CONTENTS

REQUIREMENTS AND MAJOR DECISION OUTLINE: TOTAL PROGRAM

by
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The 727 design was originally laid out in 1959 and 1960 - almost 20 years ago. Since that time, the production rate has varied but, with almost 1400 commercial airplanes and the equivalent of over ten billion 1978 dollars having passed through the factory and office doors, we are now increasing our production rate from 7 to 12 aircraft per month. While we no doubt did a good many things wrong, it would seem we must have done some things right.

As you are no doubt aware, Boeing is now involved in a design process which may eventually lead to three different new airplane designs - the 757, the 767 and the 777. This has limited the time available for developing and refining the complicated case study of the 727. Thus, this presentation has been created and will be presented by several individuals, all of whom have been involved in the total 727 program over the past two decades. Data and figures developed at the time will be mainly used. I'm going to cover the requirements and outline some major decisions encompassing the total program. Although many people were involved in 727 engineering decisions, I was the Chief Engineer of the design, and also its Program Manager during program initiation. I will be followed by Gerry Bowes with the story of the 727 aerodynamic configuration development. Gerry was one of the 727's top aerodynamicists, and today runs our wind tunnel operations. He will be followed by Fred Maxam, who will cover the design development of the 727. Fred was the 727 Chief Project Engineer - Systems and today is the Director of Engineering for the 707/727/737 Division. Following Fred will be Lew Wallick, the first pilot to fly the 727 and now Boeing's Chief of Flight Test. Lew will discuss the 727 flight test program. Next Mark Gregorie will cover the later development of the 727-200, without which the program would not be complete. Mark spent many years in 727 aerodynamics and is currently responsible for 727 Marketing Management. Finally, I will give a brief wrap-up summarizing what I believe are the overall principal lessons learned.

In working with this format, and limited time for refinement, the written material contains a little over-lap and repetition, which I hope you will excuse. *Also, some of the material would be different if created today.*

Now for the major decisions. They will not necessarily be covered in chronological order.

1. The Basic Idea

The Boeing Company became convinced in 1950 that its future lay in jets, having flown the B-47 in 1947 and having started the B-52 in 1948. We decided, at that time, to skip the entire turbo-prop field and attempted to launch a four-engine P&W JT3 powered commercial jet transport of about 100 passengers. But in 1950 we were unable to convince the airlines of the desirability of such a jet program. 1951 was spent with the same lack of success in attempting to sell a similar concept to the U.S. Government as a tanker to succeed the KC-97. With these disappointments behind us, we initiated a totally Boeing-funded single airplane prototype of the 707 in early 1952 and flew it in 1954. The KC-135 was a Government tanker off-shoot of this commercial prototype, and we finally sold the 707 as a commercial airplane in 1955 to be delivered in late 1958.

We were so convinced that the future lay in jets, even for medium and short range work, that in 1956 we initiated a study of a smaller four-engined mini-707 and also a two-engine airplane with engines mounted under the wing - 707 style. This low profile program continued until mid-1958, still five months before the first 707 delivery, when we organized a larger effort under the model number 727. (The number 717 had been assigned to the KC-135.)

The 727 basic design evolved during 1959 and 1960, and by the end of 1960, 80 airplanes had been ordered, 40 each by United and Eastern. The airplane was first flown in early 1963, with certification and first customer delivery late that year.

Meantime, the 707 program, starting with the medium range 707-120, had spawned the long range 707-320 followed by the advanced medium range 720.

We were well aware at the time of the 727 design that we were not tackling an easy job. The general situation is shown in Figure 1.

RANGE	TIMING	REQUIRED STATE-OF-THE-ART	COMPETITIVE SITUATION
MEDIUM	1	LOWEST	GREATEST IMPACT JET VS PISTON
LONG	2	IMPROVED ENGINES EXPLOITED AIRFRAME	OFFERS GREATEST SPEED IMPROVEMENT
SHORT	3	HIGHEST	MOST DIFFICULT

Figure 1.— Jet Development Sequence

In addition, the 707 program was overrunning its costs, and many within the Company felt that we had once again proved that commercial airplane programs offered nothing but grief and financial loss. Nor was the airline industry very receptive, with the Comet having had serious trouble and the 707 not as yet established.

Figure 2 is an approximation of the chase around we did on the configuration between 1957 and 1959.

There are some sidelights relative to the airline requirements that go along with Figure 2. As noted, we started with the obvious miniaturized 707 just as our competitor - Douglas - started with a miniaturized DC8, which they called the DC9. They "sold" the

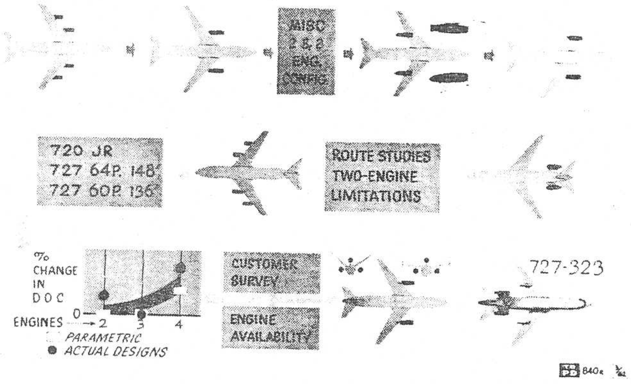

Figure 2.— 727 Development History

four-engine DC9 to United Airlines long before we sold United the 727. However, the sale was contingent on Douglas obtaining another major customer, which was never obtained and the program died.

The Boeing Board of Directors similarly insisted that we have orders from two of the major four U.S. domestic airlines which, at that time, were United, American, Eastern and TWA before we could start the 727 program. Part of the problem depicted in Figure 2 was the near impossibility of fulfilling that requirement. TWA was not in a financial condition to buy anybody's short range airplane. American had already purchased a large number of Lockheed Electras with initial delivery in October 1958, the same month as the first delivery of the 707. American had all they could do to introduce their Electra fleet and had no interest in taking on another airplane.

United, as in the case of Douglas, was willing to buy a four-engine airplane, but because of their Denver situation and its high altitude consequences, were, at that time, unwilling to consider a two-engine airplane. Eastern, even though they also had purchased a fleet of Electras, perceived the advantages of the jet and were willing to entertain the purchase of a jet replacement for the Electra, providing its economics were competitive. They believed that such economics could only be obtained through the use of two engines.

Thus, to launch the 727 program, we had to some way, find a middle ground between United's desire for four engines and Eastern's desire for two. The middle ground proved to be a three-engine airplane, and this, more than any other one factor, led to the three engines on the 727.

The physical size of the 727 was always about the same as that of the Electra, as illustrated by Figure 3.

Making airplanes smaller than the 707, in this case, created real economic problems as illustrated by Figure 4.

Thus, the 727 wound up with about the same cabin length as the Electra, but with six-abreast seating instead of five. Seat number, it must be remembered, is a function of percent first class and tourist. At the time of the 727's development, we tended to use a greater percent first class than is now the case. This partially explains the low passenger numbers noted in Figure 2. The rest of the explanation is related to adding passengers by every conceivable means in order to be economically competitive with the Electra.

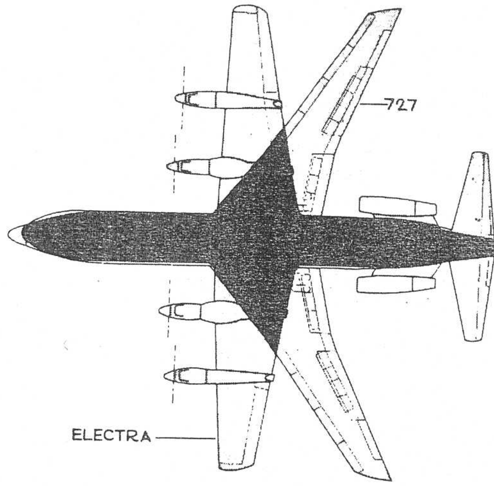

Figure 3. — Size Comparison

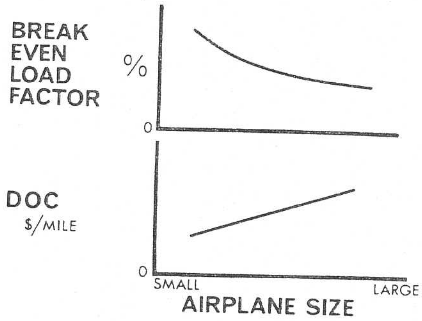

Figure 4.— D.O.C. Trends

The basic success requirements for this type of airplane are listed in Figure 5.

Meeting the requirements involved a conflict between economics and performance which shaped the entire airplane design.

- MAXIMUM PASSENGER APPEAL
- LOW DIRECT OPERATING COST
  - MINIMUM GROUND TIME
  - MAXIMUM CLIMB & DESCENT RATES
  - RELIABILITY
- SHORT FIELD CAPABILITY
- LOW COMMUNITY NOISE
- ALL WEATHER OPERATION
- OPERATIONAL FLEXIBILITY & SELF SUFFICIENCY
- HIGH PROFIT POTENTIAL

Figure 5.— Requirements for Success

2. Basic Wing Design

The most difficult single challenge on the 727 program was design of the wing. Airfoils, of course, had improved considerably since the original 707, and both NACA and Boeing technology were employed in the 727 airfoil selection. The extreme change in thickness ratio with a thin wing in the outboard two-thirds of span accompanied by rapid thickening as the wing approached the body in the inboard quarter had been pioneered on the B-52 and, of course, was used in all versions of the 707. Since the 727 was being designed for more landings per flight hour, shorter fields, and greater weather reliability, it was necessary that a top notch set of flight characteristics result. United Airlines was convinced that this required 30° of sweepback. Their DC8's had 30°, whereas all the Boeing products had 35°. While we, as engineers, knew that the difference between 30° and 35° was not very significant and could be masked by many other characteristics, we adopted a compromise position of 32-1/2° in an attempt to accommodate airline requirements and desires. (It later was called 32° and still is.) These were the easy parts of the wing design.

Selection of the flaps, slats, spoilers, and ailerons will be covered in subsequent sections. The final layout appeared as shown in Figure 6.

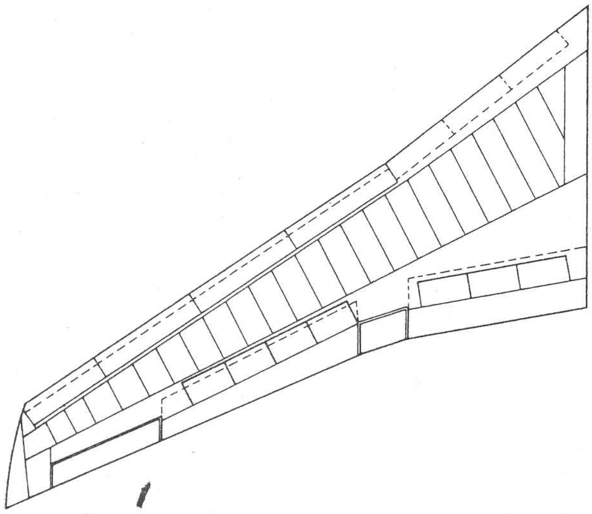

Figure 6.— Wing Layout

The real problem was the compromise between economics and performance. We wanted the smallest possible wing to help direct operating costs, and yet we wanted low approach speed and short field length - plus excellent flight handling characteristics. The landing field length objective was fixed: LaGuardia's runway 4-22, the only instrument runway at LaGuardia, with a length of 4860 feet (it's been lengthened since then).

