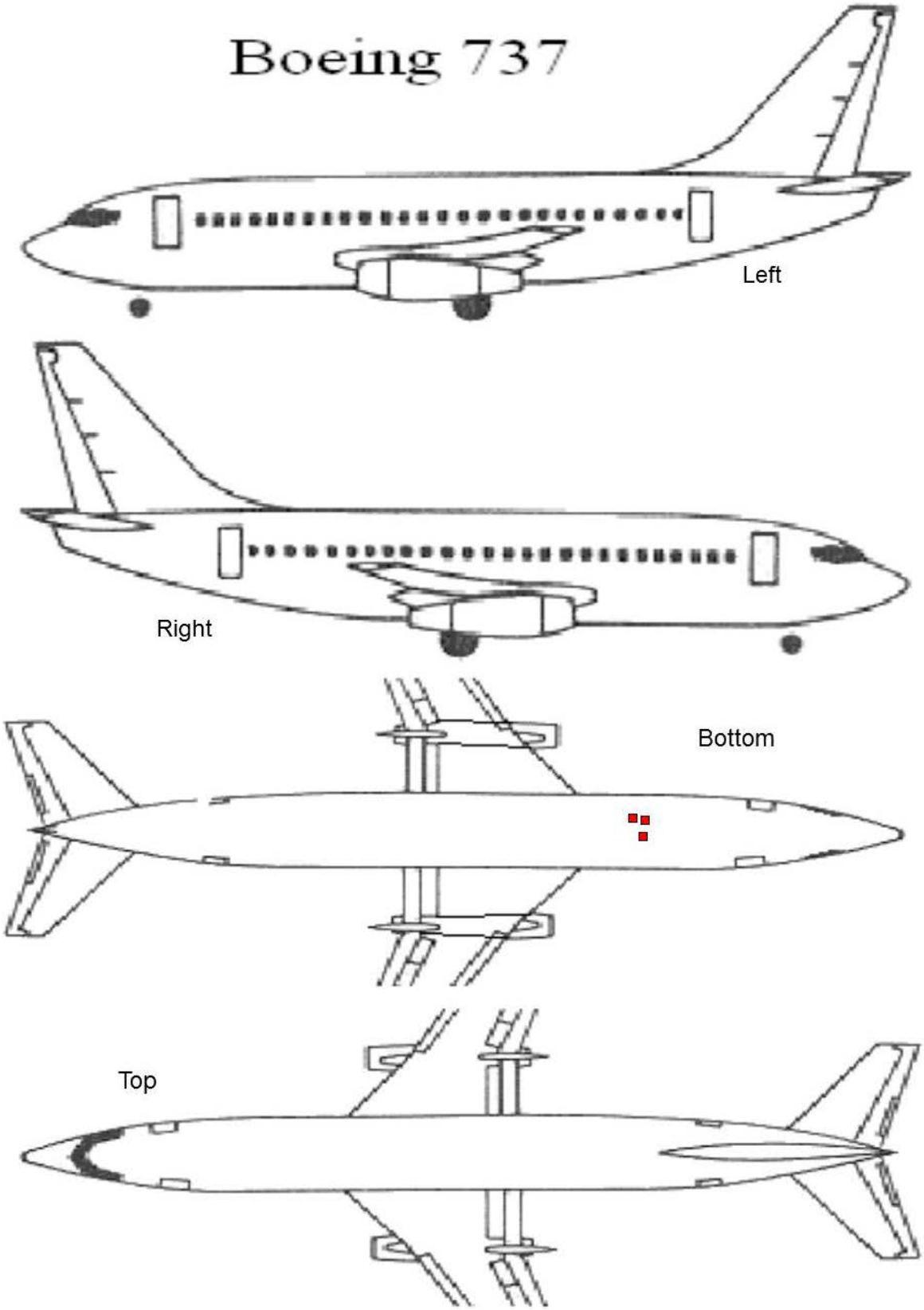


Figure A-59. RAM Location Plot Chart, Boeing 737

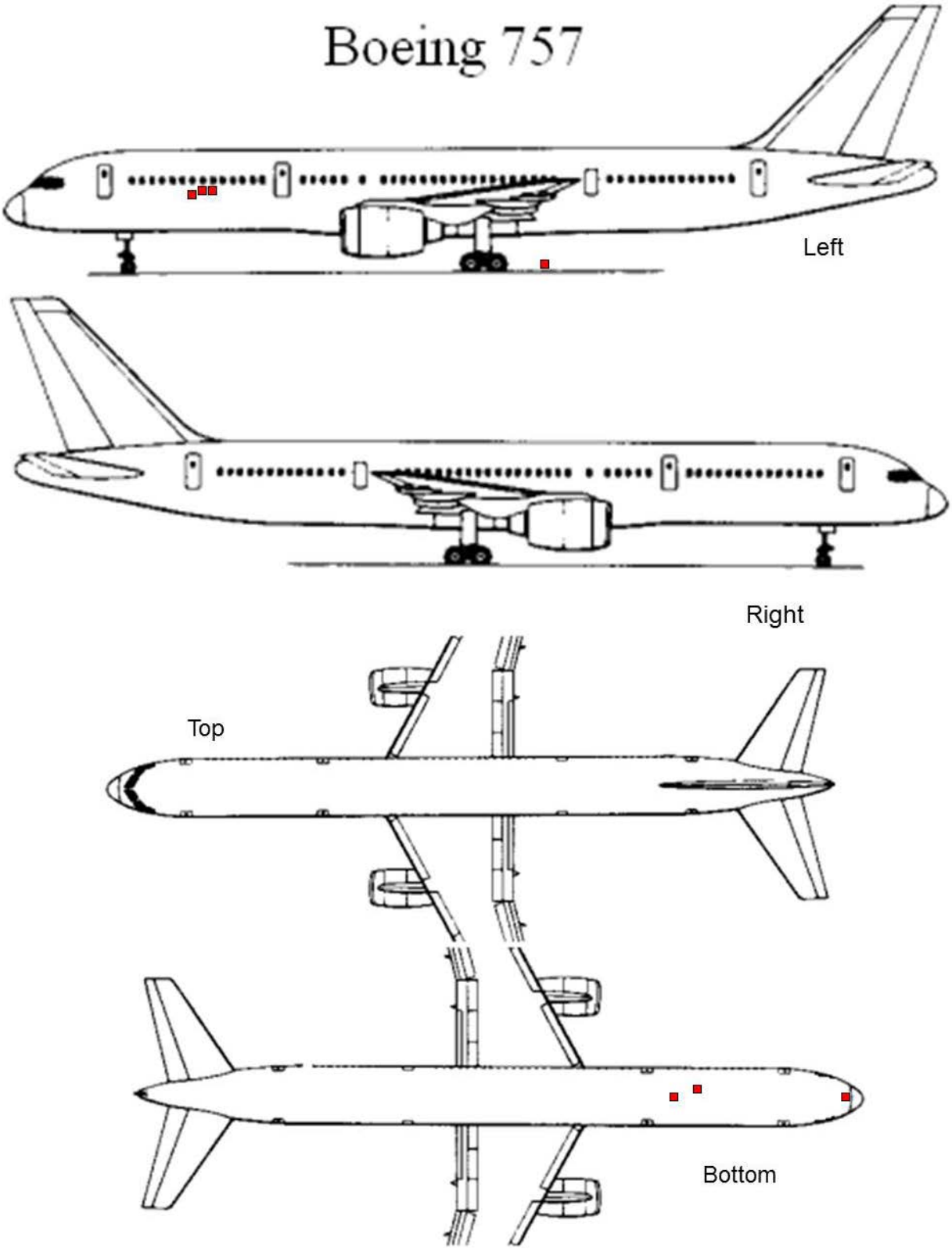


Figure A-60. RAM Location Plot Chart, Boeing 757

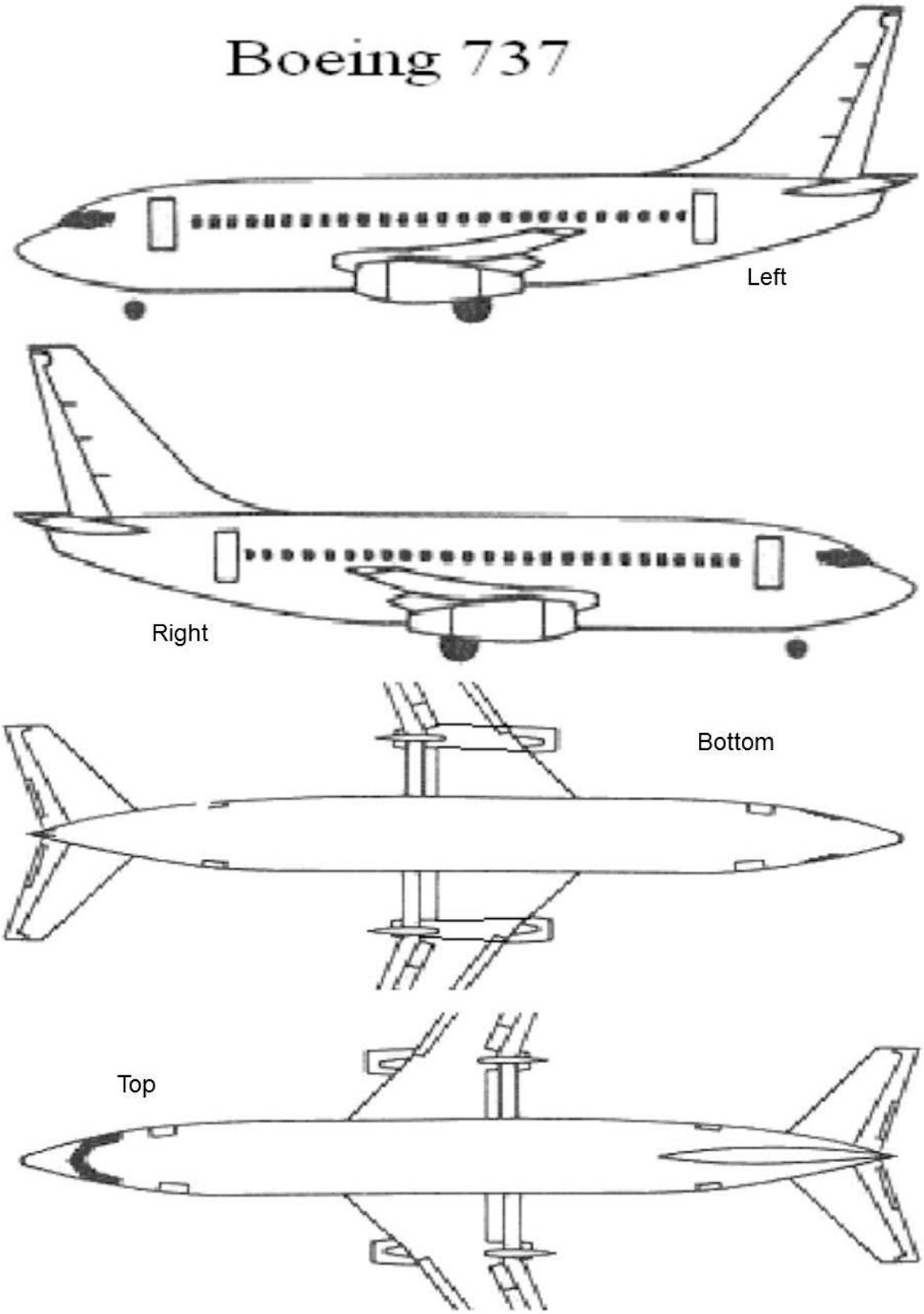


Figure A-61. RAM Location Plot Chart, Boeing 737

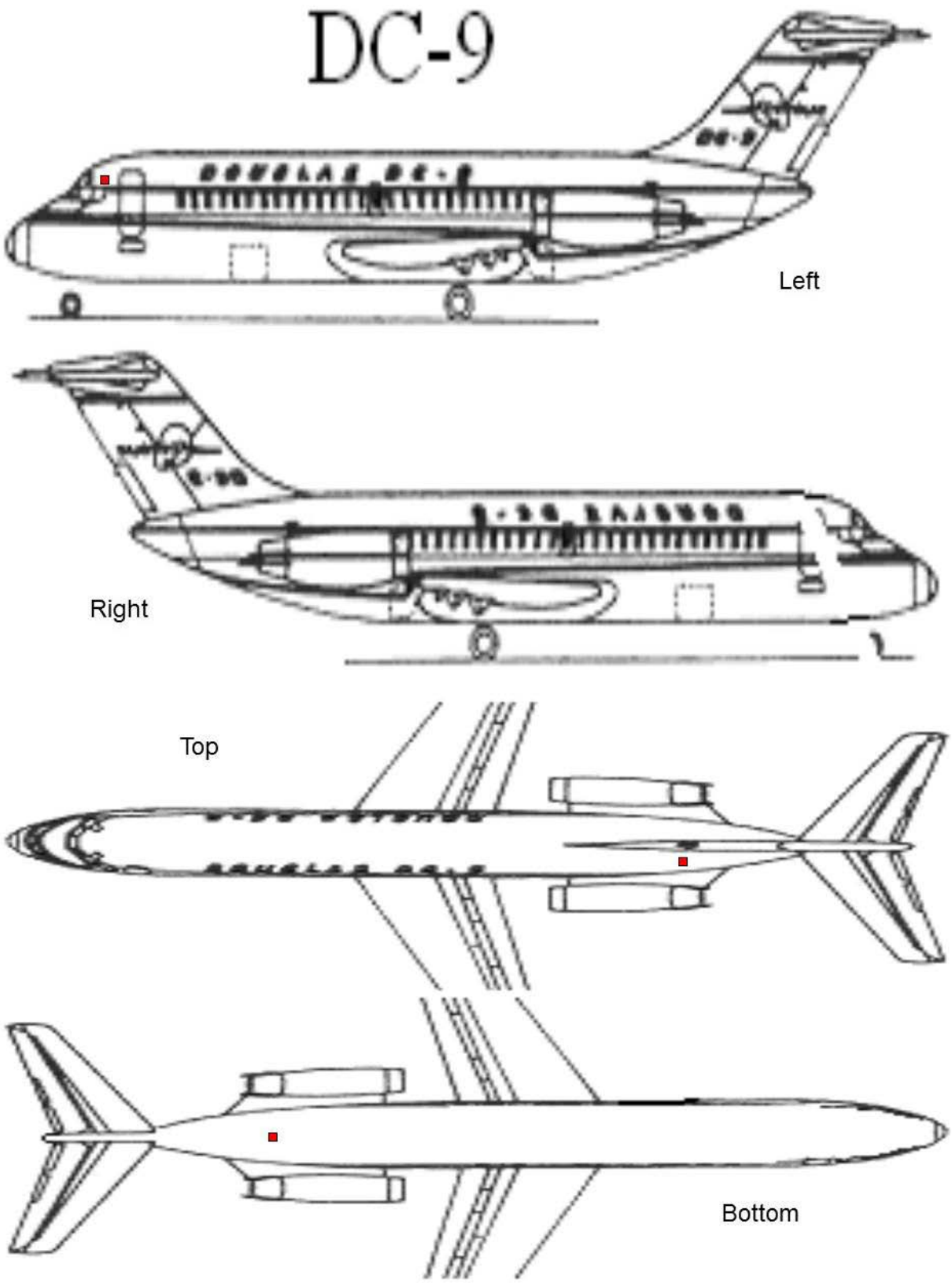


Figure A-62. RAM Location Plot Chart, DC-9

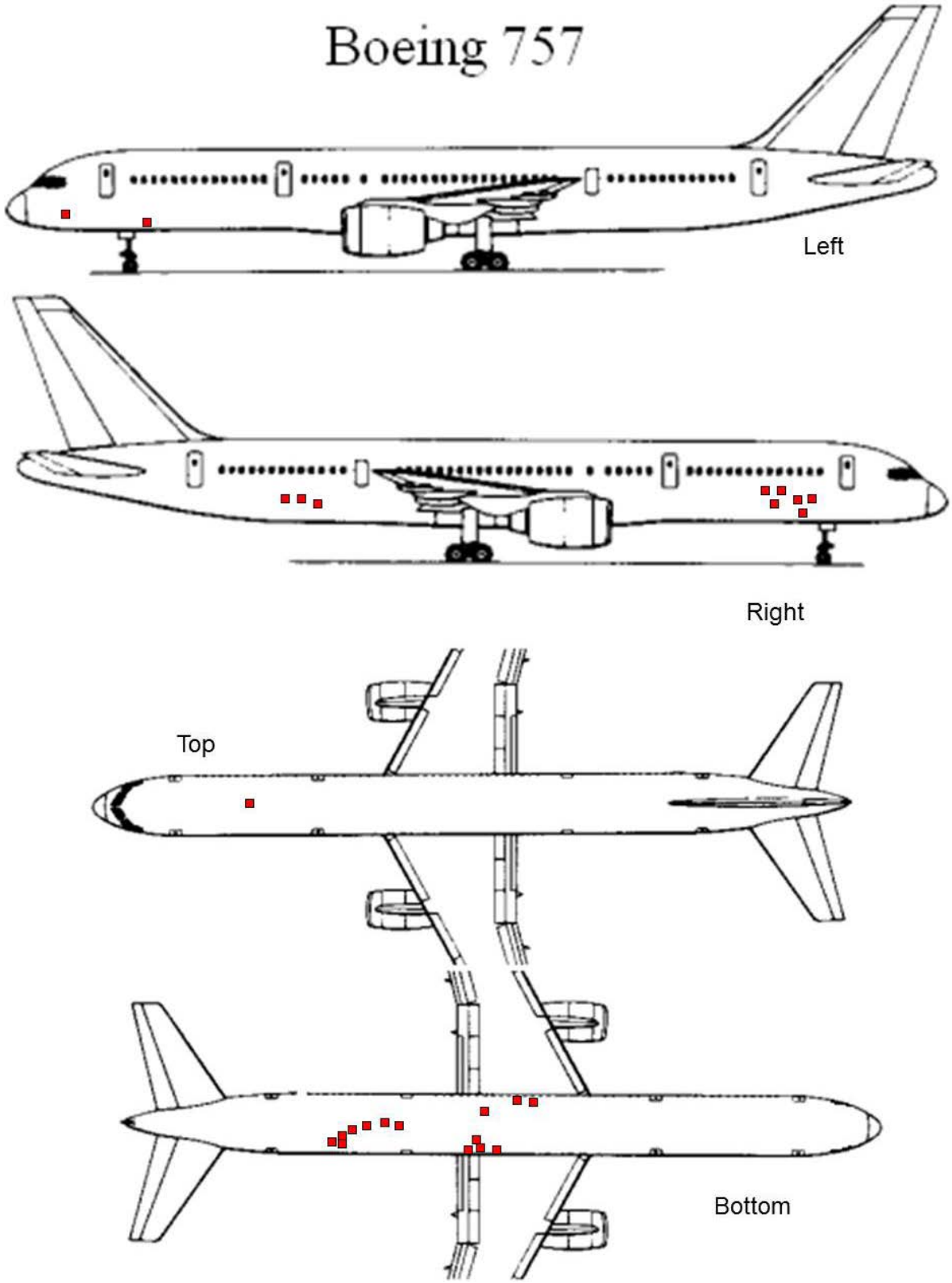


Figure A-63. RAM Location Plot Chart, Boeing 757

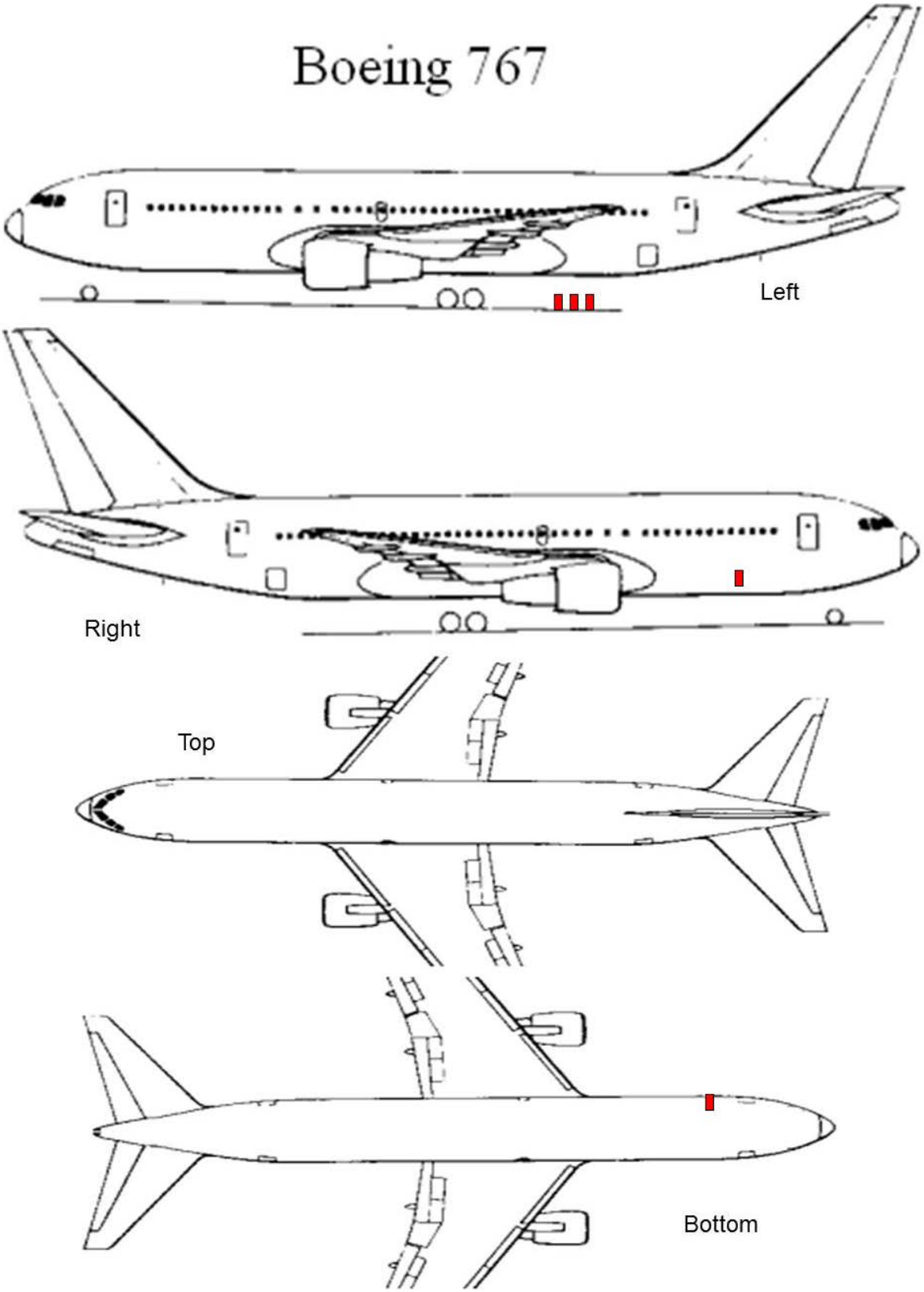


Figure A-64. RAM Location Plot Chart, Boeing 767

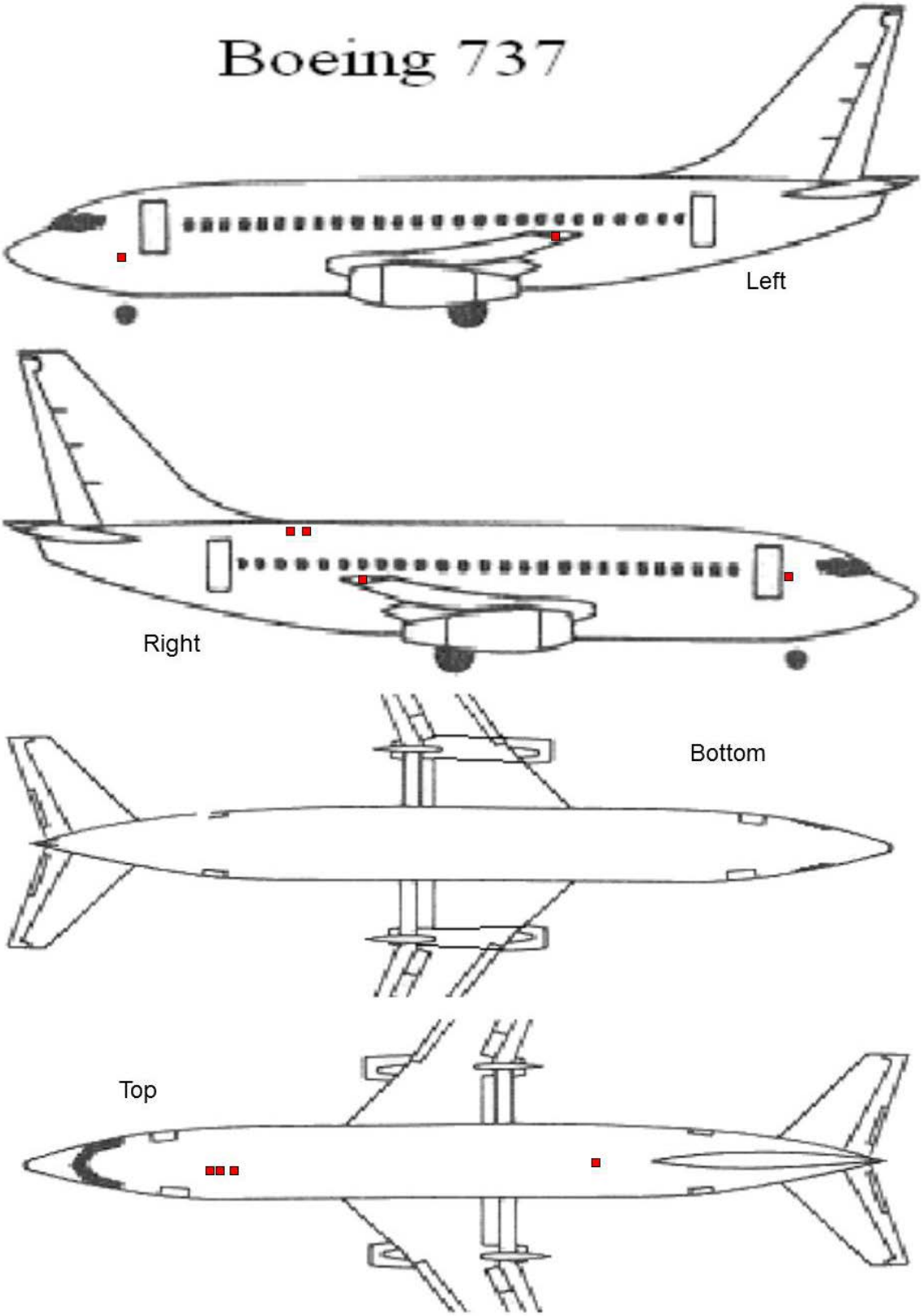


Figure A-65. RAM Location Plot Chart, Boeing 737

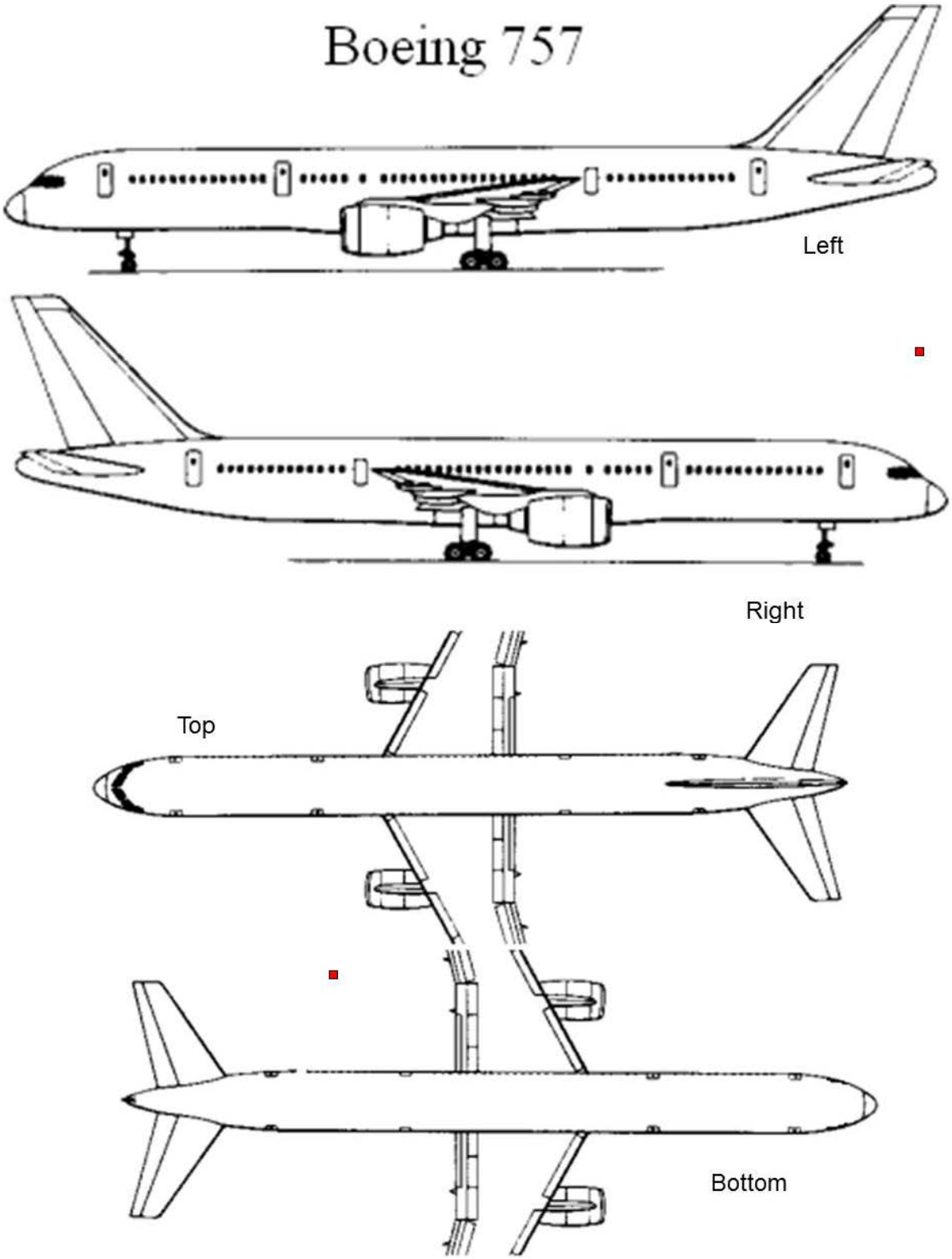


Figure A-66. RAM Location Plot Chart, Boeing 757

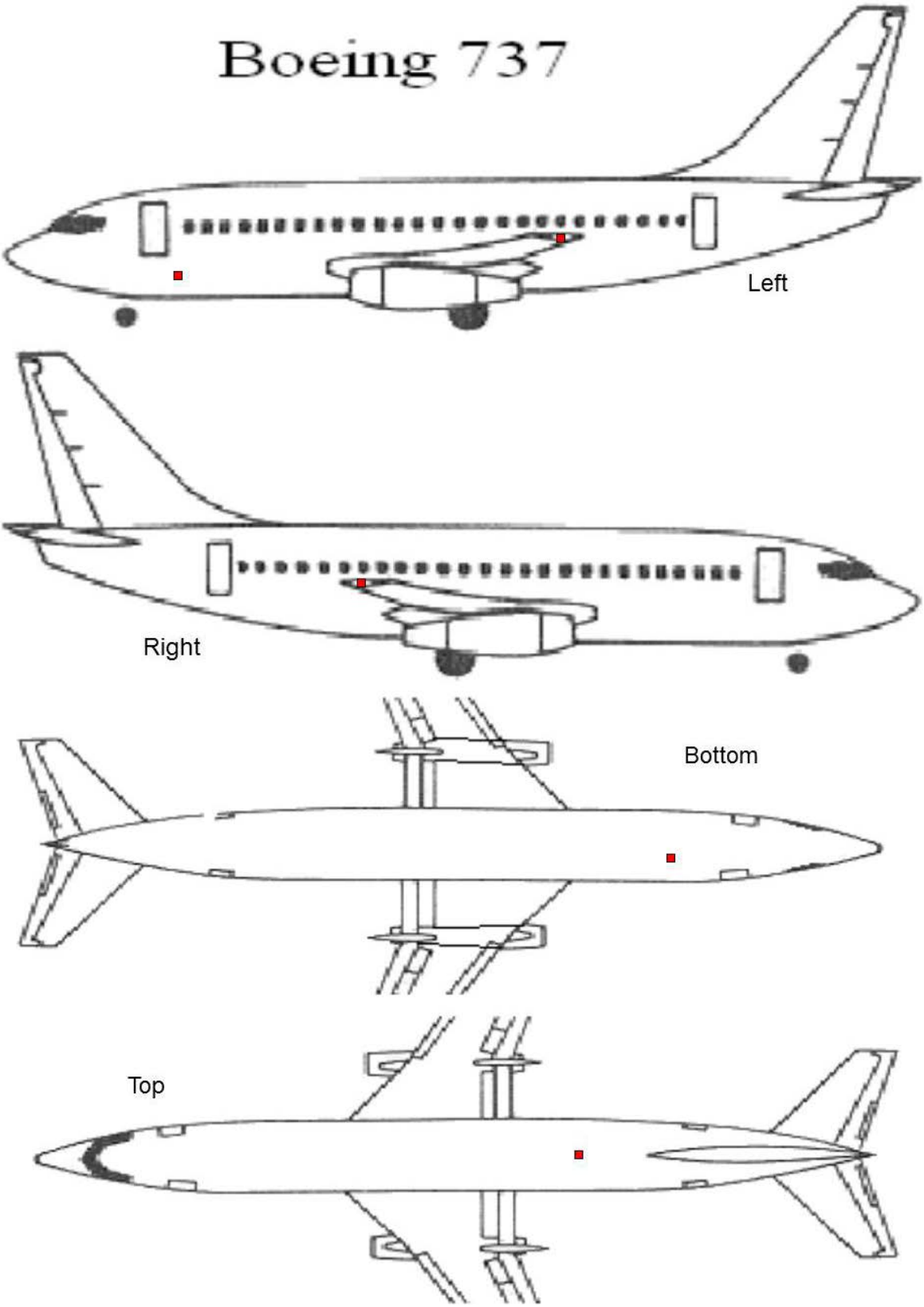


Figure A-67. RAM Location Plot Chart, Boeing 737

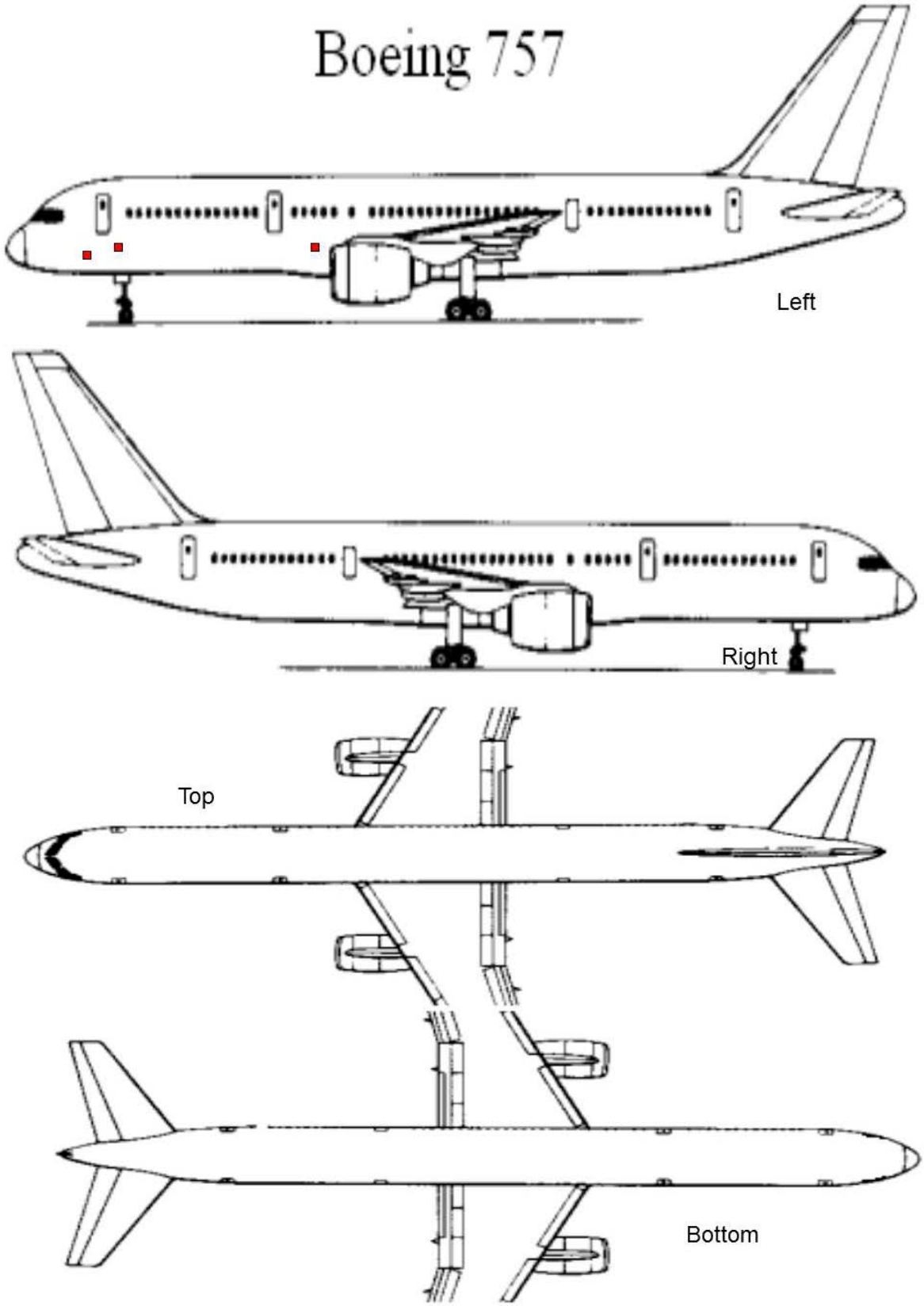


Figure A-68. RAM Location Plot Chart, Boeing 757

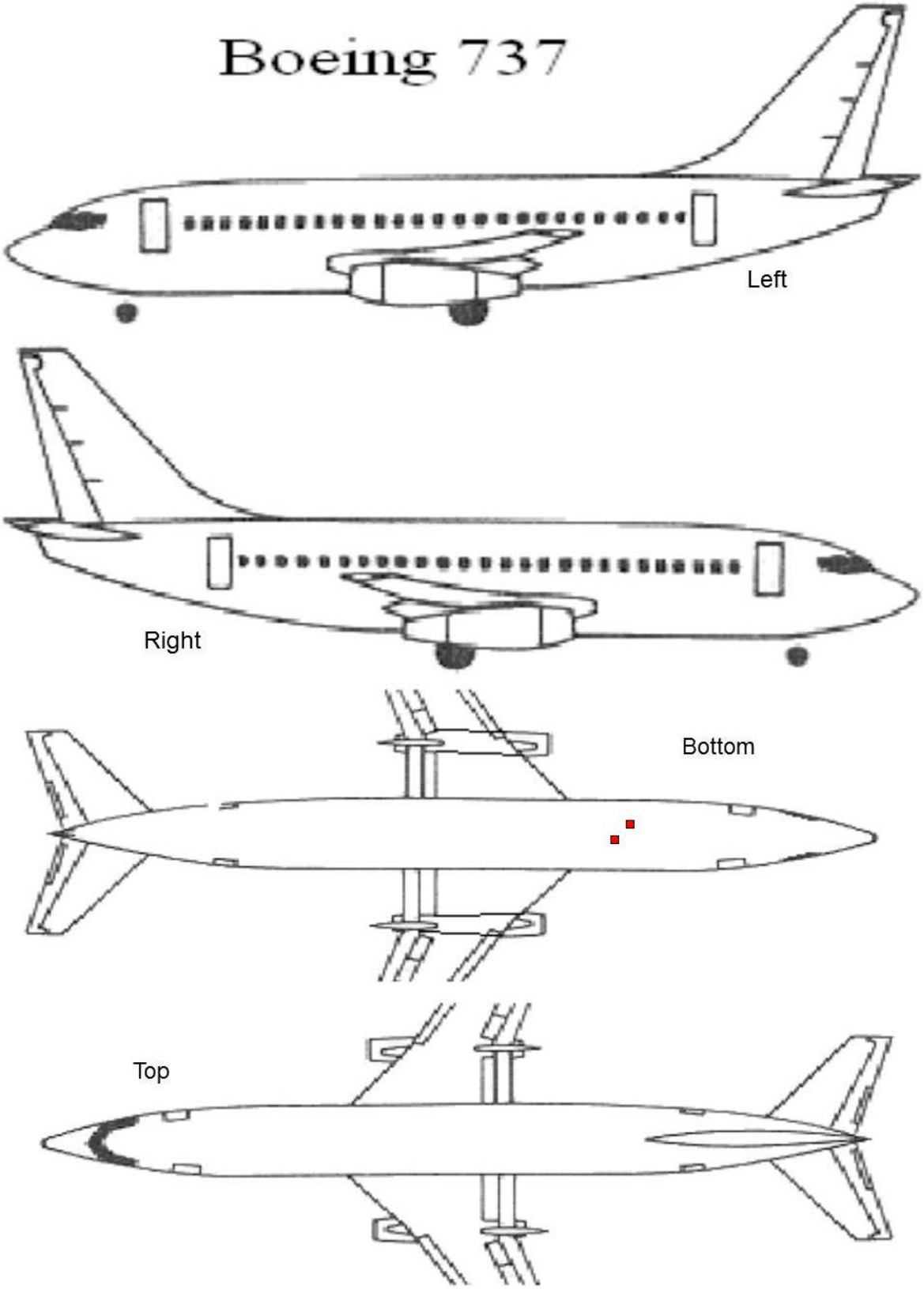

Boeing 737
Left
Right
Bottom
Top

Figure A-69. RAM Location Plot Chart, Boeing 737

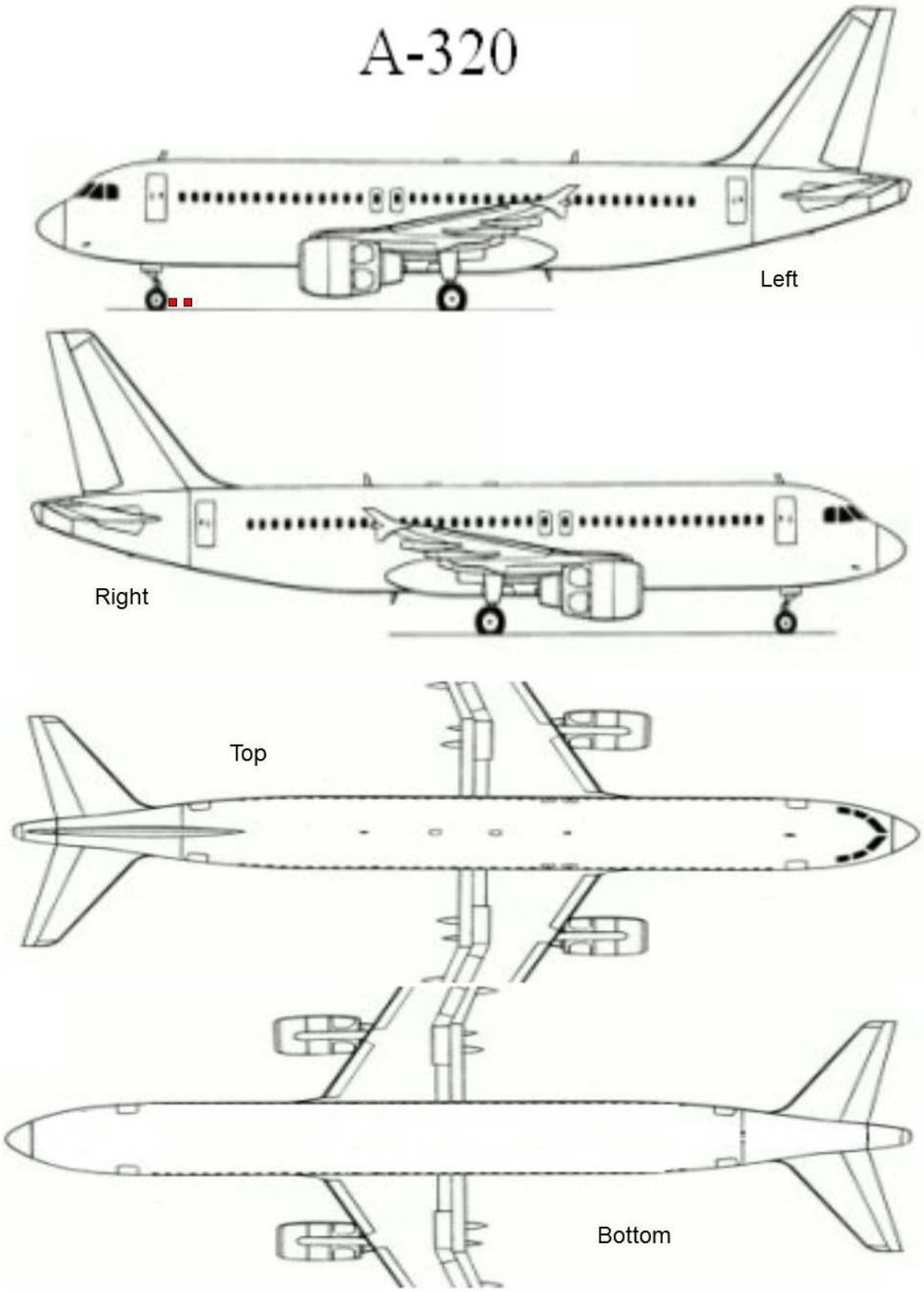


Figure A-70. RAM Location Plot Chart, A-320

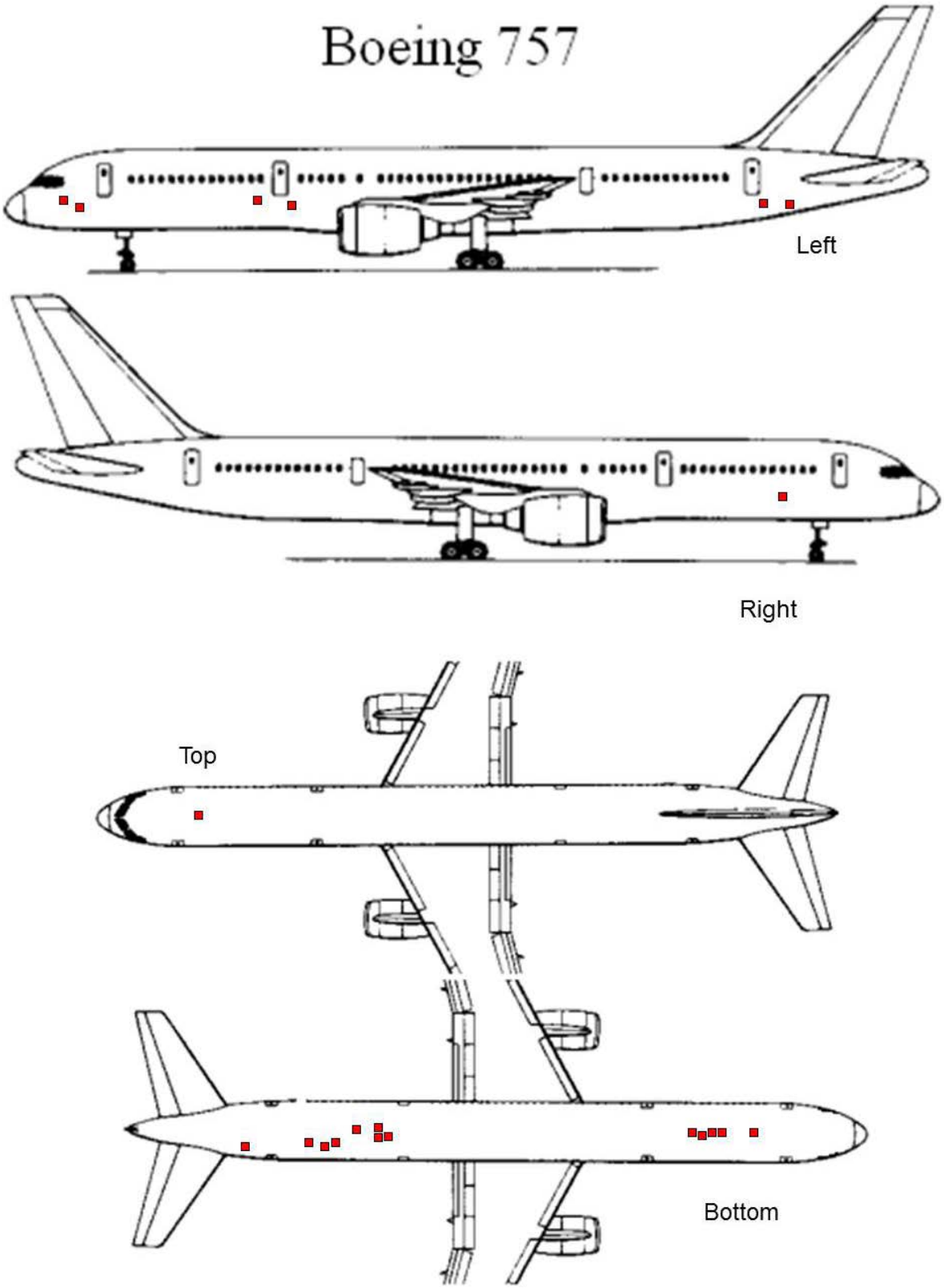


Figure A-71. RAM Location Plot Chart, Boeing 757

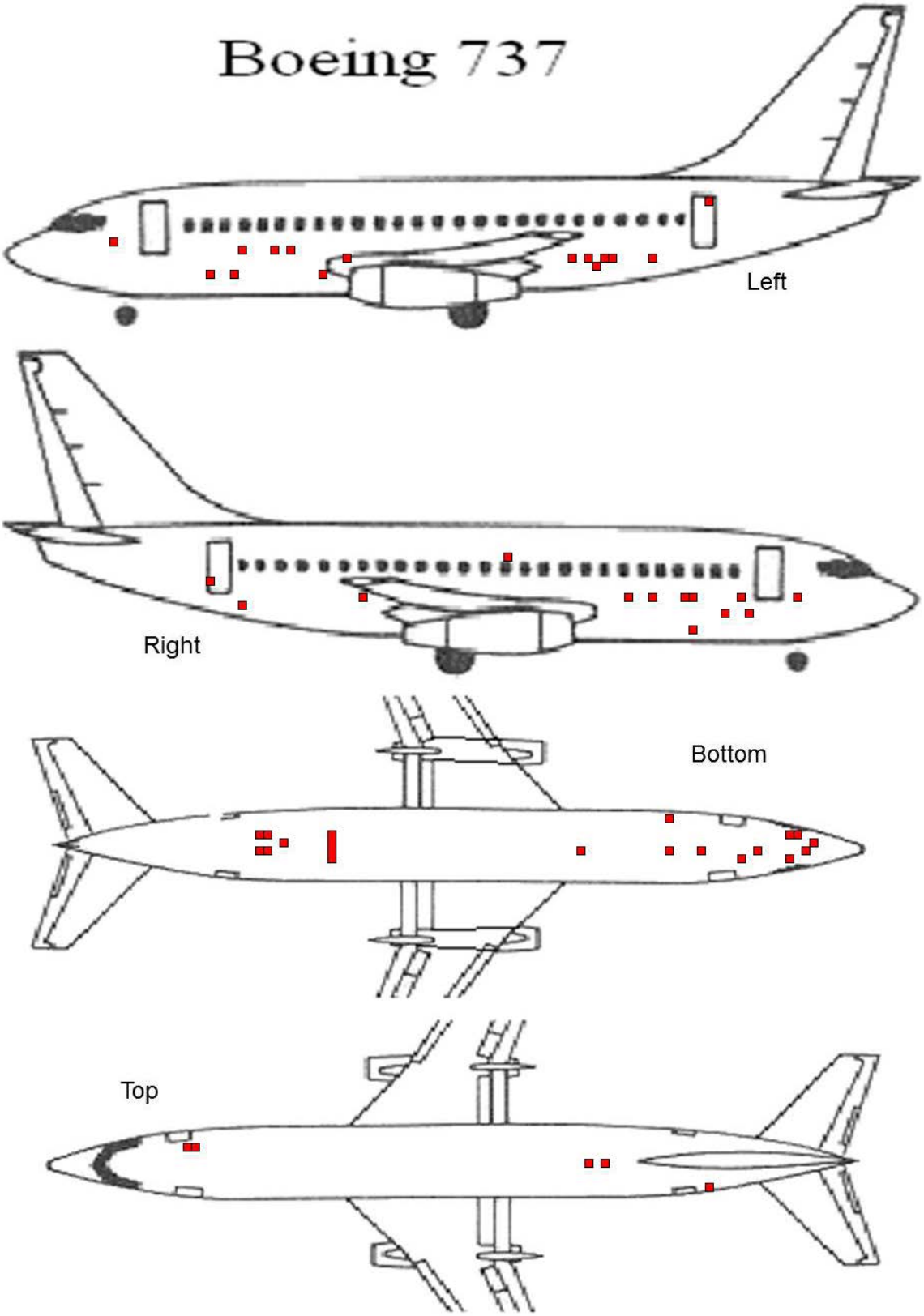


Figure A-72. RAM Location Plot Chart, Boeing 737

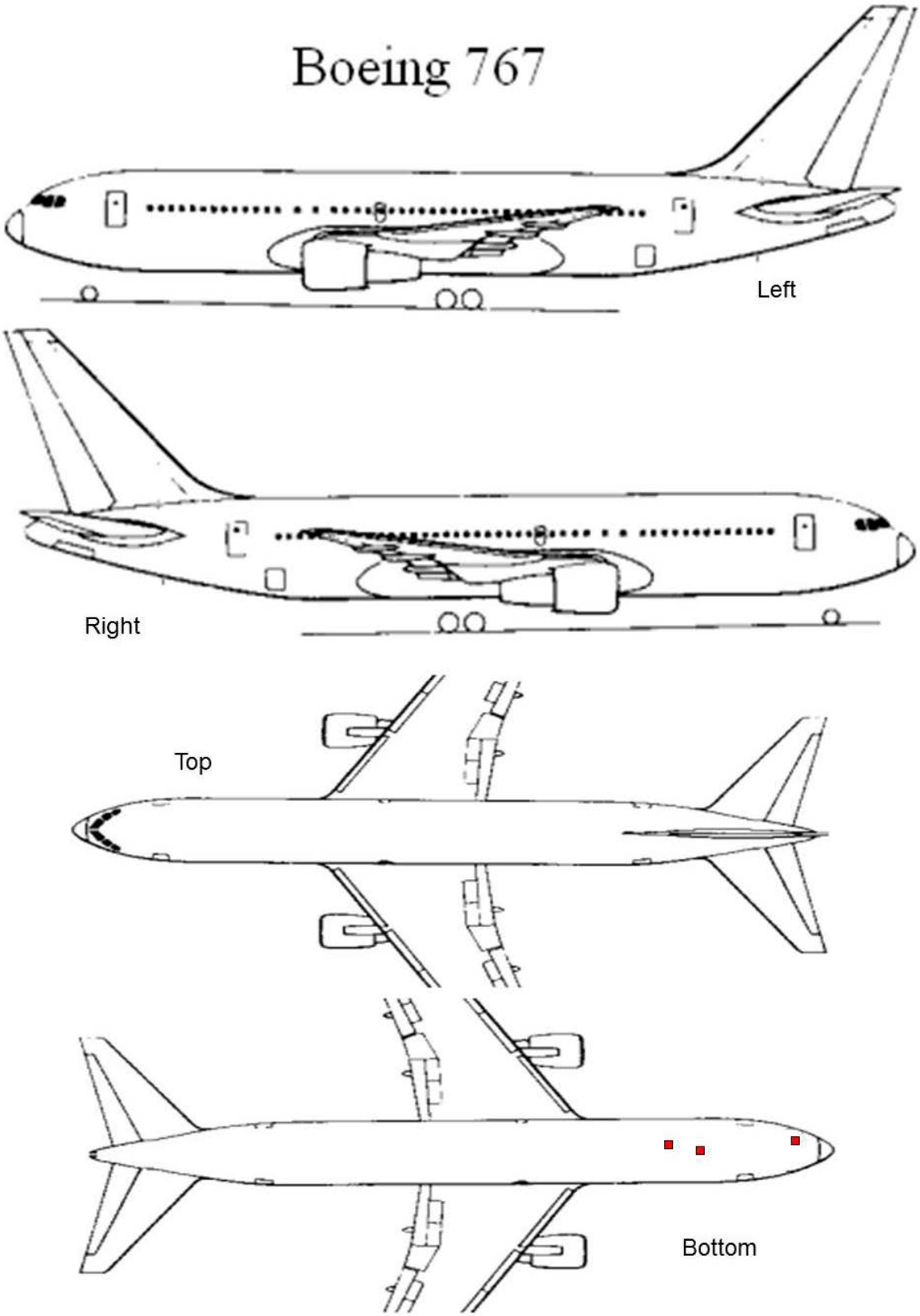


Figure A-73. RAM Location Plot Chart, Boeing 767

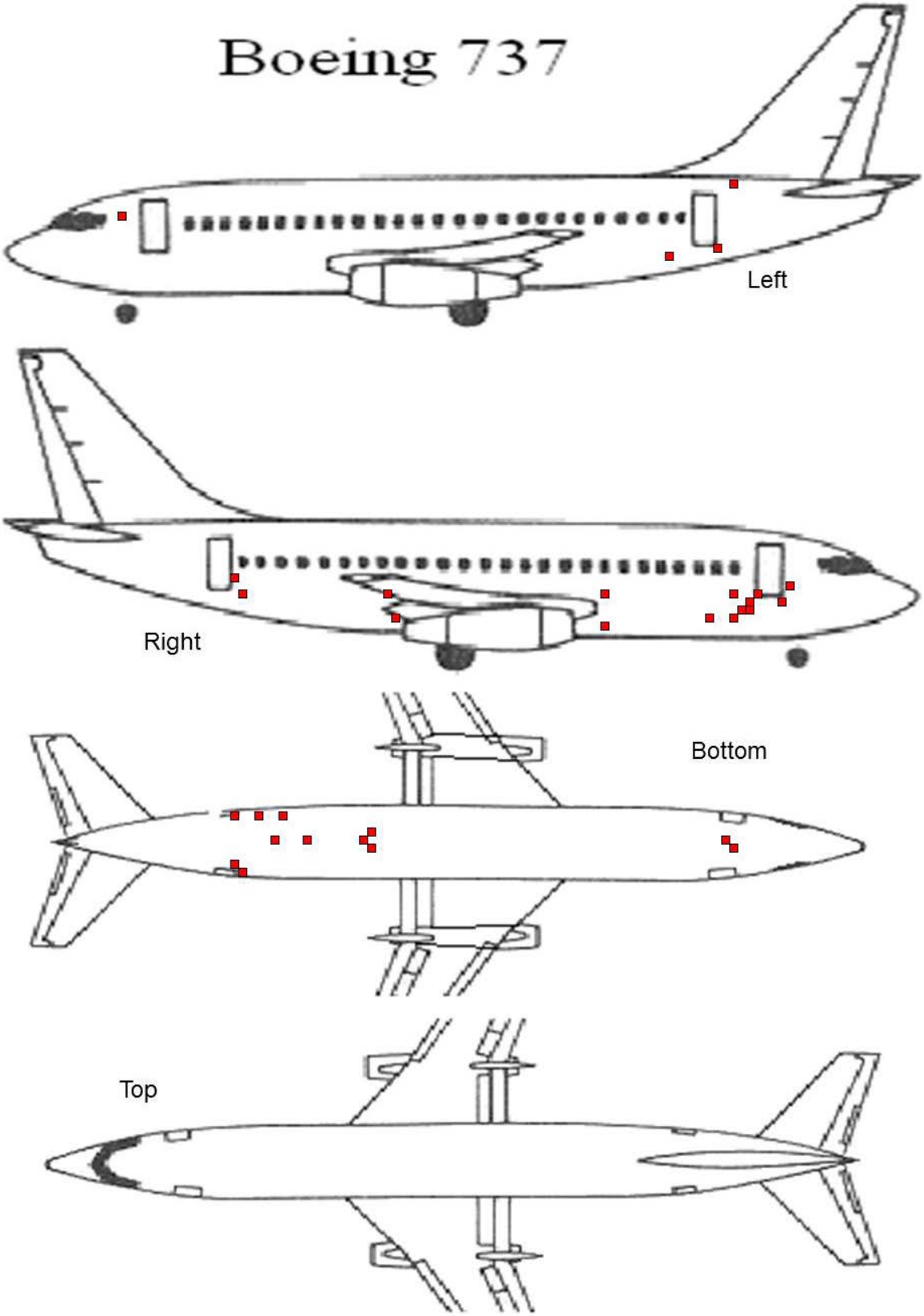


Figure A-74. RAM Location Plot Chart, Boeing 737

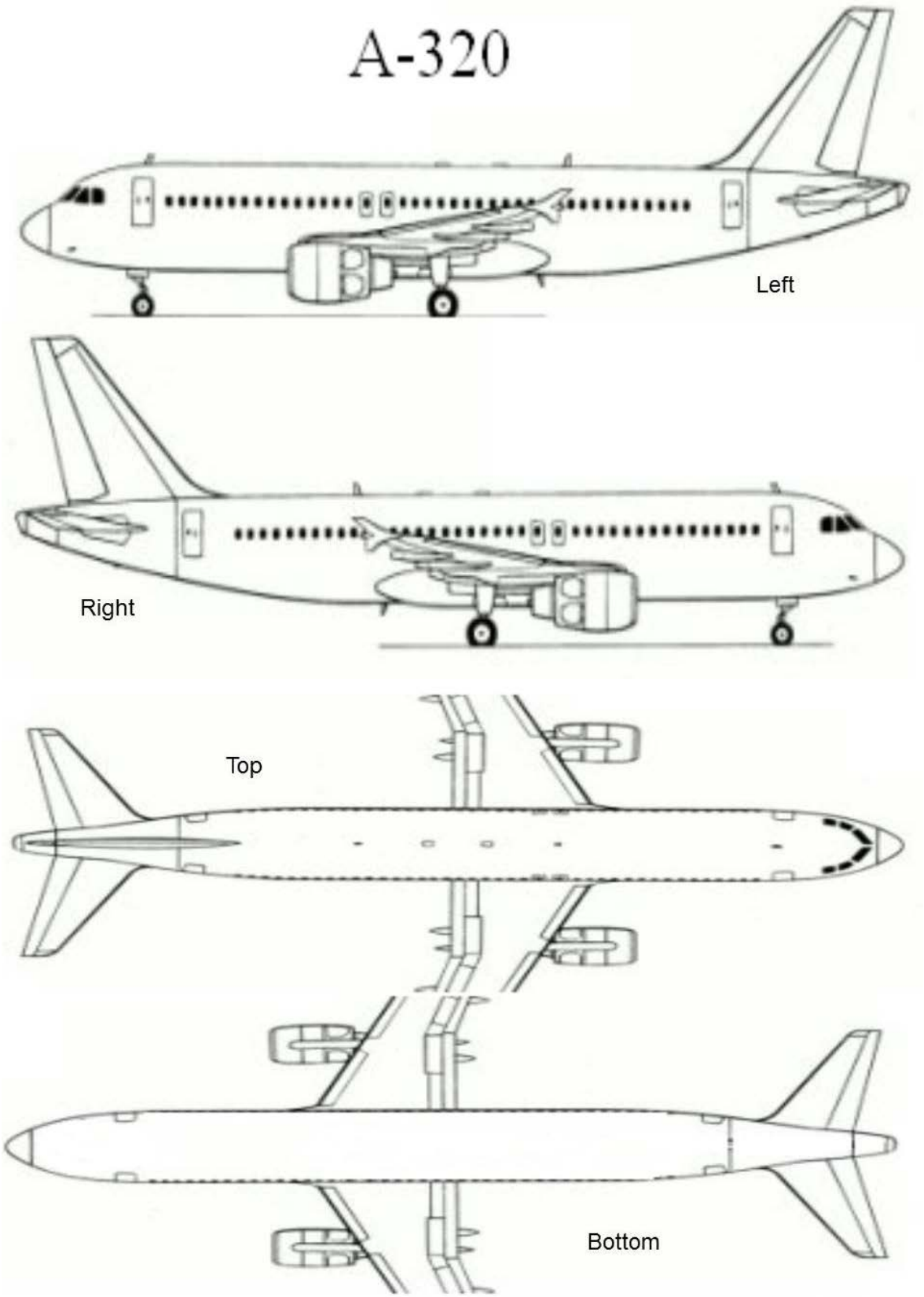


Figure A-75. RAM Location Plot Chart, A-320

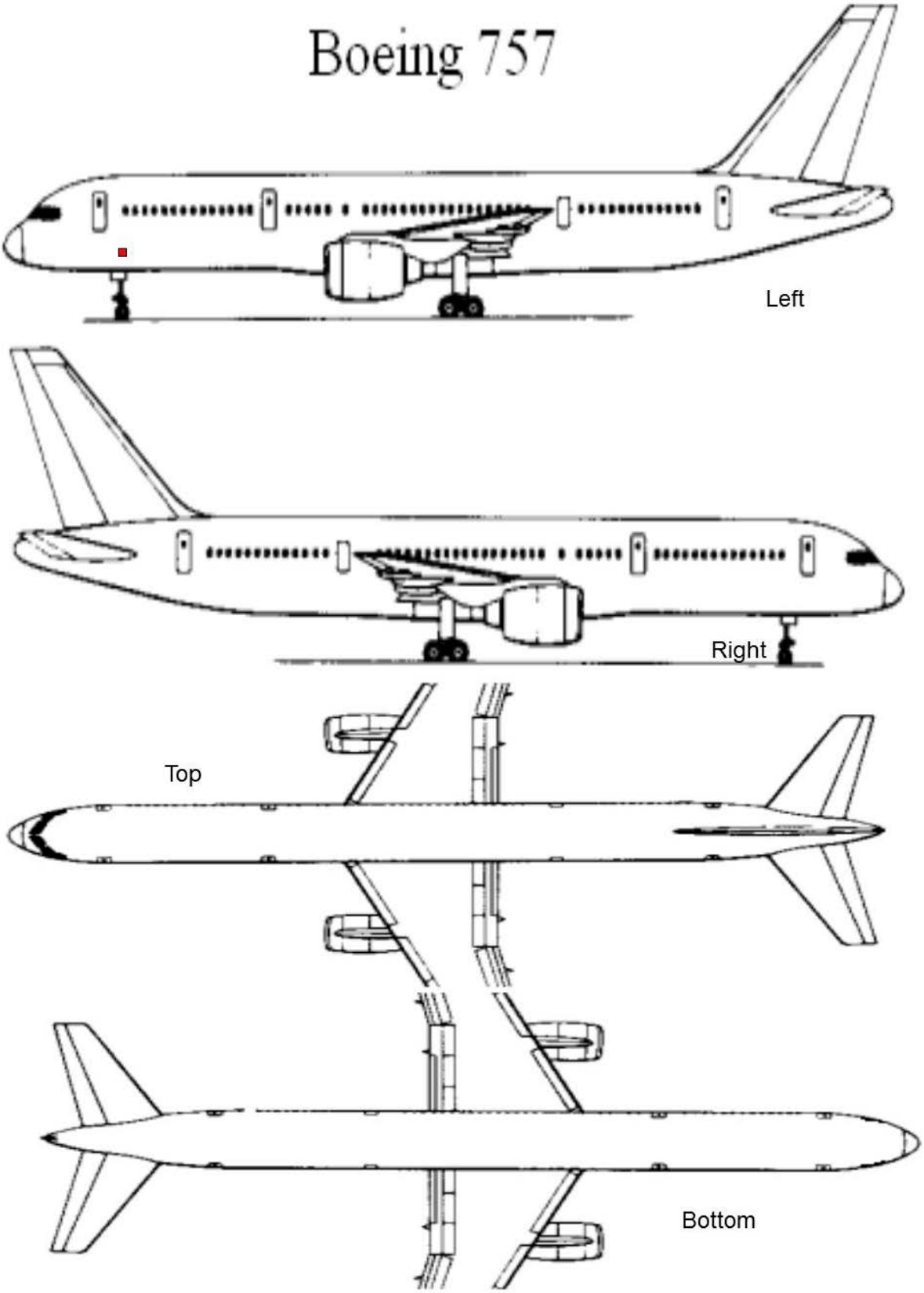


Figure A-76. RAM Location Plot Chart, Boeing 757

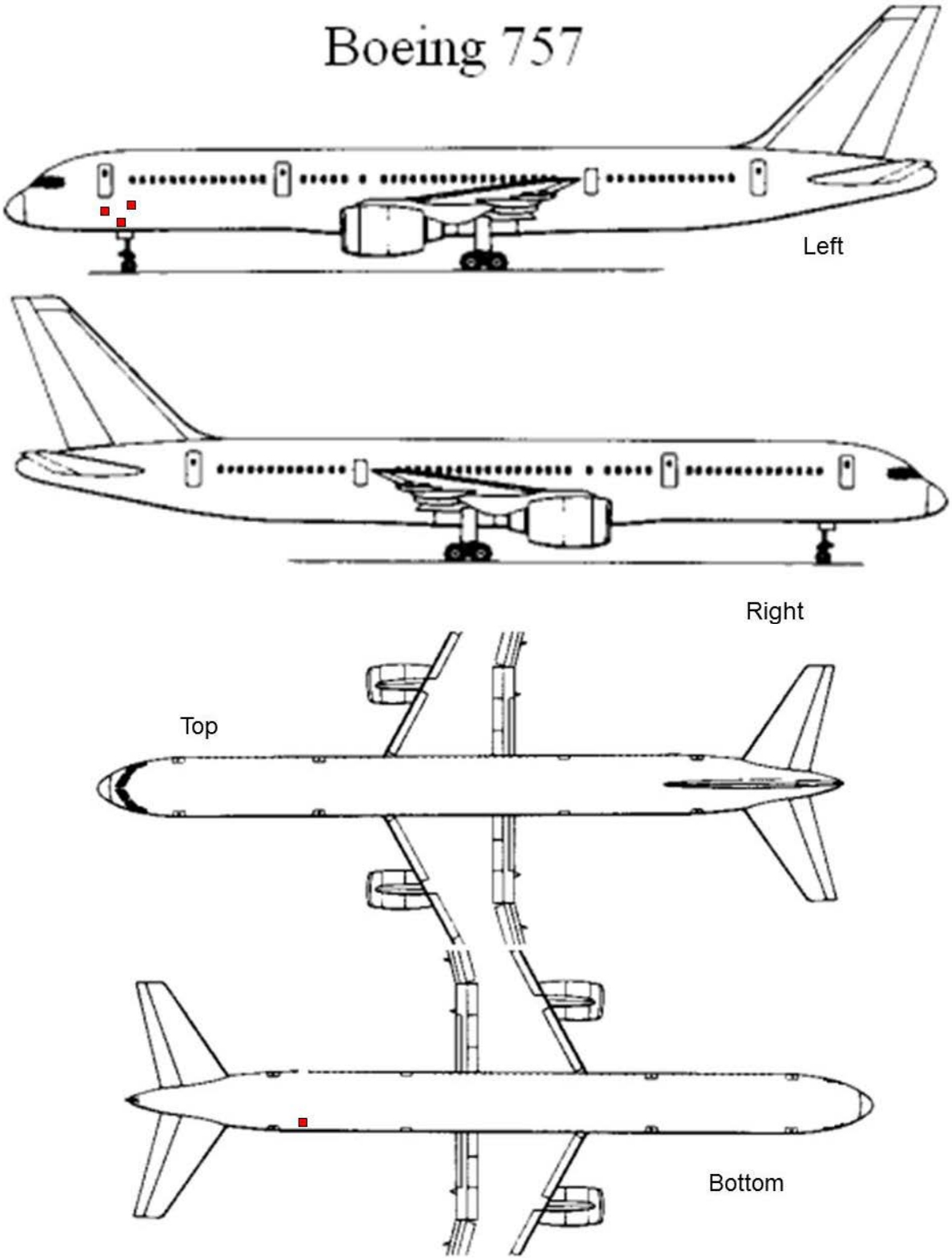


Figure A-77. RAM Location Plot Chart, Boeing 757

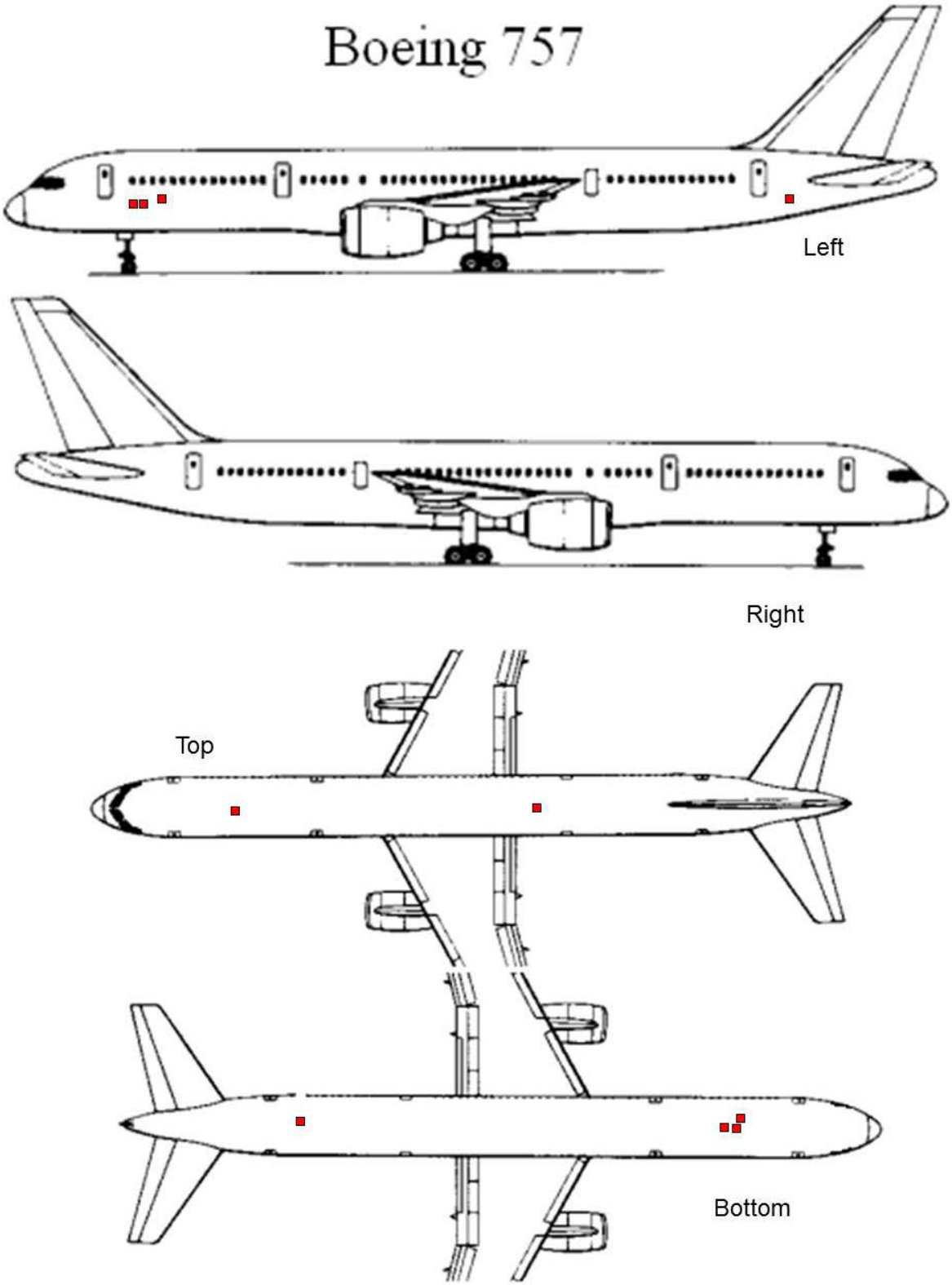


Figure A-78. RAM Location Plot Chart, Boeing 757

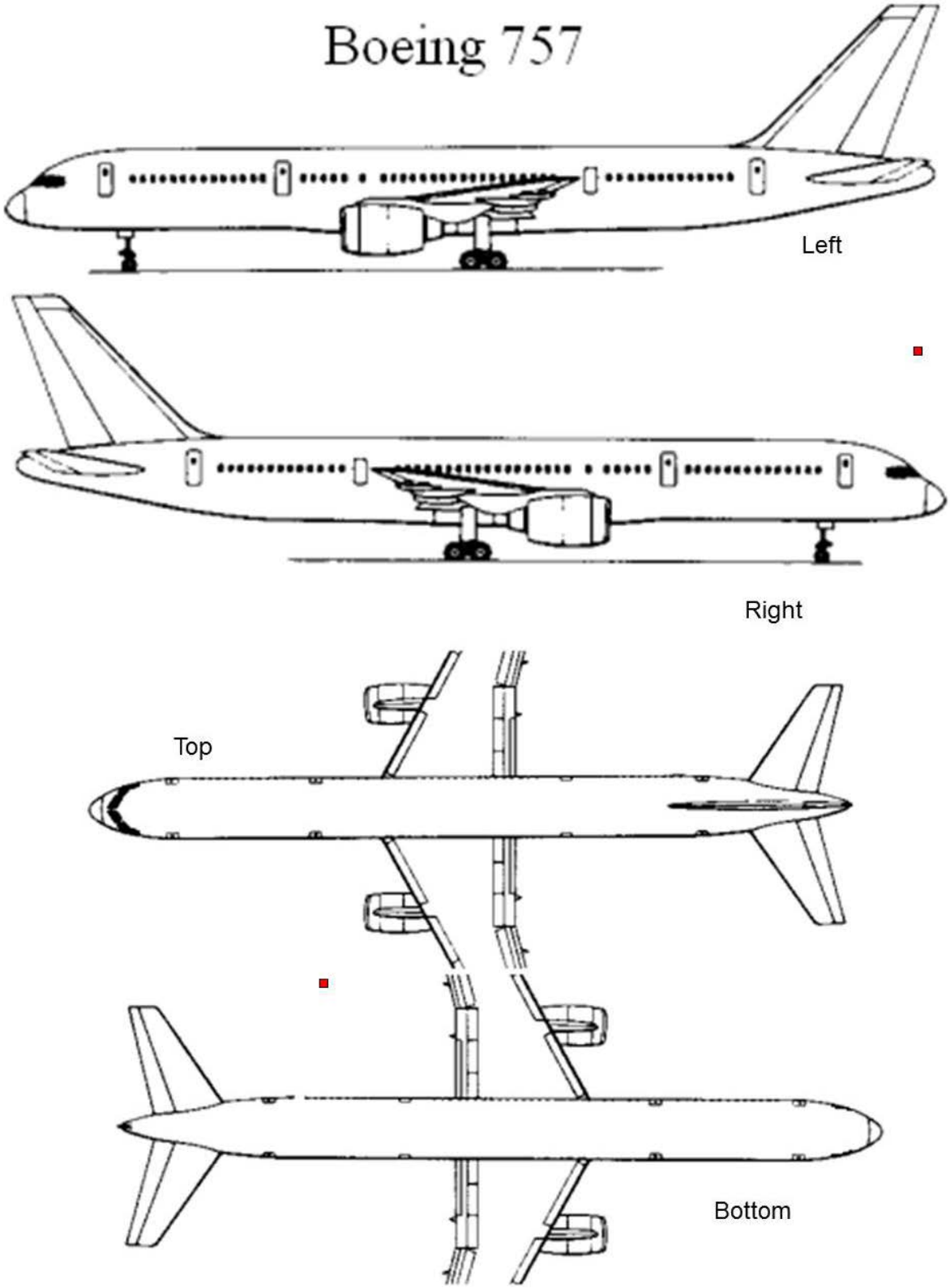