From 1959 on we had growth potential constantly in mind, and one of the limitations to growth potential is wing fuel capacity. In addition, we wanted to have an airplane that could be sold to the U.S. military, and we knew this would require longer range. Thus, we bent the front spar to allow the center section to have an increased fuel capacity (it is very thick as well). The rear spar was left straight, with the trailing edge broken to facilitate installation of the gear.

Sufficient wing fuel venting capacity was built into the wing upper surface stringers so as not only to vent the entire center section, but very large body tanks as well. This was basically targeted at the military requirement. Those vents are carried around by every 727 flying even though none were ever sold to the U. S. military. The capacity did come in handy some years later though in extended range commercial versions which used center tanks plus heavily protected fuselage tanks.

The attainment of excellent economics and very short fields meant a super high lift system and that's where the triple slotted flap system came from, plus the large leading edge slats and Kruger flaps. As noted, these will be discussed by others later in this presentation. Their development rested on a privately-funded Boeing base of high lift technology which had more or less solved the aerodynamic parts of the triple slotted flap, large slat configuration, but had not solved the mechanical parts.

3. The Landing Gear

We originally felt that regardless of engine placement, the landing gear should be housed in a pod - a small thin wing did not provide a particularly good stowage area. Some of the compromises we looked at are shown in Figure 7.

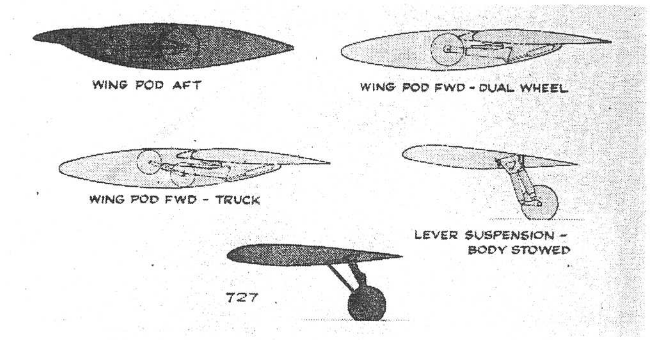

Figure 7.— Gear Configuration Examples

We finally settled on a skewed axis, dog-legged oleo strut designed as shown at the bottom of the figure. It enabled us to get rid of the external pod and still have a ground wheel position that was far aft, permitting loading flexibility.

4. The Horizontal Tail

All previous Boeing jet airplanes had had low horizontal tails (except the B-47 mid-tail) and we were acutely aware of some of the problems that "T" tails can get one into. Some of the configurations we tried are shown on Figure 8.

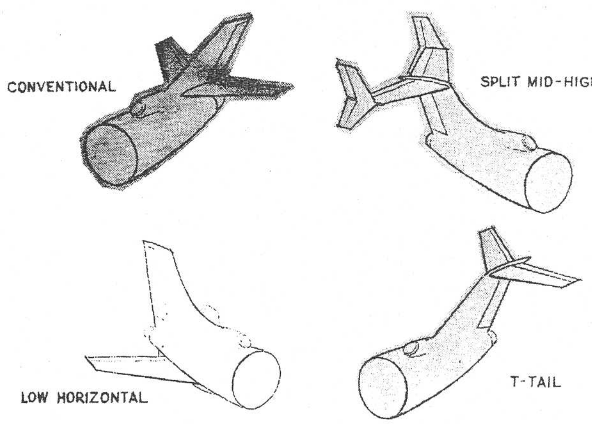

Figure 8.— Tail Configuration Examples

The one identified as "conventional" was aerodynamically unattractive, and the one identified as "low horizontal" gave us serious problems with the installation of the third engine. We finally decided on the "T" tail despite its difficulties.

Among other things, we made very extensive flutter investigations with both low and high speed flutter models. This was our first experience with high speed flutter models, one of which is shown in Figure 9. Prevention of flutter is the reason for the 727's horizontal tail anhedral.

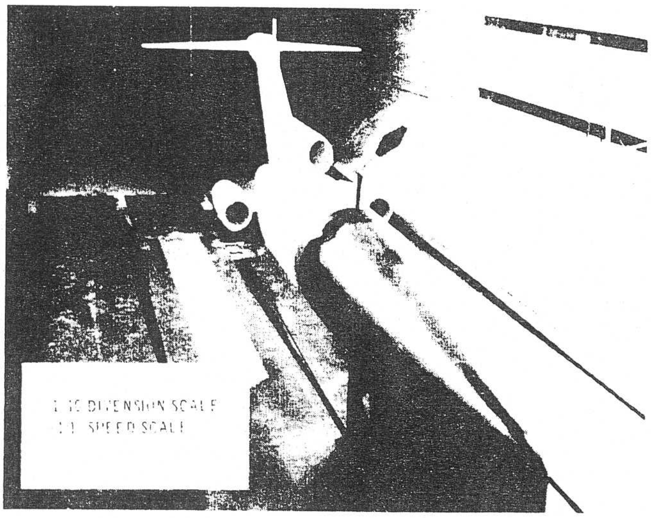

Figure 9. — Transonic Flutter Model

I noted earlier that we were familiar with "T" tail troubles and we were, more or less. However, the BAC-111 locked-in-stall accidents had not yet happened and neither we nor, so far as we knew, had anyone else really tested at angles of attack approaching 40° (we later did - both in the wind tunnel and in flight). However, we did have one previous experience with a configuration which tended to go to extreme angles of attack and coincidentally very high rates of descent, and I like to believe that this guided our elevator size and power selection. The 727 never was capable of getting into the BAC-111 situation.

5. Fuselage Cross-Section

Having gone through the agony of the 707 prototype's body width of 132 inches and the KC-135's of 144 inches, only to have to change the 707 to a body of 148 inches, we felt that the upper deck should carry the 707 cross-section as shown in Figure 10.

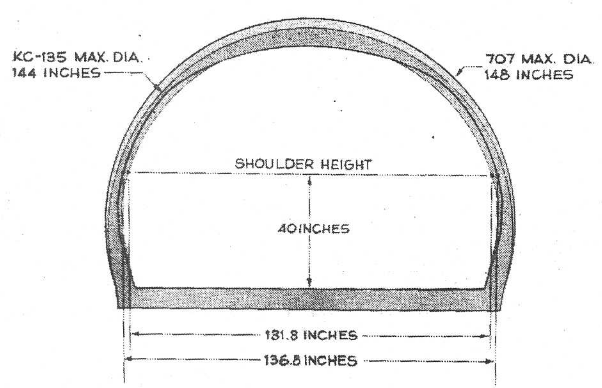

Figure 10. – Fuselage Width Comparison

We were even more certain of this decision by reason of our nearest head-on competitor - the deHavilland Trident - which had a smaller diameter and a considerably more restricted shoulder clearance, which we felt alone would prevent its selling in the United States. The lower body was a different story, however, and on a short range airplane, air freight was not felt to be as important. We thus saved weight and made the lower fuselage shallower than that of the 707 and 720. The forward fuselage was made as shallow as we felt baggage handling would allow, and the aft fuselage was made as an extension of the wheel fairing, resulting in the two different body diameters shown in Figure 11. Both were different than that of the 707 as shown.

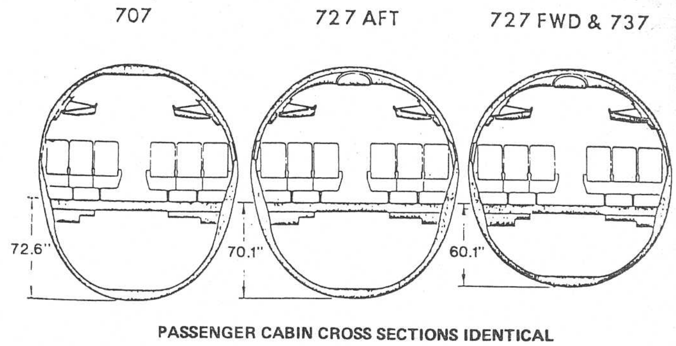

Figure 11.— Body Cross-Section Comparison

6. More About Three Engines

Given the customer situation previously noted, we attempted to find material which would defend a three-engine configuration, then a highly unpopular idea. There hadn't been a commercial 3 engine airplane built for 25-30 years, (although one, the Trident, was in work) and in using three engines we felt we had to have all the defense we could muster. Quite happily, we found that our own studies verified the original Rolls-Royce work which showed at an earlier time period that the economics of a three-engine airplane while not as good as those of two engines, were much better than a straight line variation between 2 and 4 - about as shown in Figure 12, which was published at that time.

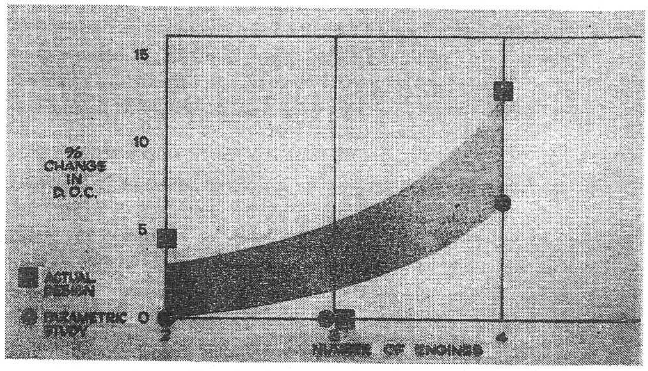

Figure 12.— D.O.C. VS. No. of Engines

In addition, FAA operating regulations were written differently concerning weather minimums to be used by two-engine airplanes and by those having more than two engines. The reason, of course, was the difference between takeoff and landing minimums and the assumption that a two-engine airplane, having an engine failure at takeoff, must land at the field from which it took off. This set of regulations produced the data shown in Figure 13. Regulations and data would be different today and more favorable to two engines.