Figure A-79. RAM Location Plot Chart, Boeing 757

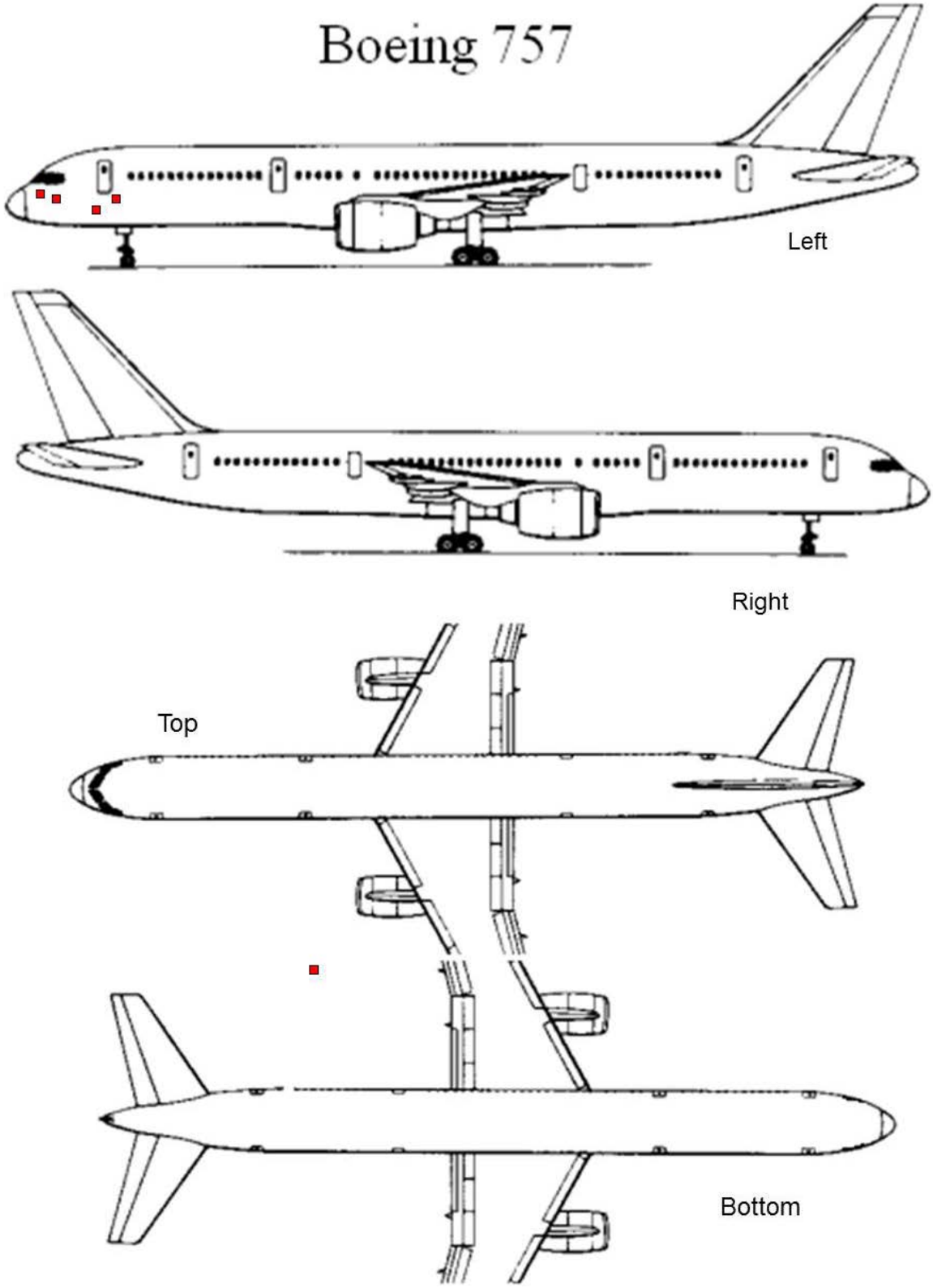


Figure A-80. RAM Location Plot Chart, Boeing 757

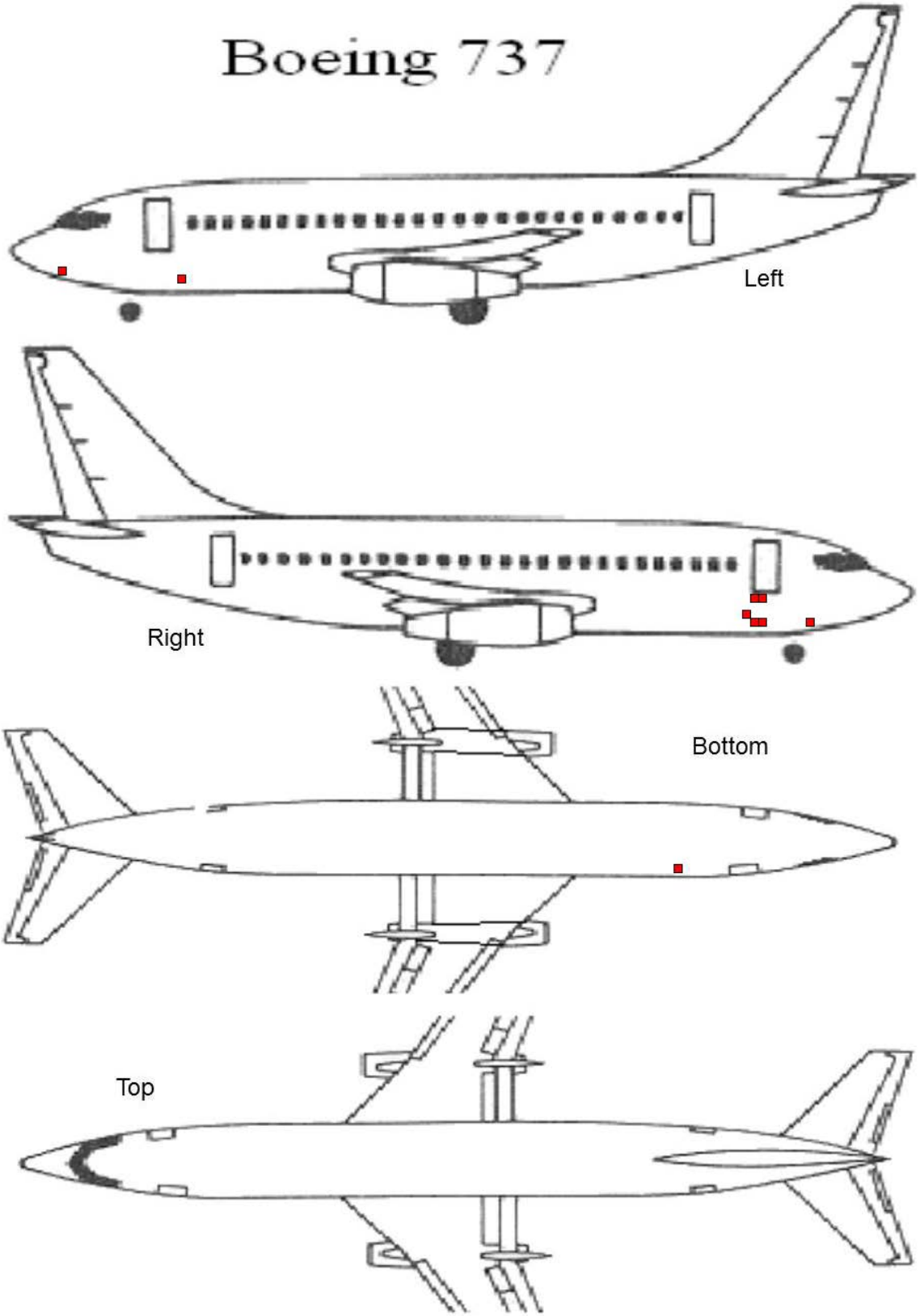


Figure A-81. RAM Location Plot Chart, Boeing 737

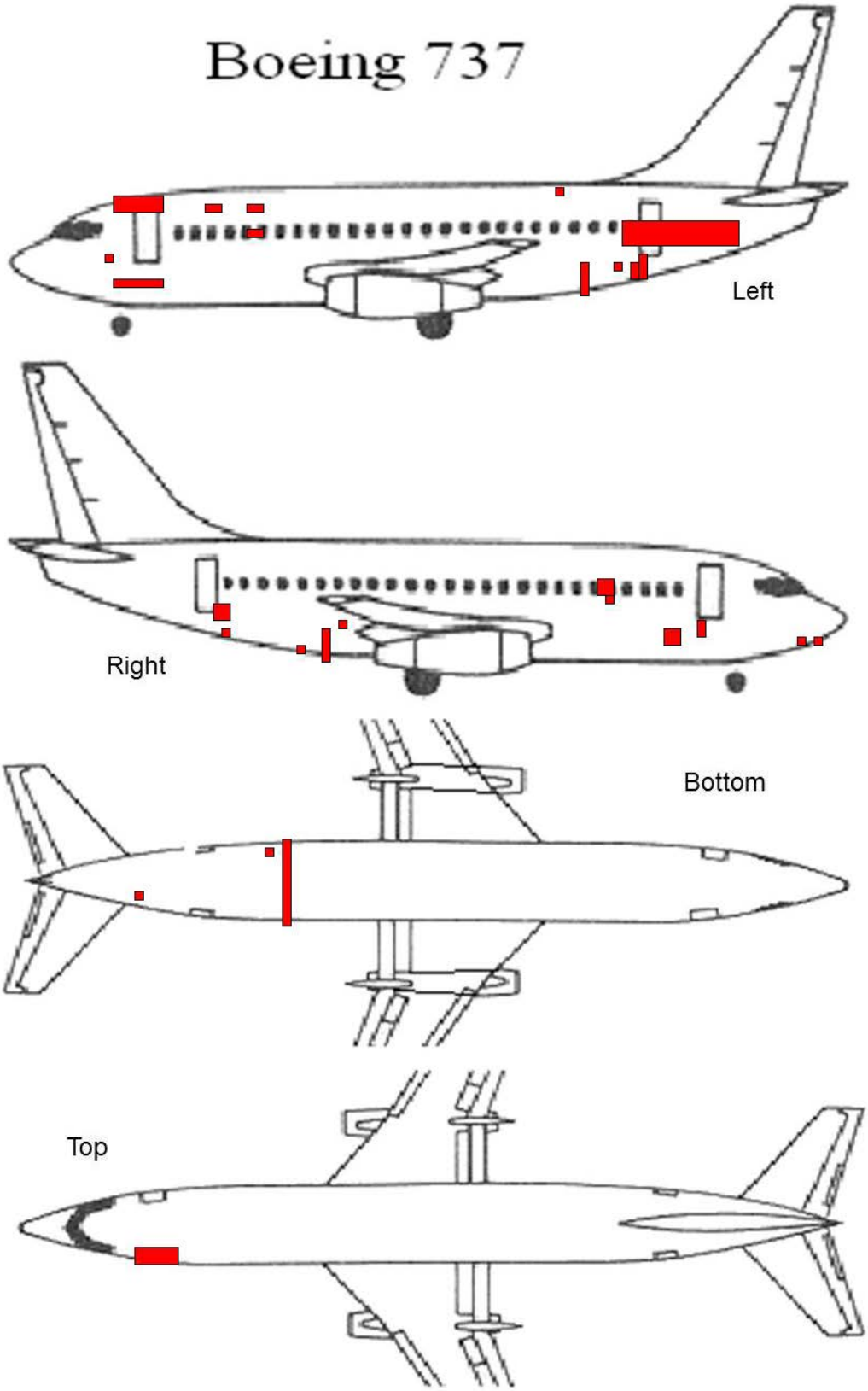


Figure A-82. RAM Location Plot Chart, Boeing 737

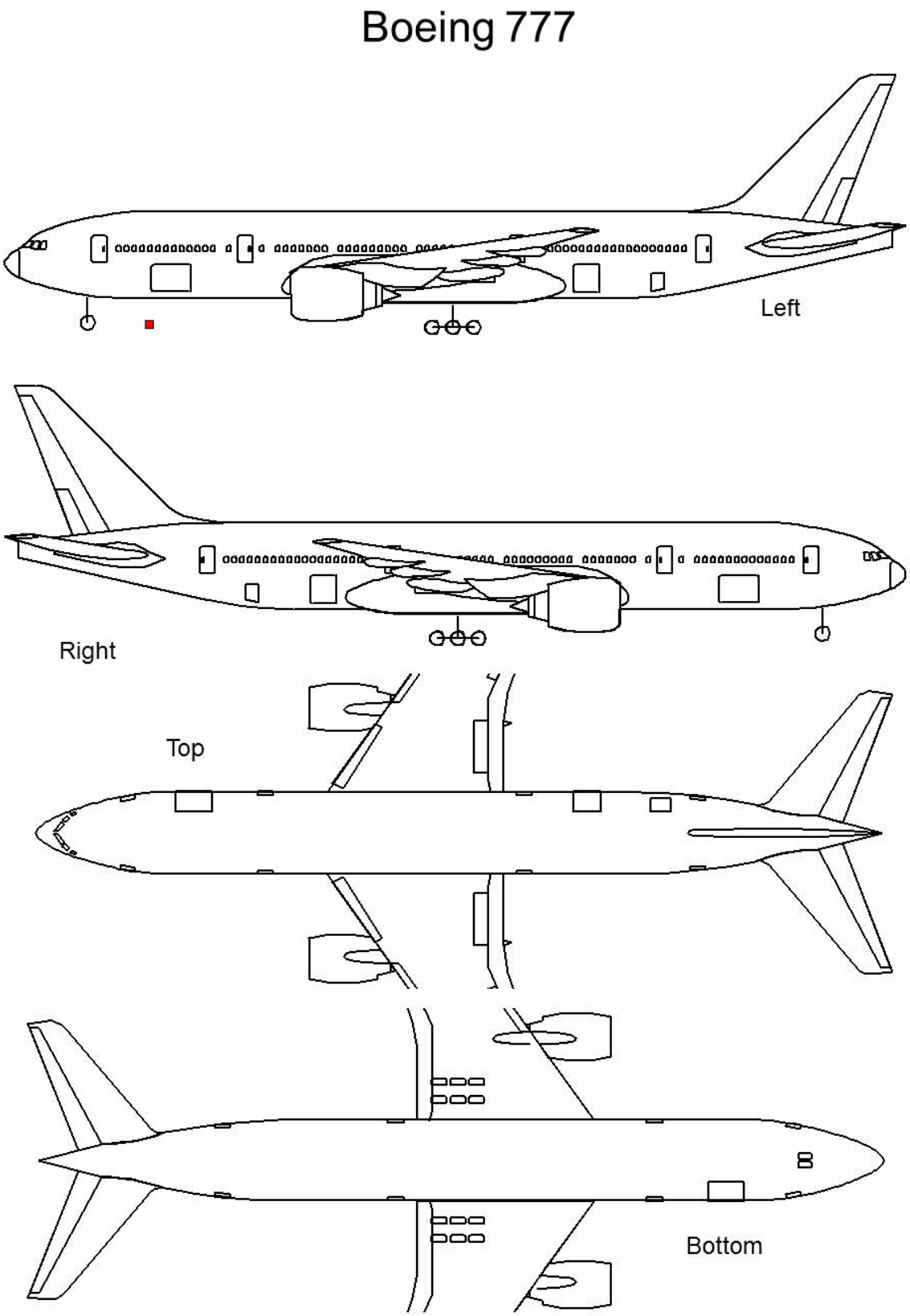


Figure A-83. RAM Location Plot Chart, Boeing 777

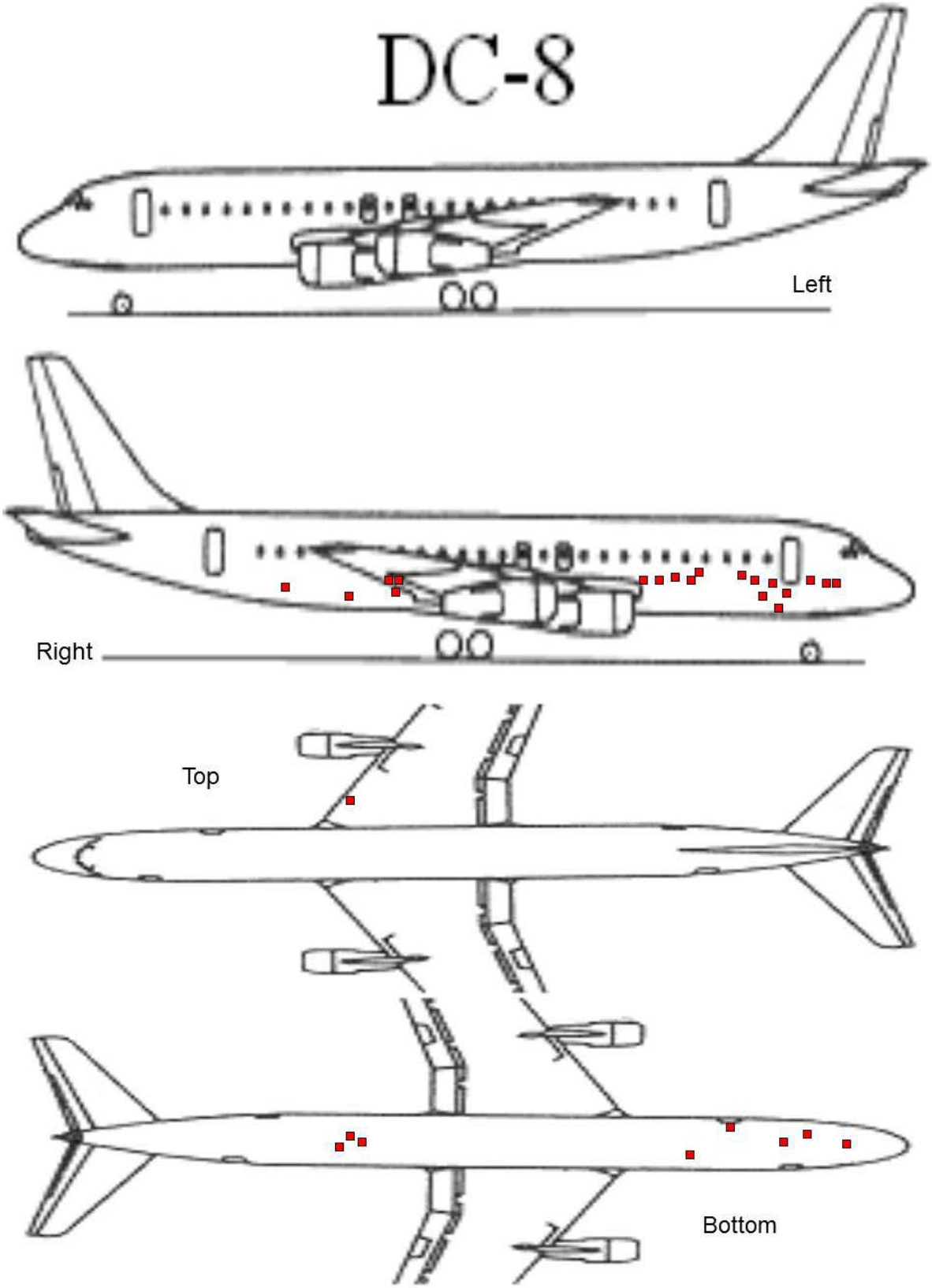


Figure A-84. RAM Location Plot Chart, DC-8

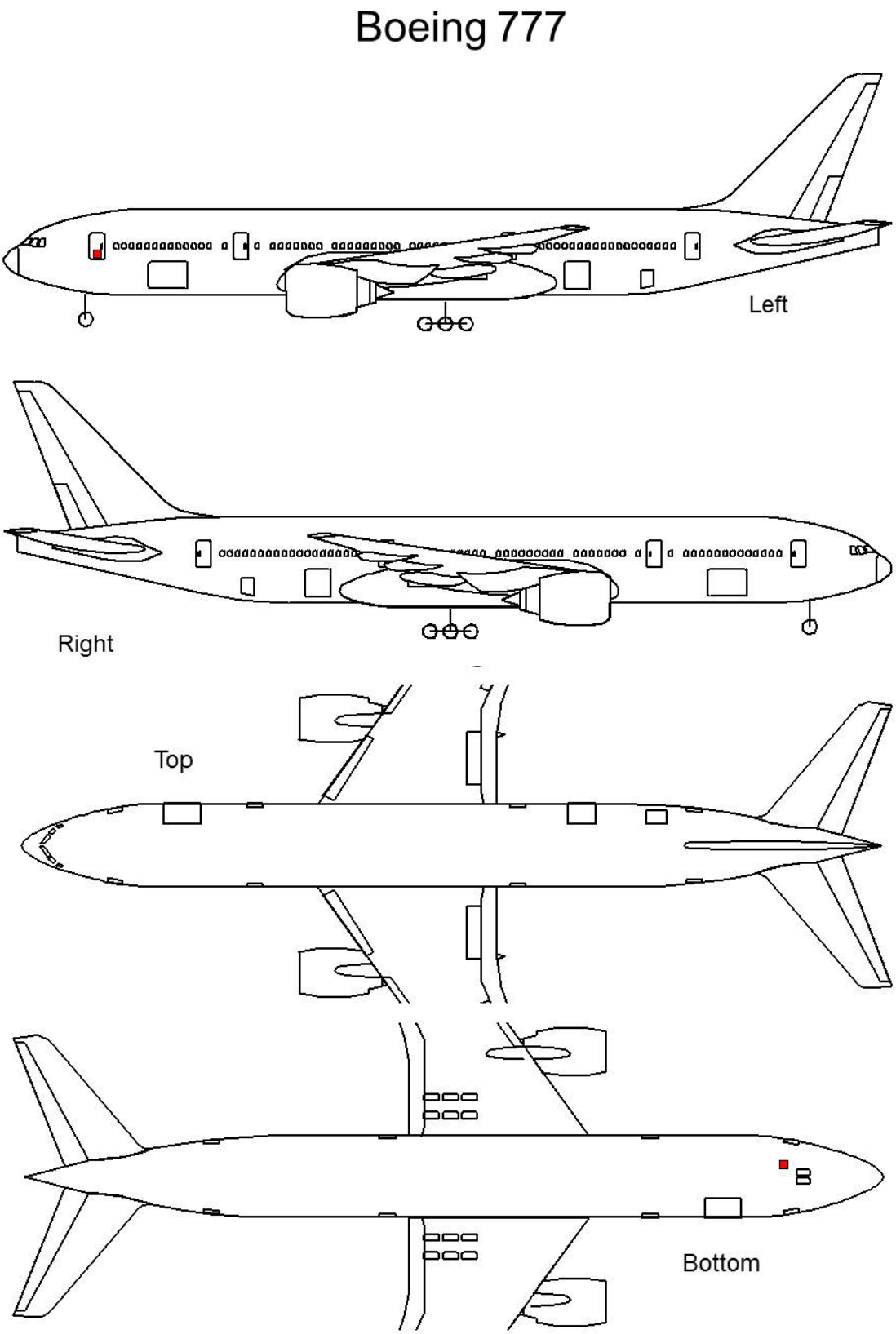


Figure A-85. RAM Location Plot Chart, Boeing 777

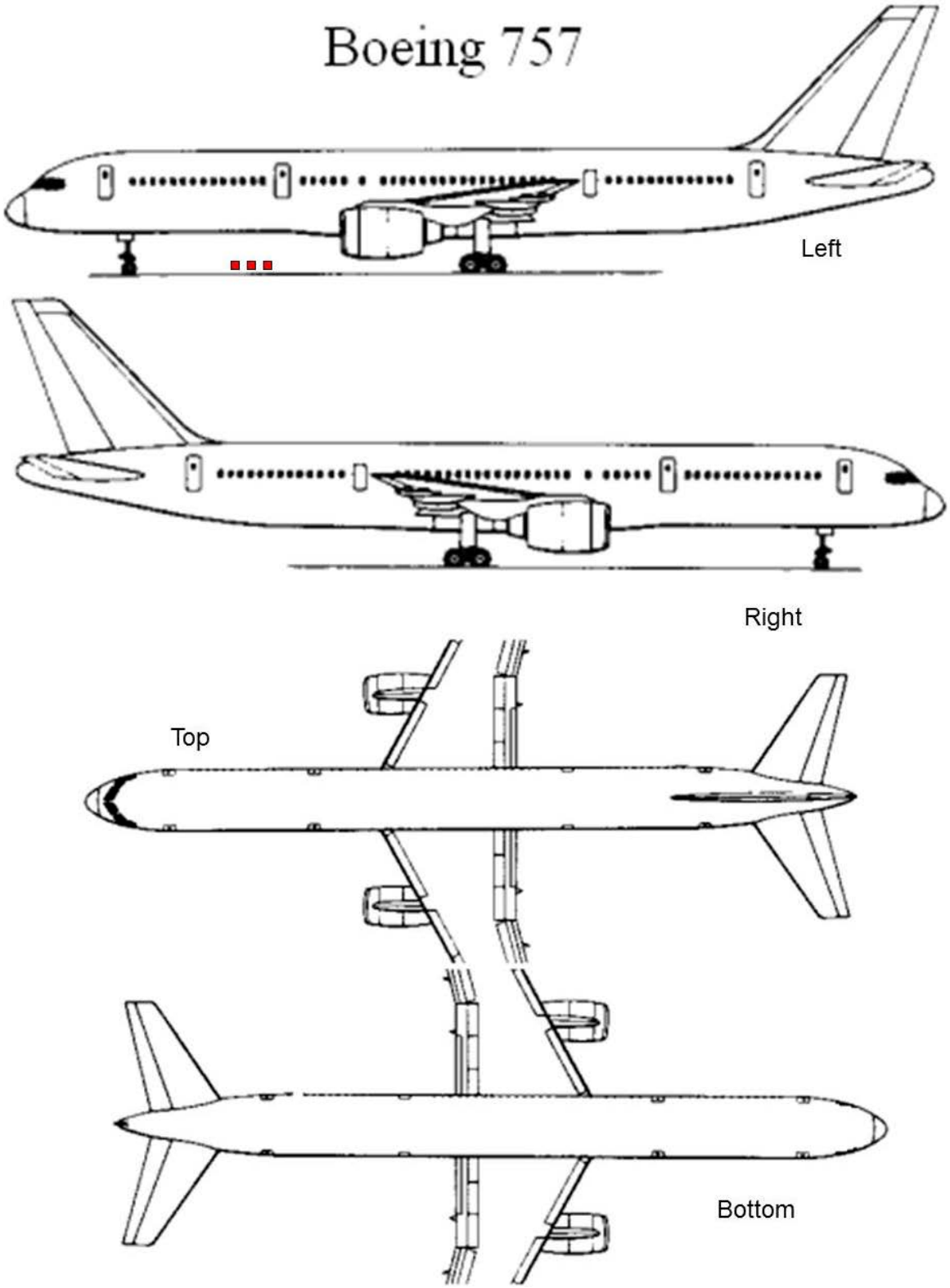


Figure A-86. RAM Location Plot Chart, Boeing 757

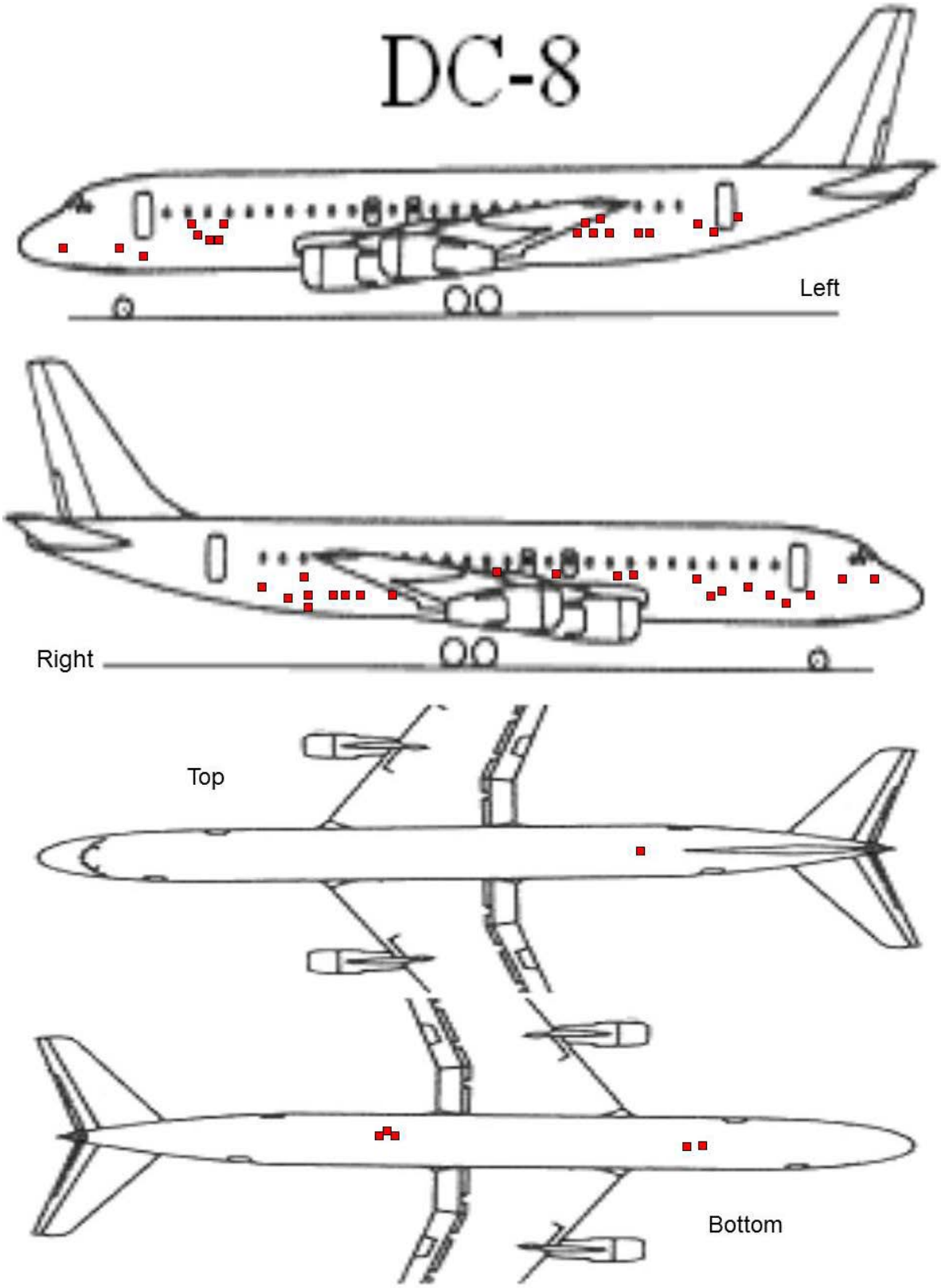


Figure A-87. RAM Location Plot Chart, DC-8

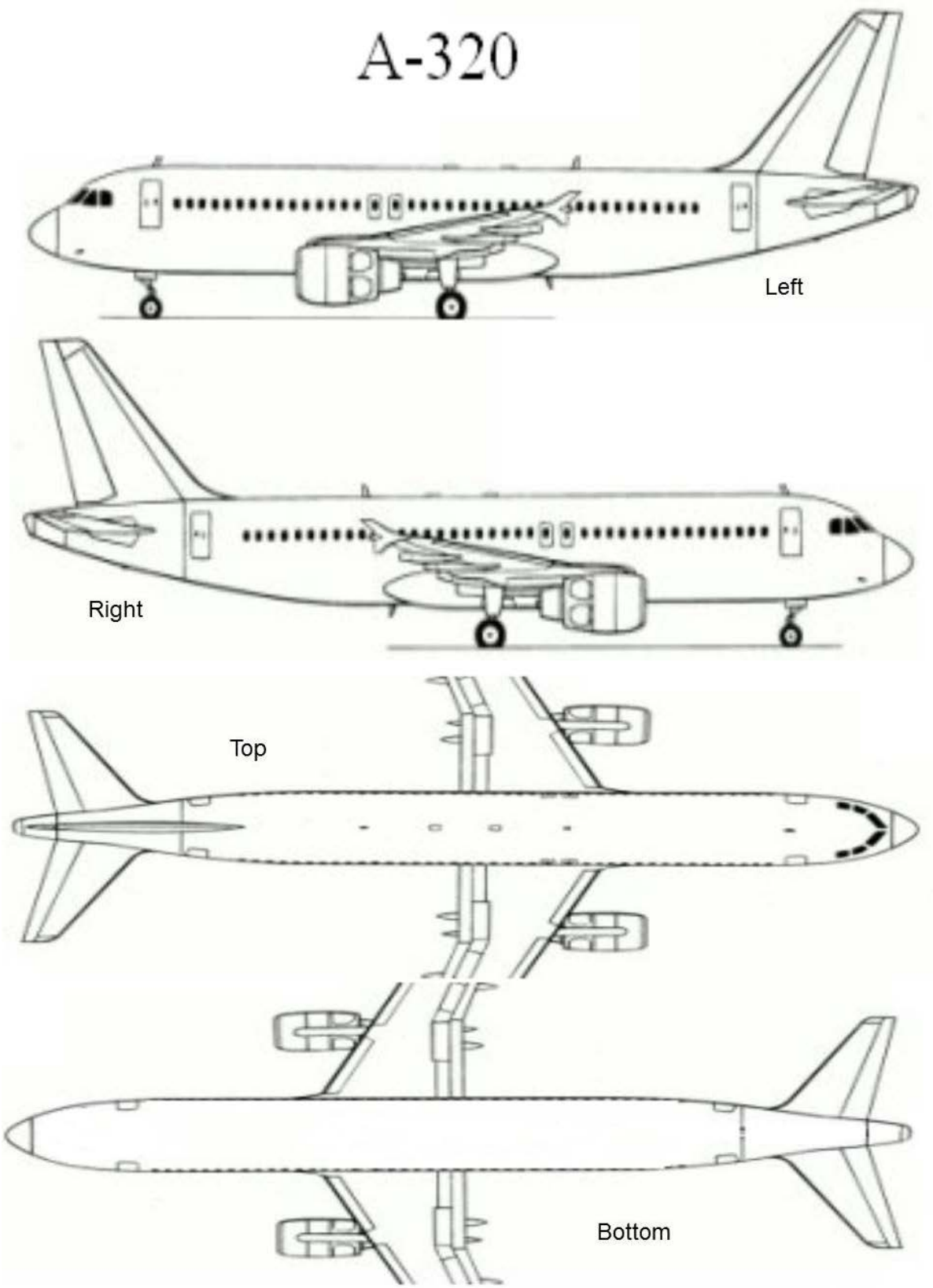


Figure A-88. RAM Location Plot Chart, A-320

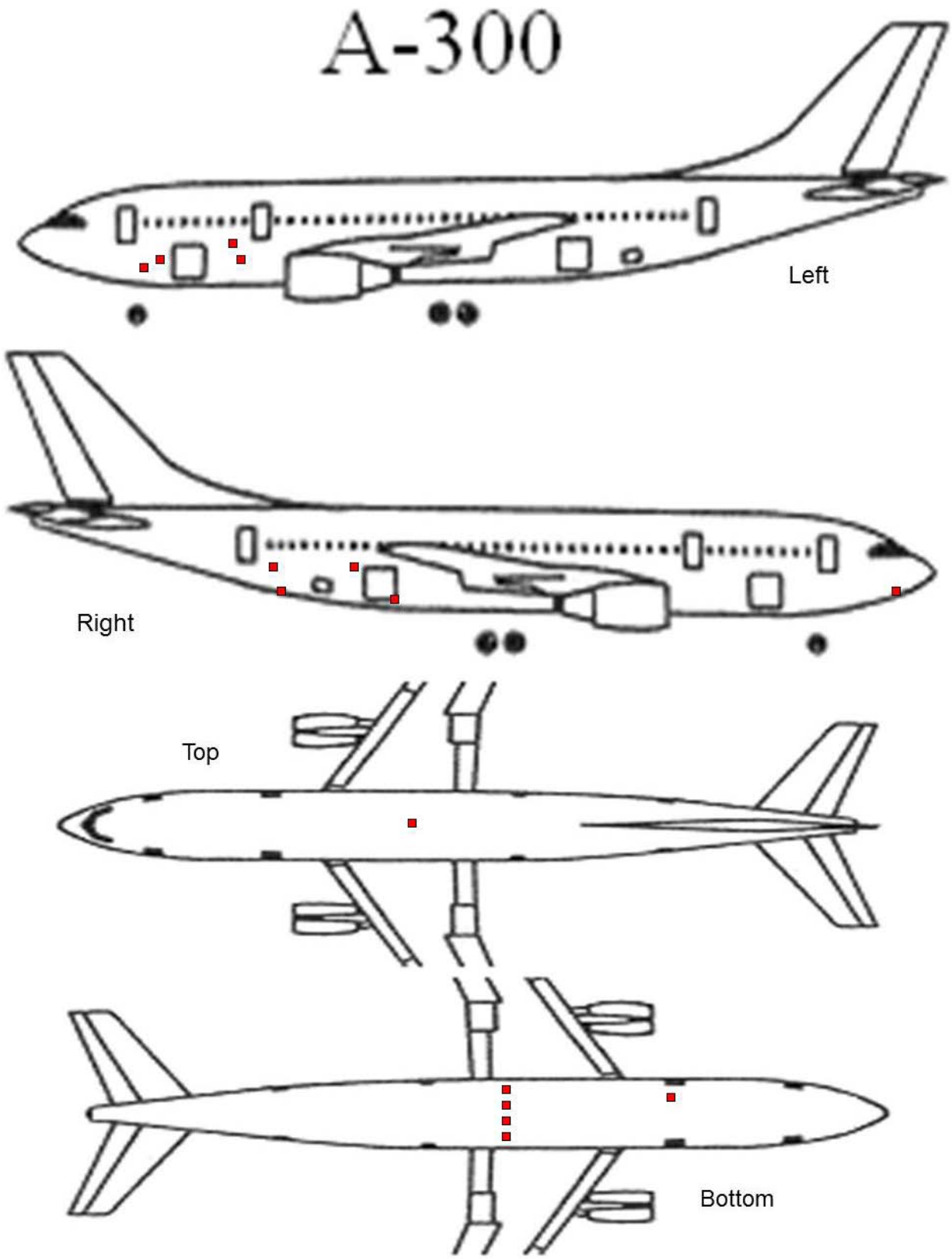


Figure A-89. RAM Location Plot Chart, A-300