(NEW YORK)	TWO ENGINE	THREE ENGINE	DIFFERENCE
DEPARTURES DELAYED ONE HR. OR MORE	3.10%	1.14%	1.96%
ANNUAL DELAYS OF ONE HR. OR MORE	342	126	216
DEPARTURES DELAYED MORE THAN 2 HRS.	2.00%	0.34%	1.66%
ANNUAL DELAYS OF MORE THAN 2 HRS.	221	38	183

Assumed takeoff minimums are:
500 ft. Ceiling & 1 mile visibility for 2 engine A/C
200 ft. Ceiling & ½ mile visibility for 3 engine A/C

Figure 13.– Weather Reliability, 2 and 3 Engines, 1959

7. Engine Placement

A long and deep argument existed for a considerable time as to whether the best configuration was three engines located aft or two on the wing and one aft. On the 727 program we set up competitive teams and assigned them the optimization of the airplanes shown in Figures 14 and 15.

The competition was a hot one as indicated by Figure 16. It produced engineering data as illustrated in Figures 17 and 18.

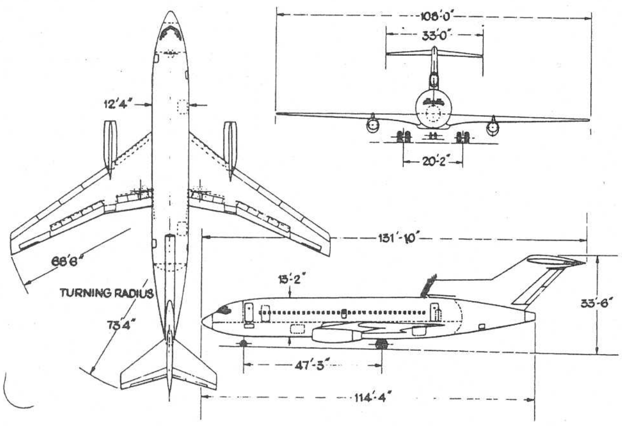

Figure 14.– Alternate 727 Configuration

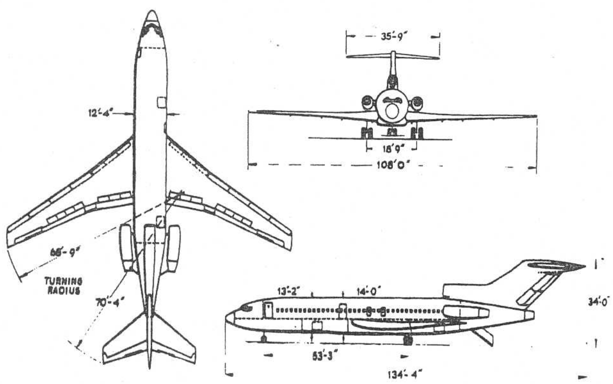

Figure 15.– General Arrangement

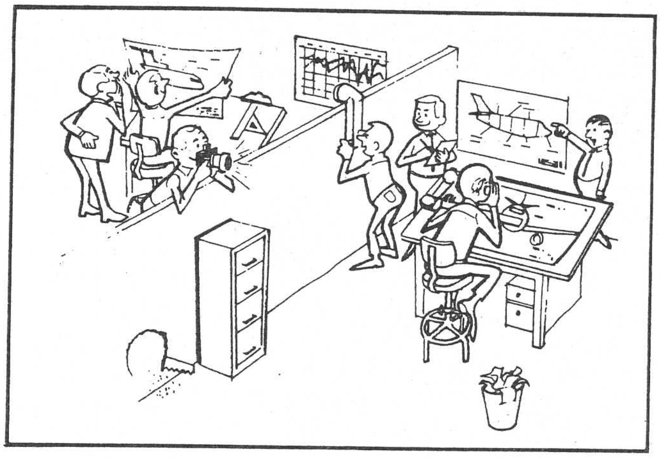

Figure 16.– Competitive Design Teams

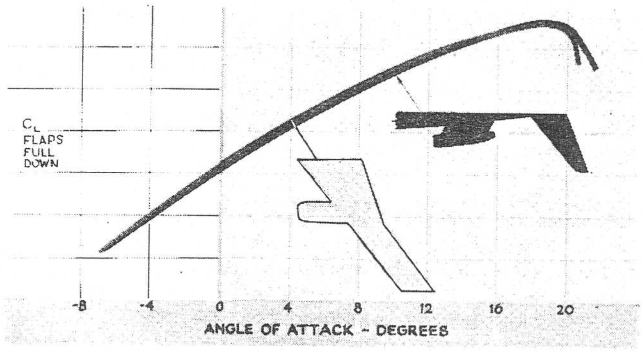

Figure 17.– Engine Location vs. Lift

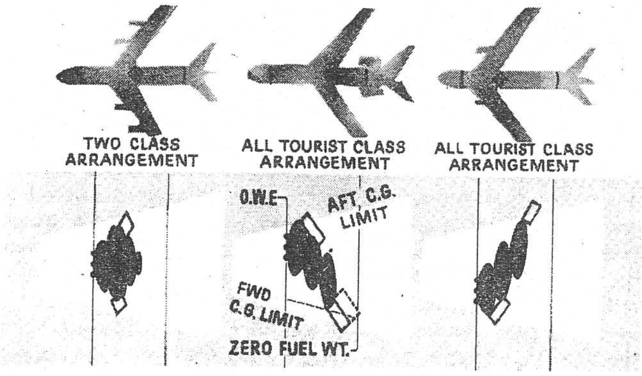

Figure 18.– Loadability vs. Engine Location, 1959

In the end we found that there were advantages and disadvantages to each. The loadability of the aft engine airplane was definitely harder, particularly as future stretch models were envisioned. However, there was some evidence of a drag improvement, particularly when the short field and very high lift plus wing area trades were considered. Wing area, of course, affected economics. There were even some indications that the aft engine airplane was slightly cheaper to build because its systems were more concentrated. None of the effects were decisive, but we finally opted for the aft engine configuration. A minor additional defense of this configuration is that it results in a very quiet front half of the passenger cabin during takeoff and climb, an advantage which becomes more or less lost as cruise speed is gained.

We became enamored with the idea of a boundary layer inlet, with a three-engine cluster as shown in Figure 19 and did quite a bit of testing, including powered wind tunnel aft body simulation. The problems appeared to be two-fold: (a) we needed

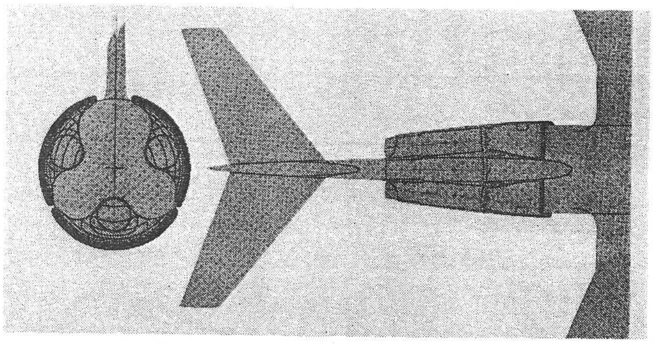

Figure 19.– Boundary Layer Inlet-Aft Engines

more time and probably a prototype, and (b) engine proximity was so close that the possibility of one engine's failure affecting another was considerably greater. In the configuration finally adopted for the 727 it was possible to separate the engines fore and aft and minimize this problem.

8. Flight Controls

The development of 727 flight controls will be described later by other speakers. However, we knew from the start that to gain our short range objectives we had to make a major state-of-the-art change in that area. To get the short field handling characteristics we considered necessary, we had to go, we felt, to an all-power control system, with no aerodynamic feedback whatsoever, and with great attention to force relationships for the three axes. We felt the two best power control airplanes in the past had been the B-47 and the Electra. We obtained the top controls engineer from the B-47 program and ran into a windfall when we found that the top Electra controls engineer had retired on his royalties from the invention of the electric-hydraulic transfer valve and was living on his yacht, which he had sailed up the Pacific Coast from California to Lake Union, about eight miles from our plant. We convinced him that he needed us (so he could buy another yacht) and those two individuals, plus the team that backed them, made the 727 control system a major state-of-the-art breakthrough - it really was. We built a flight controls test rig mockup and gave them all the money they needed to work the bugs out before we built the airplane. This is shown in Figure 20.

9. Windshield Rain Removal

Going back to Figure 5, we knew that all-weather operation was a major 727 objective and set about to develop a new rain removal system. We built a special tunnel illustrated in Figure 21.

Along with this, we developed a new chemical formula which, due to the surface tension it induced, cleared the windshield better than any windshield wiper has ever done. The system is still in use today on virtually all airplanes.

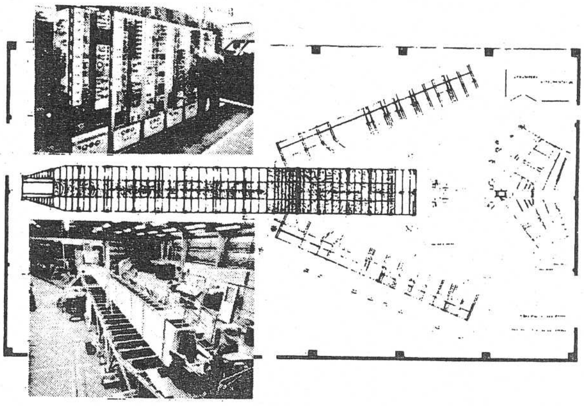

Figure 20.– Flight Controls Mockup

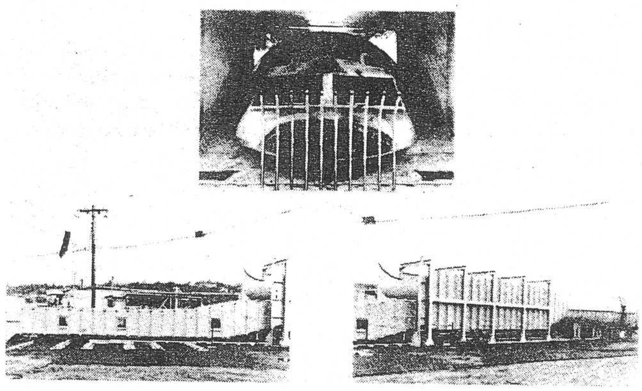

Figure 21.– Windshield Rain Removal

10. Design Speeds

Again, to meet the objectives of Figure 5, we had to have extremely high rates of climb and descent, particularly in the case of descent. This meant high airspeeds and we adopted the speed relationship with the 707 and 720 shown in Figure 22.

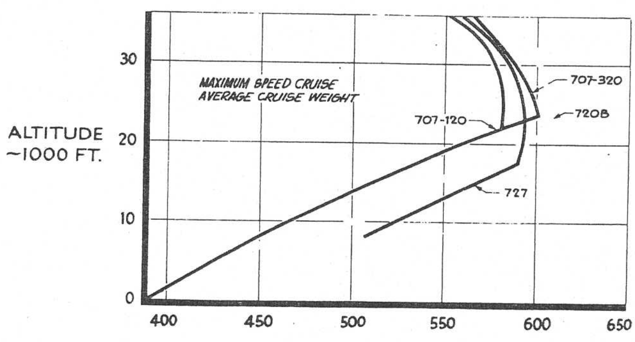

Figure 22.– Cruise Speed

11. Mechanical Dispatch Reliability

We, of course, were intimately familiar with the classical reliability determination methods. But again, in line with the objective of Figure 5, we recognized the need for very high dispatch reliability and we invented a new system for calculating it. We went to the operators of domestic 707's and 720's and sought to obtain accurate data on fleet mechanical malfunctions for a significant time period. American Airlines cooperated with an extremely helpful and carefully conducted experiment on their fleet of 720's which yielded us about a six-month sample of the actual detailed reliability malfunction causes. Knowing that their reliability had been about 96%, and that we were seeking at least 98%, we knew that we must cut malfunctions by one-half, notwithstanding the fact that the airplane we had invented was not exactly simple. The situation is illustrated by Figure 23.

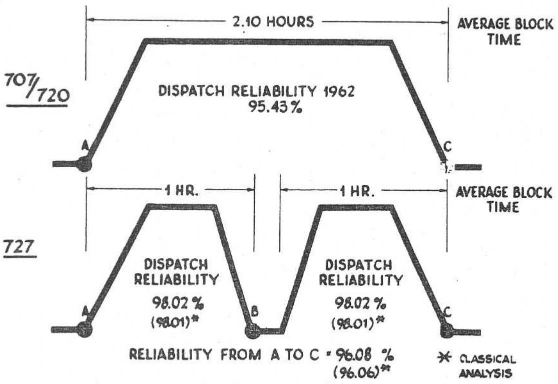

Figure 23. – Dispatch Reliability

We dissected each system and made a direct comparison conducted by the particular designers responsible for each element of the airplane to see whether they could prove, element by element, that the 720 experience translated into the 727 design would give a fifty percent better reliability. It didn't - but we changed the design until it did.

As shown on Figure 23, the empirical method gave total results not differing much from the classical method - but the breakdown of individual element reliabilities was much different and much more trustworthy. We've used the method ever since.

12. Self-Sufficiency

Again, referring to Figure 5, we had to fit the airplane into fields having little ground equipment. Thus, the 727 had self-contained airstairs aft, and an auxiliary power unit in the wing root fairing. In addition, we offered a forward self-contained airstair as an available option.

13. Engine Considerations

The 727, of course, was designed around the low by-pass ratio fan concept. This had a distinct noise advantage over the pure jet. In addition, all 727's were built with perforated inlet liners, the first use of such liners on a production airplane. Later versions, of course, were fitted with far more noise attenuation material, but even the early 727's were relatively quiet.

It is only proper in relating a case history to address engine selection. We actually wanted an engine size that did not then exist. Rolls-Royce came through with a zero-staged version of the Spey RB-163, which they then licensed to Allison, to be built in the United States as the ARB-963. We selected it to power the 727. That engine was acceptable to United Airlines, but Captain Rickenbacker of Eastern was not happy with either the great distance between New York and Miami on the one hand, and Darby, England on the other hand, or with the licensing arrangement with the Allison Company which, at that time, was having trouble with his Electra engines. We made a trip to Rolls to try to convince them that they should build a factory in the United States to produce the RB-963. They did not respond. Pratt & Whitney did however, and in taking the core of the Navy-developed J-52, built a somewhat oversized and somewhat heavier engine, called the JT8D. It was a last minute decision, Rickenbacker bought it, and United went along. Later, we found that the Pratt engine required extensive redesign before first customer delivery, since it had a nasty habit - any time it surged, its rotor blades would deflect and contact the stators.

So started what must now be the world's most successful engine program - the P & W JT8D in all its versions. No other engines have ever powered a 727.

14. Manufacturing Cost

The 727 program came on the heels of the 707 which had substantial manufacturing cost overruns, due to a variety of reasons. It was our determination that such overruns would not occur on the 727. We first tried to get a manufacturing sign-off on all drawings, but at that time our manufacturing organization was reluctant to accept such a responsibility. We did get what proved to be even better - a group of about 40 top industrial engineering and manufacturing personnel located in the exact center of the 727 engineering organization to review every layout before the drawings were made. This proved to be better than a sign-off because manufacturing could affect the design before hundreds or thousands of hours were invested in it.

To facilitate the work, we had a joint tenth-scale manufacturing and engineering working mockup built in the middle of the engineering design area. This is shown in Figure 24.

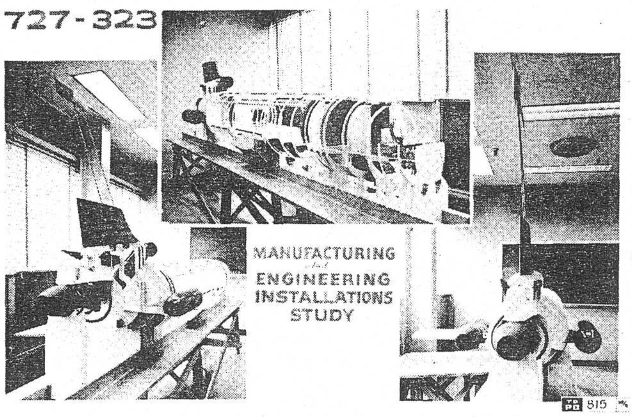

Figure 24. – Manufacturing and Engineering Installations Study

The results were astounding. For the first time in a Boeing program we were able at the initial design stage to avoid often expensive, unnecessary design changes. We had invented "design to cost" but didn't know it. The result was a manhours per pound experience for the first 200 airplanes as shown on the log log plot of Figure 25. As indicated, the crossover of one manhour per pound was reached at unit 1062. At unit 10 we were over five times that amount and at unit 200 we were almost over twice that amount.

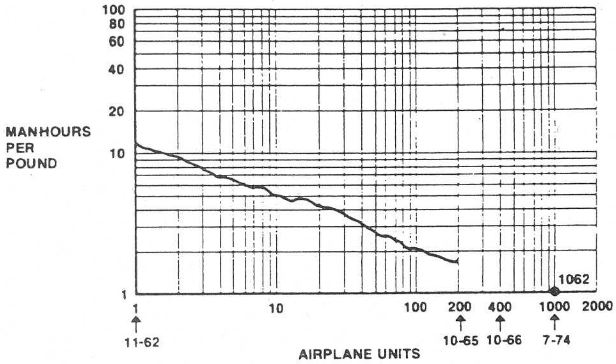

Figure 25.— Manhours per Pound

There were other cost improvements incorporated in the 727, such as the gem-core automatic riveter, which pressed the wing rivets automatically and gave us lower cost and longer fatigue life at the same time.

The 727 program has consistently had low manufacturing costs for its performance, complexity, and date of design. The program was aided by our dollar sign ($) tooling concept, pioneered on the 707, where a formal contract between engineering and manufacturing guarantees that certain surfaces will be maintained for tooling while other specified surfaces will be available for the engineer to change. This permits strength changes with essentially no manufacturing cost impact. On the 727 program it has not been unusual for three different strength wings to be in production simultaneously with no discernible adverse cost impact.

15. Derivative Models

While the 727 program had an excellent start, its continuation and present success has been due to a constant improvement in the product. As will be shown later, we have maintained an engineering group of between 500 and 1000 people dedicated to 727 improvements and customer special features during the entire 15 years since first customer delivery. A constant influx of improvements no doubt decreased our current profit, but this, I'm sure, is far overcome by the program longevity and economic viability that was created. Without it our production rate surely would not be climbing to 12 airplanes per month, as we are today.

Next, I would like to introduce Gerry Bowes, who will describe the aerodynamic development of the 727-100 airplane.

SECTION 2

AERODYNAMIC DEVELOPMENT OF THE 727-100

by
G.M. Bowes

AERODYNAMIC DEVELOPMENT OF THE 727-100

by
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INTRODUCTION

The 727 was the first jet transport designed for operation out of fields of five to six thousand feet in length. Previous jets had characteristically high take off and landing speeds ("hot" airplanes). The 727 challenge was to provide piston engine, straight wing takeoff and landing speeds with jet cruise speeds. The short field performance capability also required good handling qualities. To be successful, the airplane had to operate under airline conditions at elevated temperatures from both sea level as well as high altitude airports, climb quickly to altitude and there cruise at competitive speeds. These performance objectives are shown on Figure 1, and are further emphasized with the following comments:

- CARRY A FULL PAYLOAD 1500 N.M. FROM A 6000 FOOT LONG RUNWAY (SEA LEVEL, 90°F), CRUISING AT 30,000 FT. AT A SPEED OF M = .80, AND LAND ON A RUNWAY NO LONGER THAN 4900 FEET IN LENGTH
- CARRY A USEFUL PAYLOAD (75 PASSENGERS) FROM DENVER TO CHICAGO, WITH TAKEOFF TEMPERATURE OF 90°F.
- CERTIFY TO 35 KNOT CROSSWIND FOR TAKE OFF
- MEET WET RUNWAY LANDING DISTANCE REQUIREMENTS UNDER OPERATIONAL AIRLINE CONDITIONS

Figure 1. – Performance Objectives - 727-100

Short Field/Range Requirement

The airplane had to be able to carry a full pay load (90 to 100 passengers) a distance of approximately 1500 nautical miles from a runway no longer than 6000 feet, assuming sea level and 90° F temperatures. It had to cruise at 30,000 feet at an economic speed of at least Mach 0.8, and be able to land on a runway no longer than 4900 feet.

High Altitude Airport Operation

The long range transports operated mostly from sea level runways; the requirement for a short range airplane to take off at altitude is typified by the Denver Airport with its runway of over 11,000 feet in length and summer temperatures of at least 90° F. The 727 had to carry a respectable payload (60%-70% maximum) at least as far as Chicago.

Other Operational Runway Requirements

The crosswind requirement of 35 knots was more severe than previous large jets required, again indicating the need for uninterrupted service into smaller airports. Likewise, the operational wet runway performance requirement (developed in response to a request by American Airlines) represented a new commitment for Boeing transports.

Handling Qualities

Handling quality objectives were described in far greater detail than on earlier airplanes. The specifications were developed from strong inputs by the airline pilots. Likewise, Boeing experience from designing and flying the "big" and "hot" jets led to more stringent demands for low control forces and improved airplane stability and control qualities.

Airplane Description

Although smaller than its predecessors, the 727 exhibited some similarity to and commonness with the 707 in many of the design details. On Figure 3 a view of the control surfaces is shown. The 727 has a high speed inboard aileron, a supplemental low speed aileron outboard, and large wing spoilers used for airbrakes and lateral control. The lateral control surfaces are therefore generally similar with the design philosophy of the 707 aircraft. The longitudinal control surfaces are likewise similar to the 707 with a movable stabilizer for trim and an elevator for maneuvering.