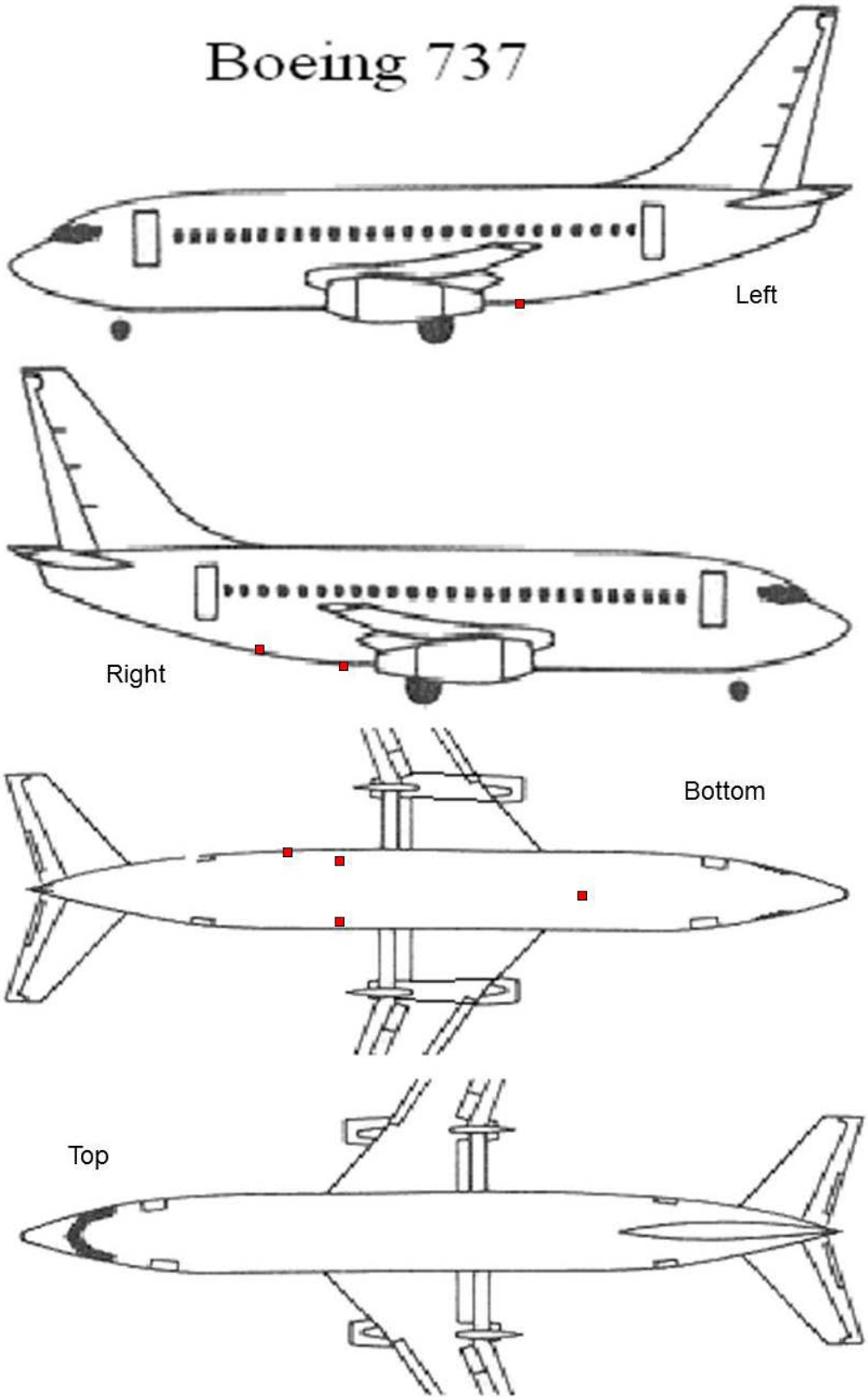


Figure A-90. RAM Location Plot Chart, Boeing 737

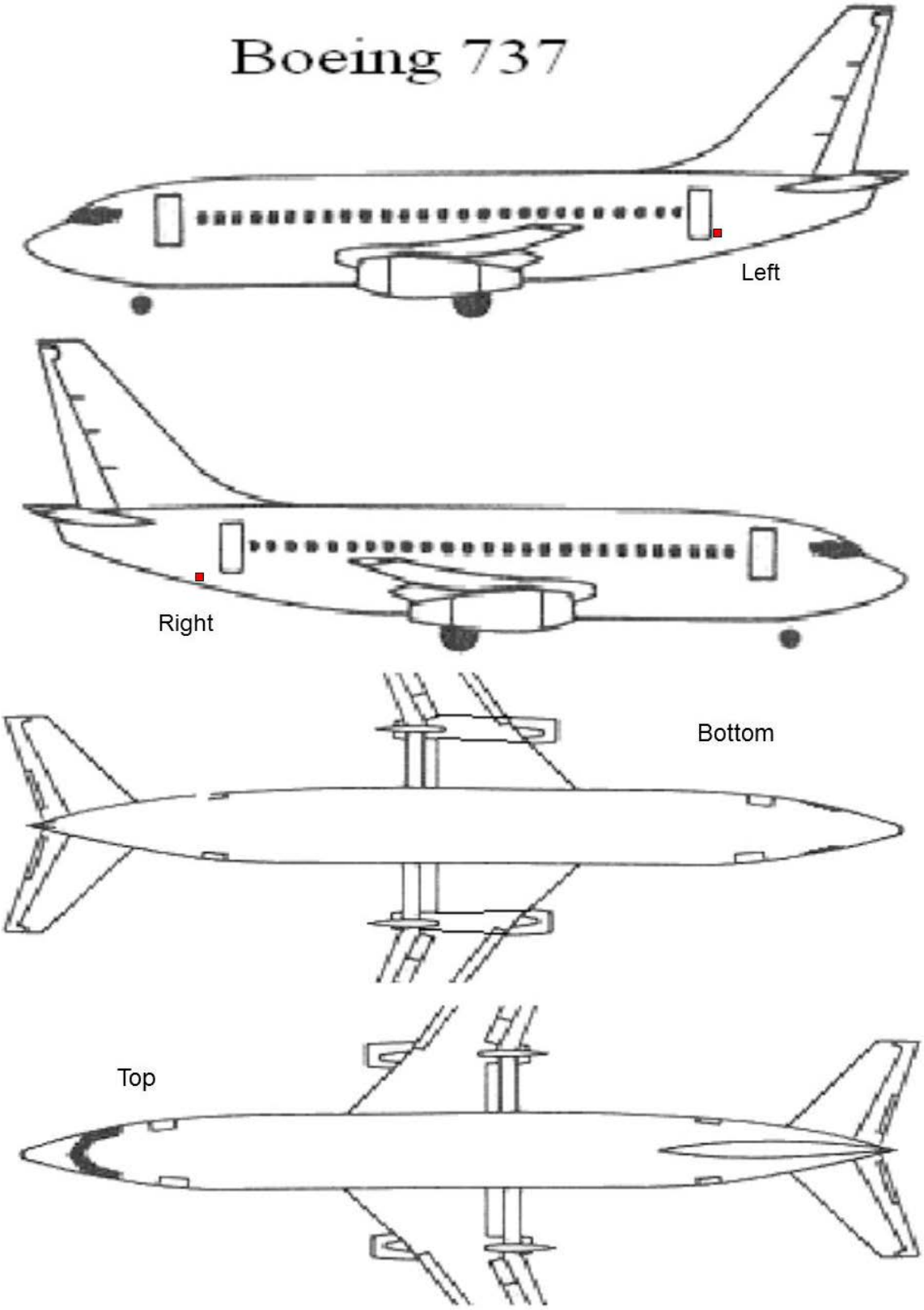


Figure A-91. RAM Location Plot Chart, Boeing 737

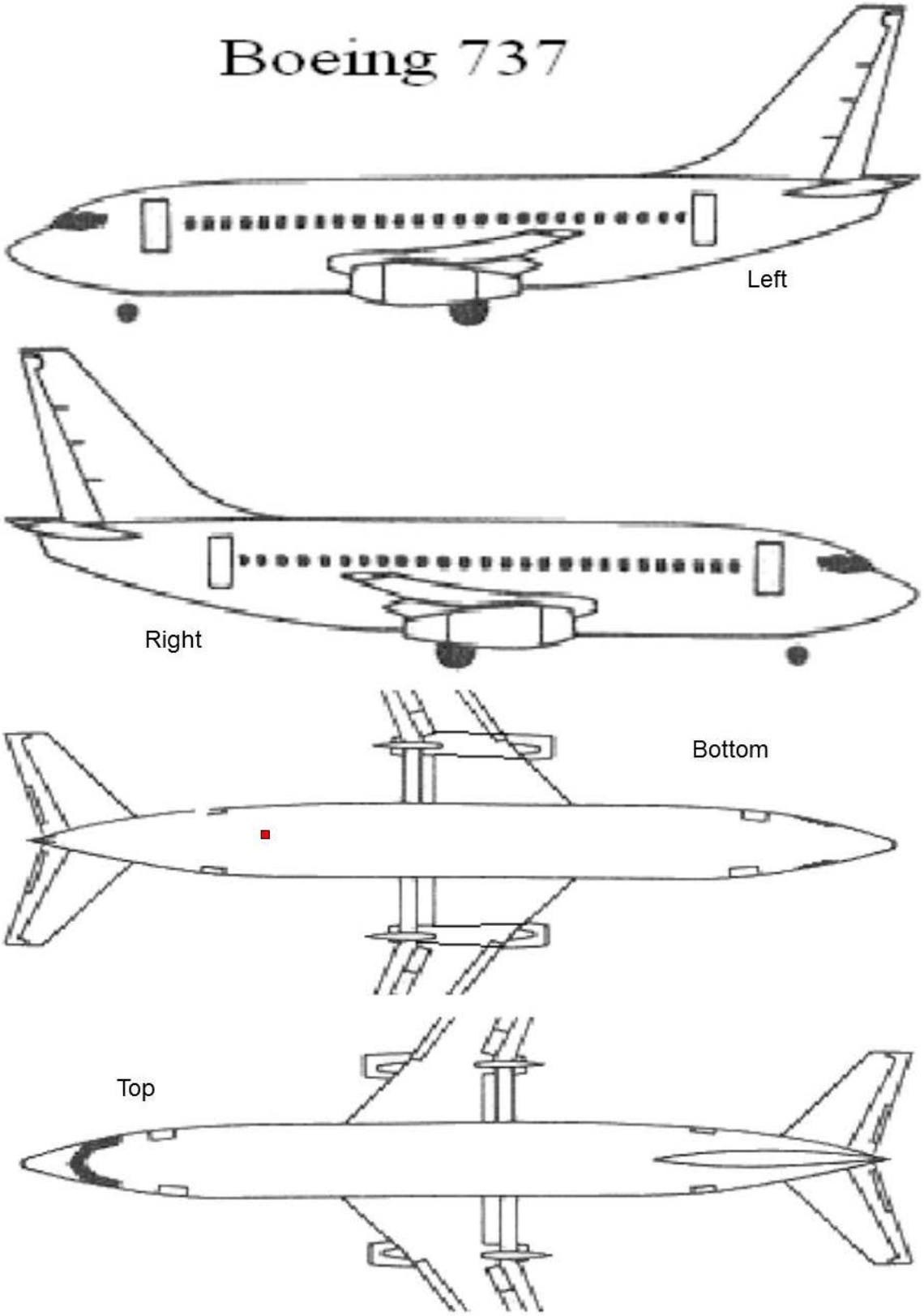


Figure A-92. RAM Location Plot Chart, Boeing 737

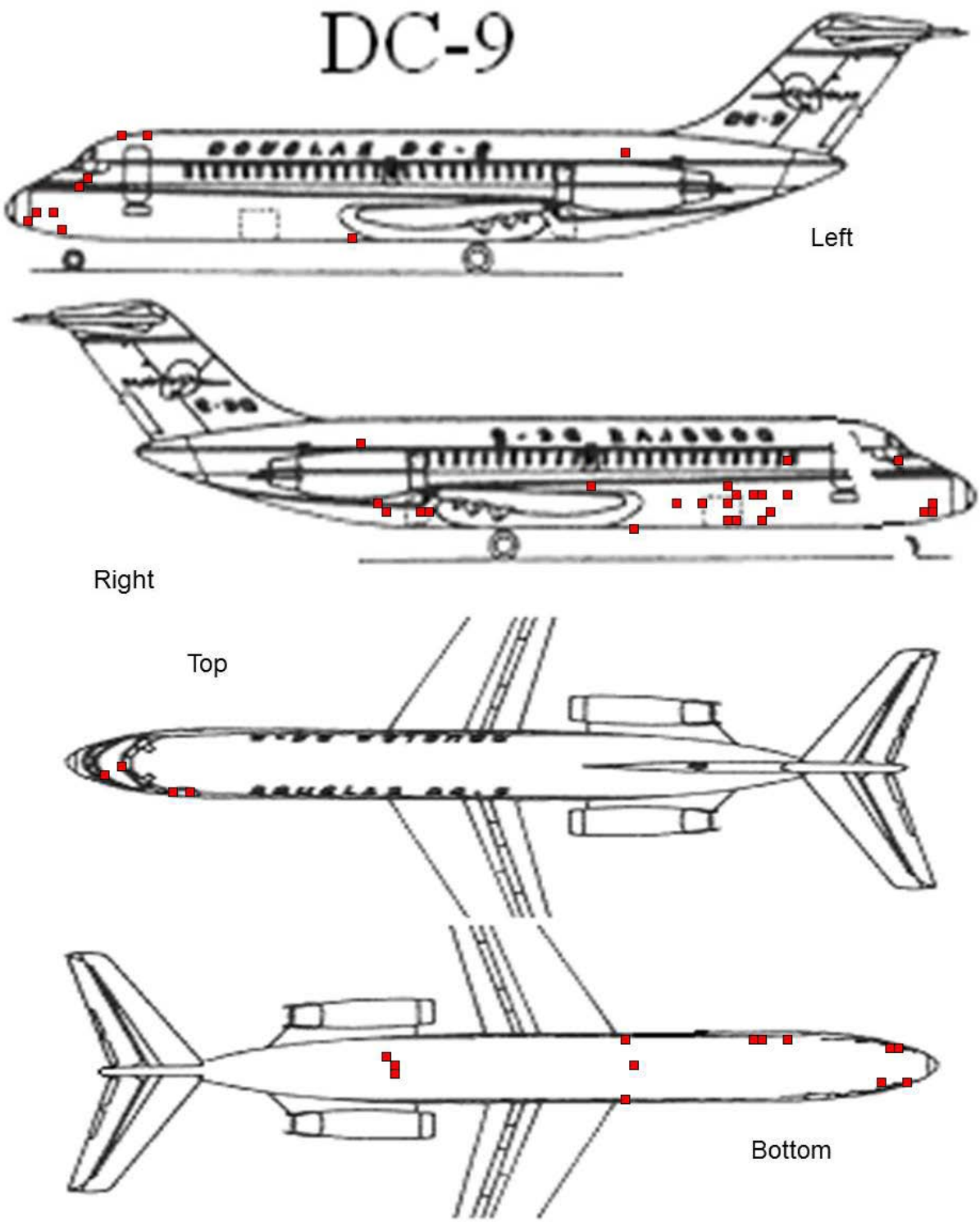


Figure A-93. RAM Location Plot Chart, DC-9

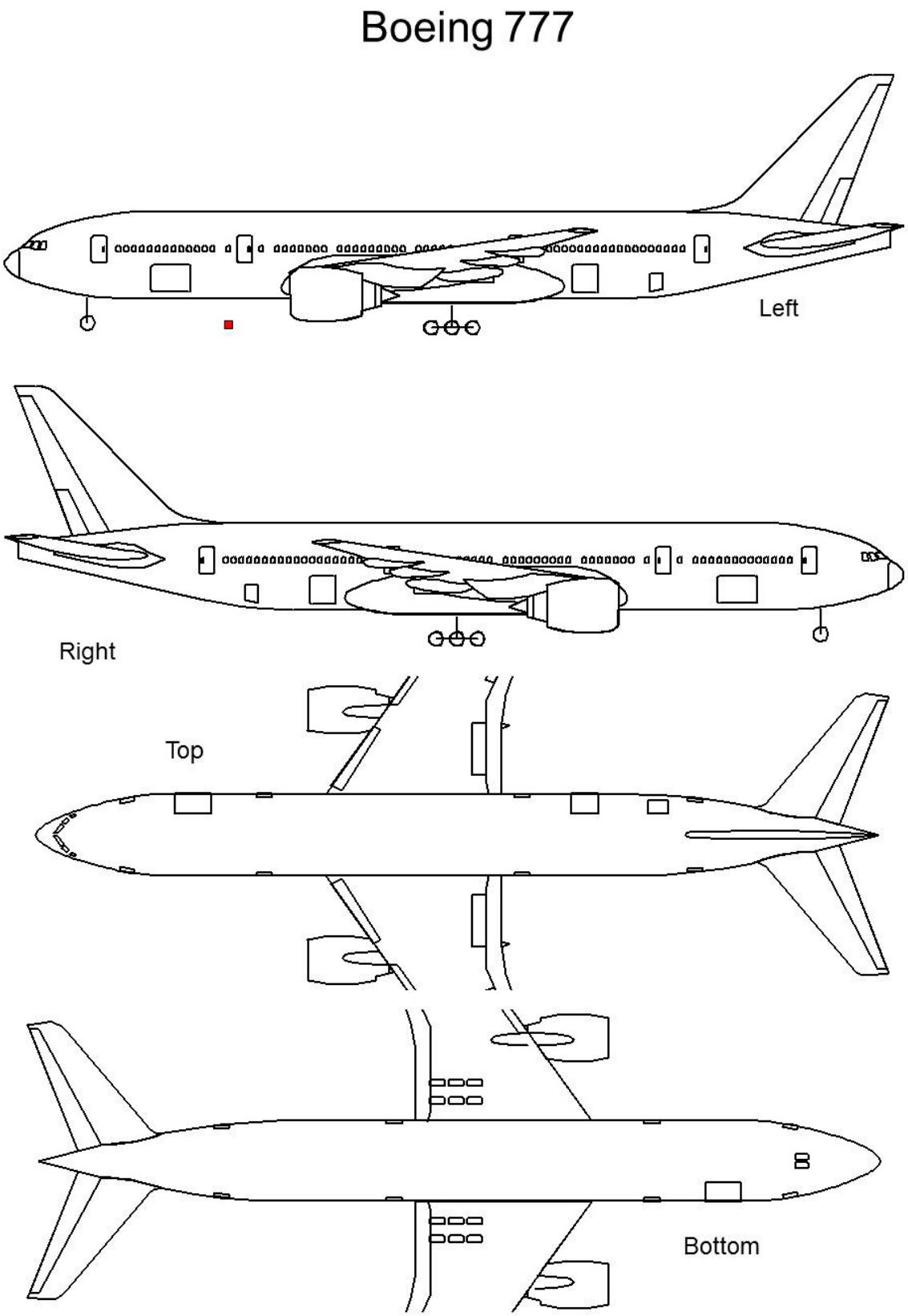


Figure A-94. RAM Location Plot Chart, Boeing 777

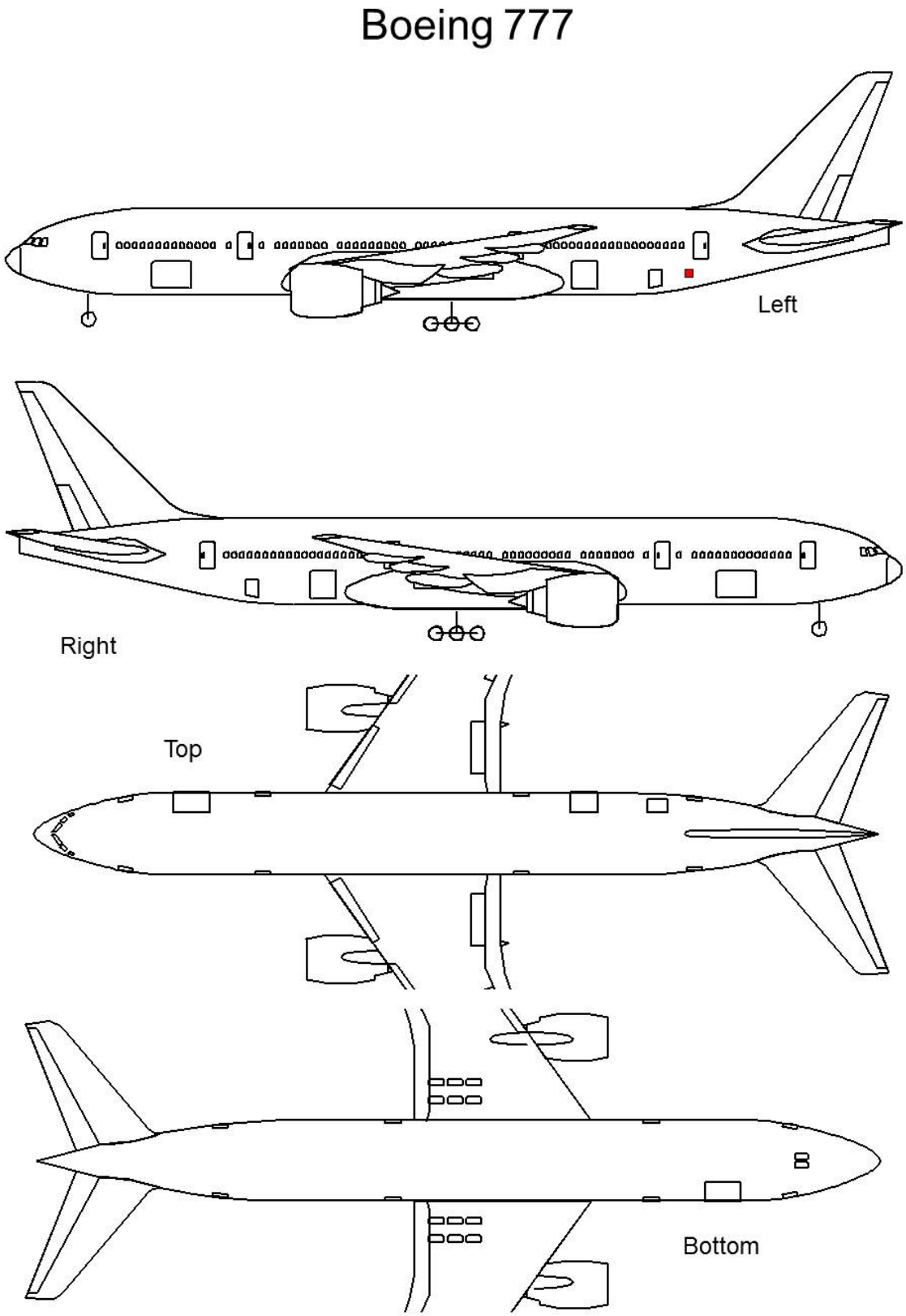


Figure A-95. RAM Location Plot Chart, Boeing 777

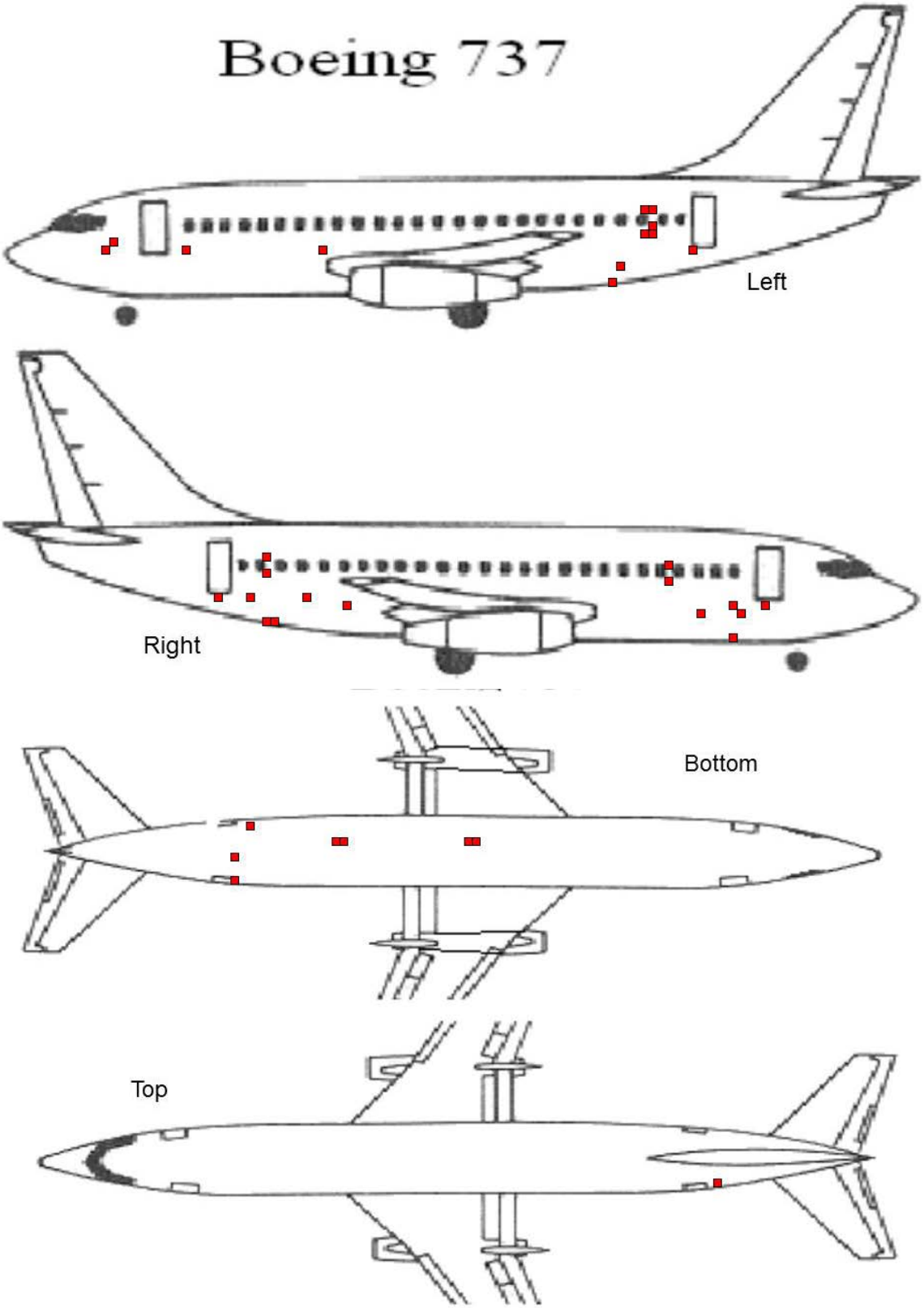


Figure A-96. RAM Location Plot Chart, Boeing 737

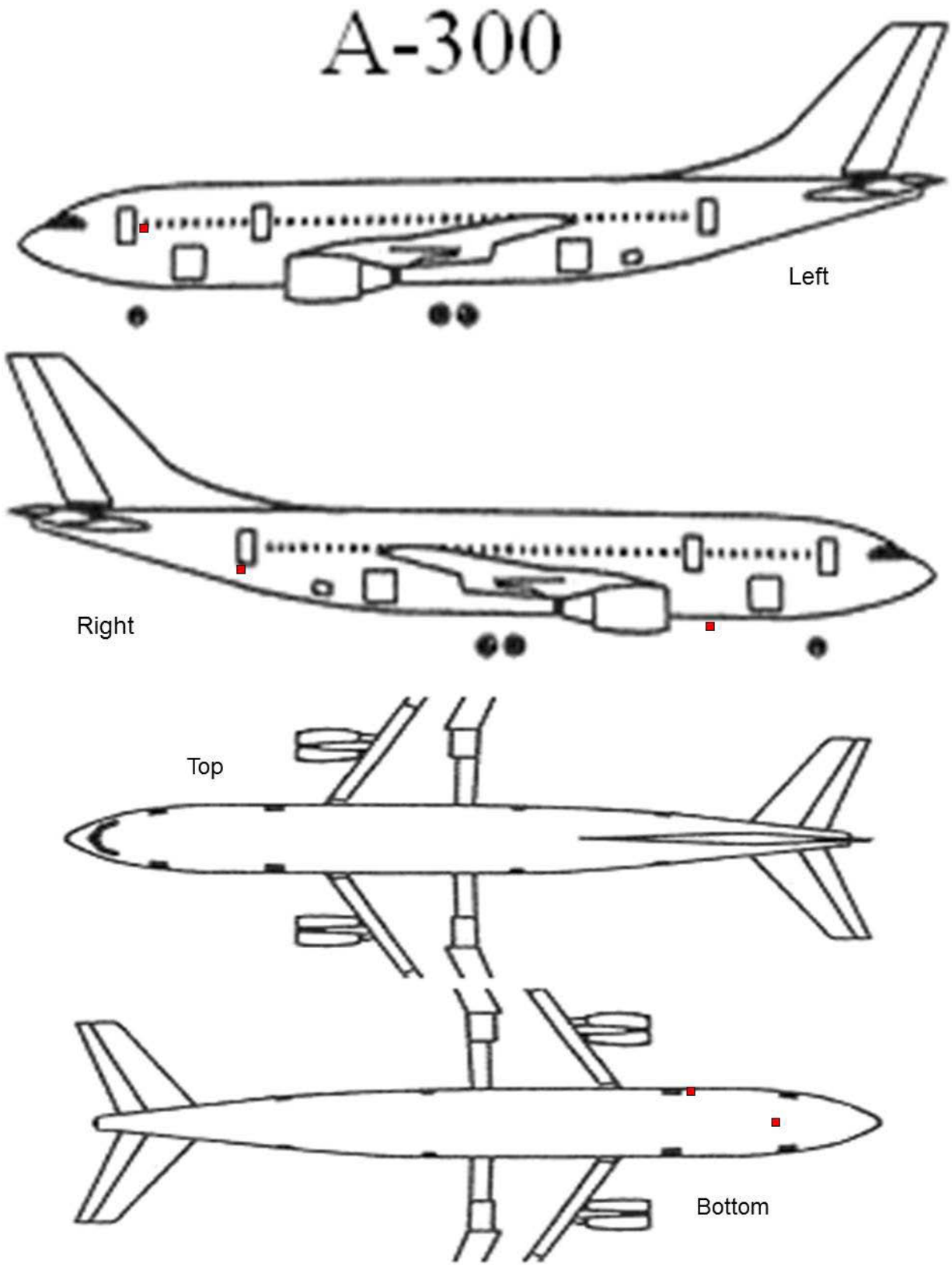


Figure A-97. RAM Location Plot Chart, A-300

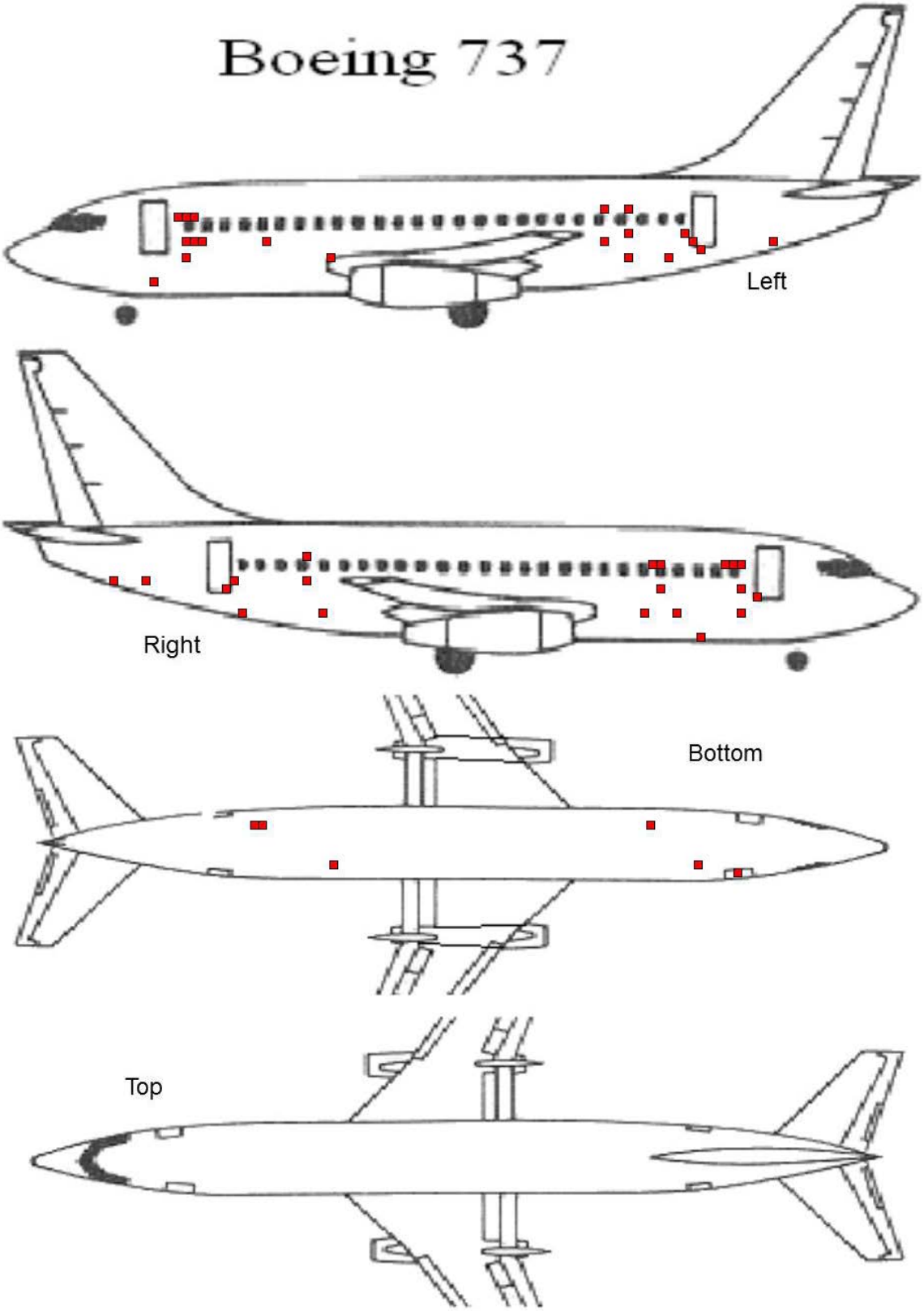


Figure A-98. RAM Location Plot Chart, Boeing 737

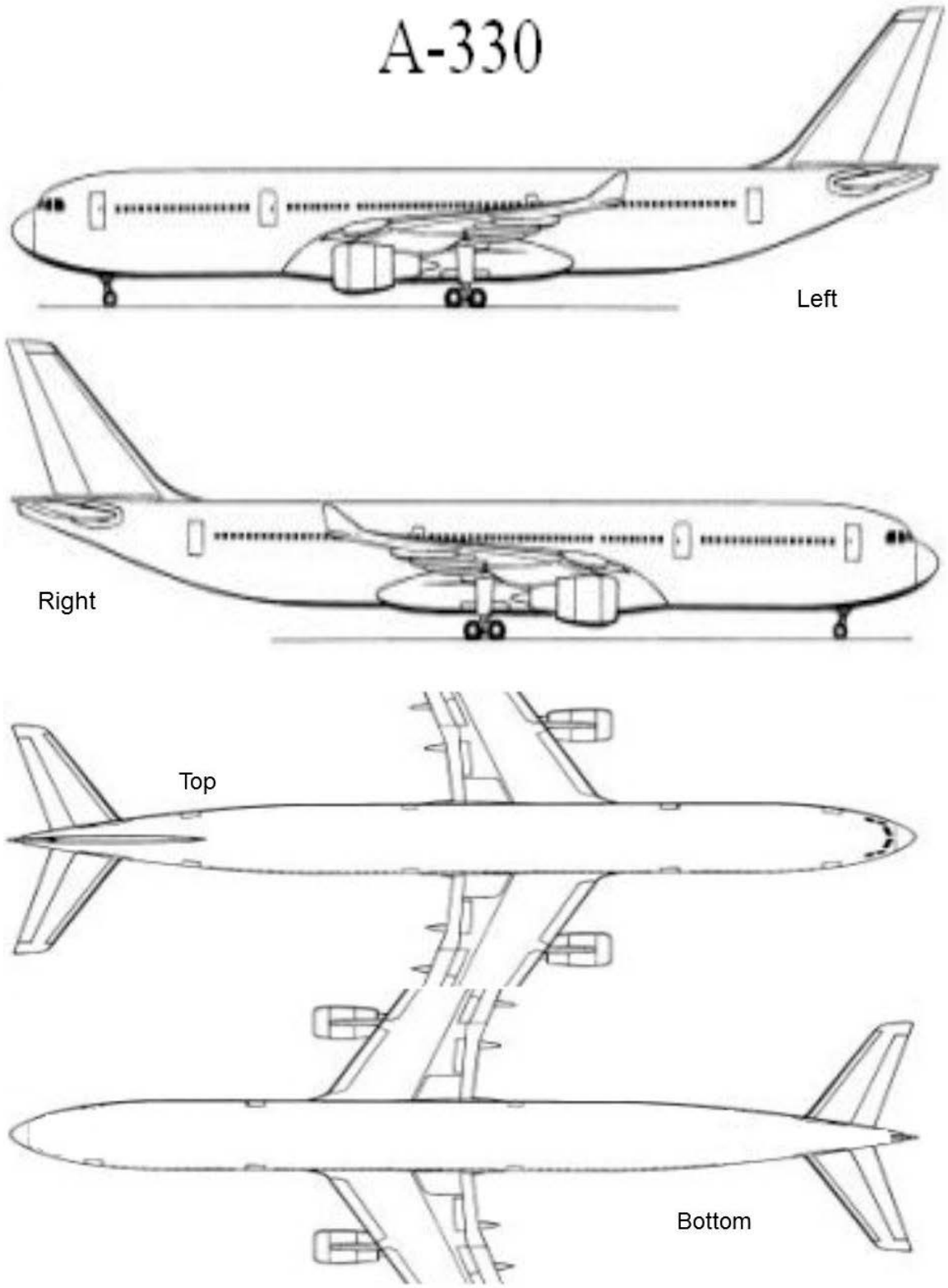


Figure A-99. RAM Location Plot Chart, A-330

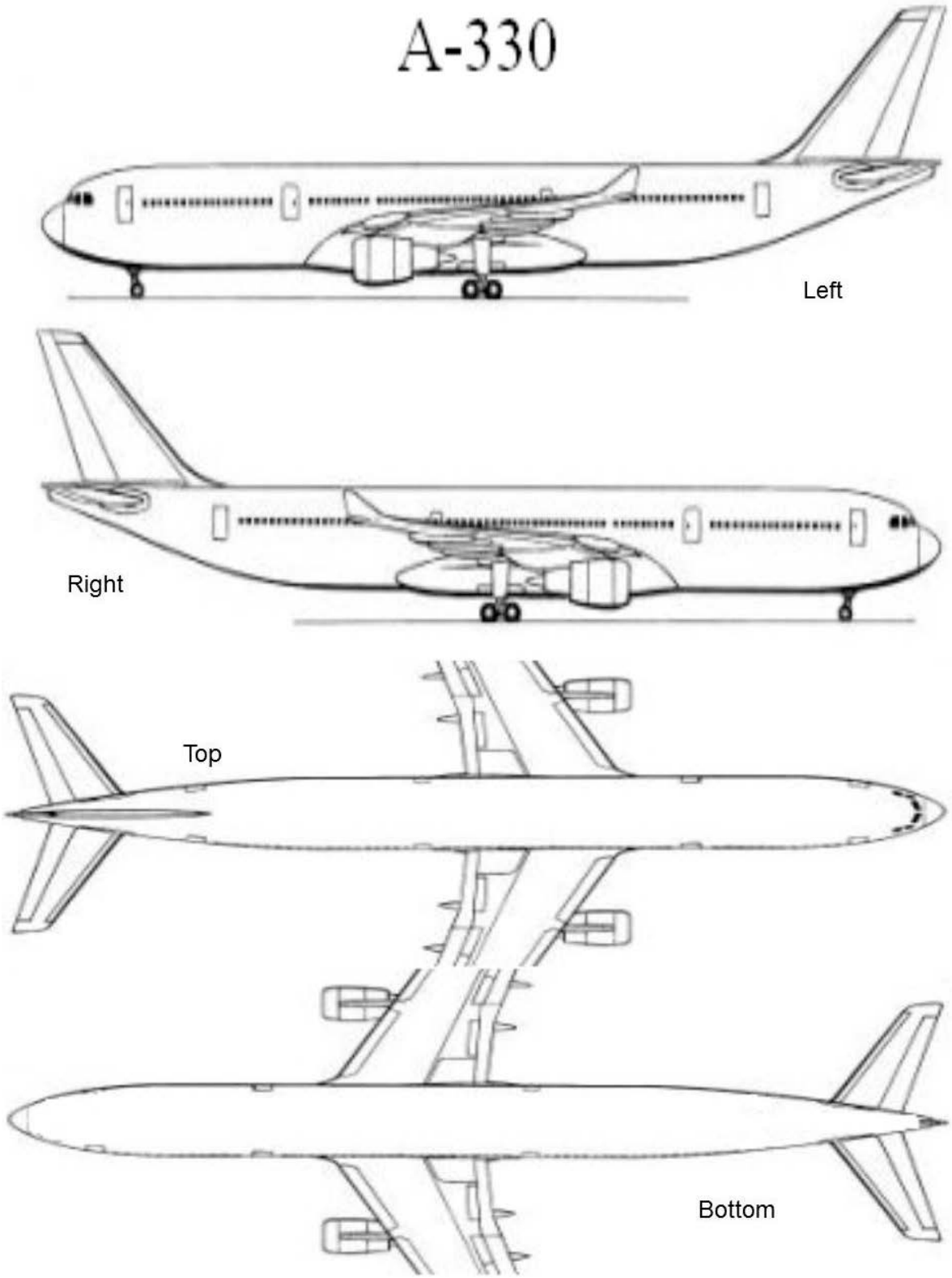


Figure A-100. RAM Location Plot Chart, A-330

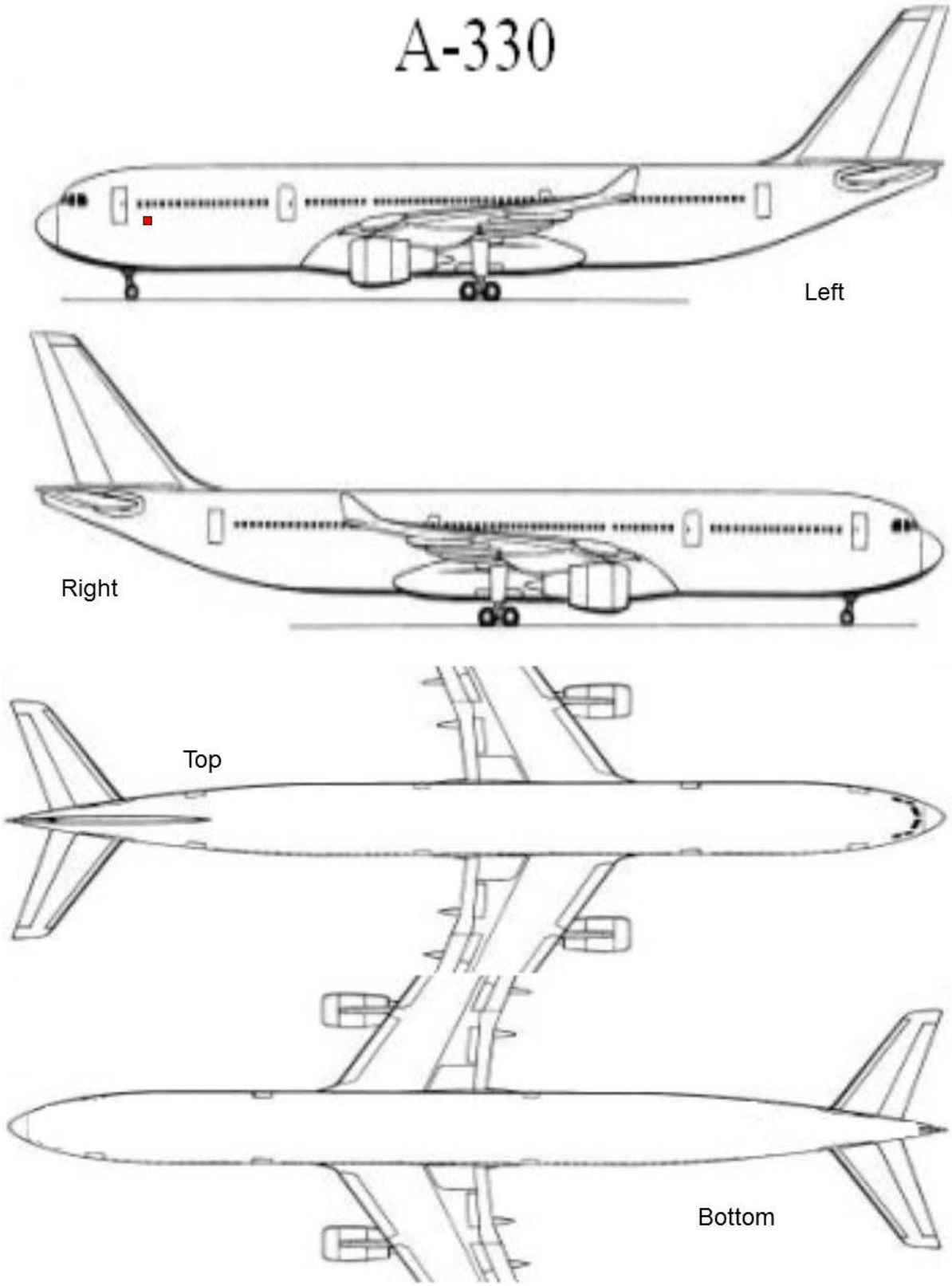


Figure A-101. RAM Location Plot Chart, A-330

Boeing 727

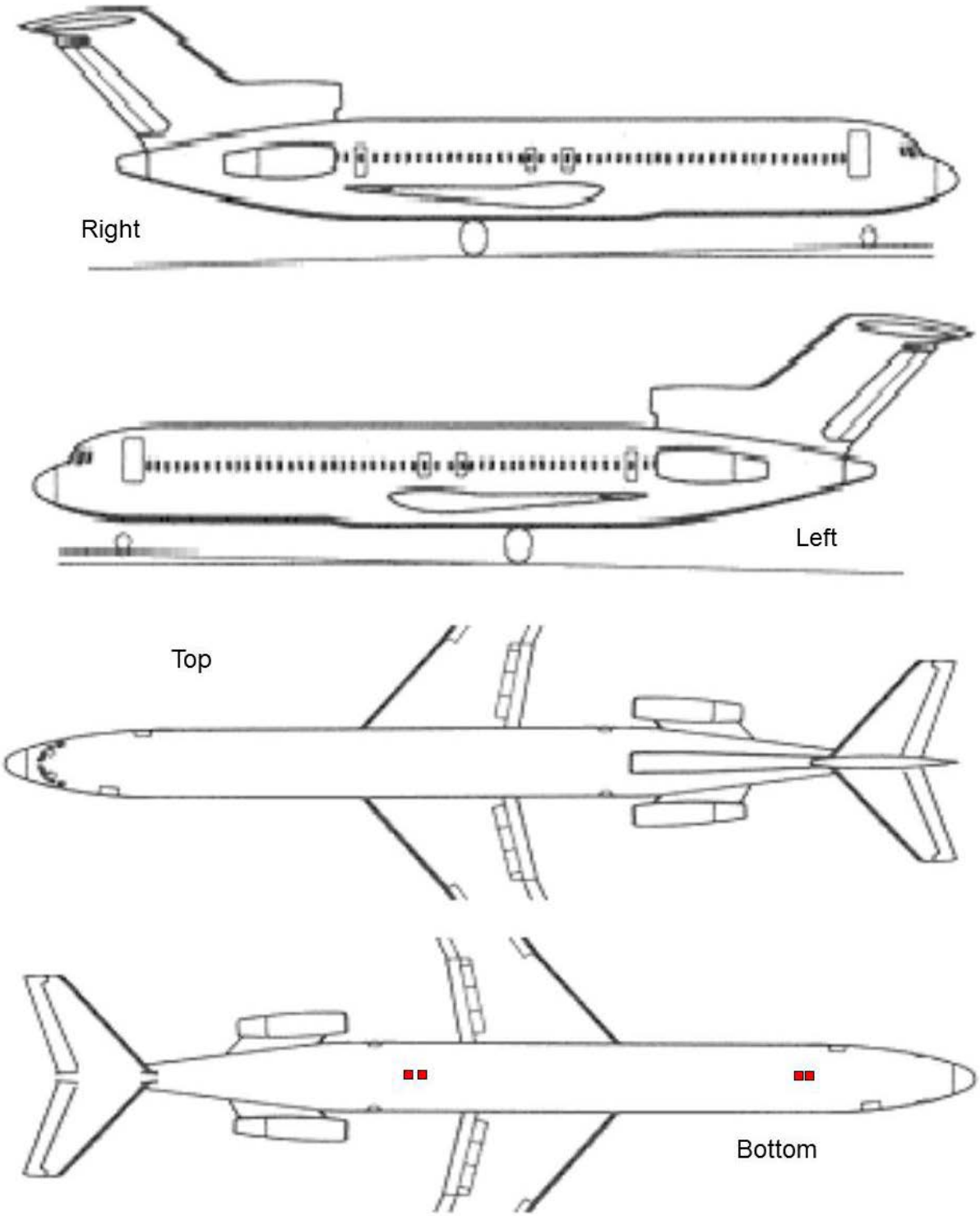


Figure A-102. RAM Location Plot Chart, Boeing 727

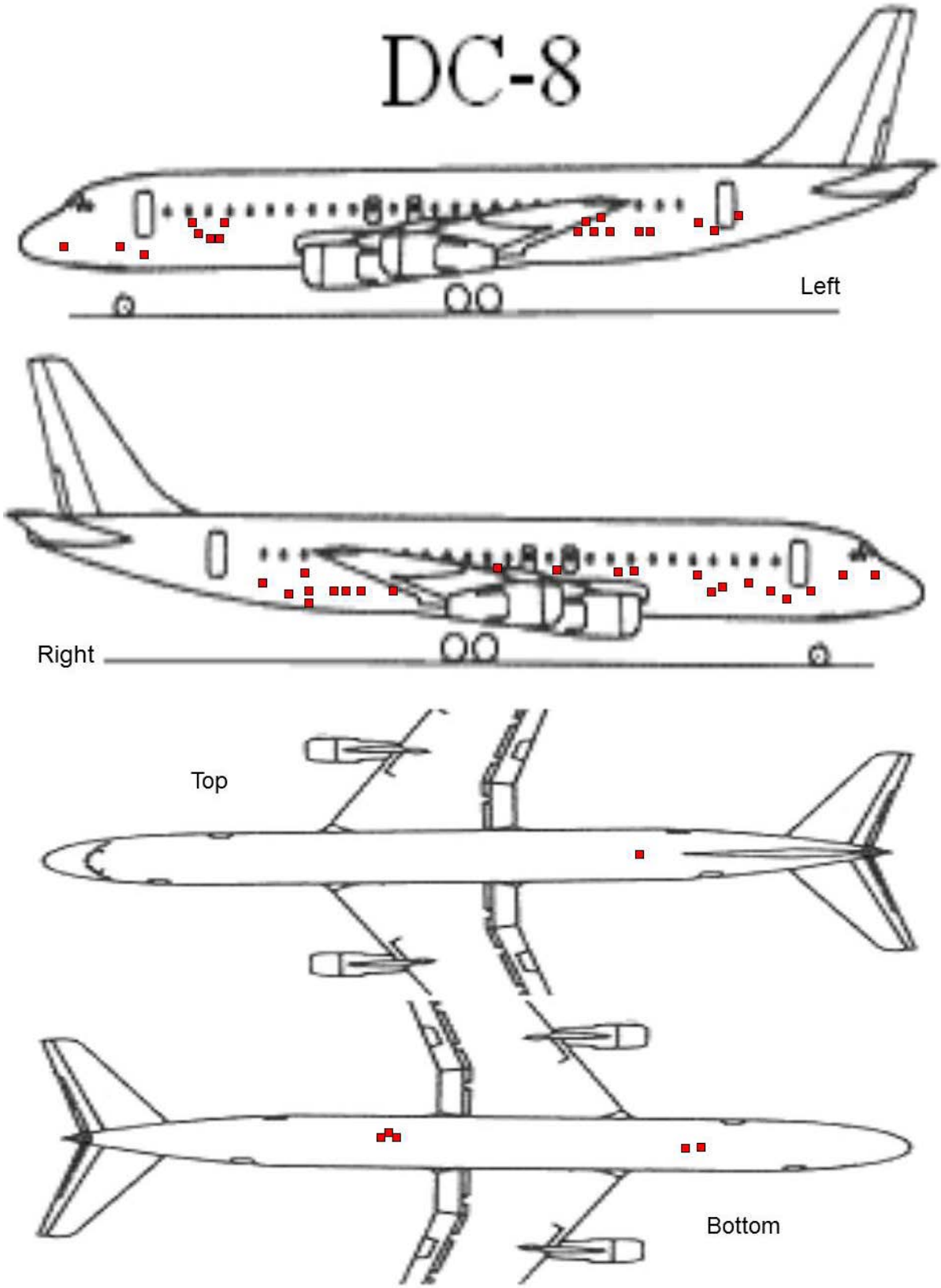


Figure A-103. RAM Location Plot Chart, DC-8

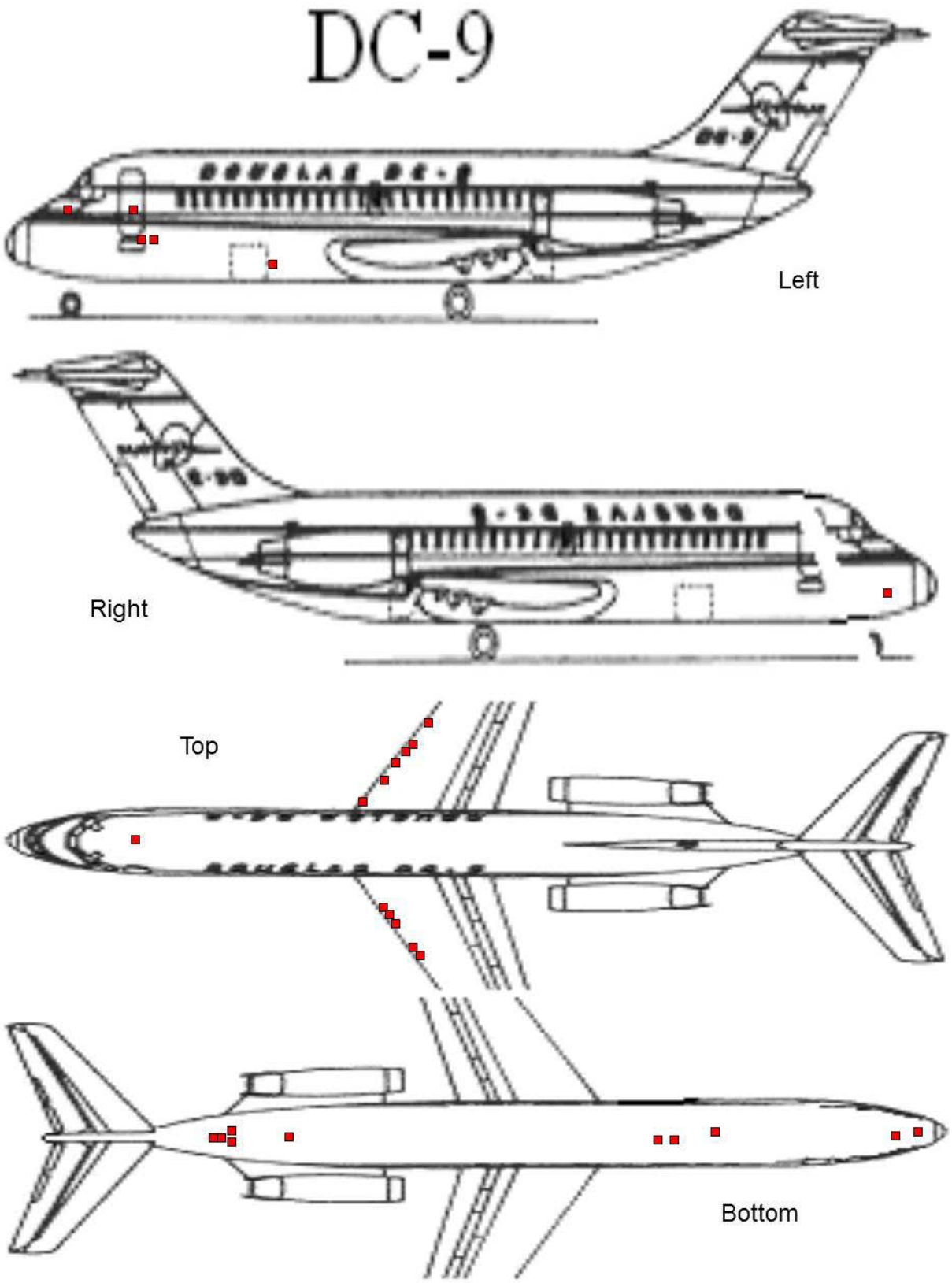


Figure A-104. RAM Location Plot Chart, DC-9

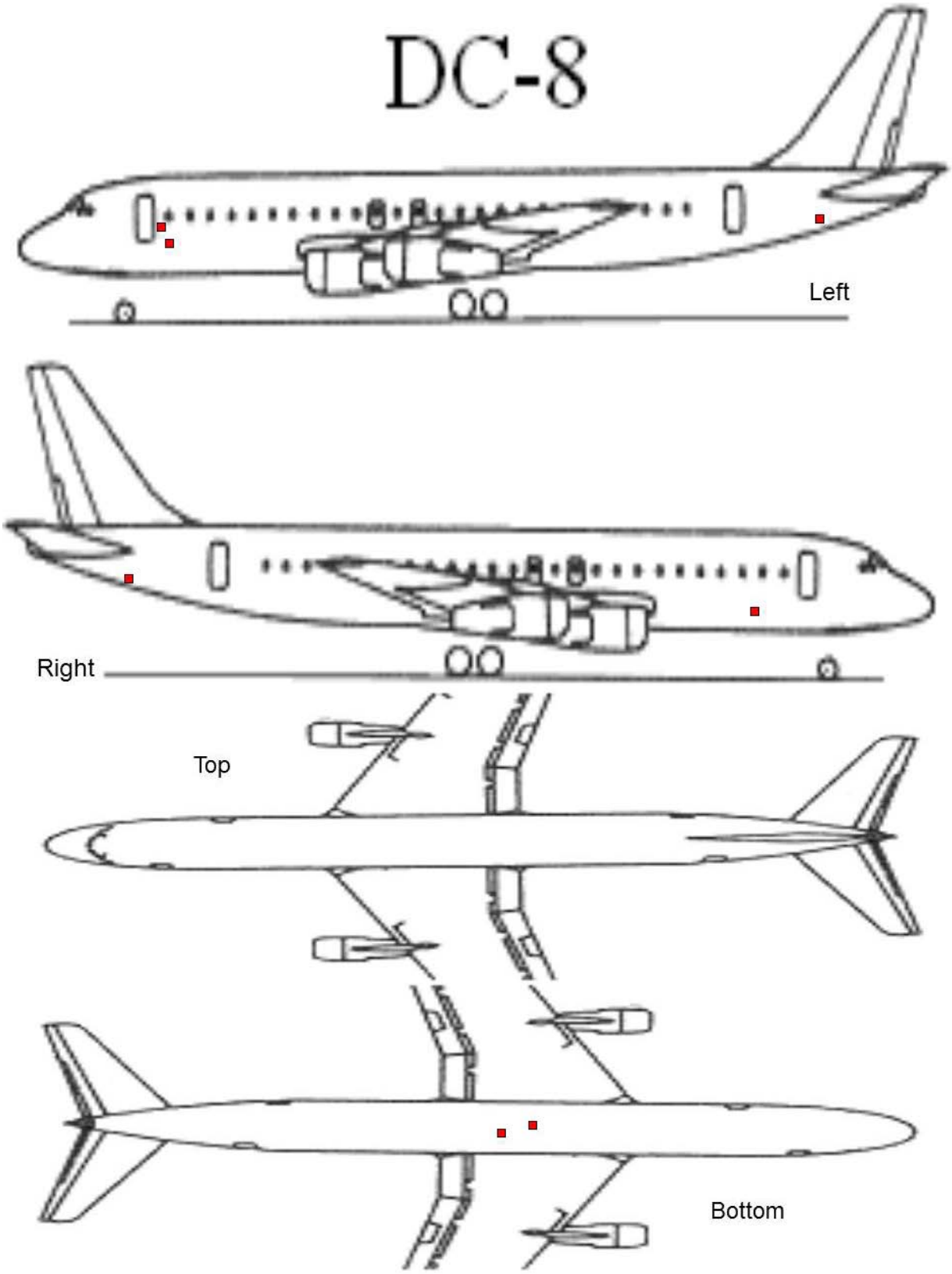


Figure A-105. RAM Location Plot Chart, DC-8

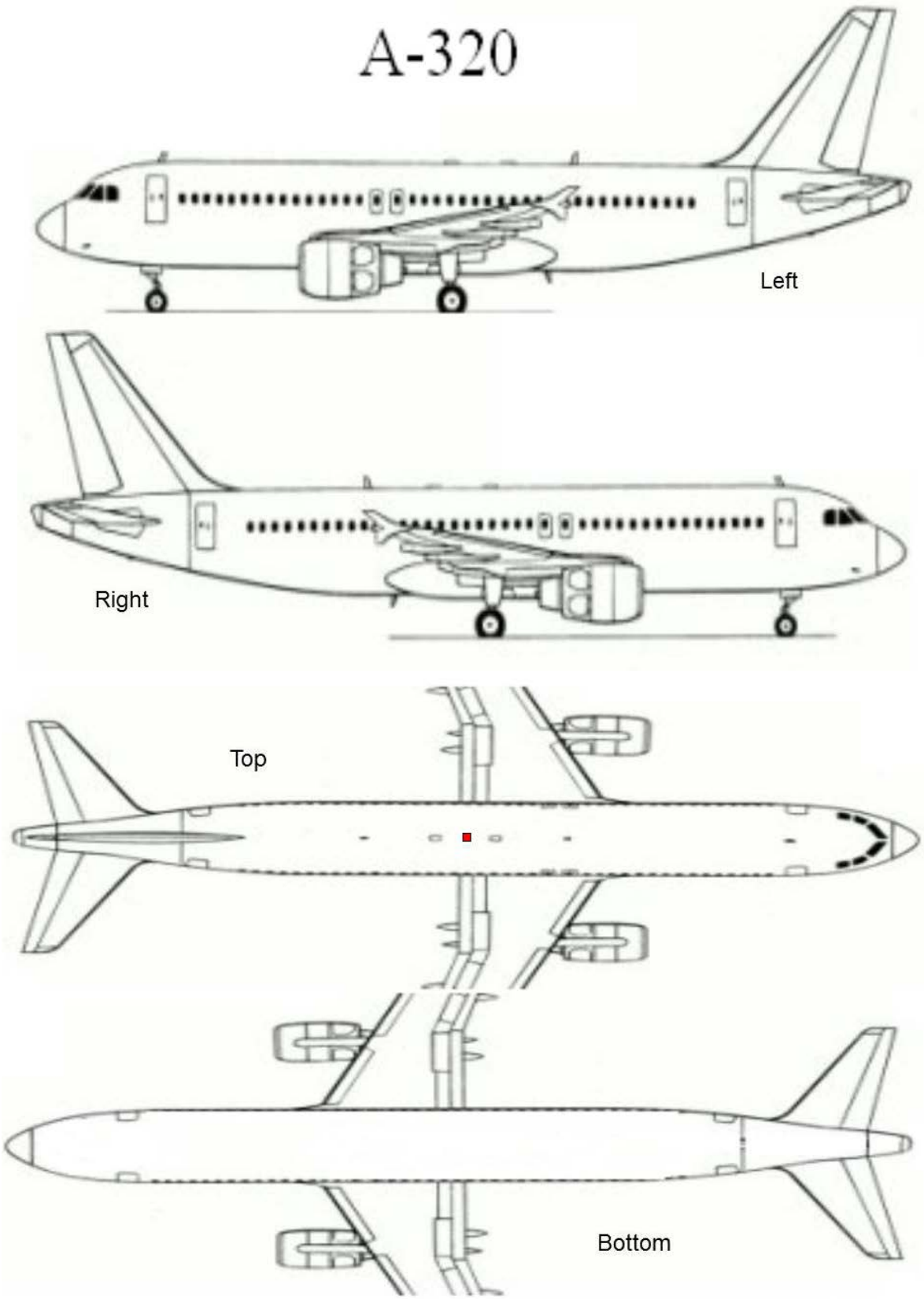


Figure A-106. RAM Location Plot Chart, A-320

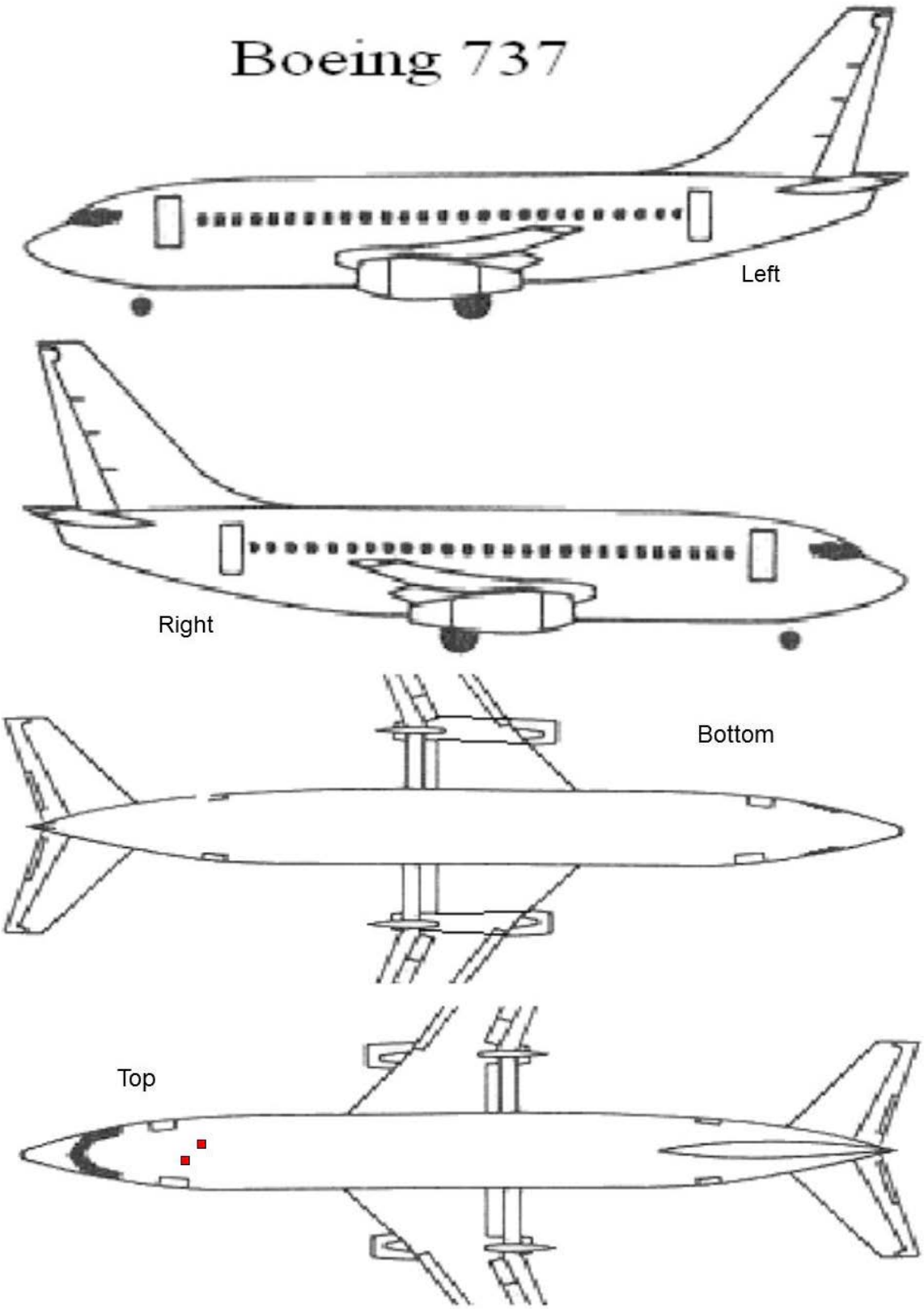


Figure A-107. RAM Location Plot Chart, Boeing 737

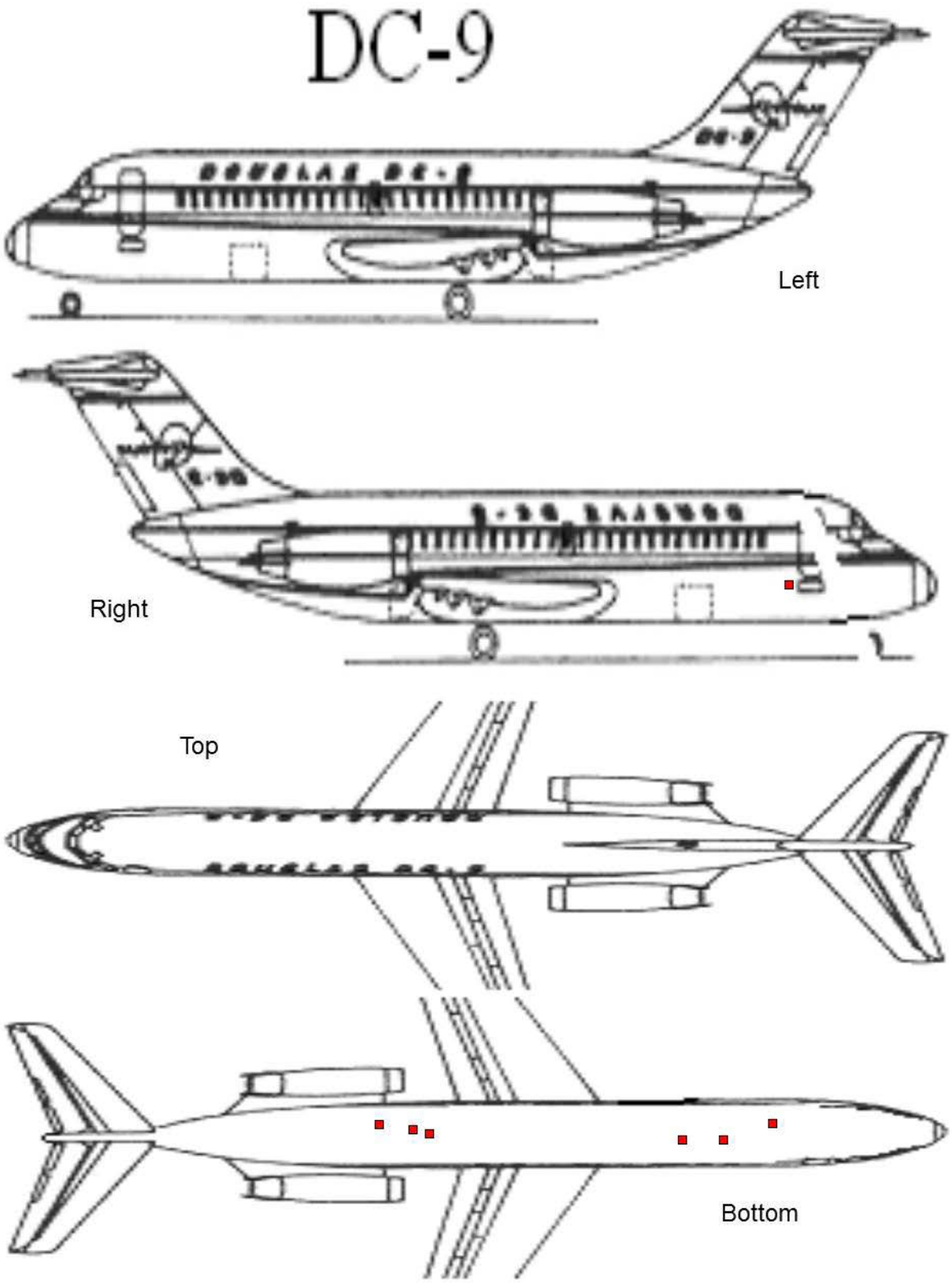


Figure A-108. RAM Location Plot Chart, DC-9

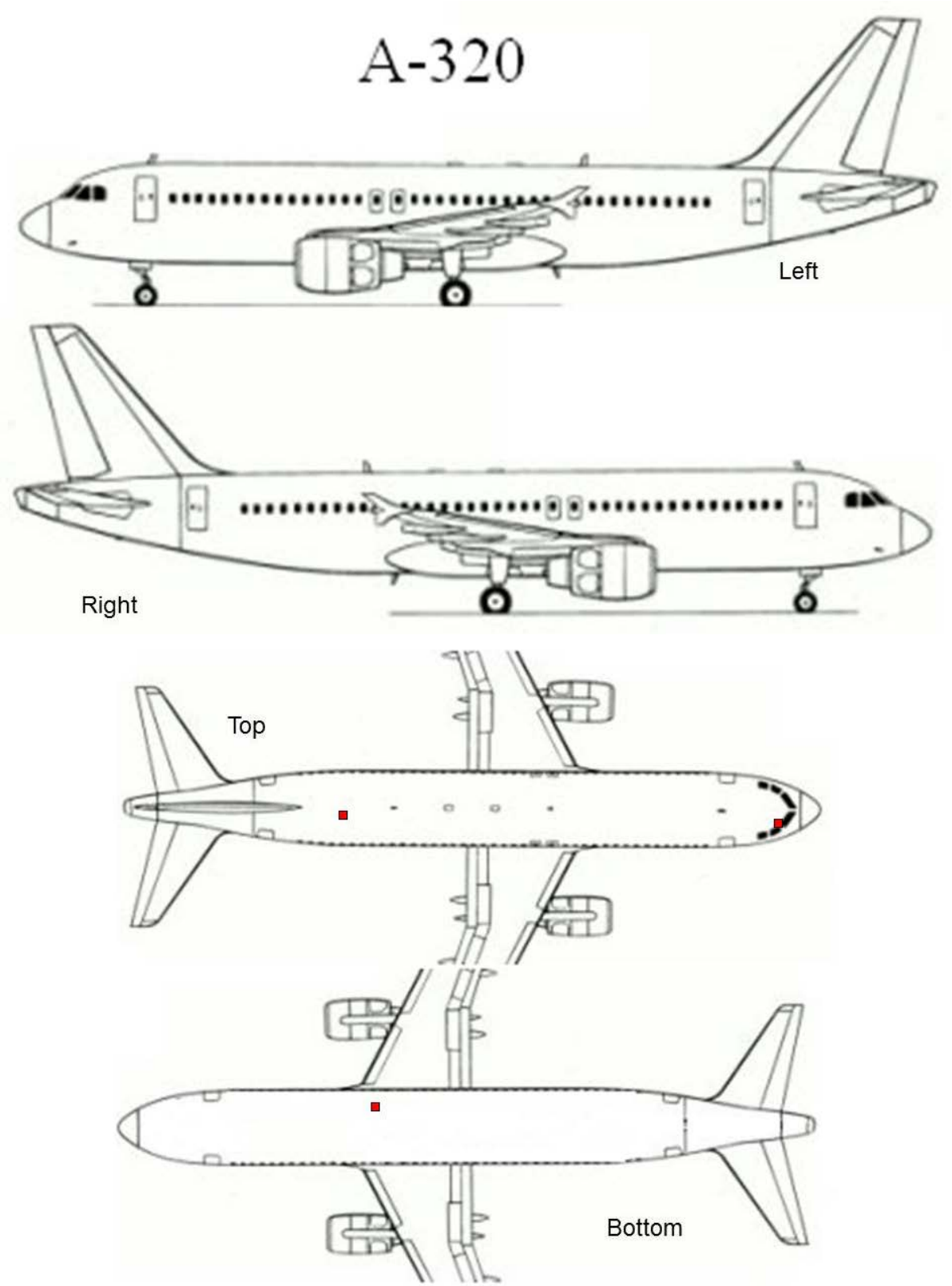


Figure A-109. RAM Location Plot Chart, A-320

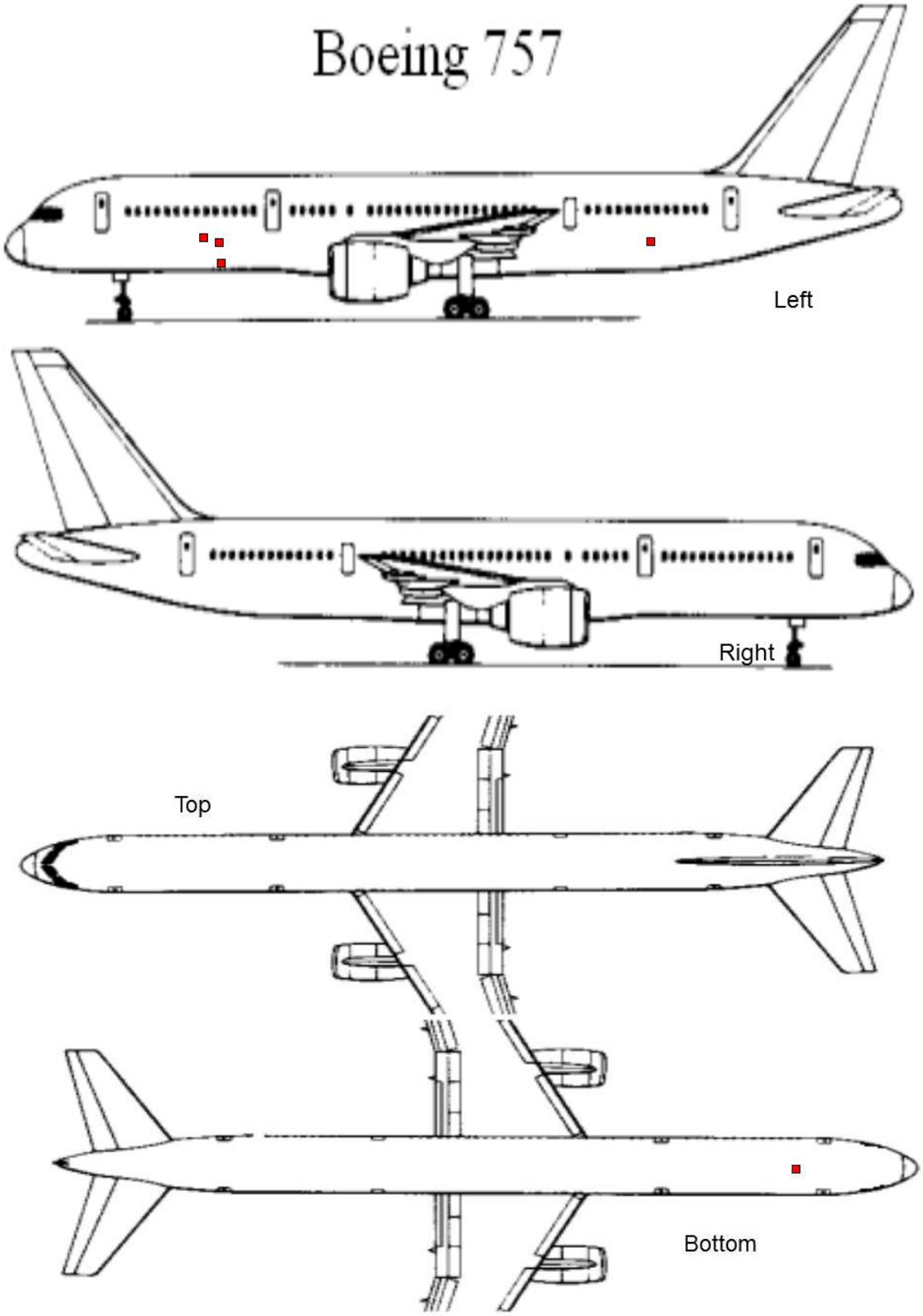
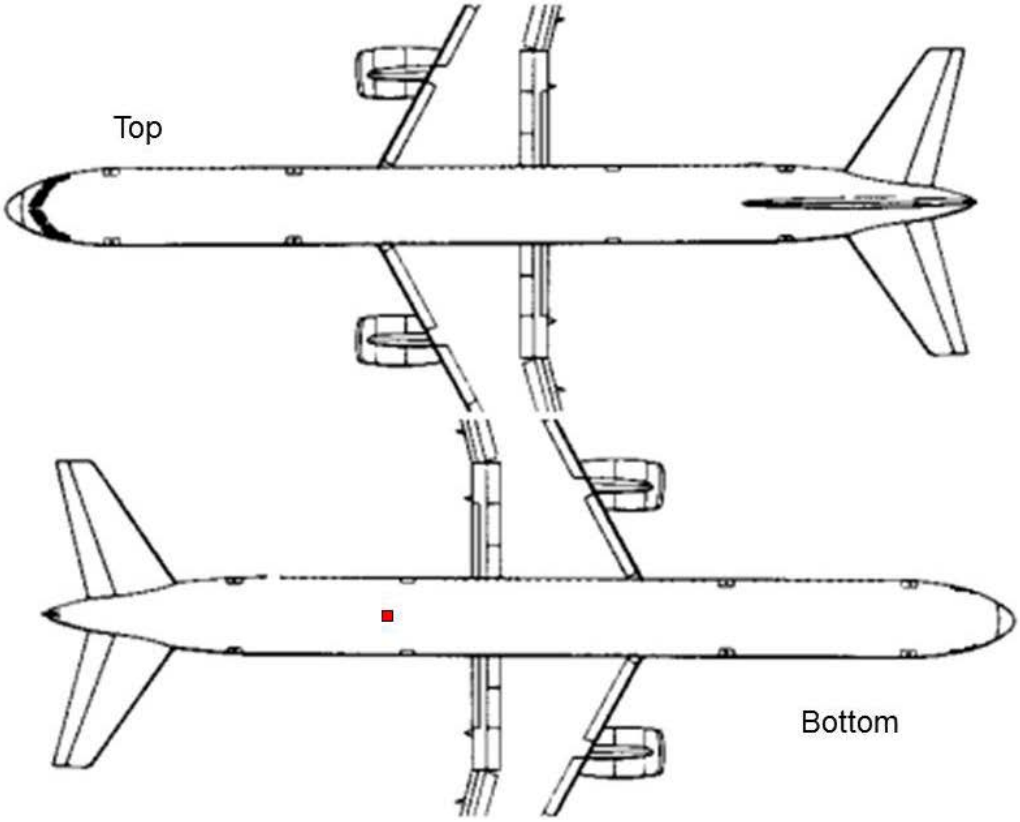