REPRESENTATIVES OF AIRLINE MANAGEMENT PILOTS, WORKING TOGETHER WITH BOEING TEST PILOTS AND AERODYNAMICISTS, DEVELOPED COMPREHENSIVE DETAILED SPECIFICATIONS FOR

- CONTROL FORCES
- LONGITUDINAL STABILITY
- LATERIAL-DIRECTIONAL STABILITY
- LONGITUDINAL, LATERAL AND DIRECTIONAL CONTROL

Figure 2. – Handling Quality Objectives

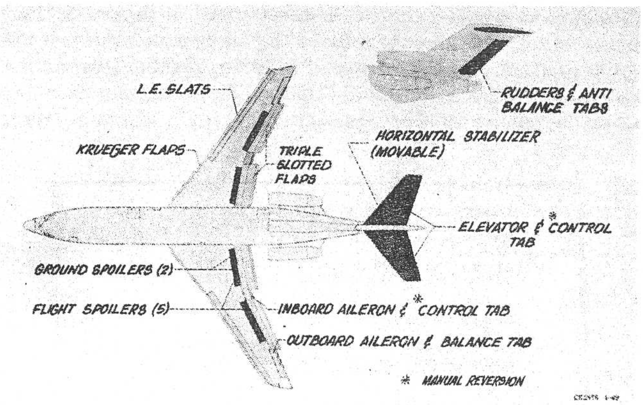


Figure 3. – Control Surfaces

Departure from 707 practice is exhibited in control features described below: Directional control is provided by a rudder which is split into two surfaces, each with a separate full time yaw damper. All of the control surfaces are powered by irreversible hydraulic power packages. Two separate hydraulic systems service the boost packages. In the unlikely event of complete loss of hydraulic pressure of both systems, a final emergency flight control is available through automatic manual reversion. One fundamental design requirement for the control systems was that redundant control capability must be available to the pilot in the case of malfunctions in the control. For instance, lateral control power is available through the ailerons by means of two separate, independent hydraulic powered systems, by direct pilot forces to the aileron tab, and by wing spoilers operated by individual actuators through two separate hydraulic systems.

Novel aerodynamic features on the 727 are listed in Figure 4. They include the large leading edge slats, the T-tail arrangement, and the grouping of the three engines in the aft part of the airplane. The power plant installation consists of two engines symetrically placed on each side of the aft fuselage and a third engine on the airplane center line with an air linlet at the base of the vertical tail. This power plant arrangement was evolved from lengthy design studies of the requrements of this type of airplane, considering the number of engines, airplane take-off and range performance, and operating costs. These studies and discussions with interested potential airline customers clearly showed that three engines were optimum for performance, yet offered operating costs close to a twin. The most logical engine arrangement grouped them in a cluster on the aft fuselage.

TRIPLE SLOTTED FLAP SYSTEM AND ASSOCIATED LEADING EDGE SLATS
"T" TAIL
THREE ENGINES, AFT MOUNTED
FULLY POWERED FLIGHT CONTROL SYSTEM

Figure 4. – Unique Features

Aerodynamic Risks

An assessment of the aerodynamic configuration risks made during the wind tunnel development period of the 727 by a Boeing engineering executive is summarized on Figure 5. There was a concern for the capability of the airplane to achieve its low speed performance and low speed handling qualities (particularly roll and sideslip control during landing). There was also a concern as to the choice of wing area and engine size considering future growth required by the airlines, since this could result in an airplane which would not have enough thrust to meet some of the critical flight conditions. History has shown that none of the concerns became problems; the success of the 727-100 and -200 program reflects the capability of the engine manufacturer to provide the thrust growth necessary to meet increased payload/range, and the airframe was sized so that it has been able to support continued improvements requested by the airlines.

- STALL PERFORMANCE AND HANDLING QUALITIES – TAKEOFF AND LANDING CONFIGURATION, IN AND OUT OF GROUND EFFECT
- LATERAL CONTROL FOR TAKE-OFF AND LANDING, CONSIDERING GUSTS, CROSSWINDS, SIDE SLIP REQUIREMENTS
- POTENTIAL AIRPLANE GROWTH TO MEET INCREASED PAYLOAD/RANGE REQUIREMENTS
- CRUISE CONFIGURATION DEVELOPMENT TO MEET L/D GOALS AND SATISFY FLAPS UP LONGITUDINAL STABILITY REQUIREMENTS

Figure 5.– Aerodynamic Configuration Risks 727-100 Development

Aerodynamic Design Approach

The tools available to the aerodynamicist for this design are shown on Figure 6 and they include:

1. A strong basis of commercial airplane performance estimation capability derived from flight test experience on the B-47, B-52, KC-135, and the 707 series of airplanes.

2. The wind tunnel facilities, principally the Boeing Transonic Wind Tunnel, and the University of Washington Low Speed Wind Tunnel.

3. The use of the 367-80 as a prototype flight test article for critical flight hardware: namely, the high lift system and the aft fuselage mounted JT8D engine.

- PERFORMANCE OF SWEPT WING, JET POWERED BOEING AIRPLANES
- WIND TUNNEL TESTS
- FLIGHT TESTS ON 367-80 "BOILER PLATE"

Figure 6.– Aerodynamic Design Tools

PERFORMANCE

The successive steps which ideally generate airplane performance definitions and accompanying guarantees to support airplane sales are presented in Figure 7. The several tasks are initially followed in the order shown: but on many programs these activities soon become successive overlapping cycles of effort. The forcing inputs are developed from airline contacts plus the evolution and refinement of basic data from wind tunnel tests or engine developments.

1. AIRPLANE OBJECTIVES
2. CONFIGURATION DEFINITION/PARAMETRIC PERFORMANCE STUDIES
3. DETAILED PERFORMANCE DATA
4. SALES BROCHURES
5. APPLICATION TO AIRLINE ROUTES
6. GUARANTEED PERFORMANCE

Figure 7.– Performance Development Cycle

Many parametric performance studies were conducted on the 727 during 1957 and 1958 to examine twins, tri-jets and four engine airplane designs, in order to compare performance and economic capabilities. In the usual order of preliminary performance calculations, a parametric survey of design constraints such as cruise altitude, field length, etc., is first conducted. These studies are presented as "thumbprints". In 1960 we could not quickly generate comprehensive data by the computerized calculation process we now have, but the basic analysis approach was similar in concept. In order to verify these paper performance studies, parallel configuration and design efforts must of course be conducted to verify these parametric trends by "point design" airplane definitions.

By the fall of 1959 the decision to develop a three engine airplane had been made, and the program began to move along around this configuration definition. At this time it was necessary to establish a firmer basis for performance estimates, so a wind tunnel test program was initiated and the program which ultimately followed the path shown on Figure 8 was launched. Intensive sales studies and route analyses studies were made in conjunction with the airlines who showed an interest in the 727, concurrent with the development of the airplane performance basis.

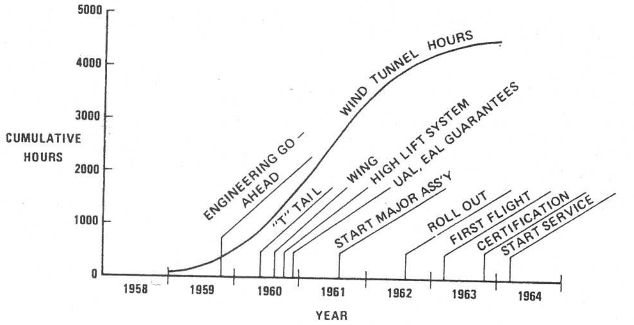


Figure 8.— Aerodynamic Configuration Development, 727-100

The critical time period for performance definitions occurred during the last six months of 1960. In this brief interval the first low speed and high speed wind tunnel results became available to support guarantees offered in September, 1960 on orders which launched the program. The major wing design features, the high lift system, and the engine arrangement was determined. Concurrently some items which were thought to be settled were also changing significantly, as with the switch from the Allison-Rolls 963-9 engine (13,000 lb. sea level static thrust) to the P & W JT8D-1 engine (14,000 lb. thrust). New requirements from the airlines were being examined, and a rapid interchange of performance information was occuring between the Boeing Company and the airlines as well as between groups inside Boeing. The wing span was increased by 6 feet to accommodate the United Airlines performance requirements out of Denver (a high altitude airport). The airplane gross weight grew from 135,000 to 142,000 lbs. Although the total wind tunnel test program involved in design of the airplane amounted to over 5000 hours, the performance commitments were released based upon about 1500 hours of high speed and low speed wind tunnel testing.

This effort to update and integrate new data put extreme demands on the aerodynamic performance group; nevertheless the rapid airplane evolution in response to airline comments provided a better design. Configuration changes imposed on us by the initial airline customers for unique route conditions were useful later to satisfy requirements from other airlines. For instance, a prime 727 requirement from Eastern Airlines was to operate a Boston - La Guardia - Washington - Atlanta - Miami flight without refueling; in order to achieve this mission it was necessary that the first landing at La Guardia be made within a field length of 4900 feet with a full payload plus a heavy load of fuel (maximum landing weight). Other airlines were interested in flying out of La Guardia to airports in Oklahoma, Texas, or Puerto Rico, and this again imposed a take off field length-range requirement which proved useful in meeting other airline needs. Another example of the benefits of this short field capability appeared in our sales campaign in Australia in which the 727 could achieve a far more competitive payload on the Melbourne-Perth transcontinental route than other airplanes being evaluated. These requirements exploited the capabilities of the unique high lift system on the design and substantiated the basic approach for developing this airplane.

The airplane characteristics are listed on Figure 9 and it will be observed that an alternate gross weight of 152,000 lbs. with increased fuel capacity was being offered as an option. This reflected a growing desire by the airlines to achieve longer range flights - over 2,000 nautical miles. An illustration of the different types of cruise conditions that might be used for the airplane is shown on Figure 10. Other performance predictions are shown on Figure 11 and 12. The goal of low approach speeds (110 knots) and landing field lengths below 5,000 feet is clearly identified, along with takeoff field lengths of 6,000 to 7,000 feet.

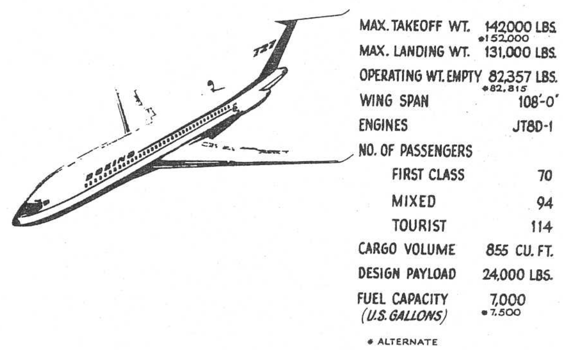


Figure 9.– General Characteristics

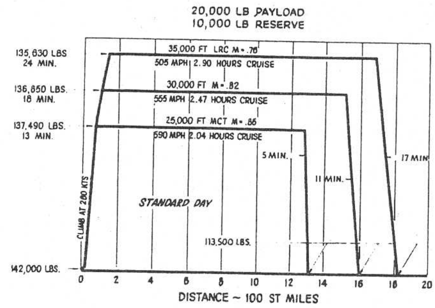


Figure 10.– Flight Profile — Typical Cruise Conditions

During early flight testing, it became apparent that the airplane performance was significantly better than had been estimated. This amazing turn of events is seldom experienced, and it resulted in accusations that the aerodynamicists had been very conservative in their performance estimates because the airplane had no competition. This was certainly not the state of mind of those of us involved in the program nor had we been motivated to compromise our professional judgment. Careful consideration was given to the unique high lift system with all its attendant possibilities for "roughness" and "leakage" during cruise flight. This was a legitimate cause for concern in pre-flight drag estimates. XB-47 flight tests had shown cruise drag penalties of 10% due to slat roughness and leakage.

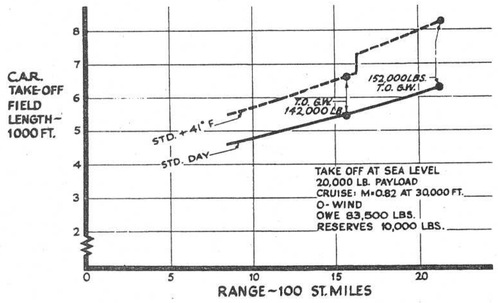


Figure 11.– Takeoff vs Range

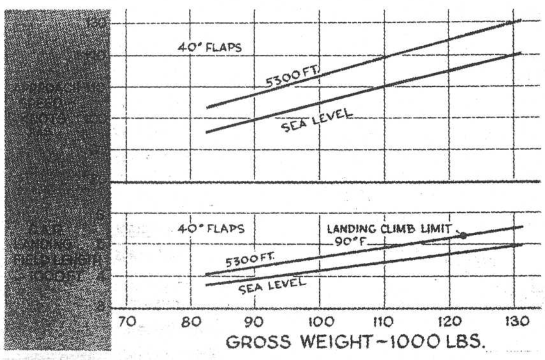


Figure 12.- Approach Speed and Landing Distance

One example of the competitive nature of the 727 performance is shown by a chart used during our sales campaigns, (Figure 13) which compared the approach speeds of the 727 and the corresponding landing field length of competing airplanes. Not only did we face competition with the Caravelle, the Trident and the Electra, but Boeing was continually meeting new offerings from General Dynamics and Douglas.

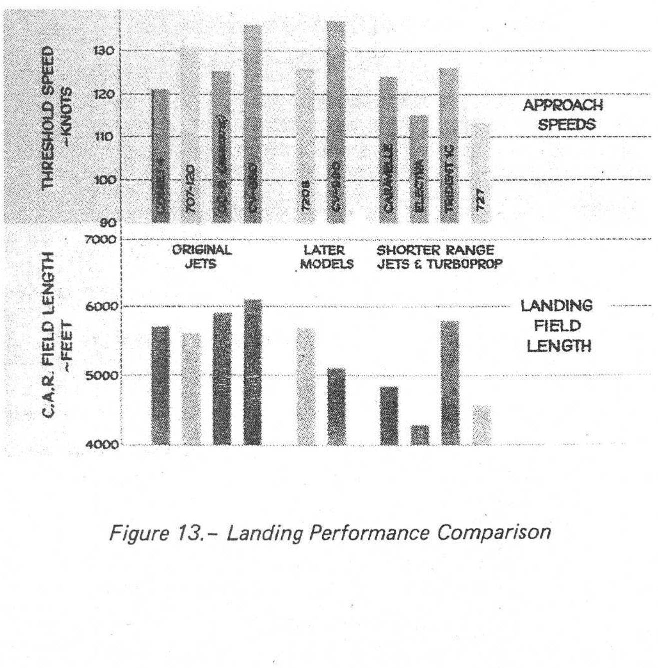


Figure 13.- Landing Performance Comparison

Comparisons of just one portion of the flight test results with the pre-flight performance estimates are shown on Figure 14. This shows range capability improvement observed referencing the parameter of miles per pound of fuel burned. It also shows the more significant gain in cruise operation which accompanied the low drag level - a gain in cruise speed/altitude capability equivalent to over 10,000 lbs. of weight. A more complete discussion of these data is presented in the Flight Test section of this study. Almost every contributory item affecting airplane performance turned out to be favorable, which resulted in a cumulative beneficial impact on range capability. Usually there are offsetting results or, even worse, both airframe and engine performance is degraded, resulting in a snowballing deterioration of performance. On the 727, items affecting airplane range which turned out better than the estimated range included airplane drag, engine specific fuel consumption, and engine installation losses.

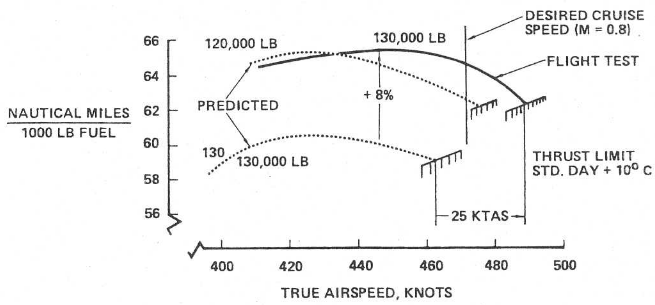
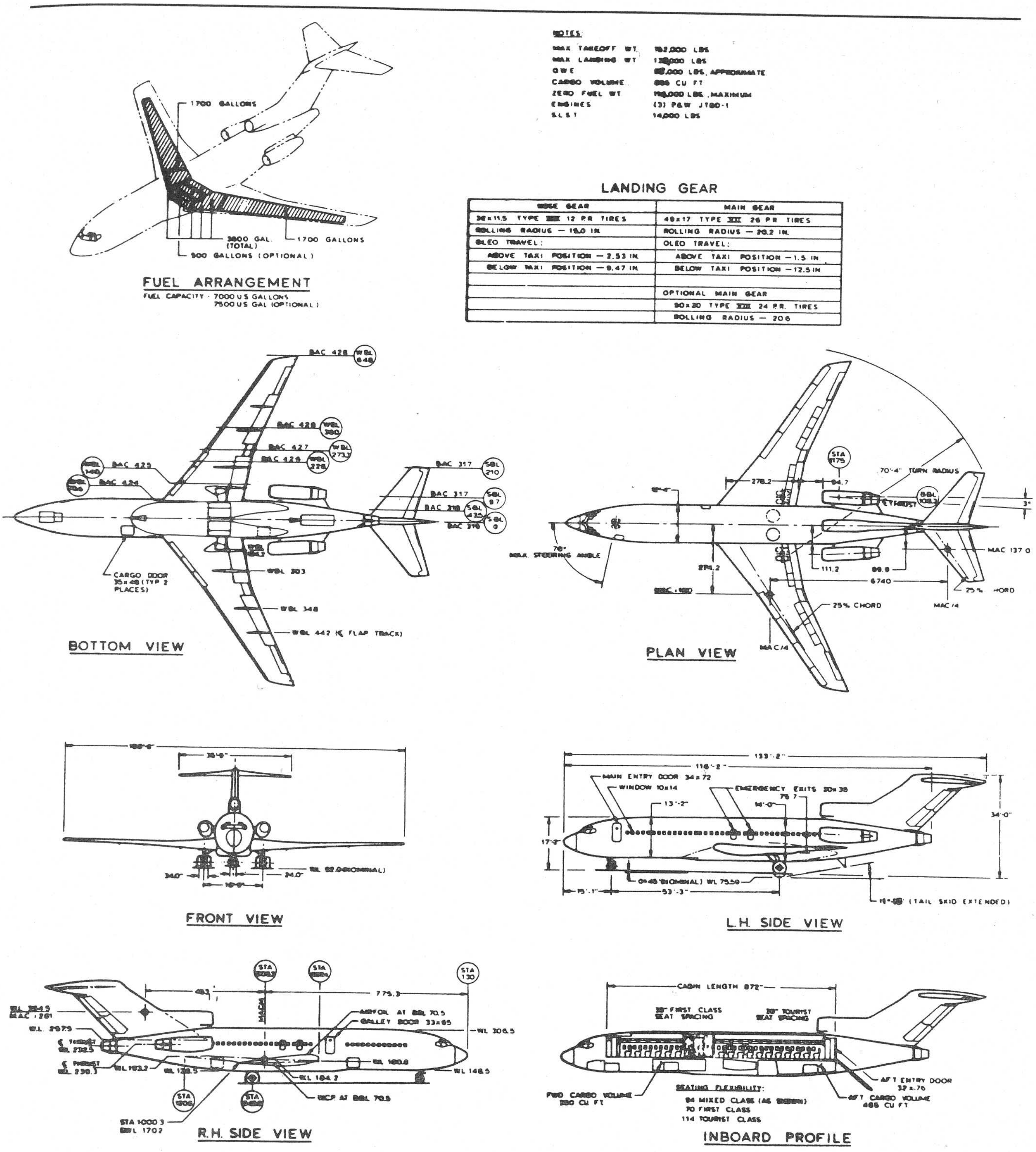


Figure 14.— 727 Flight Test vs Predicted Cruise Performance

To summarize this section on performance development, traditional methods of performance estimation and studies of airplane sizing were used. Our data for cruise drag estimates was based on wind tunnel increments applied to flight test levels obtained on previous aircraft, especially the 720. For the low speed performance estimation, we relied on wind tunnel tests and the results of prototype "boilerplate" hardware on the Dash 80 flying test bed. We included estimates of changes from the previous aircraft caused by the unique features of the 727, such as the location of the propulsion pods, or the potential out of contour mismatch and leakage in cruise of the leading edge slat. Engine manufacturer's performance was adjusted to account for installation losses. Every effort was made to ensure that the original performance quotes would be met by close monitoring of project drawing releases during detail design releases and by additional wind tunnel testing for refinement of exterior shapes.

A description of the airplane is given in the drawings on Figure 15, along with geometric dimensions on Figure 16.