Figure A-110. RAM Location Plot Chart, Boeing 757

Boeing 757

Left

Right



Top

Bottom

Figure A-111. RAM Location Plot Chart, Boeing 757

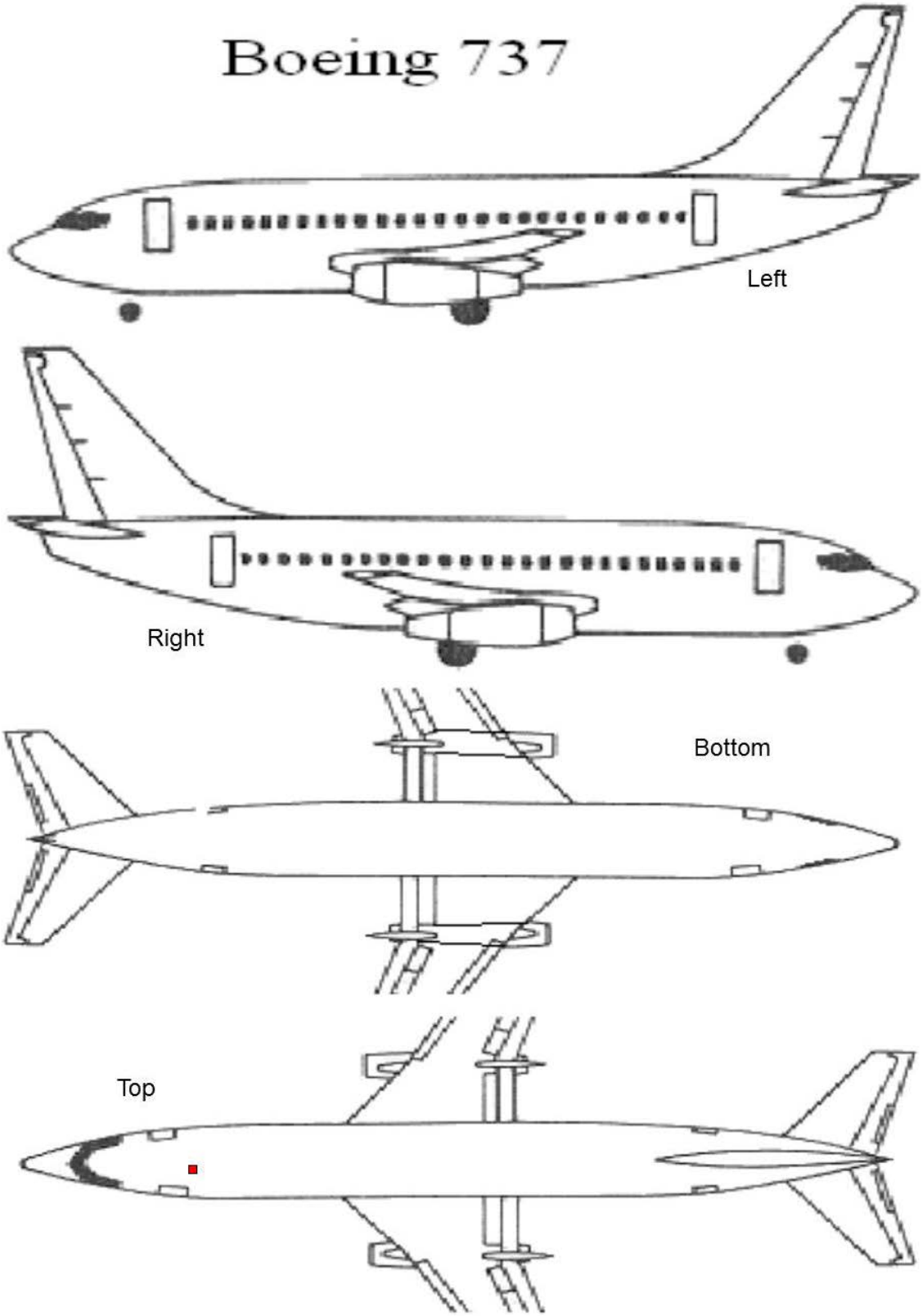


Figure A-112. RAM Location Plot Chart, Boeing 737

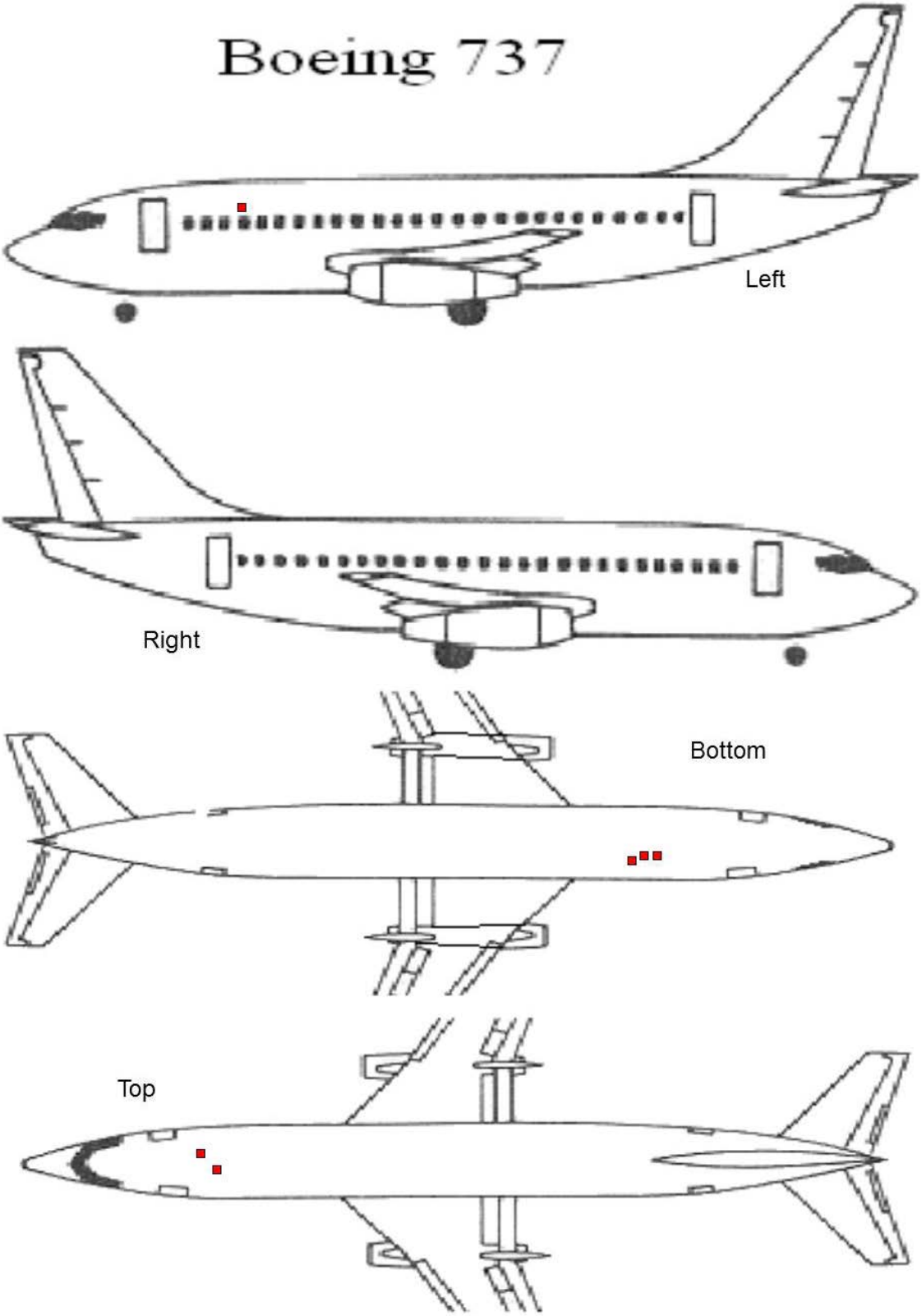


Figure A-113. RAM Location Plot Chart, Boeing 737

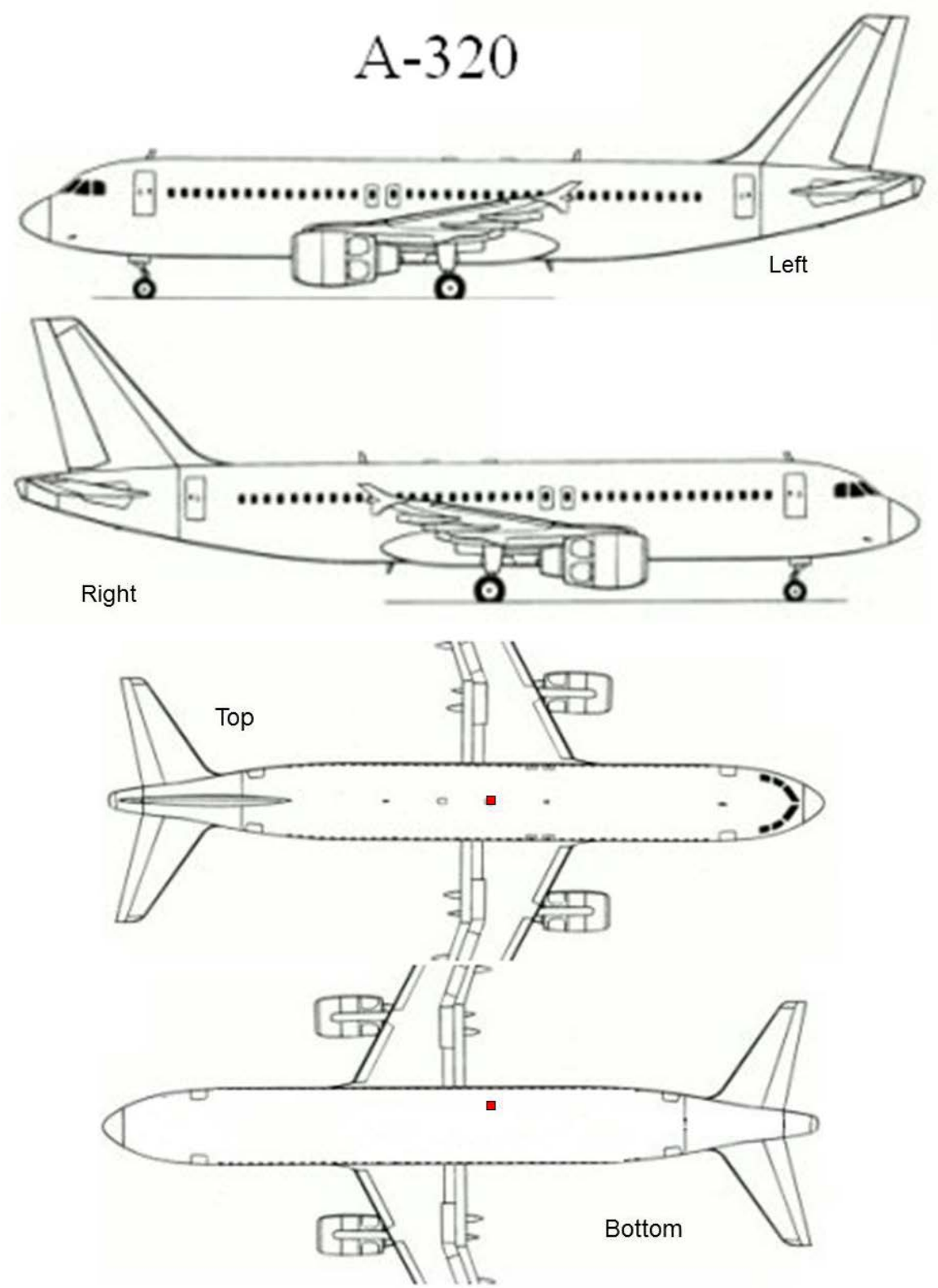


Figure A-114. RAM Location Plot Chart, A-320

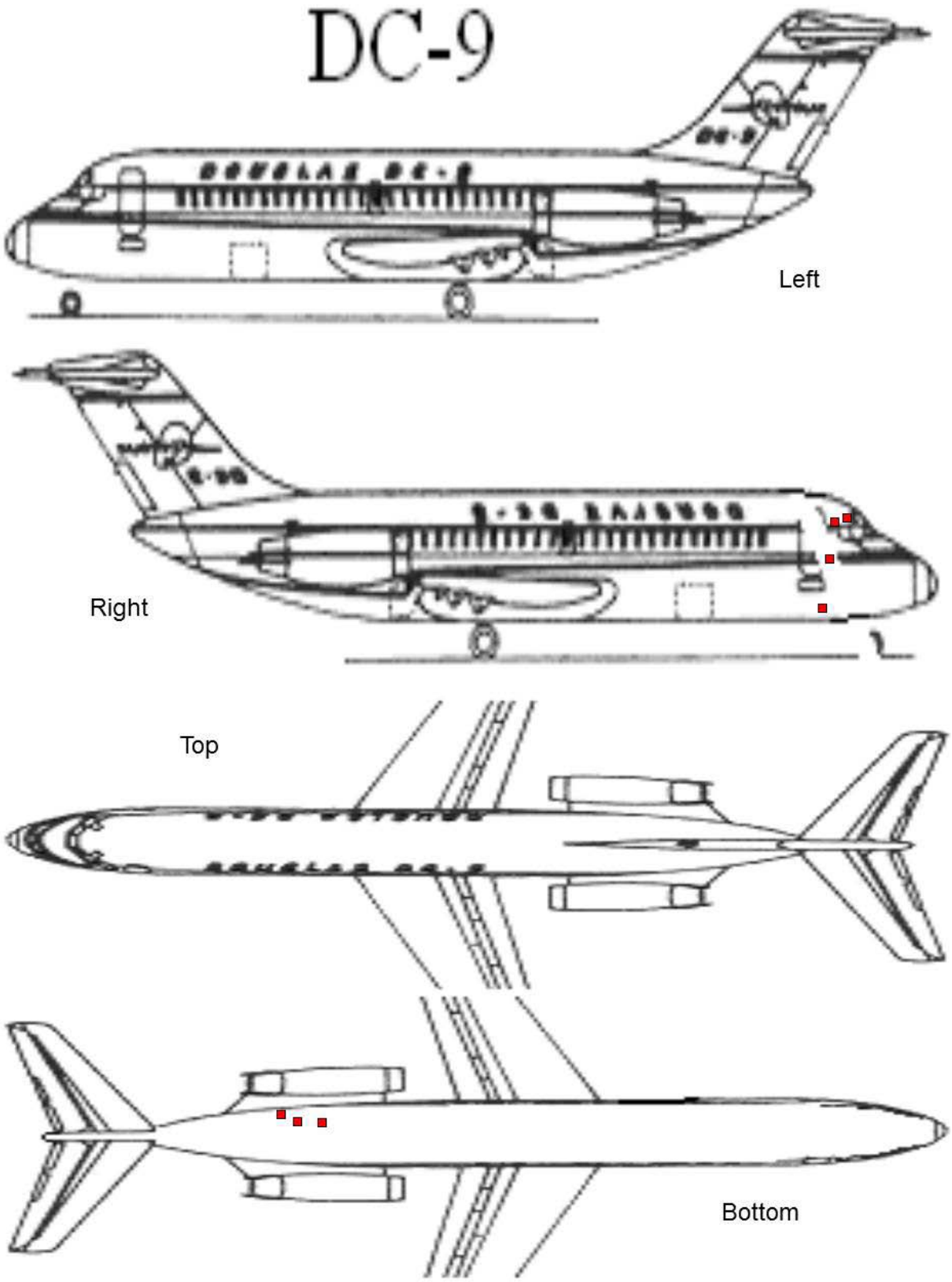


Figure A-115. RAM Location Plot Chart, DC-9

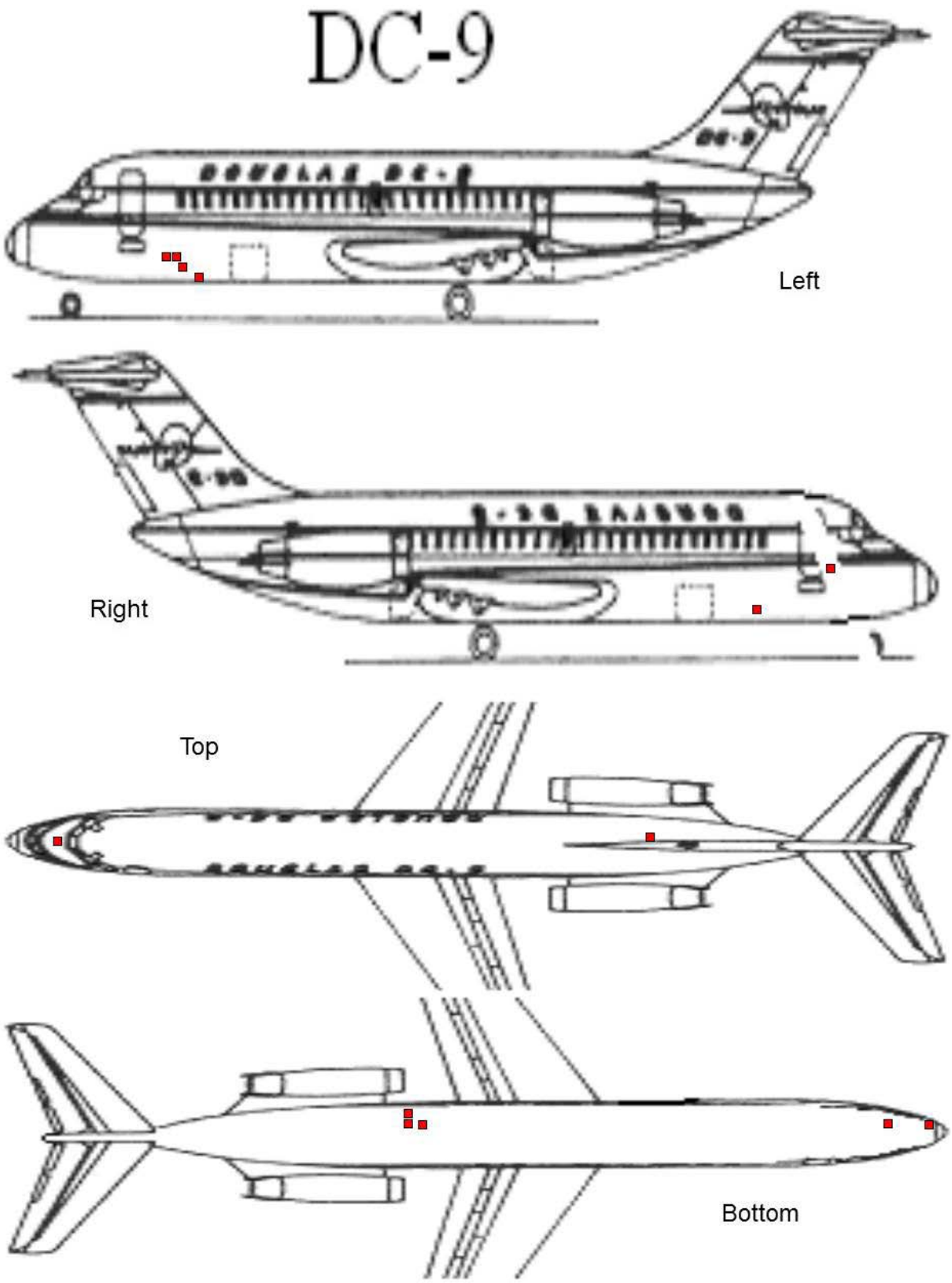


Figure A-116. RAM Location Plot Chart, DC-9

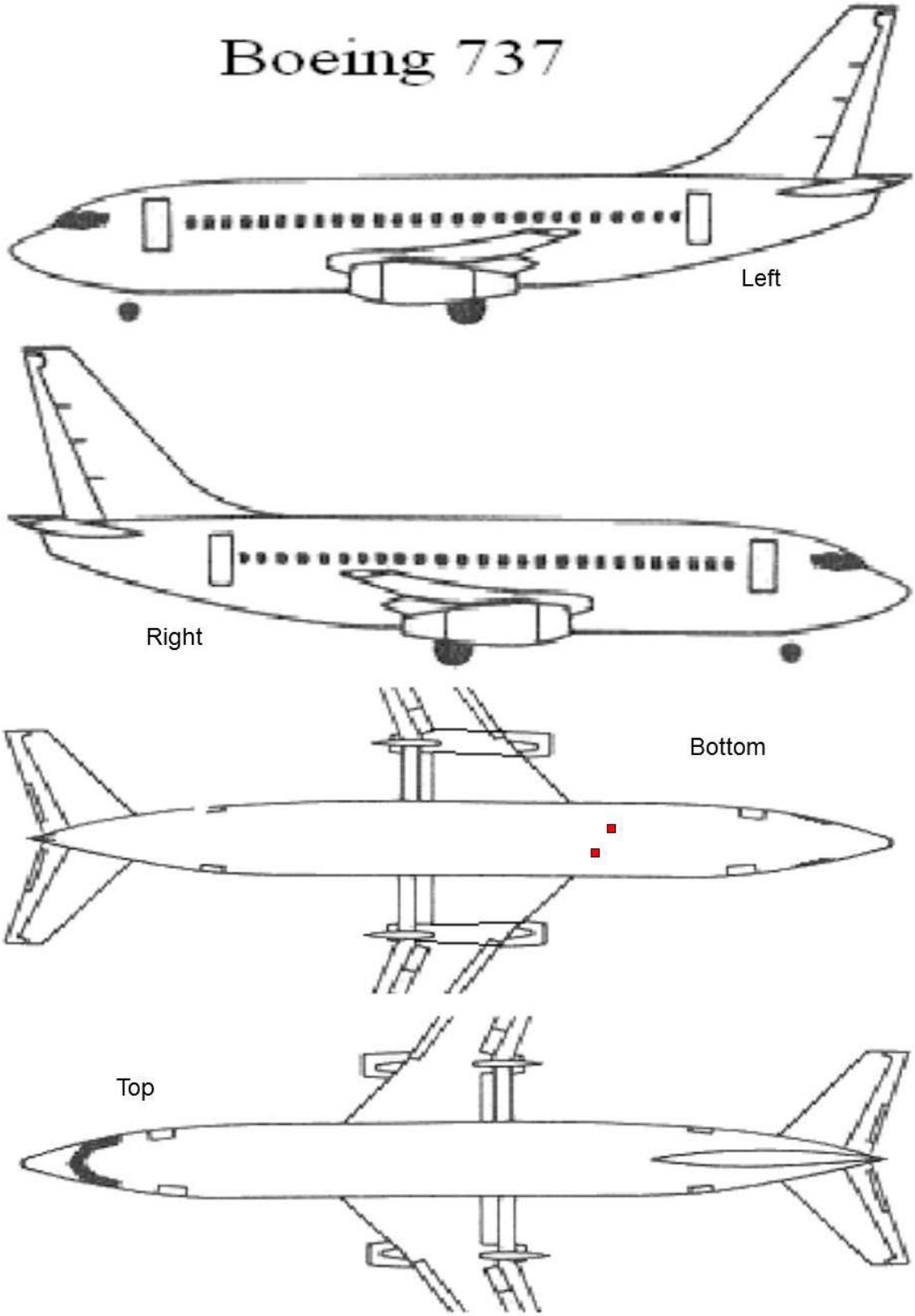


Figure A-117. RAM Location Plot Chart, Boeing 737

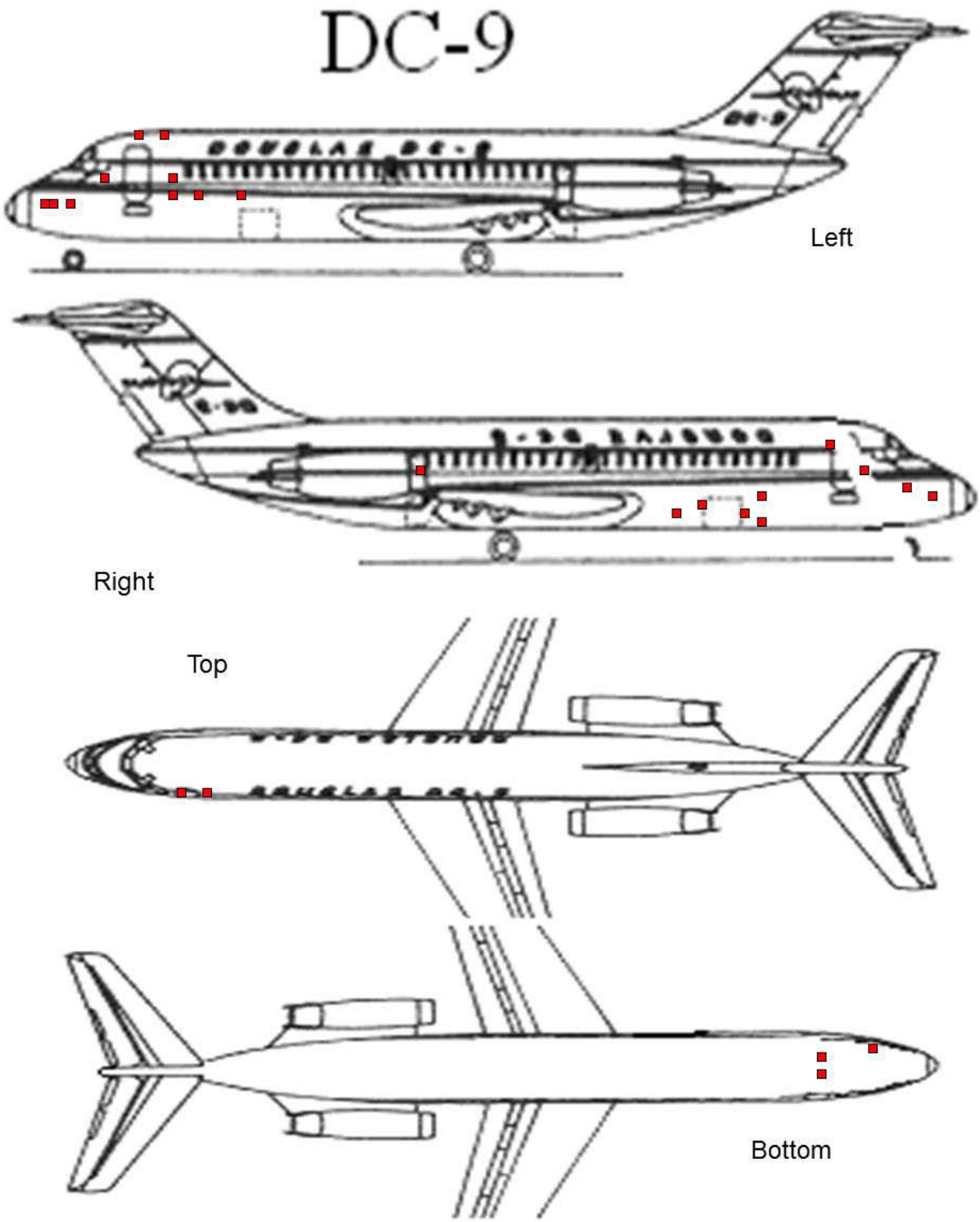


Figure A-118. RAM Location Plot Chart, DC-9

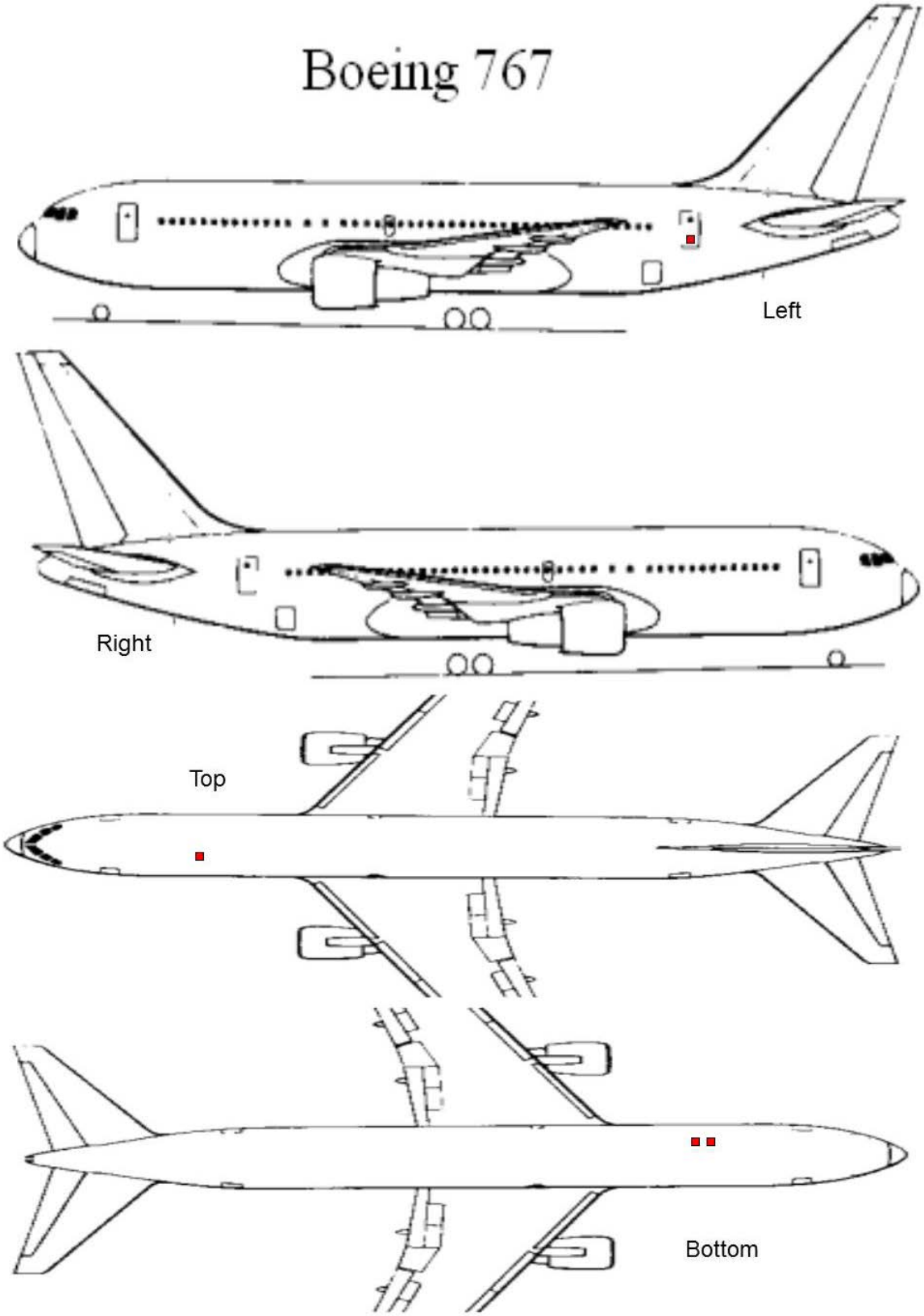


Figure A-119. RAM Location Plot Chart, Boeing 767

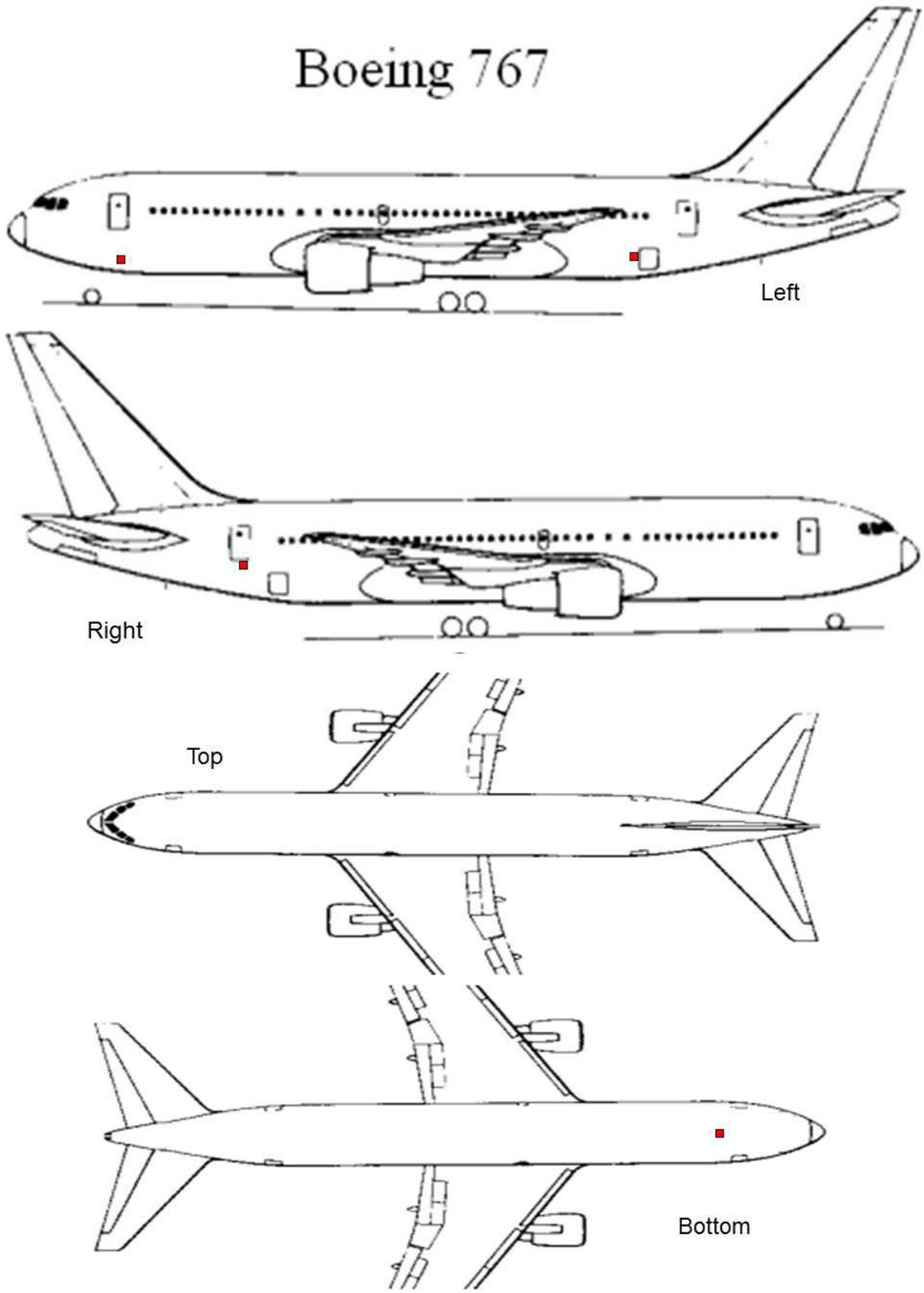


Figure A-120. RAM Location Plot Chart, Boeing 767

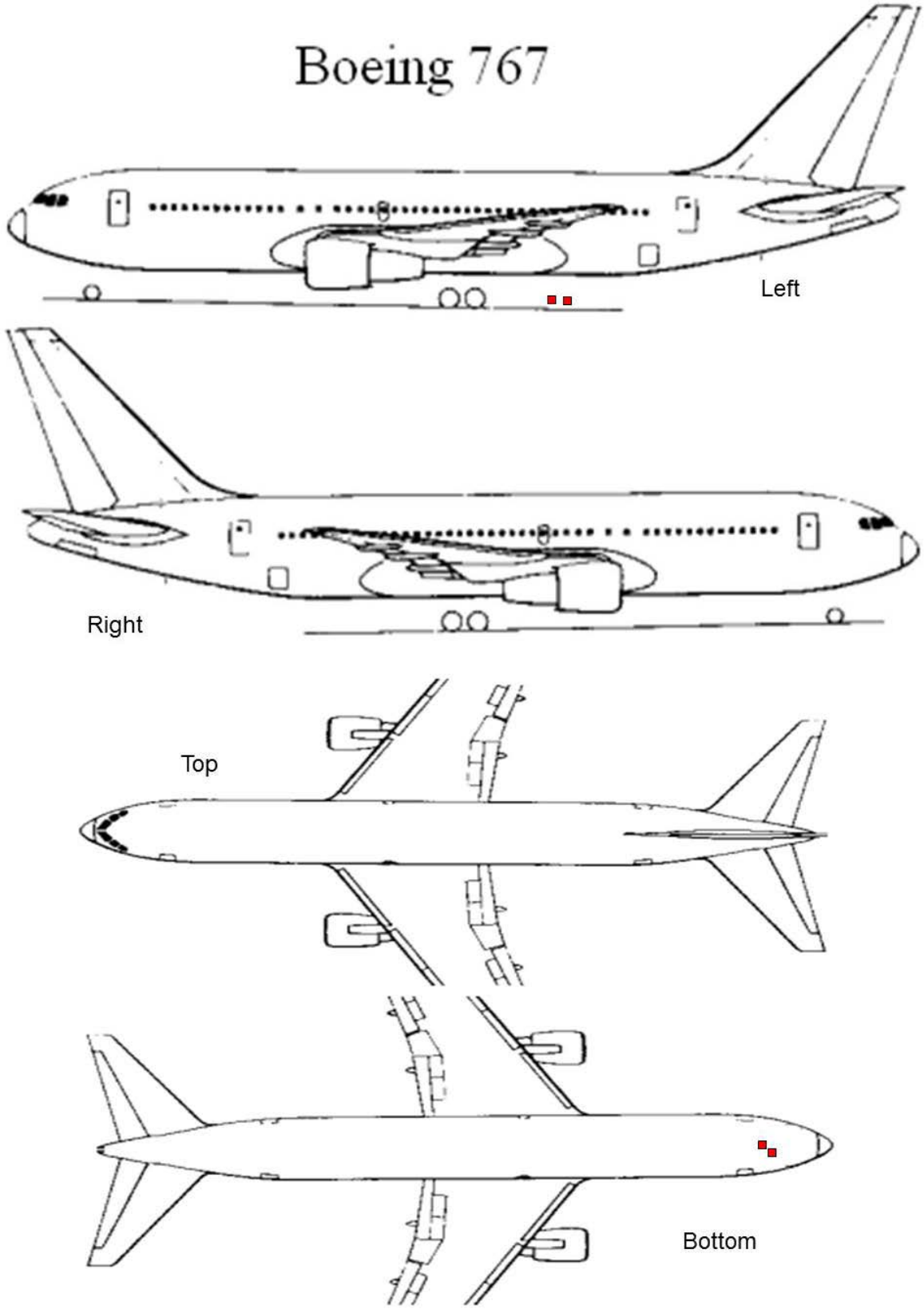


Figure A-121. RAM Location Plot Chart, Boeing 767

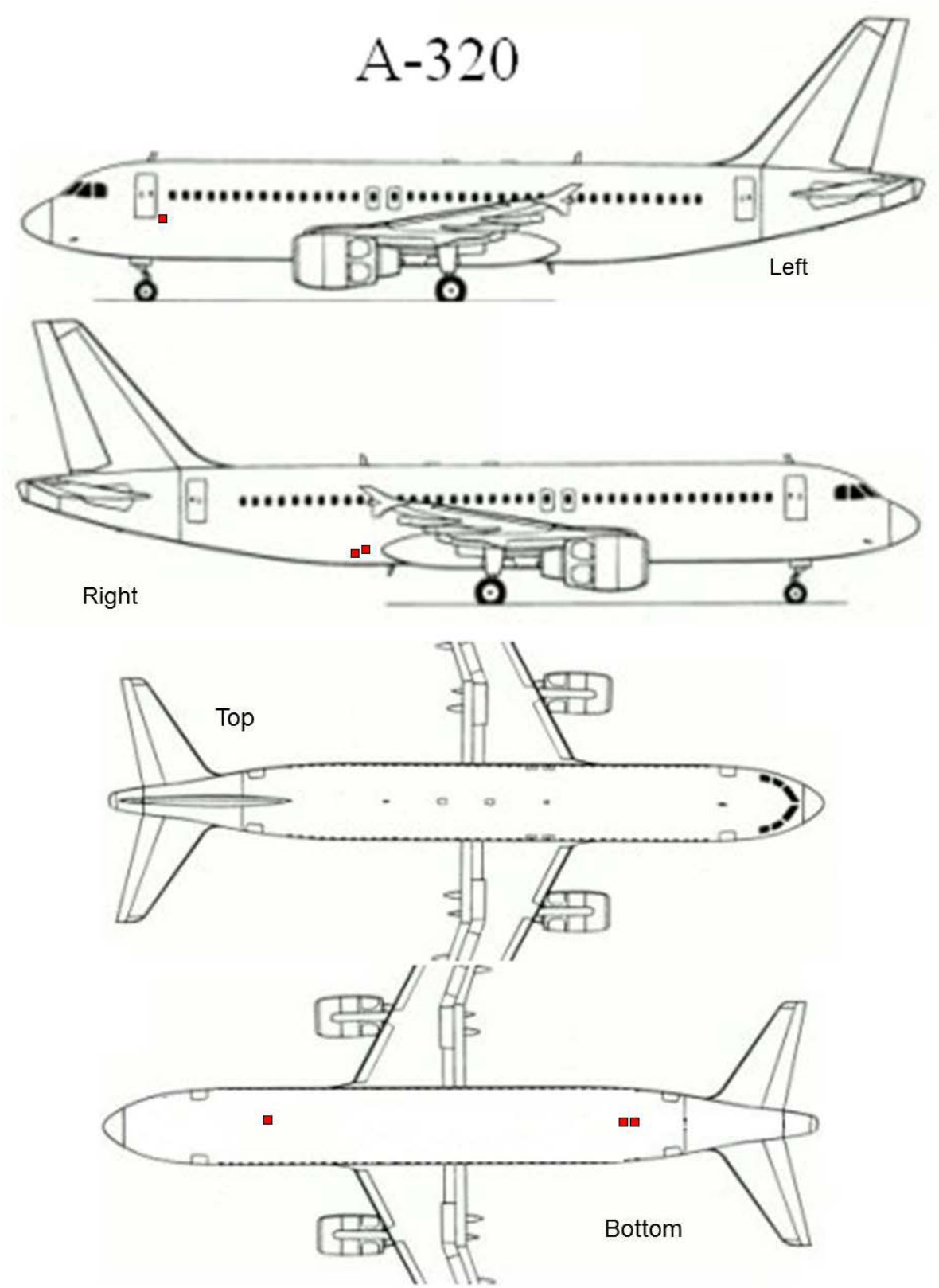


Figure A-122. RAM Location Plot Chart, A-320

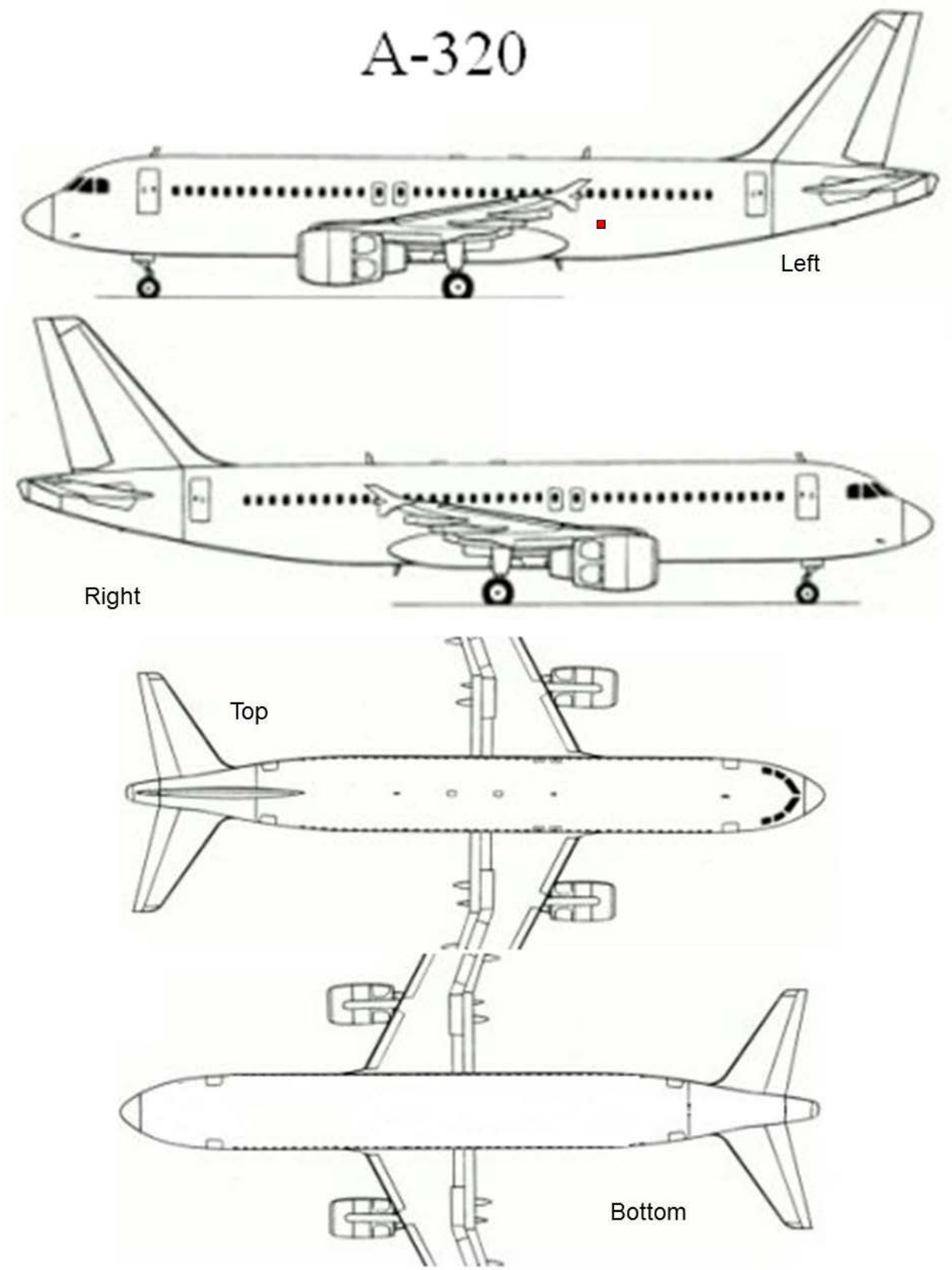


Figure A-123. RAM Location Plot Chart, A-320

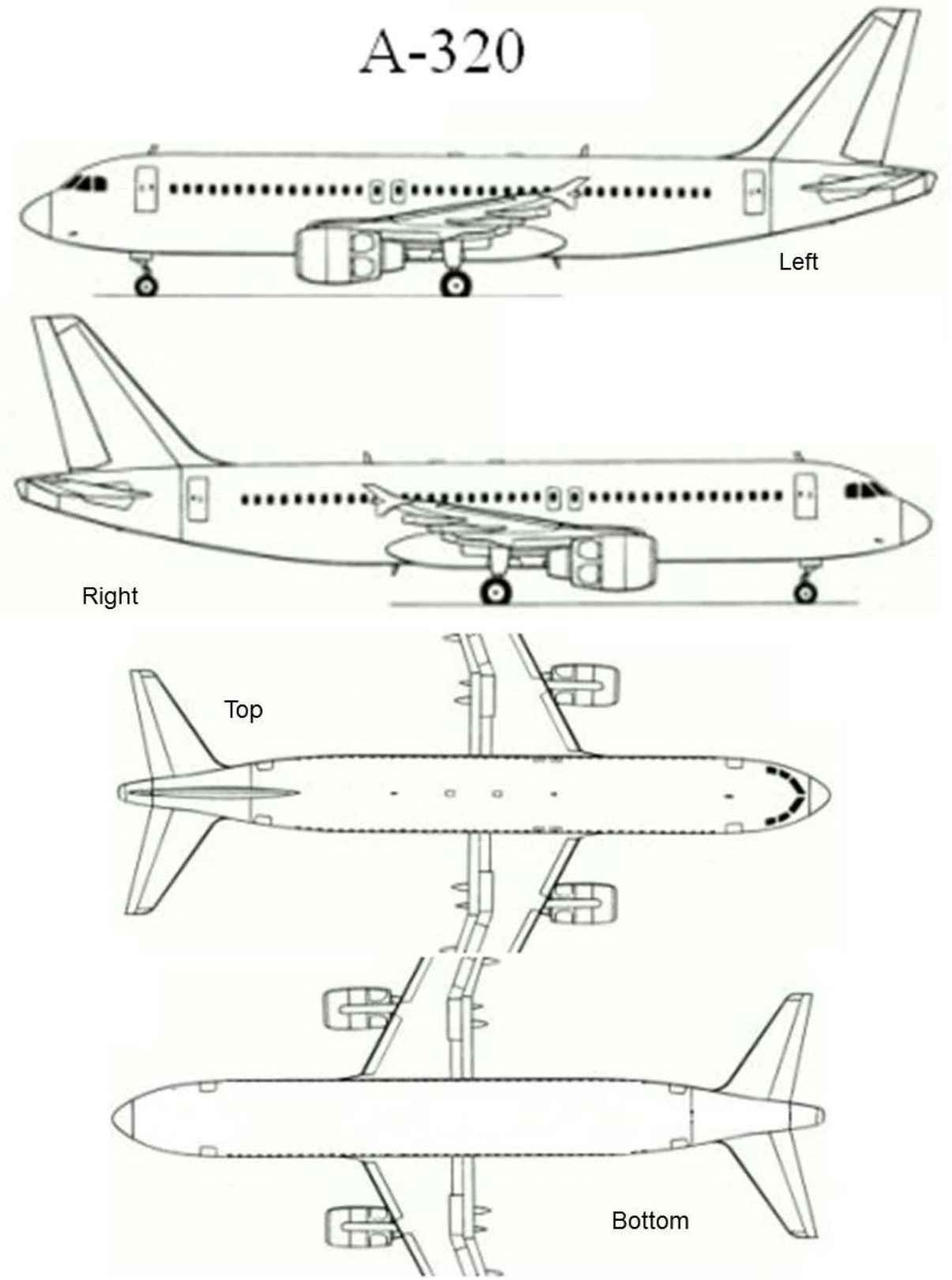


Figure A-124. RAM Location Plot Chart, A-320

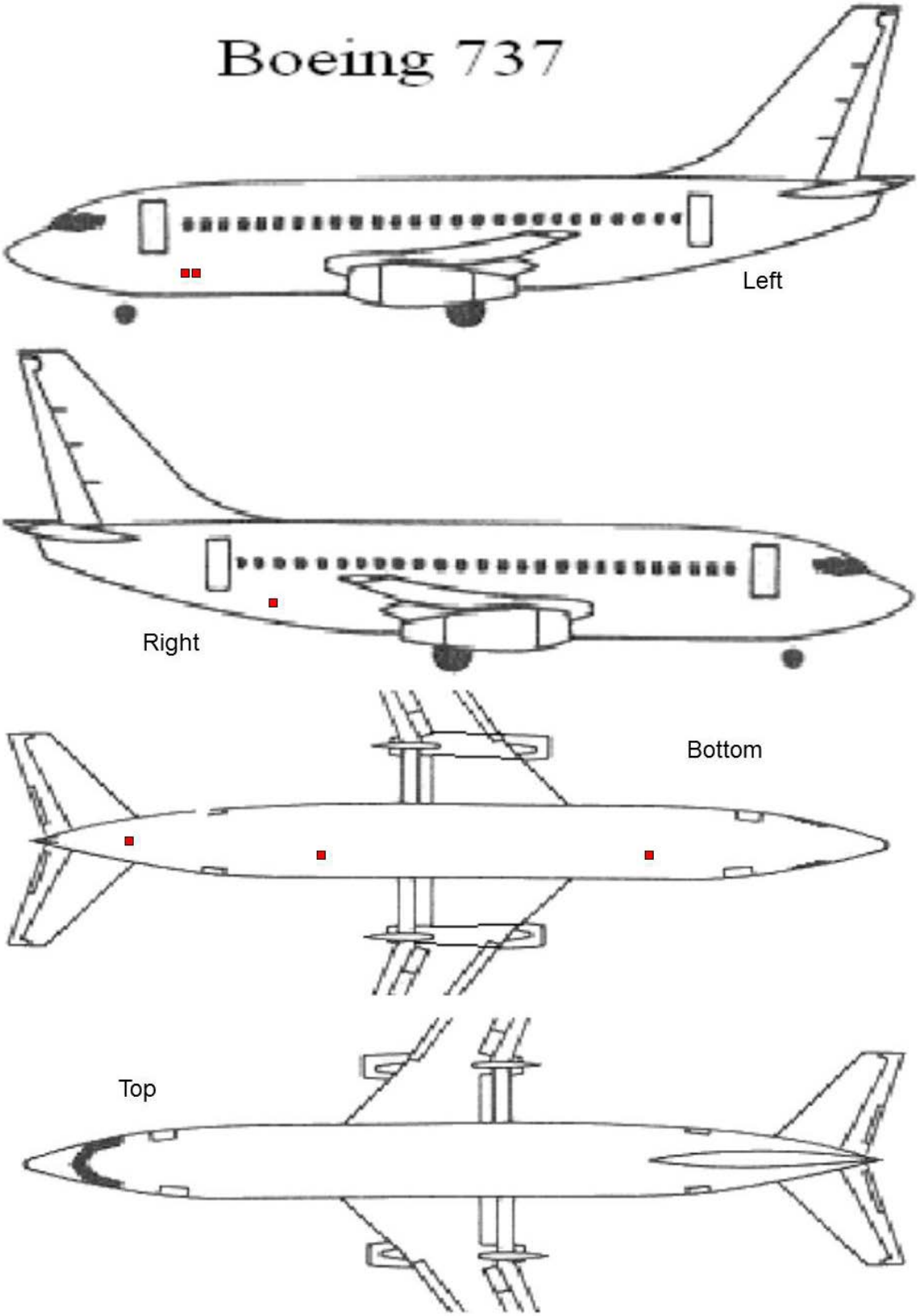


Figure A-125. RAM Location Plot Chart, Boeing 737

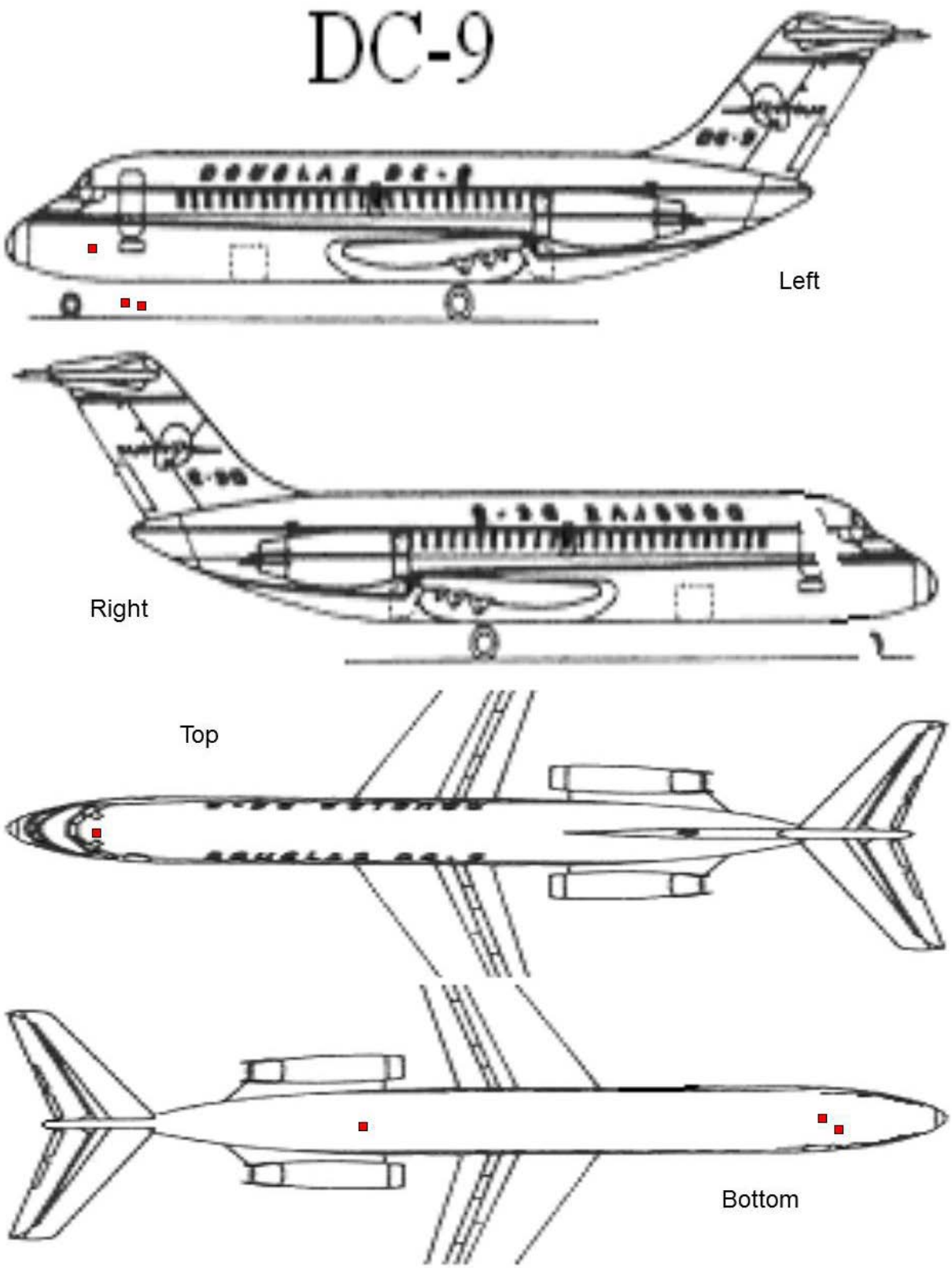


Figure A-126. RAM Location Plot Chart, DC-9

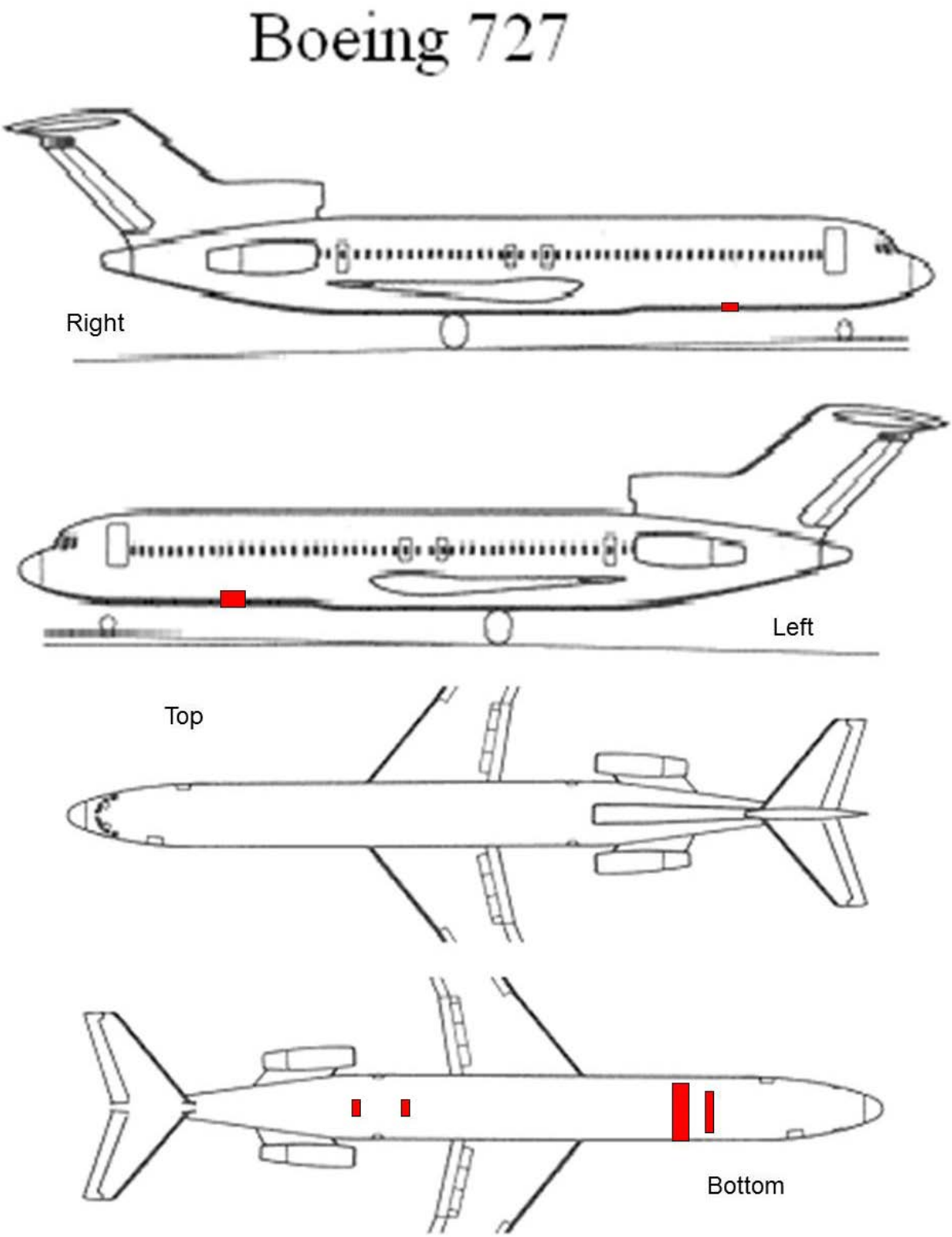