NOSE GEAR	MAIN GEAR
[illegible] x 11.5 TYPE [illegible] 12 P.R. TIRES	49 x 17 TYPE VII 26 P.R. TIRES
ROLLING RADIUS — 15.0 IN.	ROLLING RADIUS — 20.2 IN.
OLEO TRAVEL:	OLEO TRAVEL:
ABOVE TAXI POSITION — 2.53 IN.	ABOVE TAXI POSITION — 1.5 IN.
BELOW TAXI POSITION — 9.47 IN.	BELOW TAXI POSITION — 12.5 IN.
	OPTIONAL MAIN GEAR
	50 x 20 TYPE VIII 24 P.R. TIRES
	ROLLING RADIUS — 20.6

Figure 15.– Configuration Summary

WING GROUP	
GROSS WING AREA WITH WING LEADING AND TRAILING EDGE CARRIED TO THE BODY CENTERLINE	1700 FT.^{2}
AERODYNAMIC REFERENCE AREA	1560 FT.^{2}
SPAN	108 FT. 7 IN.
ASPECT RATIO	7.5
ROOT CHORD, BASED ON BASIC WING LINES EXTENDED TO BODY CENTERLINE	20.52 FT.
TIP CHORD	7.63 FT.
SWEEPBACK C/4	32°
FLAP AREA (TRAILING EDGE TOTAL) - RETRACTED	280 FT.^{2}
- EXTENDED 40°	388 FT.^{2}
MEAN AERODYNAMIC CHORD	180.7 IN.
INCIDENCE ANGLE	2°
CONTROL SURFACES	
AILERON AREA (AFT OF HINGE LINE)	55.1 FT.^{2}
HORIZONTAL TAIL AREA	379 FT.^{2}
HORIZONTAL TAIL VOLUME COEFFICIENT ($\bar{V}_h$)	0.96
VERTICAL TAIL AREA	356 FT.^{2}
VERTICAL TAIL VOLUME COEFFICIENT ($\bar{V}_V$)	0.071
FUSELAGE	
LENGTH	116.2 FT.

Figure 16.- 727 Pertinent Dimensions

HIGH-LIFT SYSTEM

Design Goals

The need for a major advance in flap system design was recognized at the beginning of the 727 effort.

Based on early testing we set our goal on airplane stall lift coefficient of 2.9, with the requirement that flight qualities at approach speed and stall characteristics had to be satisfactory. This represented a 50% increment in C_L compared to the 720 (Figure 17). This meant a wind tunnel $C_{L_{max}}$ of about 2.6, and angle of attack at $1.3V_s$ (approach speed) of no more than 5 deg, and that the approach condition would be above the speed for best L/D (on the "front side" of the thrust required curve). Further, it meant that the stall "break" would be gradual with no large loss in lift to well beyond $C_{L_{max}}$ and, most important, that the pitching moment would break, nose down, at the stall. Wind tunnel tests soon demonstrated that while the $C_{L_{max}}$ goal could be reached, the other qualifying conditions were more difficult. The problem of stall characteristics was three dimensional, involving the details of trailing and leading flap type, chord, and span; and wing planform and sweep.

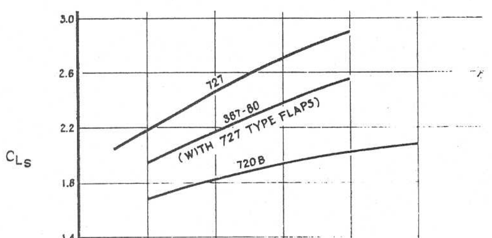


Figure 17.- Stall C_L Comparison

Field length requirements and approach speed for the 727 are compared to the then contemporary airplanes in Figure 18. The 727 data on Figure 18 show what was required and also achieved in spite of higher landing wing loading and a higher ratio of landing to takeoff weight. The effect of takeoff lift coefficient may be most readily compared at a wing loading of 92 psf. Thrust loadings are comparable. Note that landing field length is nearly as short as takeoff and that both are under 5000 feet for most of the weight range.

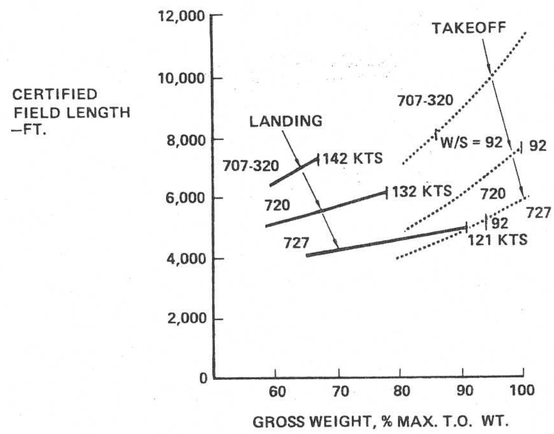


Figure 18.– Field Length Performance

Three things are fundamental to short landing capability; low approach speed, the ability to touchdown near the end of the runway and good stopping capability. The latter is fairly straightforward, but requires the ability to get weight on the wheels and good anti-skid braking. Touchdown accuracy depends on many factors, but there is no question that a stable, maneuverable airplane with the lowest approach speed possible is important. Low approach speed buys time for a pilot to assess his situation and make corrections. It means deviations will occur at a slower rate and tighter corrections can be made.

In Figure 19 the relative role of leading and trailing edge flaps is also shown. The trailing edge flap increases lift at a constant angle of attack and, for given $C_{L_{max}}$, determines the approach attitude and drag. The leading edge flap controls the level of $C_{L_{max}}$, with a given trailing edge flap, and controls stall characteristics. If too much reliance is put on leading edge flap effect, the attitude for approach is increased to an impractical value. Our wind tunnel tests showed that best results would be obtained with maximum Fowler action, maximum chord foreflap, and an aft or auxiliary flap. These features contribute to a maximum radius of curvature (wing camber) with minimum adverse pressure gradients.

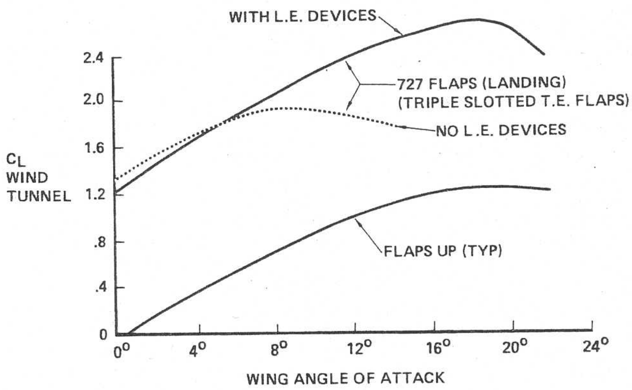


Figure 19.– Wing Lift Comparison

Wind Tunnel Testing

Trailing edge flap types are compared for 40 deg flap deflection in Figure 20. For each case, the flap chord in the stowed (flaps up) position was the same. Perhaps the fairest comparison is to look at C_L values at an angle of attack of about 8 deg, assuming that the differences in $C_{L_{max}}$ could be altered by a more powerful leading edge flap. The increments obtained by the movable foreflap and aft flap are clearly shown.

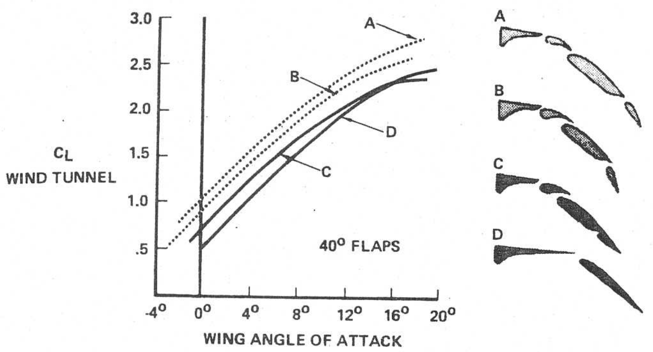


Figure 20.– Trailing Edge Flaps - Lift Comparsion

All these flaps were mounted on tracks under the wing. We found that keeping the slots clear was extremely important aerodynamically and had important structural advantages also. Tracks and mechanism in this position are in a near-stagnation area followed by a favorable pressure gradient, so that disturbance at the flap slots is nil. At cruise conditions, track fairings are in the lowest local velocity area and pressure gradient is not extremely adverse. Tracks are shaped to match local streamlines as much as practical. The care taken to duplicate full scale flap support hardware on the wind tunnel model is shown on Figure 21, and the airplane parts are shown on Figure 22.

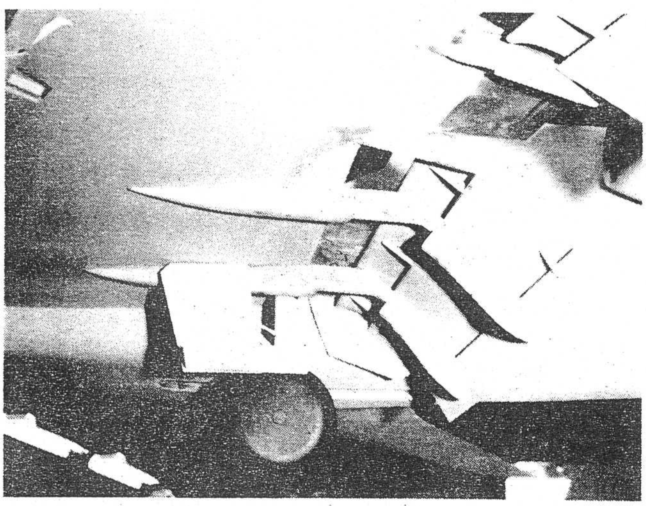


Figure 21.– Wind Tunnel Model of Flap Support Hardware

As was discussed previously, when powerful trailing edge flaps are used, the angle of attack at which stall occurs and the value of $C_{L_{max}}$ itself depends on the ability of the leading edge device to prevent leading edge stall. This applies as well to the pitching moment behavior at the stall. Outboard wing stall produces pitch-up, inboard wing stall causes pitch-down. The leading edge devices compared in Figure 23 were installed over the outboard two-thirds of a 25 deg swept wing. The model has large triple-slotted trailing edge flaps and a Krueger flap on the inboard leading edge. Two significant points are made by these data:

1. $C_{L_{max}}$ depend on the chord of the device.

2. The slotted devices have a slightly lower $C_{L_{max}}$, but lose lift gradually at the stall. The devices without slots lose lift very abruptly.

Tests demonstrated that the value of $C_{L_{max}}$ attainable with good stall characteristics would be limited by the slat chord that could be installed over the outboard 25% of the wing. There was considerable hesitation to use slats because their actuation was more complicated than Krueger flaps, and because of the fit-and-fair problem for cruise flight. Flight test results on the 367-80 prototype convinced us that it was worthwhile to solve any construction problem which slats incurred.