Figure A-127. RAM Location Plot Chart, Boeing 727

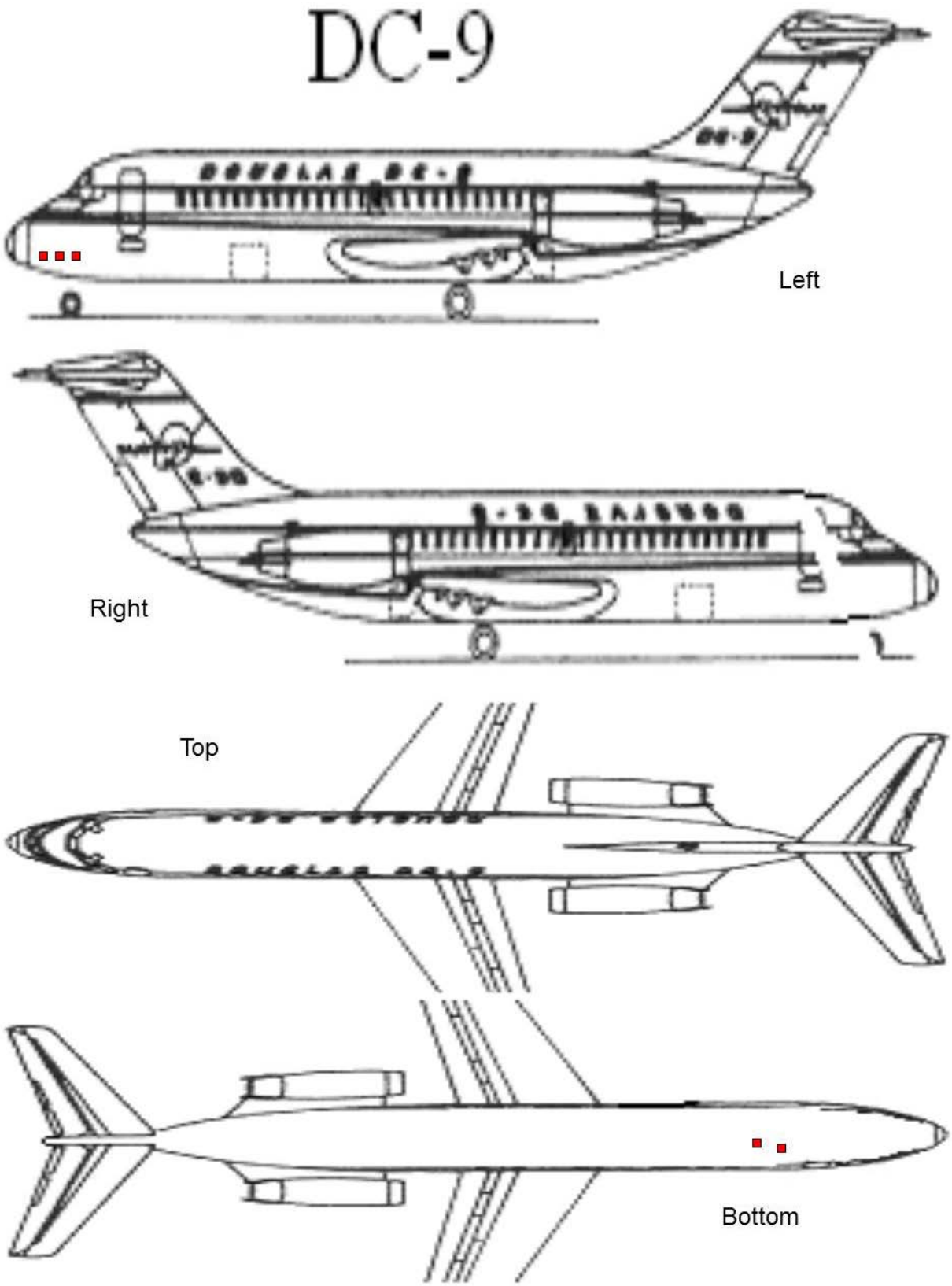


Figure A-128. RAM Location Plot Chart, DC-9

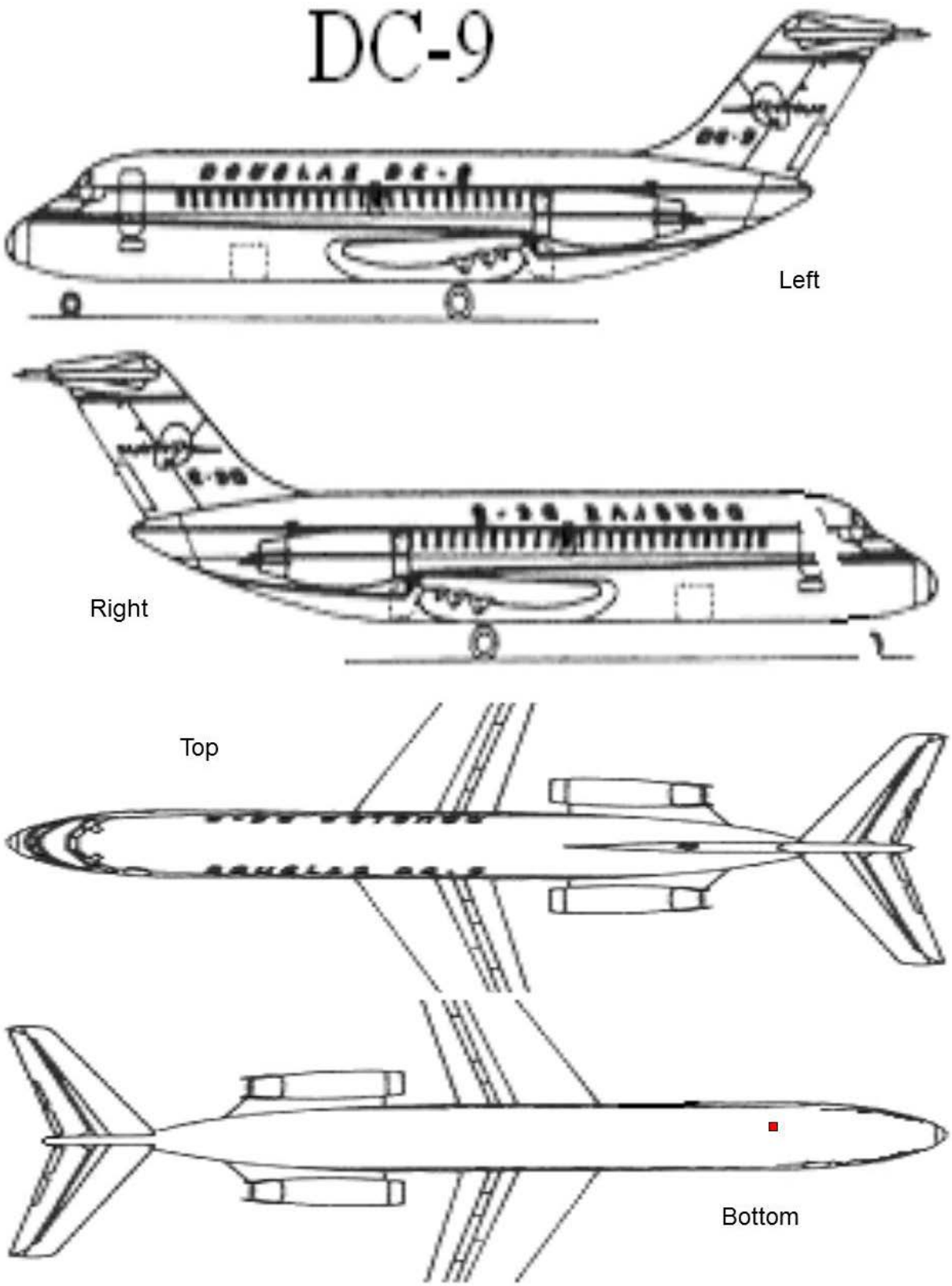


Figure A-129. RAM Location Plot Chart, DC-9

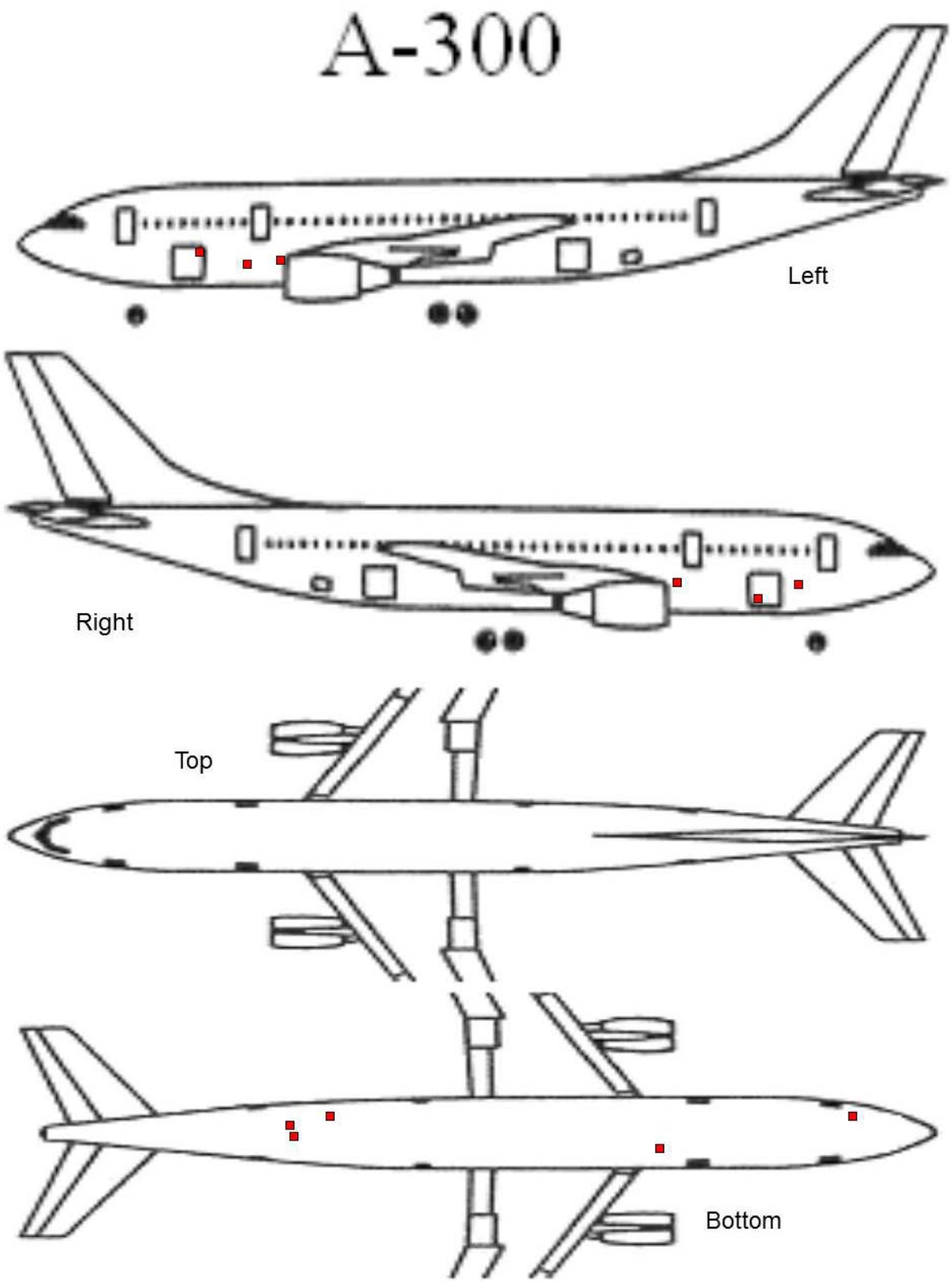


Figure A-130. RAM Location Plot Chart, A-300

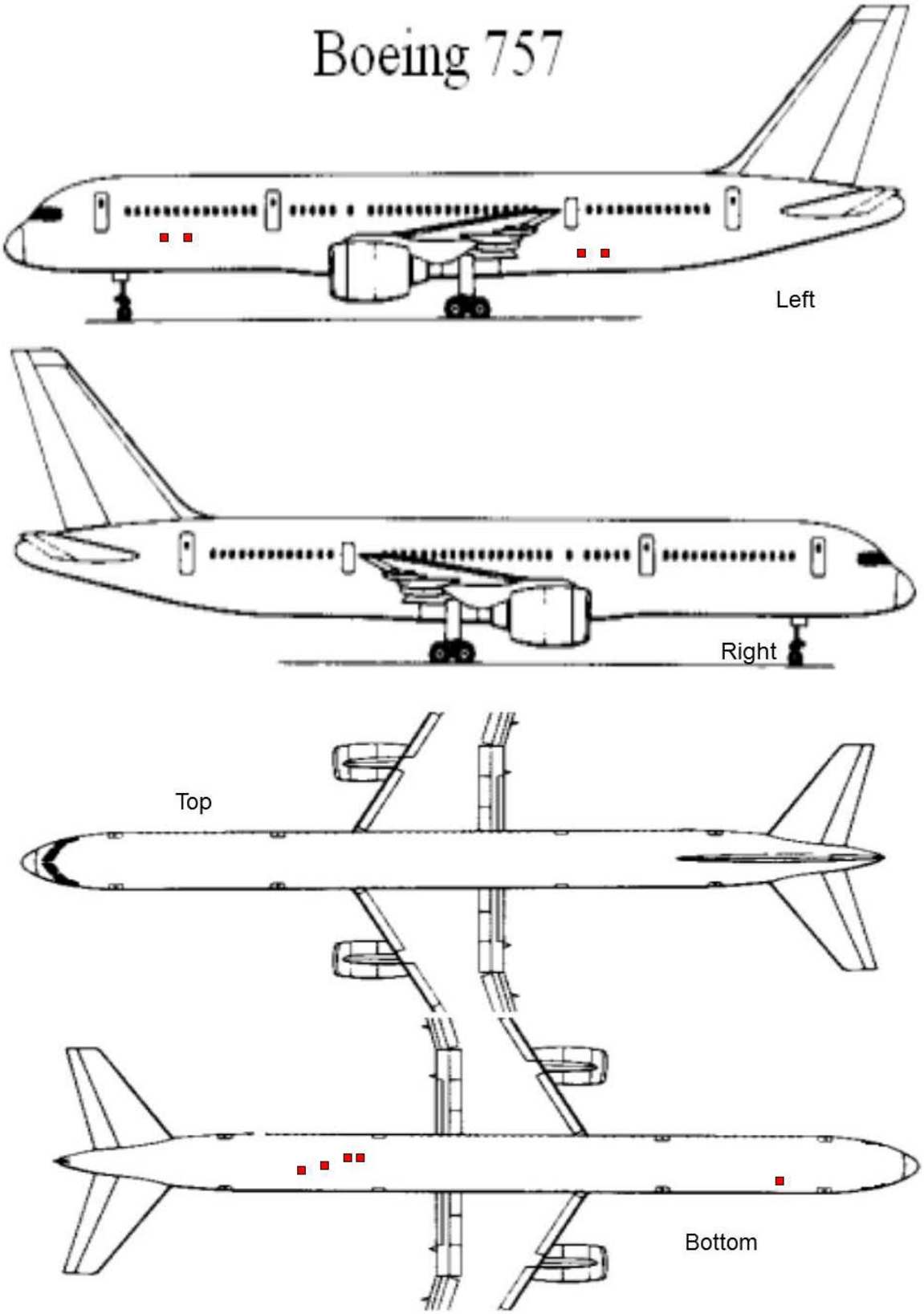


Figure A-131. RAM Location Plot Chart, Boeing 757

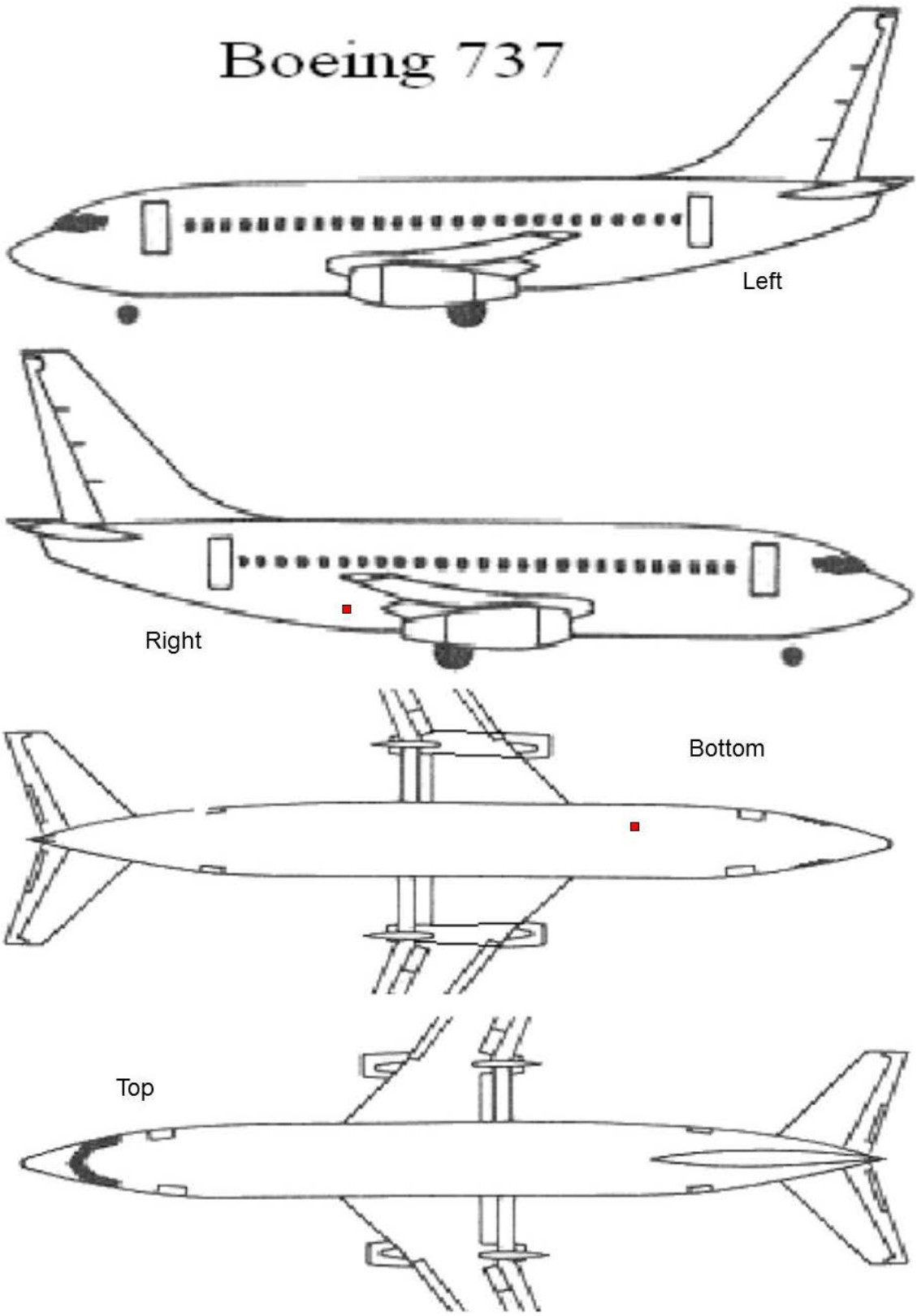


Figure A-132. RAM Location Plot Chart, Boeing 737

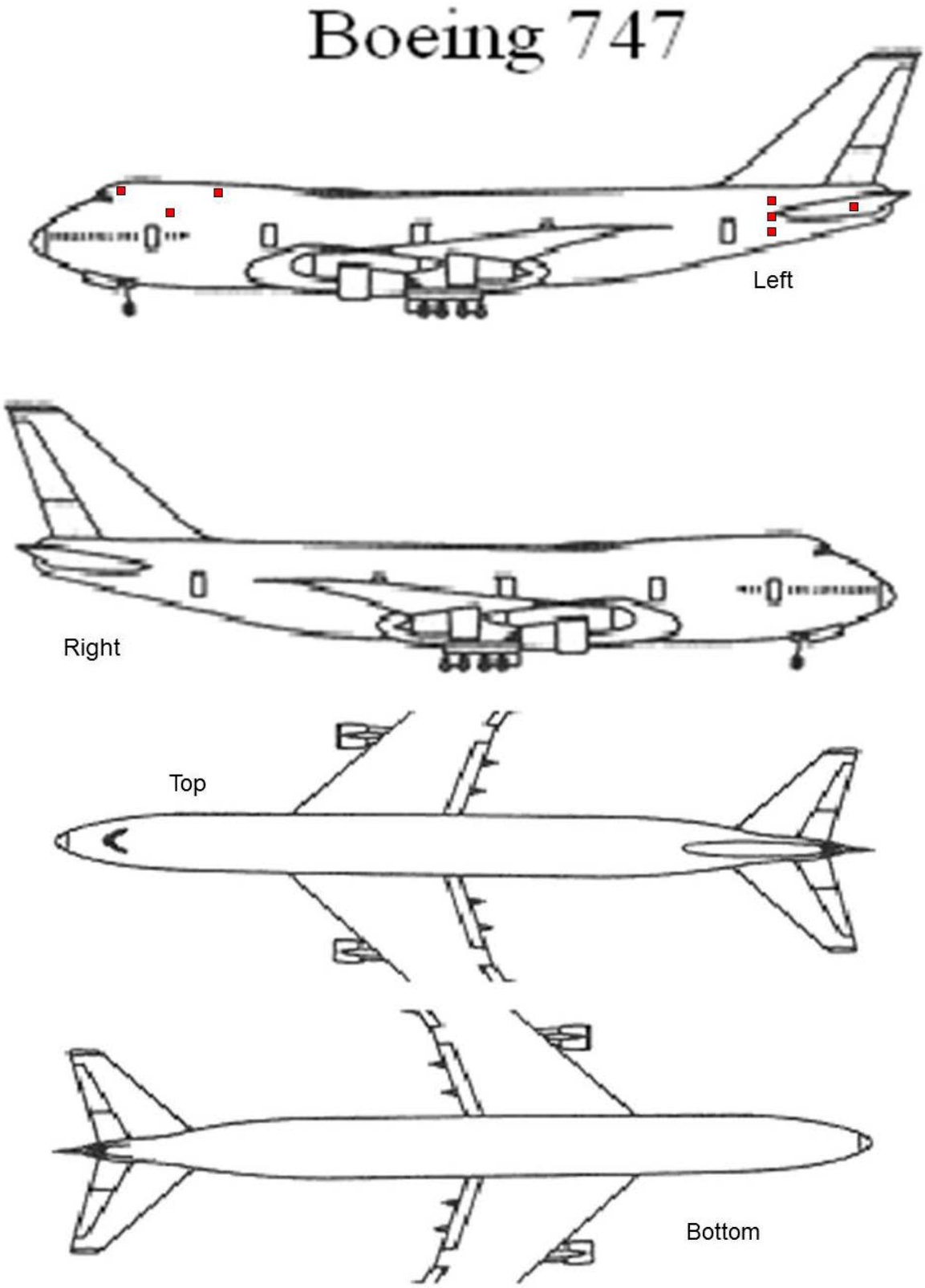


Figure A-133. RAM Location Plot Chart, Boeing 747

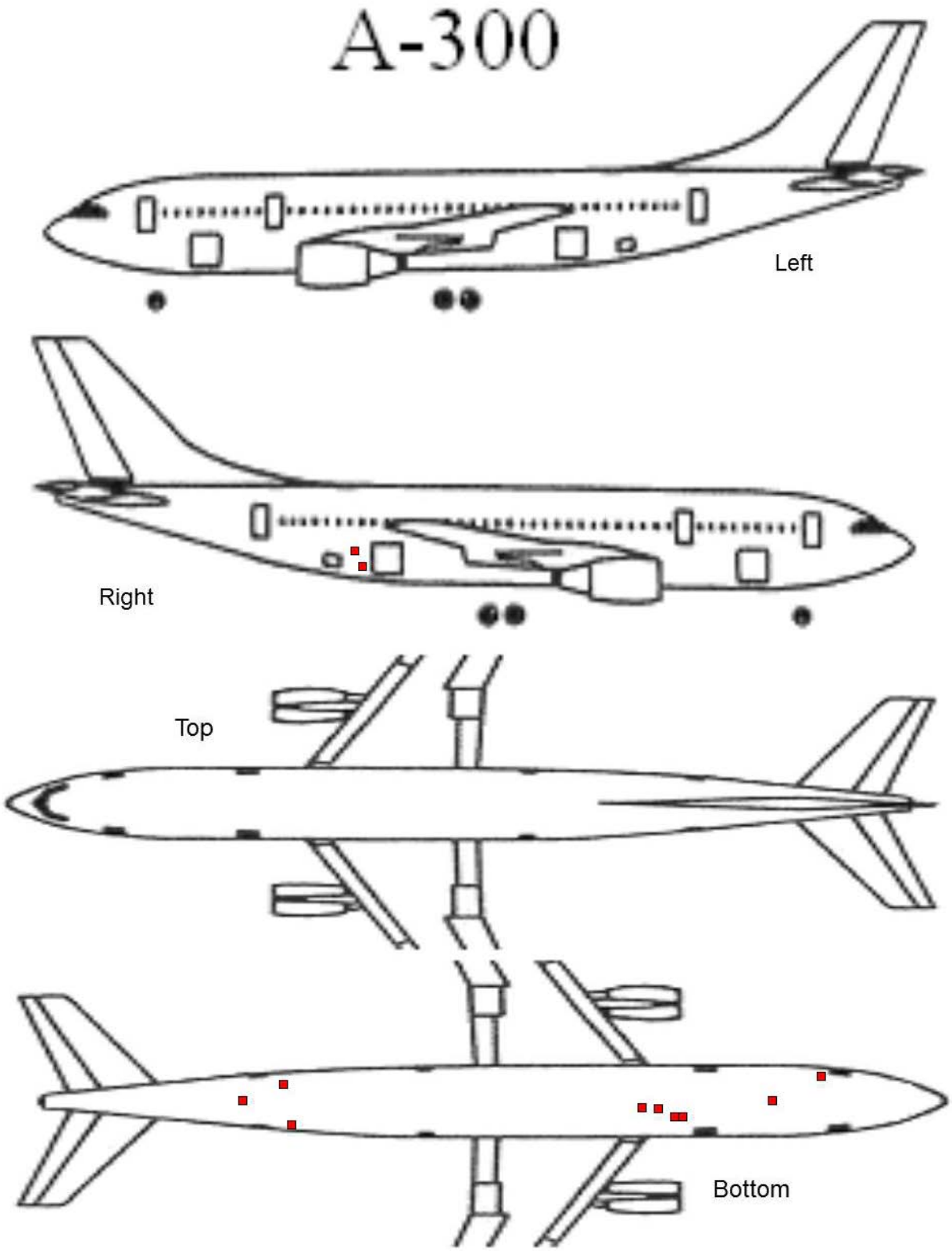


Figure A-134. RAM Location Plot Chart, A-300

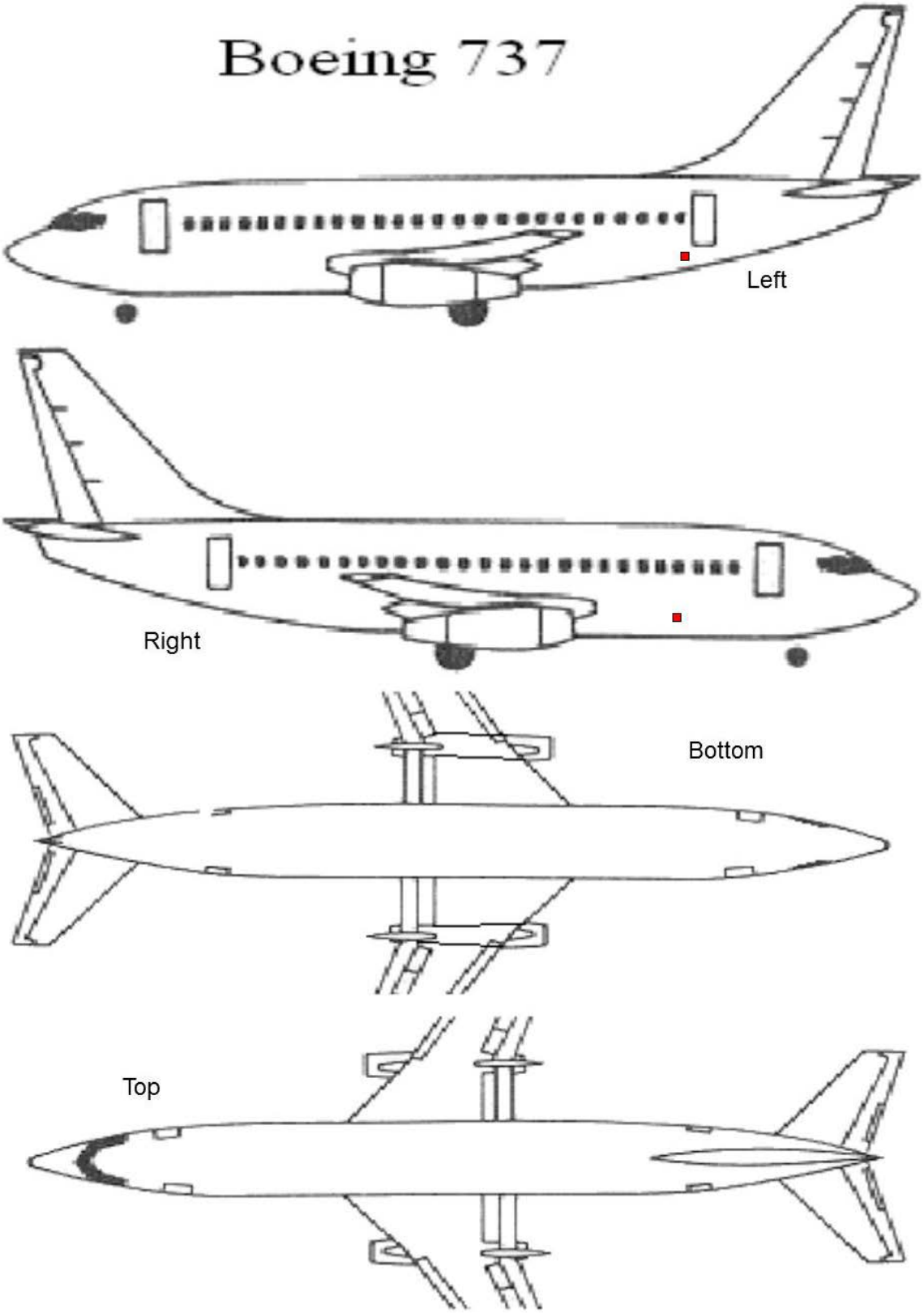


Figure A-135. RAM Location Plot Chart, Boeing 737

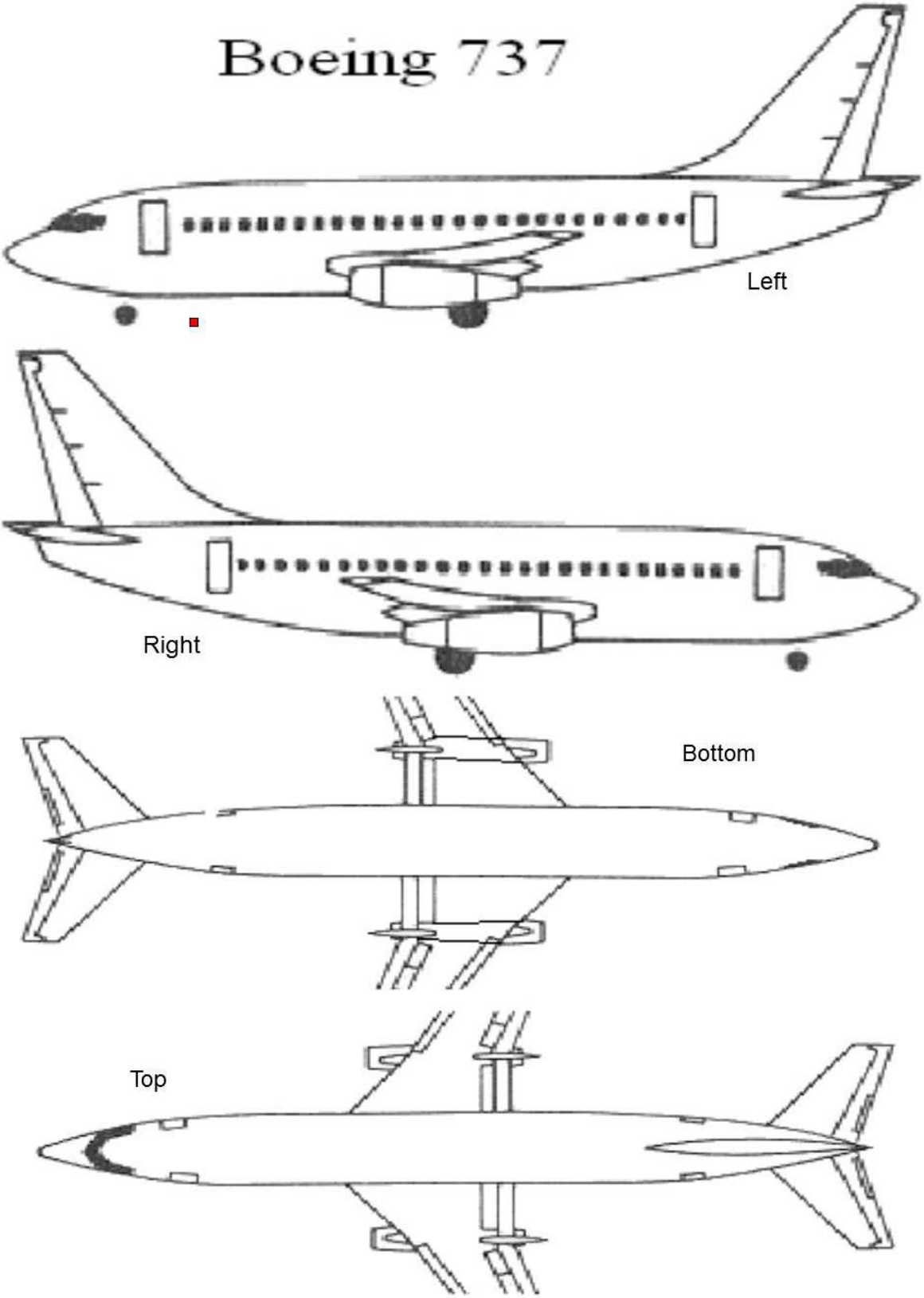


Figure A-136. RAM Location Plot Chart, Boeing 737

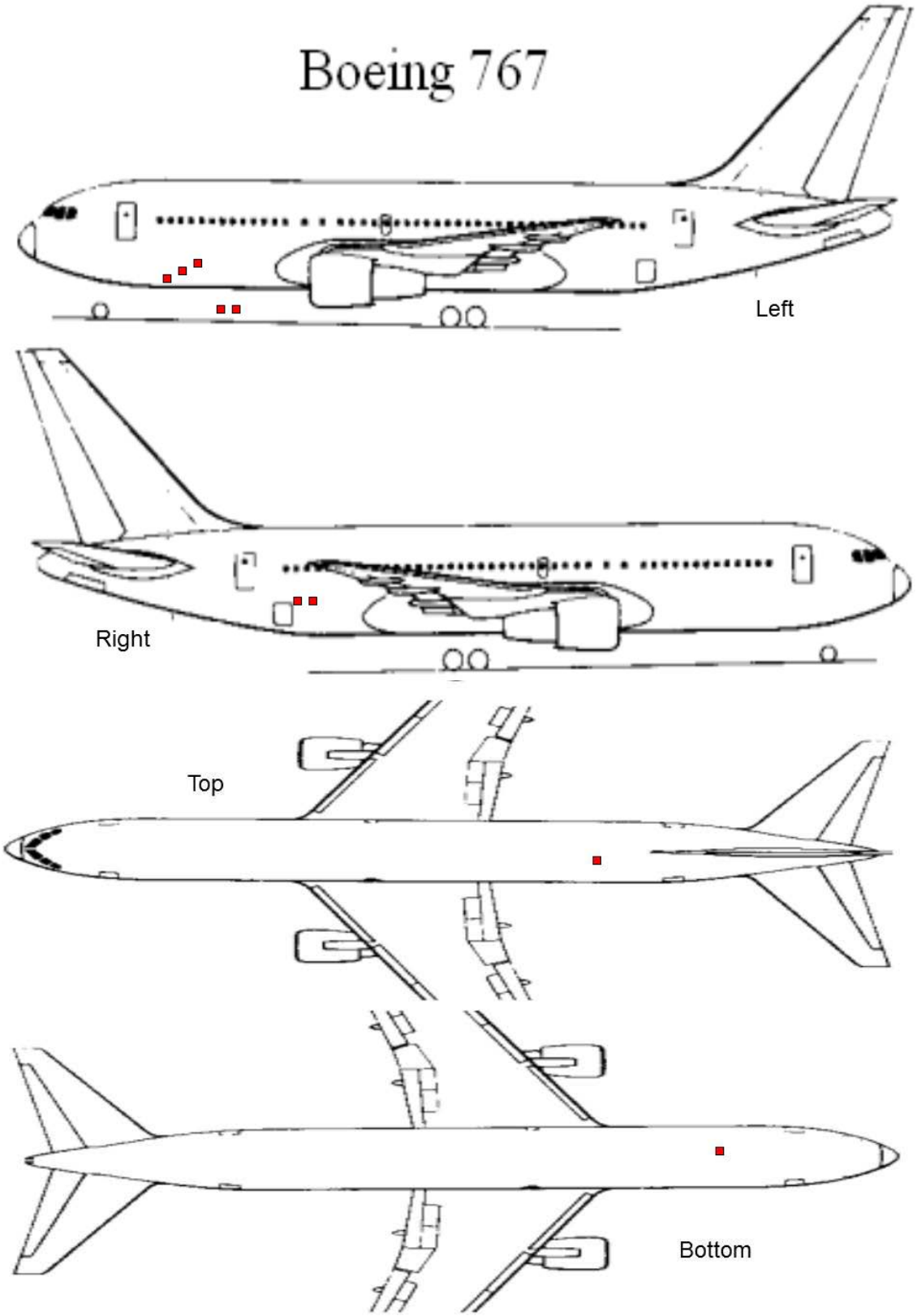


Figure A-137. RAM Location Plot Chart, Boeing 767

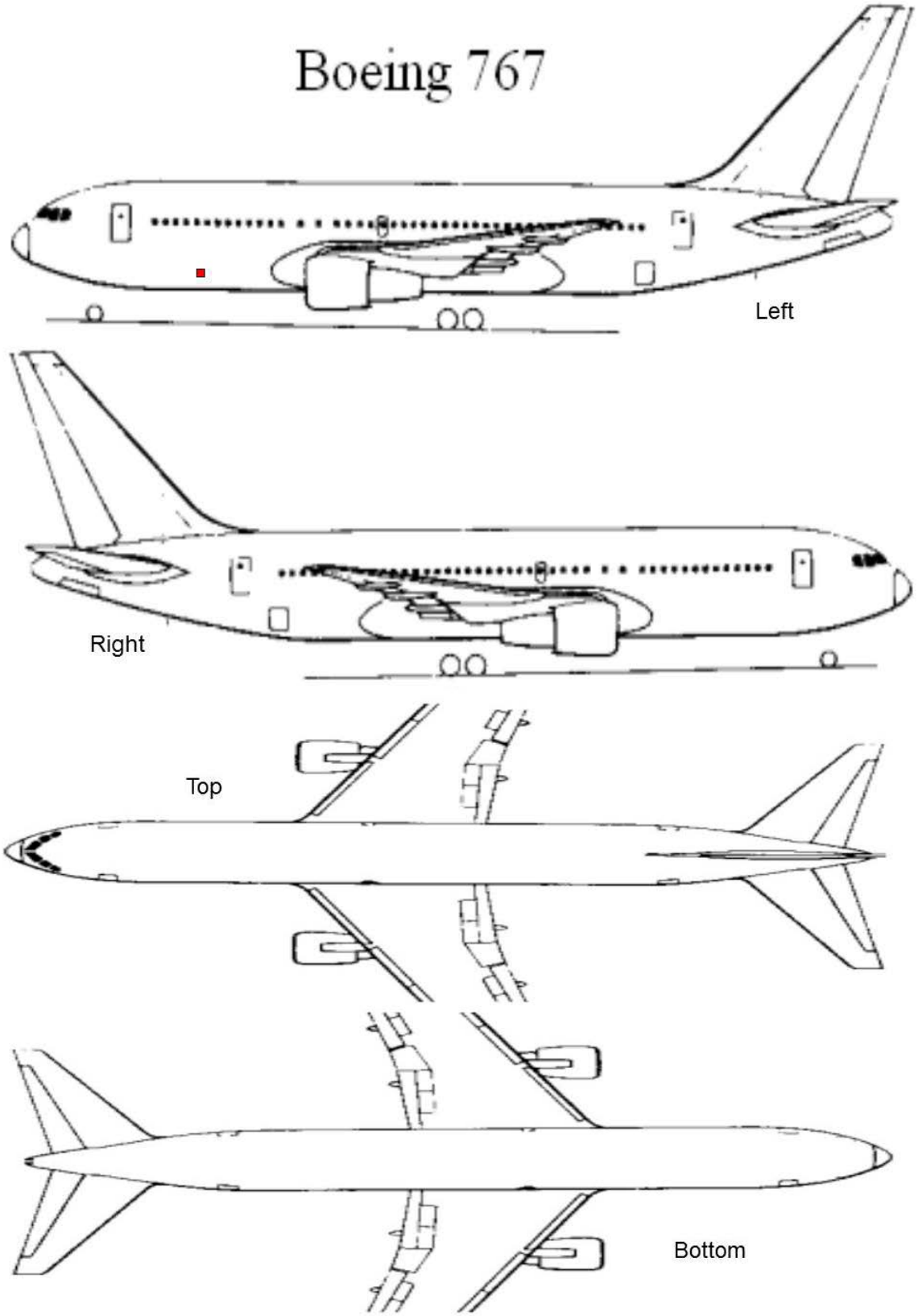


Figure A-138. RAM Location Plot Chart, Boeing 767

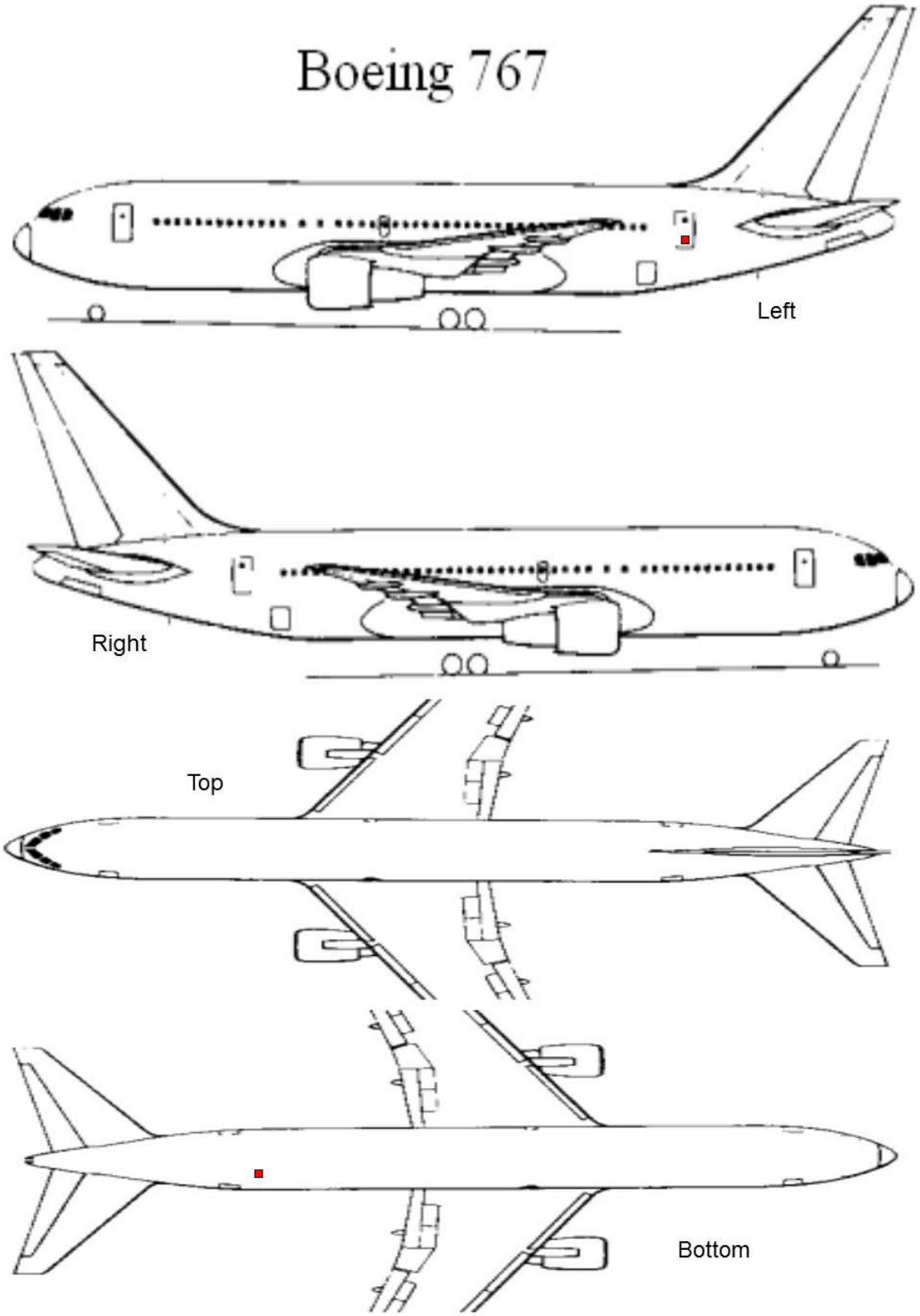


Figure A-139. RAM Location Plot Chart, Boeing 767

APPENDIX B—TABLES AND FIGURES ILLUSTRATING RAM TEARDOWN AND INSPECTION RESULTS (NON-PROPRIETARY)

Table B-1. Teardown Specimen Information, Specimen 1, and Associated RAM Information

Teardown Specimen Master

Specimen #	1	Date in Service	8/13/1981
Description	Right window lap joint modification	Total FC	73383
Model	737-200	Total FH	50255
Date Acquired	3/25/2008	Date Retired	10/17/2006

RAM

	RAM 1	RAM 2	RAM 3
RAM Location	Fuselage	Fuselage	Fuselage
Body Stations	727-907	727-907	727+11-727A+4
Stringer Numbers	10	14	14-15
Left/Right	R	R	R
Top/Bottom	-	-	-
RAM Shape	Rectangular	Rectangular	Rectangular
RAM Size (sq. in.)	2446.5	2446.5	115.5
Date RAM Applied	10/19/2000	10/19/2000	9/11/2003
FH When RAM Applied	40428	40428	45294
FC When RAM Applied	51181	51181	62880
Age of RAM (FH/FC)	9827 / 22202	9827 / 22202	4961 / 10503
Inspection Findings	No WFD indications	No WFD indications	Two holes with four cracks No WFD indications

FC = flight cycles; RAM = repairs, alterations, and modifications; FH = flight hours; WFD = widespread fatigue damage

Figure B-1. Location of Teardown Specimen for Table B-1

Table B-2. Teardown Specimen Information, Specimen 1-1, and Associated RAM Information

Teardown Specimen Master

Specimen #	1-1	Date in Service	8/13/1981
Description	-	Total FC	73383
Model	737-200	Total FH	50255
Date Acquired	3/25/2008	Date Retired	10/17/2006

RAM

ORIGINAL STRUCTURE	FROM RAM 1
RAM Location	Fuselage
Body Stations	727-907
Stringer Numbers	13-15
Left/Right	R
Top/Bottom	-
RAM Shape	Rectangular
RAM Size (sq. in.)	12349
Date RAM Applied	NA
FH When RAM Applied	NA
FC When RAM Applied	NA
Age (FH/FC)	See above
Inspection Findings	20 cracks in 11 holes

FC = flight cycles; RAM = repairs, alterations, and modifications; FH = flight hours; WFD = widespread fatigue damage

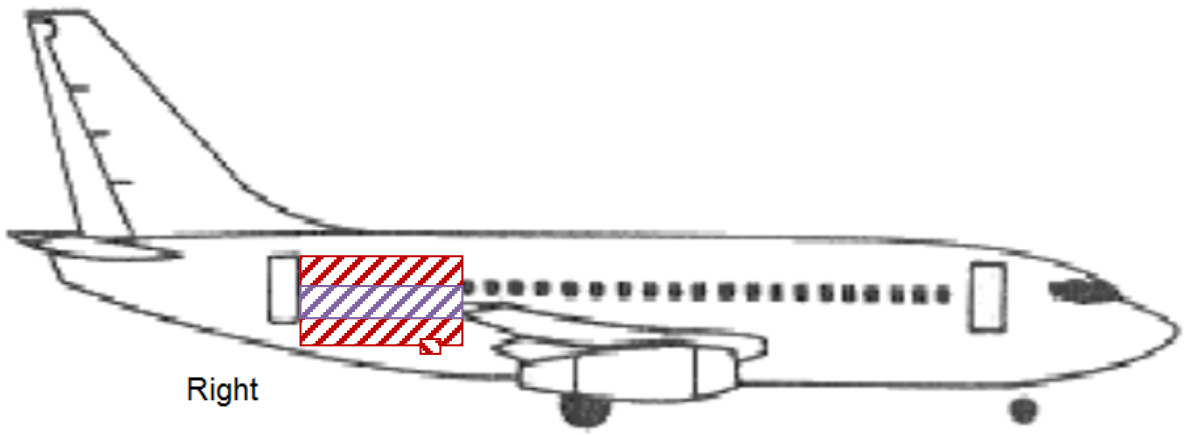


Figure B-2. Location and Teardown Specimen for Table B-2

Table B-3. Teardown Specimen Information, Specimen 2, and Associated RAM Information

Teardown Specimen Master

Specimen #	2	Date in Service	8/13/1981
Description	Left window lap joint modification	Total FC	73383
Model	737-200	Total FH	50255
Date Acquired	3/25/2008	Date Retired	10/17/2006

RAM

	RAM 1	RAM 2	RAM 3	RAM 4
RAM Location	Fuselage	Fuselage	Fuselage	Fuselage
Body Stations	727-907	727-907	767-777	727-907
Stringer Numbers	9-11	13-15	12-13	11-13
Left/Right	L	L	L	L
Top/Bottom	-	-	-	-
RAM Shape	Rectangular	Rectangular	L Shaped	Rectangular
RAM Size (sq. in.)	2446.5	2446.5	108	4
Date RAM Applied	10/19/2000	10/19/2000	5/31/2002	5/31/2002
FH When RAM Applied	40428	40428	42682	42682
FC When RAM Applied	51181	51181	58078	58078
Age of RAM (FH/FC)	9827 / 22202	9827 / 22202	Approx/15305	Approx /15305
Inspection Findings	No WFD indications	No WFD indications	No WFD indications	No WFD indications

FC = flight cycles; RAM = repairs, alterations, and modifications; FH = flight hours; WFD = widespread fatigue damage

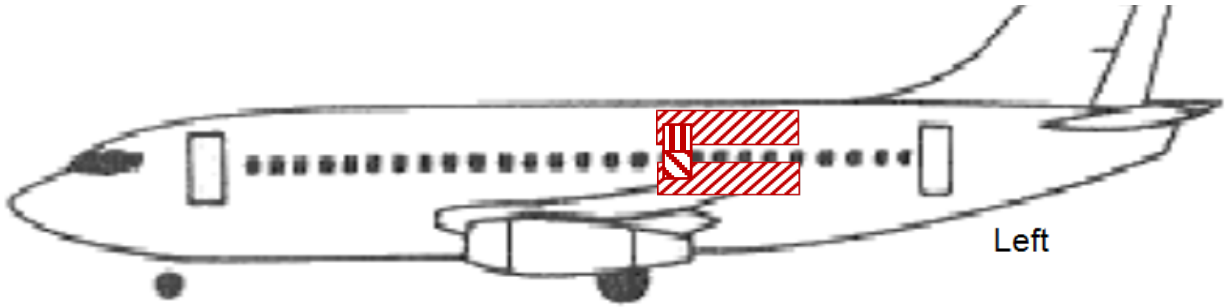


Figure B-3. Location and Teardown Specimen for Table B-3

Table B-4. Teardown Specimen Information, Specimen 3, and Associated RAM Information

Teardown Specimen Master

Specimen #	3	Date in Service	8/13/1981
Description	Left crown lap joint modification	Total FC	73383
Model	737-200	Total FH	50255
Date Acquired	3/25/2008	Date Retired	10/17/2006

RAM

	RAM 1
RAM Location	Fuselage
Body Stations	540-907
Stringer Numbers	4
Left/Right	L
Top/Bottom	-
RAM Shape	Rectangular
RAM Size (sq. in.)	4037
Date RAM Applied	3/25/2008
FH When RAM Applied	40428
FC When RAM Applied	51181
Age of RAM (FH/FC)	9827 / 22202
Inspection Findings	No WFD indication

FC = flight cycles; RAM = repairs, alterations, and modifications; FH = flight hours; WFD = widespread fatigue damage

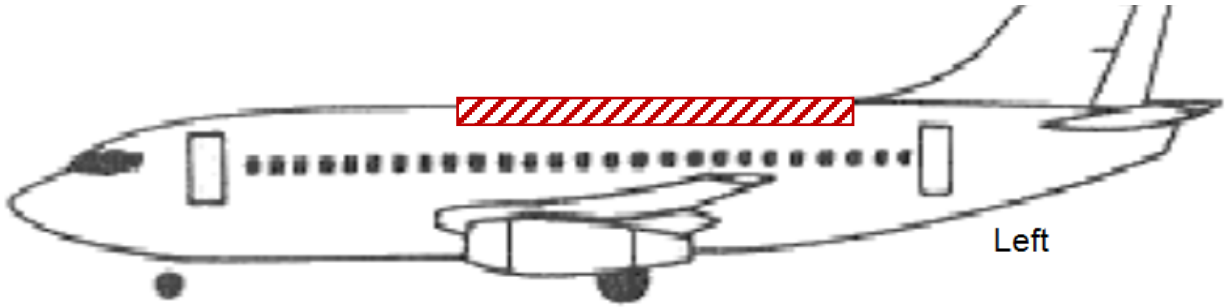


Figure B-4. Location and Teardown Specimen for Table B-4

Table B-5. Teardown Specimen Information, Specimen 4, and Associated RAM Information

Teardown Specimen Master

Specimen #	4	Date in Service	8/13/1981
Description	Right crown lap joint modification	Total FC	73383
Model	737-200	Total FH	50255
Date Acquired	3/25/2008	Date Retired	10/17/2006

RAM

	RAM 1
RAM Location	Fuselage
Body Stations	540-907
Stringer Numbers	4
Left/Right	R
Top/Bottom	-
RAM Shape	Rectangular
RAM Size (sq. in.)	4037
Date RAM Applied	10/19/2000
FH When RAM Applied	40428
FC When RAM Applied	51181
Age of RAM (FH/FC)	9827 / 22202
Inspection Findings	Cracking at two holes in stringer

FC = flight cycles; FH = flight hours; RAM = repairs, alterations, and modifications

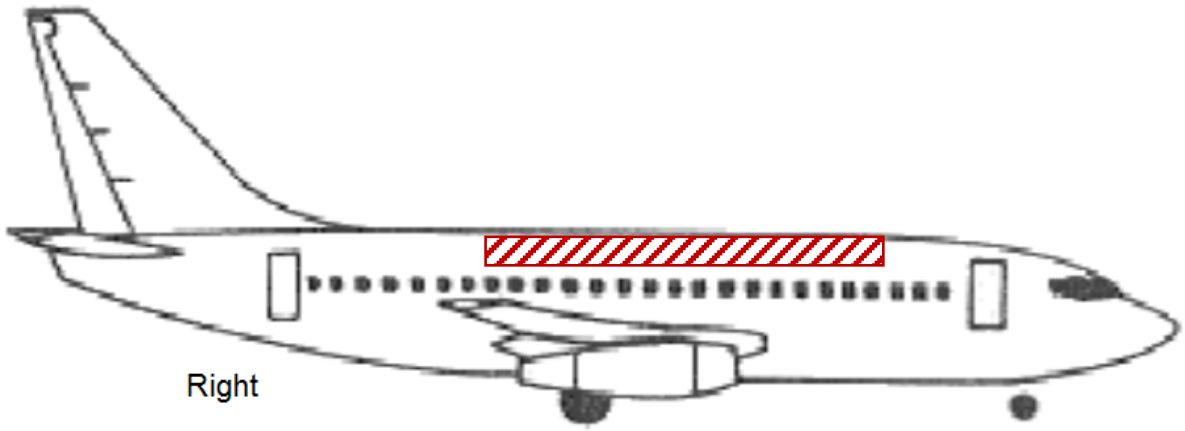


Figure B-5. Location and Teardown Specimen for Table B-5

Table B-6. Teardown Specimen Information, Specimen 5, and Associated RAM Information

Teardown Specimen Master

Specimen #	5	Date in Service	12/9/1977
Description	STC cargo door modification	Total FC	22145
Model	DC-10-30F-30	Total FH	100793
Date Acquired	4/5/2010	Date Retired	2/12/2008

RAM

	RAM 1
RAM Location	Pressurized door
Body Stations	525-869
Stringer Numbers	5-36
Left/Right	L
Top/Bottom	T
RAM Shape	Rectangular
RAM Size (sq. in.)	106640
Date RAM Applied	10/12/1995
FH When RAM Applied	71236
FC When RAM Applied	14965
Age of RAM (FH/FC)	29557 / 7180
Inspection Findings	No WFD indications

FC = flight cycles; FH = flight hours; RAM = repairs, alterations, and modifications; WFD = widespread fatigue damage

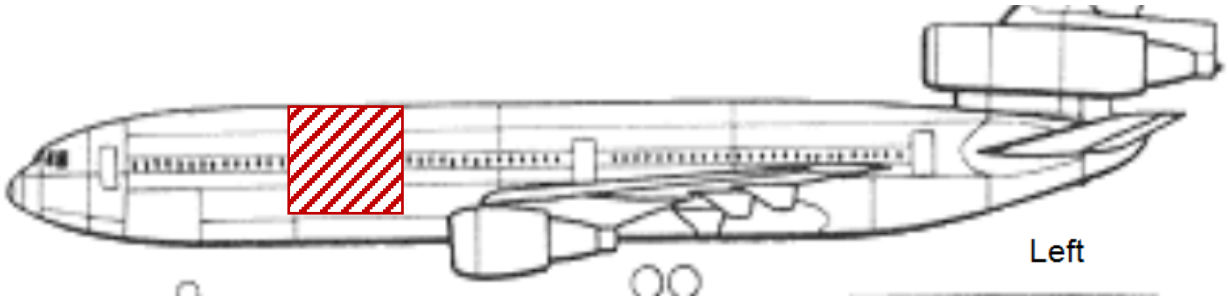


Figure B-6. Location and Teardown Specimen for Table B-6

Table B-7. Teardown Specimen Information, Specimen 6, and Associated RAM Information

Teardown Specimen Master

Specimen #	6	Date in Service	12/15/1980
Description	STC cargo door modification	Total FC	26113
Model	727-200	Total FH	39723
Date Acquired	10/9/2011	Date Retired	9/19/2008

RAM

	RAM 1
RAM Location	Pressurized door
Body Stations	480-680
Stringer Numbers	1-20
Left/Right	L
Top/Bottom	-
RAM Shape	Rectangular
RAM Size (sq. in.)	40000
Date RAM Applied	12/6/1993
FH When RAM Applied	30063
FC When RAM Applied	20712 est.
Age of RAM (FH/FC)	Est.9660 / 5401
Inspection Findings	2 cracks lower door frame in RAM. No WFD indications

FC = flight cycles; FH = flight hours; RAM = repairs, alterations, and modifications; WFD = widespread fatigue damage

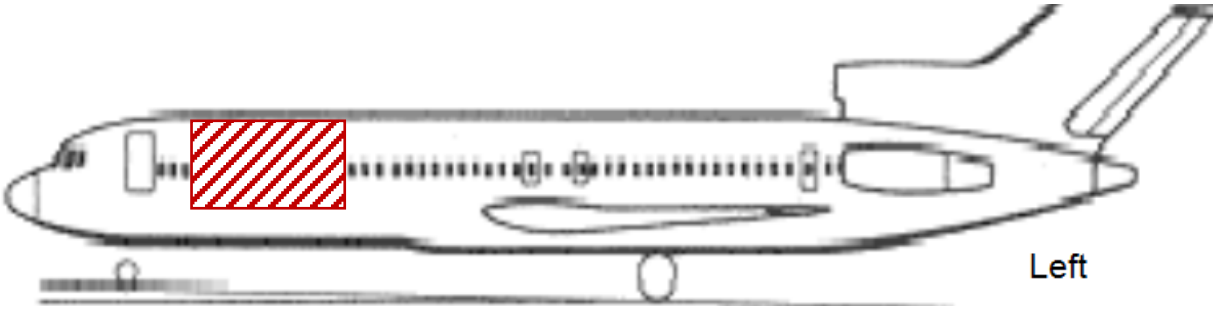


Figure B-7. Location and Teardown Specimen for Table B-7

Table B-8. Teardown Specimen Information, Specimen LR1, and Associated RAM Information

Teardown Specimen Master

Specimen #	LR1	Date in Service	9/25/1980
Description	Left lower aft lap joint repair	Total FC	18036
Model	747-200	Total FH	82768
Date Acquired	10/15/2010	Date Retired	3/12/2007

RAM

	RAM 1
RAM Location	Fuselage
Body Stations	1700-1835
Stringer Numbers	38-42
Left/Right	L
Top/Bottom	B
RAM Shape	Rectangular
RAM Size (sq. in.)	4185
Date RAM Applied	5/19/1997
FH When RAM Applied	57587
FC When RAM Applied	14259
Age of RAM (FH/FC)	25181 / 3777
Inspection Findings	No WFD indications

FC = flight cycles; FH = flight hours; RAM = repairs, alterations, and modifications; WFD = widespread fatigue damage

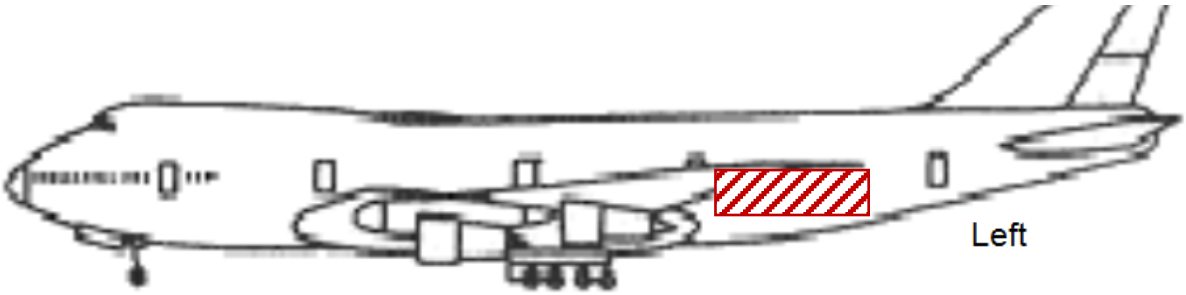


Figure B-8. Location and Teardown Specimen for Table B-8

Table B-9. Teardown and Specimen Information, Specimen LR2, and Associated RAM Information

Teardown Specimen Master

Specimen #	LR2	Date in Service	5/31/1984
Description	Fuselage skin aft pressure bulkhead web and t-cord repair	Total FC	11672
Model	747-200	Total FH	76995
Date Acquired	10/15/2010	Date Retired	3/12/2007

RAM

	RAM 1	RAM 2	RAM 3	RAM 4	RAM 5
RAM Location	Fuselage	Fuselage	Pressurized Bulkhead AFT	Pressurized Bulkhead AFT	Pressurized Bulkhead AFT
Body Stations	2360-2375	2360-2370	2360-2372	2360-2366	2360-2366
Stringer Numbers	6Rt-11Rt	14Rt-20Rt	7Rt-10Rt	16Rt-17Rt	18Rt-20Rt
Left/Right	R	R	R	R	R
Top/Bottom	T	T	T	T	T
RAM Shape	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular
RAM Size (sq. in.)	720	390	288	60	45
Date RAM Applied	3/31/2000	3/31/2000	3/31/2000	3/31/2000	3/31/2000
FH When RAM Applied	64419	64419	64419	64419	64419
FC When RAM Applied	9711	9711	9711	9711	9711
Age of RAM (FH/FC)	12576/1961	12576/1961	12576/1961	12576/1961	12576/1961
Inspection Findings	No WFD indication	No WFD indication	No WFD indication	No WFD indication	No WFD indication

FC = flight cycles; FH = flight hours; RAM = repairs, alterations, and modifications; WFD = widespread fatigue damage

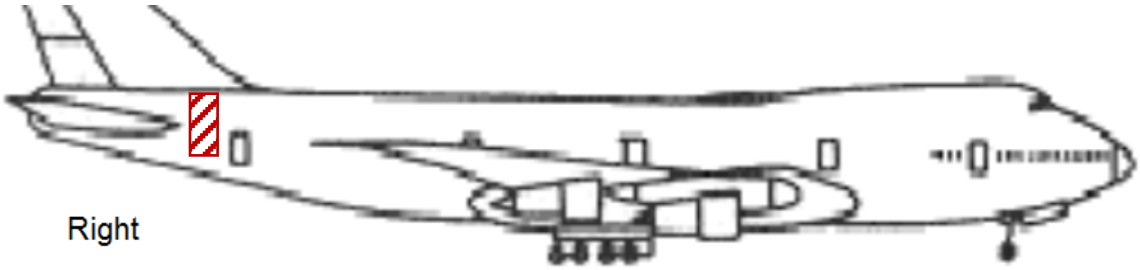


Figure B-9. Location and Teardown Specimen for Table B-9

Table B-10. Teardown Specimen Information, Specimen LR3, and Associated RAM Information

Teardown Specimen Master

Specimen #	LR3	Date in Service	4/15/1983
Description	Fuselage skin repair	Total FC	34580
Model	757-200	Total FH	77163
Date Acquired	1/8/2010	Date Retired	2/8/2010

RAM

	RAM 1	RAM 2	RAM 3
RAM Location	Fuselage	Fuselage	Fuselage
Body Stations	570-580	600-618	645-652
Stringer Numbers	15-16	14-22	20-21
Left/Right	L	L	L
Top/Bottom	-	-	-
RAM Shape	Rectangular	Rectangular	Rectangular
RAM Size (sq. in.)	120	864	195
Date RAM Applied	9/27/2007	10/2/2007	1/15/2003
FH When RAM Applied	71370	71370	57861
FC When RAM Applied	32226	32226	26286
Age of RAM (FH/FC)	5793 / 2350	5793 / 2350	19302 / 8294
Inspection Findings	No WFD indications	No WFD indications	No WFD indications

FC = flight cycles; FH = flight hours; RAM = repairs, alterations, and modifications; WFD = widespread fatigue damage

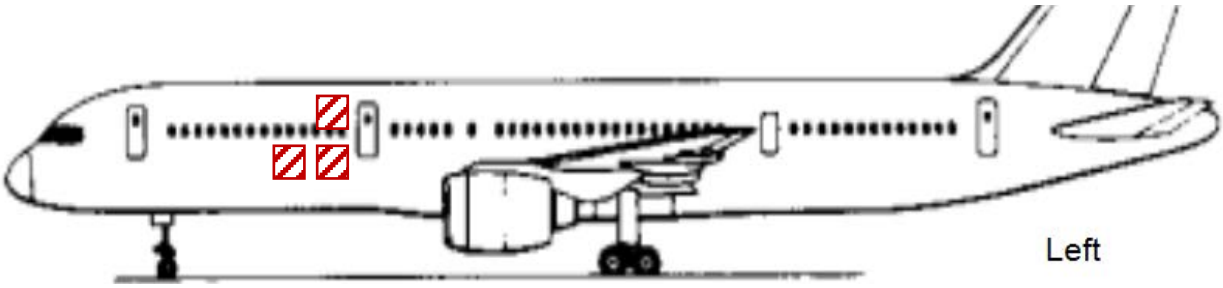


Figure B-10. Location and Teardown Specimens for Table B-10

Table B-11. Teardown Specimen Information, Specimen LR4, and Associated RAM Information

Teardown Specimen Master

Specimen #	LR4	Date in Service	1/18/1980
Description	Left rear wing spar	Total FC	34671
Model	A300-B4-203	Total FH	48289
Date Acquired	10/30/2010	Date Retired	10/22/2010

RAM

	RAM 1
RAM Location	Wing
Wing Station	47
Stringer Numbers	N/A
Left/Right	L
Top/Bottom	B
RAM Shape	Rectangular
RAM Size (sq. in.)	> 500
Date RAM Applied	7/12/2002
FH When RAM Applied	32468
FC When RAM Applied	24640
Age of RAM (FH/FC)	15817 / 10031
Inspection Findings	Hole #s 44 and 187 cracked. No WFD indications

FC = flight cycles; FH = flight hours; RAM = repairs, alterations, and modifications; WFD = widespread fatigue damage

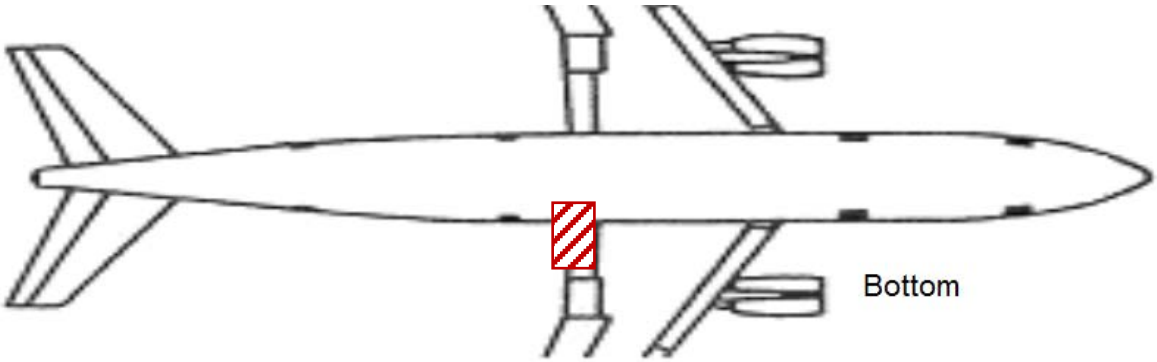


Figure B-11. Location and Teardown Specimen for Table B-11

Table B-12. Teardown Specimen Information, Specimen LR5, and Associated RAM Information

Teardown Specimen Master

Specimen #	LR5	Date in Service	1/18/1980
Description	Right window lap joint modification	Total FC	34671
Model	A300-B4-203	Total FH	48289
Date Acquired	10/30/2010	Date Retired	10/22/2010

RAM

	RAM 1
RAM Location	Fuselage
Body Stations	33-40
Stringer Numbers	22
Left/Right	R
Top/Bottom	-
RAM Shape	Rectangular
RAM Size (sq. in.)	1250
Date RAM Applied	1/4/1997
FH When RAM Applied	39554
FC When RAM Applied	27905
Age of RAM (FH/FC)	8735 / 6766
Inspection Findings	No WFD indications

FC = flight cycles; FH = flight hours; RAM = repairs, alterations, and modifications; WFD = widespread fatigue damage

Figure B-12. Location and Teardown Specimen for Table B-12

Table B-13. Teardown Specimen Information, Specimen LR6, and Associated RAM Information

Teardown Specimen Master

Specimen #	LR6	Date in Service	1/18/1980
Description	Right window lap joint modification	Total FC	34671
Model	A300-B4-203	Total FH	48289
Date Acquired	10/30/2010	Date Retired	10/22/2010

RAM

	RAM 1
RAM Location	Fuselage
Body Stations	28-36
Stringer Numbers	31
Left/Right	R
Top/Bottom	-
RAM Shape	Rectangular
RAM Size (sq. in.)	1550
Date RAM Applied	10/21/1998
FH When RAM Applied	14041
FC When RAM Applied	10066
Age of RAM (FH/FC)	34248 / 24605
Inspection Findings	No WFD indications

FC = flight cycles; FH = flight hours; RAM = repairs, alterations, and modifications; WFD = widespread fatigue damage

Figure B-13. Location and Teardown Specimen for Table B-13

Table B-14. Teardown Specimen Information, Specimen LR7, and Associated RAM Information

Teardown Specimen Master

Specimen #	LR7	Date in Service	1/18/1980
Description	Gross weight increase skin doubler modification	Total FC	34671
Model	A300-B4-203	Total FH	48289
Date Acquired	10/30/2010	Date Retired	10/22/2010

RAM

	RAM 1	RAM 2
RAM Location	Fuselage	Fuselage
Body Stations	54A-55	54A-55
Stringer Numbers	34-41	34-41
Left/Right	L	R
Top/Bottom	-	-
RAM Shape	Rectangular	Rectangular
RAM Size (sq. in.)	2560	2560
Date RAM Applied	2/17/1998	2/17/1998
FH When RAM Applied	40357	40357
FC When RAM Applied	28254	28254
Age of RAM (FH/FC)	7932 / 6417	7932 / 6417
Inspection Findings	No WFD indications	No WFD indications

FC = flight cycles; FH = flight hours; RAM = repairs, alterations, and modifications; WFD = widespread fatigue damage

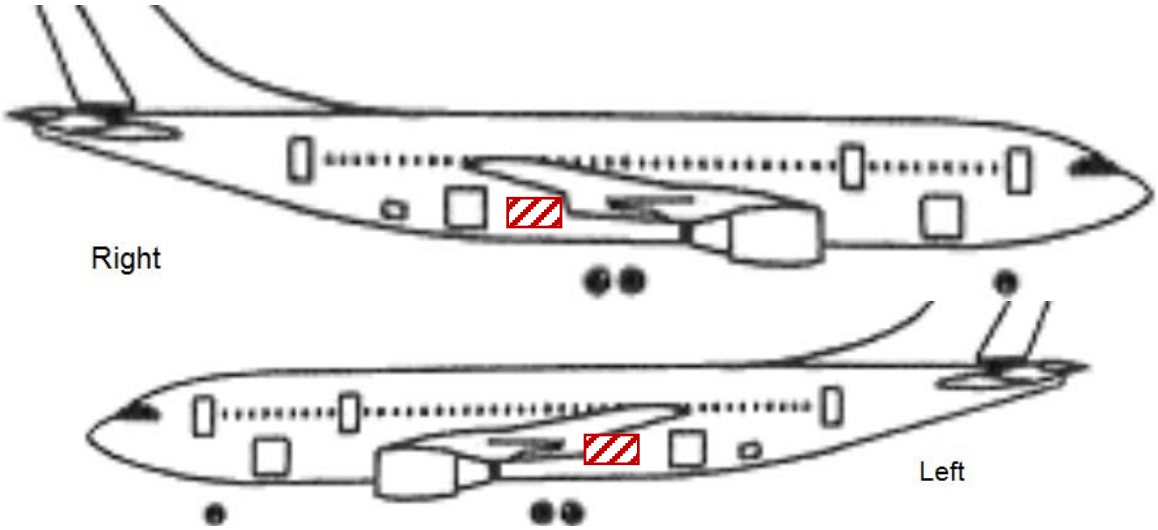


Figure B-14. Location and Teardown Specimen for Table B-14

Table B-15. Teardown Specimen Information, Specimen LR8, and Associated RAM Information

Teardown Specimen Master

Specimen #	LR8	Date in Service	8/13/1981
Description	Fuselage skin repair	Total FC	73383
Model	737-200	Total FH	50255
Date Acquired	7/19/2010	Date Retired	10/17/2006

RAM

	RAM 1
RAM Location	Fuselage
Body Stations	727+14 – 727B+10
Stringer Numbers	15-19
Left/Right	L
Top/Bottom	-
RAM Shape	Rectangular
RAM Size (sq. in.)	600
Date RAM Applied	5/20/2005
FH When RAM Applied	48697
FC When RAM Applied	68711
Age of RAM (FH/FC)	1558 / 4672
Inspection Findings	Cracking in original skin only. No WFD indications

FC = flight cycles; FH = flight hours; RAM = repairs, alterations, and modifications; WFD = widespread fatigue damage

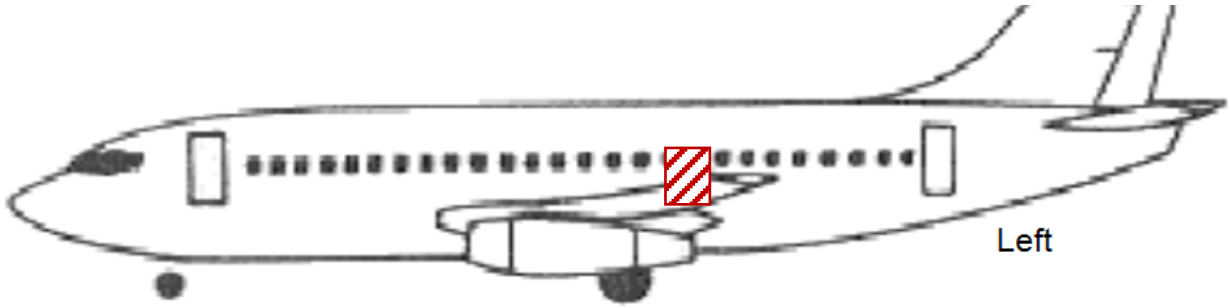


Figure B-15. Location and Teardown Specimen for Table B-15

Table B-16. Teardown Specimen Information, Specimen LR9, and Associated RAM Information

Teardown Specimen Master

Specimen #	LR9	Date in Service	8/13/1981
Description	Fuselage skin repair at potable water port	Total FC	73383
Model	737-200	Total FH	50255
Date Acquired	7/19/2010	Date Retired	10/17/2006

RAM

	RAM 1	RAM 2
RAM Location	Fuselage	Fuselage
Body Stations	930-970	955-970
Stringer Numbers	23-27	21-23
Left/Right	L	L
Top/Bottom	B	B
RAM Shape	Rectangular	Rectangular
RAM Size (sq. in.)	1144	145
Date RAM Applied	4/18/2001	Unknown
FH When RAM Applied	41258	Unknown
FC When RAM Applied	53009	Unknown
Age of RAM (FH/FC)	8997 / 20374	Unknown
Inspection Findings	No WFD indications	No WFD indications

FC = flight cycles; FH = flight hours; RAM = repairs, alterations, and modifications; WFD = widespread fatigue damage

Figure B-16. Location and Teardown Specimen for Table B-16

Table B-17. Teardown Specimen Information, Specimen LR10, and Associated RAM Information

Teardown Specimen Master

Specimen #	LR10	Date in Service	8/13/1981
Description	Lower aft fuselage skin repair	Total FC	73383
Model	737-200	Total FH	50255
Date Acquired	7/19/2010	Date Retired	10/17/2006

RAM

	RAM 1
RAM Location	Fuselage
Body Stations	834-899
Stringer Numbers	25L-25R
Left/Right	Spans both
Top/Bottom	B
RAM Shape	L shaped
RAM Size (sq. in.)	2020
Date RAM Applied	6/19/2001
FH When RAM Applied	40752 approx.
FC When RAM Applied	57201 approx.
Age of RAM (FH/FC)	9503 / 16182
Inspection Findings	No WFD indications

FC = flight cycles; FH = flight hours; RAM = repairs, alterations, and modifications; WFD = widespread fatigue damage

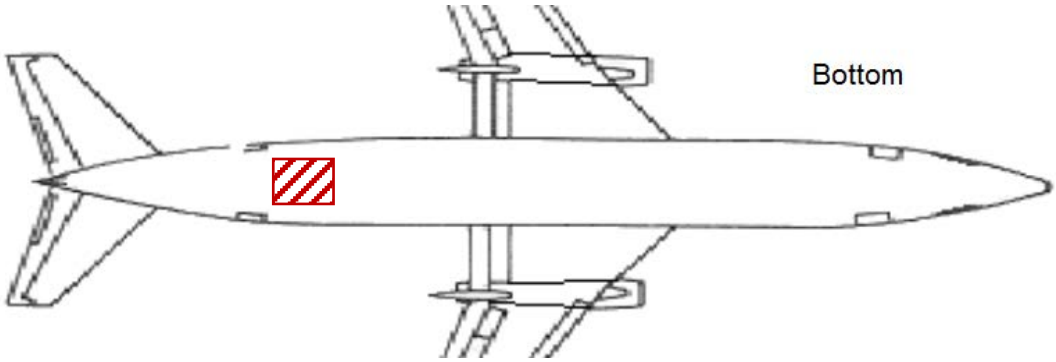


Figure B-17. Location and Teardown Specimen for Table B-17

Table B-18. Teardown Specimen Information, Specimen LR11, and Associated RAM Information

Teardown Specimen Master

Specimen #	LR11	Date in Service	4/15/1983
Description	Fuselage skin repair	Total FC	34580
Model	757-200	Total FH	77163
Date Acquired	11/30/2010	Date Retired	2/8/2010

RAM

	RAM 1
RAM Location	Fuselage
Body Stations	290-340
Stringer Numbers	11-19
Left/Right	L
Top/Bottom	T
RAM Shape	Rectangular
RAM Size (sq. in.)	900
Date RAM Applied	5/6/2005
FH When RAM Applied	64535
FC When RAM Applied	29259
Age of RAM (FH/FC)	12628 / 5321
Inspection Findings	No WFD indications

FC = flight cycles; FH = flight hours; RAM = repairs, alterations, and modifications; WFD = widespread fatigue damage

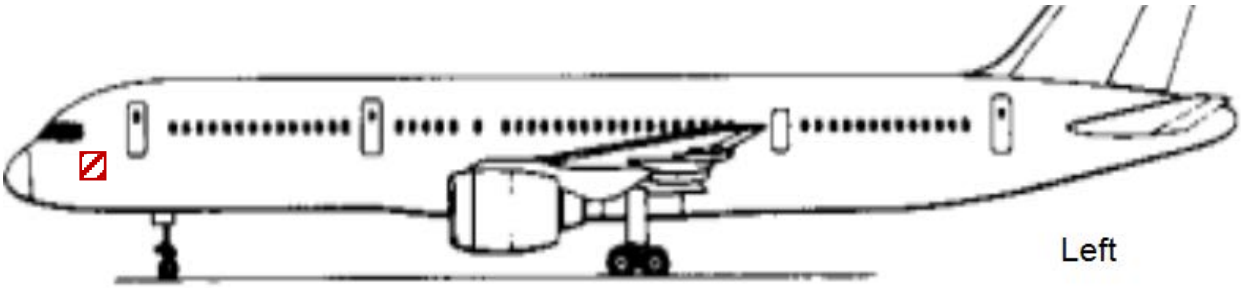


Figure B-18. Location and Teardown Specimen for Table B-18

Table B-19. Teardown Specimen Information, Specimen LR12, and Associated RAM Information

Teardown Specimen Master

Specimen #	LR12	Date in Service	12/22/1982
Description	Fuselage skin repair	Total FC	34678
Model	757-200	Total FH	77821
Date Acquired	11/8/2010	Date Retired	2/3/2010

RAM

	RAM 1
RAM Location	Fuselage
Body Stations	590-630
Stringer Numbers	17-18
Left/Right	L
Top/Bottom	-
RAM Shape	L shaped
RAM Size (sq. in.)	1072
Date RAM Applied	4/19/2000
FH When RAM Applied	46699
FC When RAM Applied	21490
Age of RAM (FH/FC)	31122 / 13188
Inspection Findings	No WFD indications

FC = flight cycles; FH = flight hours; RAM = repairs, alterations, and modifications; WFD = widespread fatigue damage

Figure B-19. Location and Teardown Specimen for Table B-19

Table B-20. Teardown Specimen Information, Specimen LR13, and Associated RAM Information

Teardown Specimen Master

Specimen #	LR13	Date in Service	1/1/1969
Description	Fuselage skin repair	Total FC	49153
Model	DC-9-33F	Total FH	52809
Date Acquired	11/30/2010	Date Retired	2/28/2008

RAM

	RAM 1
RAM Location	Fuselage
Body Stations	760-813
Stringer Numbers	14-22
Left/Right	R
Top/Bottom	B
RAM Shape	Rectangular
RAM Size (sq. in.)	1344
Date RAM Applied	5/17/1999
FH When RAM Applied	50832
FC When RAM Applied	45832
Age of RAM (FH/FC)	1977 / 3321
Inspection Findings	No WFD indication

FC = flight cycles; FH = flight hours; RAM = repairs, alterations, and modifications; WFD = widespread fatigue damage

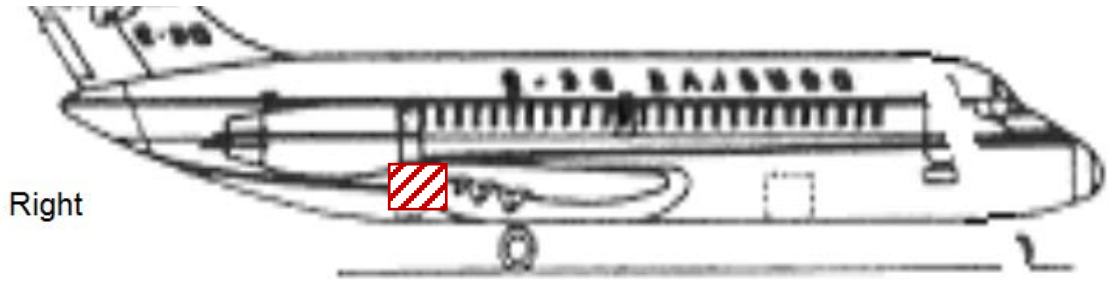


Figure B-20. Location and Teardown Specimen for Table B-20

Table B-21. Teardown Specimen Information, LR14, and Associated RAM Information

Teardown Specimen Master

Specimen #	LR14	Date in Service	4/13/1994
Description	Fuselage skin repair	Total FC	40238
Model	A320-200	Total FH	Unknown
Date Acquired	12/10/2010	Date Retired	3/1/2010

RAM

	RAM 1	RAM 2
RAM Location	Fuselage	Fuselage
Body Stations	69-70	69-70
Stringer Numbers	16-19	22-25
Left/Right	L	L
Top/Bottom	-	-
RAM Shape	Rectangular	Rectangular
RAM Size (sq. in.)	320	200
Date RAM Applied	6/23/99	6/23/99
FH When RAM Applied	9386	9386
FC When RAM Applied	12333	12333
Age of RAM (FH/FC)	Unknown / 27905	Unknown/27905
Inspection Findings	No WFD indications	1 crack at door corner. No WFD indications

FC = flight cycles; FH = flight hours; RAM = repairs, alterations, and modifications; WFD = widespread fatigue damage

Figure B-21. Location and Teardown Specimen for Table B-21

Table B-22. Teardown Specimen Information, LR15, and Associated RAM Information

Teardown Specimen Master

Specimen #	LR15	Date in Service	4/13/1992
Description	Fuselage skin repair at static ports	Total FC	23909
Model	A320-200	Total FH	52804
Date Acquired	7/7/2010	Date Removed	11/20/2009

RAM

	RAM 1	RAM 2	RAM 3
RAM Location	Fuselage	Fuselage	Fuselage
Body Stations	813-874	813-950	709-737
Stringer Numbers	26-27	26-27	24-26
Left/Right	R	R	R
Top/Bottom	B	B	B
RAM Shape	Rectangular	Rectangular	Rectangular
RAM Size (sq. in.)	375	564	104.5
Date RAM Applied	1/15/2009	1/15/2009	1/15/2009
FH when RAM Applied	40454	40454	40454
FC when RAM Applied	17912	17912	17912
Age of RAM (FH/FC)	12350 / 5997	12350 / 5997	12350 / 5997
Inspection Findings	No WFD indications	No WFD indications	No WFD indications

FC = flight cycles; FH = flight hours; RAM = repairs, alterations, and modifications; WFD = widespread fatigue damage

Figure B-22. Location and Teardown Specimen for Table B-22

Table B-23. Teardown Specimen Information, LR16, and Associated RAM Information

Teardown Specimen Master

Specimen #	LR16	Date in Service	1/16/1984
Description	Fuselage skin repair at VHF antenna	Total FC	38240
Model	757-200	Total FH	74294
Date Acquired	11/30/2010	Date Retired	6/13/2008

RAM

	RAM 1
RAM Location	Fuselage
Body Stations	715-740
Stringer Numbers	28L-28R
Left/Right	Spans bottom
Top/Bottom	Spans bottom
RAM Shape	Rectangular
RAM Size (sq. in.)	2100
Date RAM Applied	10/22/2002
FH When RAM Applied	57311
FC When RAM Applied	31311
Age of RAM (FH/FC)	16984 / 6929
Inspection Findings	No WFD indications

FC = flight cycles; FH = flight hours; RAM = repairs, alterations, and modifications; WFD = widespread fatigue damage

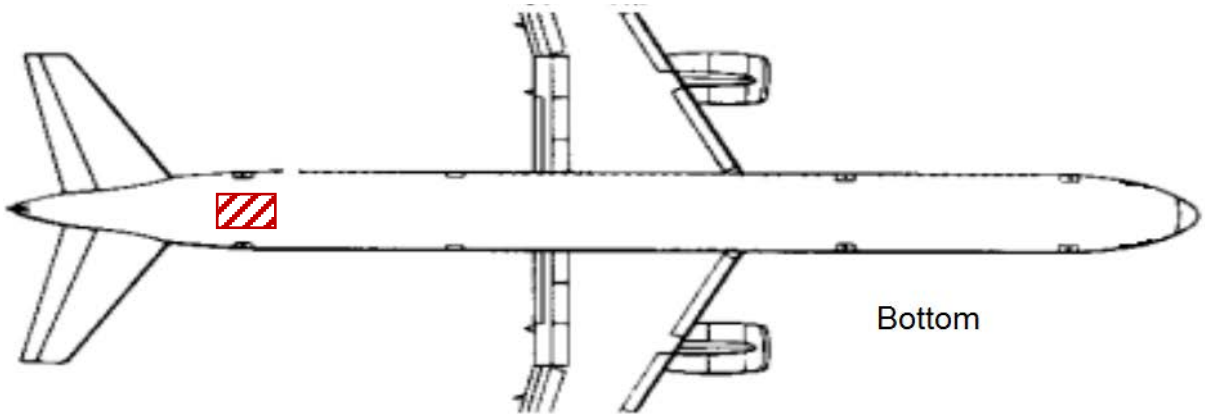


Figure B-23. Location and Teardown Specimen for Table B-23