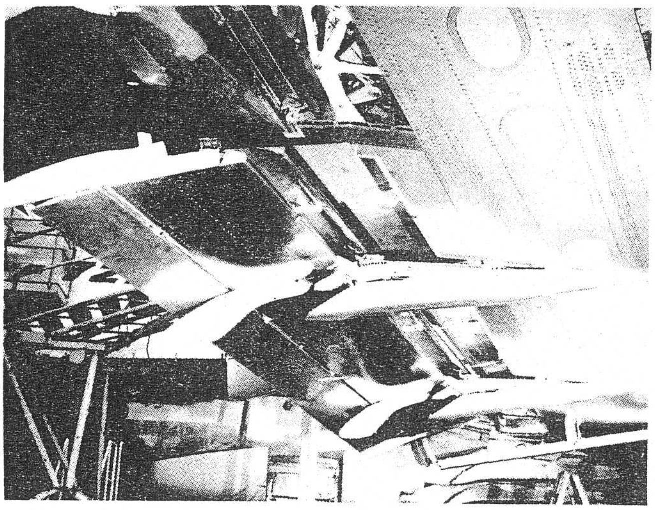


Figure 22.– Airplane Flap Support System

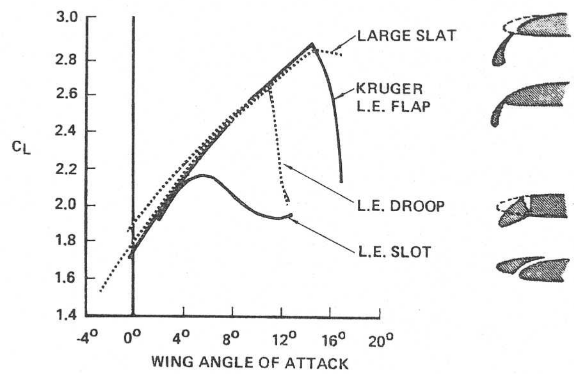


Figure 23.– Leading Edge Devices

There are several fundamental reasons why the outboard 25% of the leading edge is critical from a leading-edge edge stall standpoint:

1. Sweepback causes the local lift coefficient due to angle of attack to be highest at about 75% span.

2. Wing planform taper has essentially the same effect as sweepback.

3. A further increase in loading is induced just outboard of the end of trailing-edge flap tip.

4. High-speed wing design generally dictates a small leading edge radius for the outboard airfoils.

5. Without wing mounted nacelles to promote stall inboard, the tip problem is more difficult.

An example of the lift and pitching moment differences between outboard slats and outboard Krueger flaps is shown in Figure 24. This comparison was made on a 32 deg swept wing with Krueger flaps over the inboard one-third span and with triple-slot trailing edge flaps. Note the gradual stall and nose down pitching moment during the stall in the case of the slat. Tests were also made with slats inboard as well as outboard. An increase in $C_{L\,max}$ can be gained with slats inboard, but it is accompanied by unacceptable pitch-up.

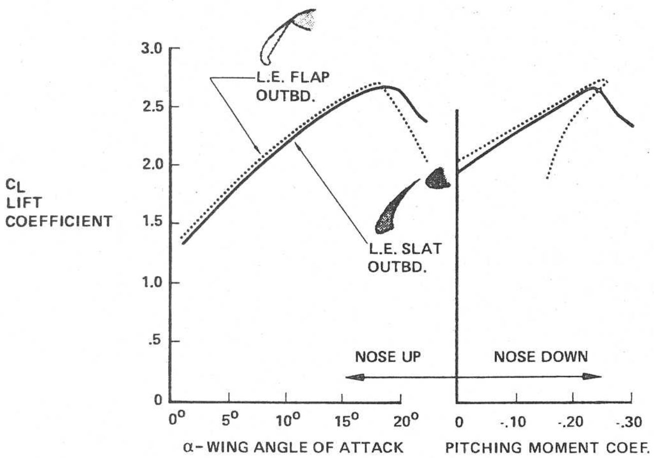


Figure 24.– Outboard Leading Edge Devices

As mentioned previously, the ability to get weight on the wheels is a primary factor in landing or refused takeoff braking. The ground airbrakes used to "dump" lift on the 727 produce negative lift coefficients when extended with takeoff flap settings.

Low speed wind tunnel testing on mechanical flaps applicable to the 727 is summarized in Figure 25, boundary layer control flap research is not shown. Tests applicable to the 727 began in July, 1959 and continued through August, 1962 for over 1500 low-speed wind tunnel hours. Preliminary tests were run on a 720 model for general investigation of the problem. By May 1960 we had a 727 configuration firm enough to make a first model.

The ends of the bars indicate the approximate data certain configuration items were settled. For example, although we decided on the general type of flap fairly early in the program, the final details were not set until wing plan form and flap motion were settled. Aileron droop for $C_{L\,max}$ and L/D improvements was investigated, but was rejected as too complex for the gains produced.

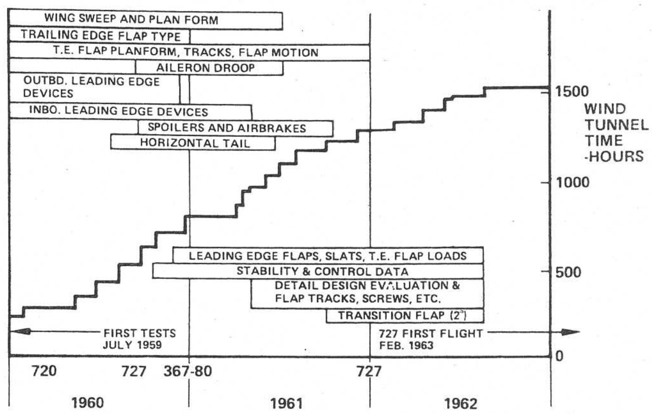


Figure 25.- High-Lift Wind Tunnel Testing

Testing concerning flap loads was done as the design firmed up. In general, these data were shown by flight test to be very accurate. Slat loads at low angles of attack based on tunnel results were underestimated because of a load relieving separation which was not as severe in flight as on the wind tunnel model, so the slat actuators had to be increased in size after the first airplane was flown.

Securing stability and control data on all axes and control surfaces occupied a good deal of the latter portion of the wind tunnel testing, as did evaluation of many design refinements. Photographs showing the complete low speed wind tunnel model (1/20 scale) are shown on Figure 26. The airplane with extended flaps is illustrated on Figure 27. The flight photograph on Figure 28 shows the 5 flap position and emphasizes the large amount of rearward flap movement prior to deflection.

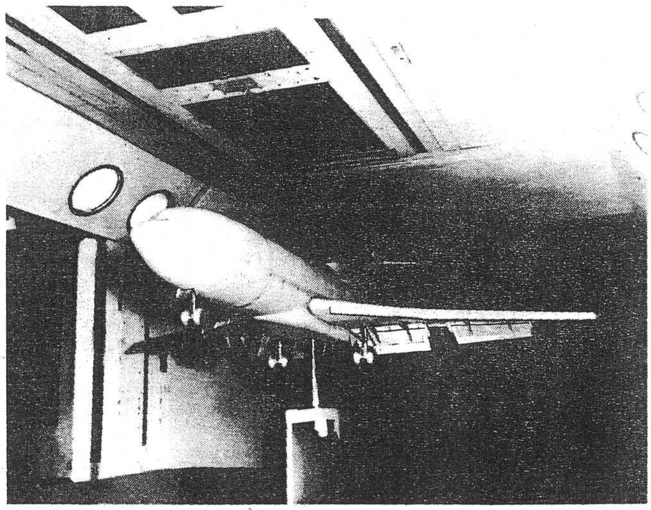


Figure 26.- 727 Low Speed Wind Tunnel Model

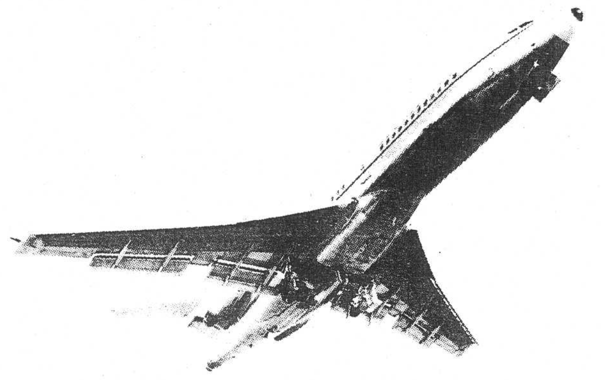


Figure 27.- 727 Extended Flaps View

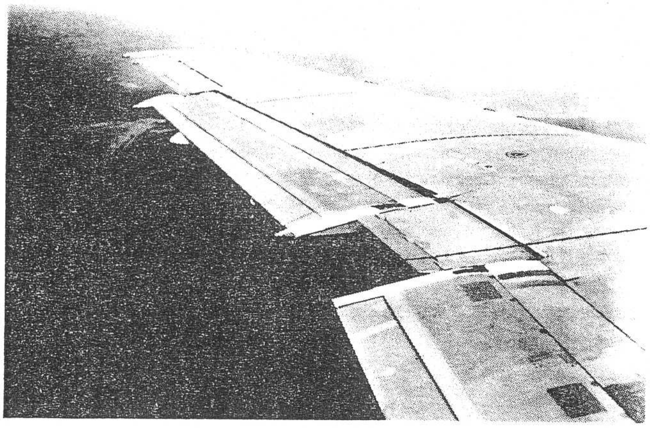


Figure 28.- 727 5° Flap Position

Flight Test High-Lift Program - 367 - 80

Concurrent with the wind tunnel high-lift program, many configurations were tested on the 707 prototype airplane (Model 367-80). These tests included various leading edge devices and BLC trailing edge flaps. This program is summarized in Figure 29.

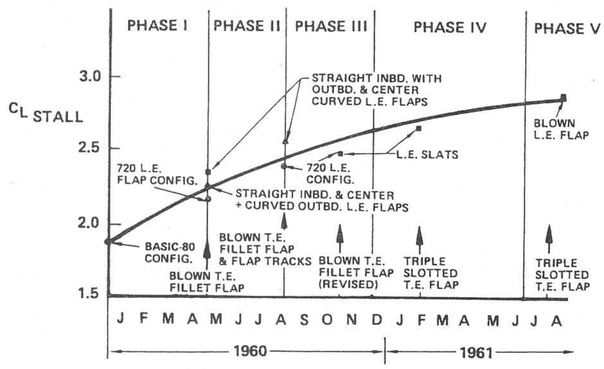


Figure 29.– Flight Test High-Lift Program - 367-80

When the 727 design began to firm up on large slats and triple-slotted flaps, a full scale flight check was initiated. A triple-slotted flap was designed for the inboard position on the 367-80. The configuration, which included large leading edge slats, was wind tunnel and then flight tested to establish correlation. Such variables as slat angle, slat gap, and fore flap slot and overlaps were checked.

These tests confirmed the correlation factors we had been using, and the flight qualities predicted by the wind tunnel. Slat and flap gaps proved to be insensitive to reasonably large variations.

Following these tests, the decision was made to use triple-slotted flaps and slats for the 727. While boundary layer control (BLC) had shown considerable promise, development timing and certification rules were in question. In addition, blowing efficiency had not reached an acceptable level and there was a possibility that BLC would require auxiliary engines.

Flap Geometry

On the basis of many test results like the foregoing, the flap geometry was chosen. Figure 30 shows the motion of the trailing edge flap. From the flaps-up position, motion is nearly straight aft for the first 55% of screw travel. This is the 5 deg position (lowest takeoff setting). Between 5 and 10 deg flap, the fore-flap stops moving aft and begins to rotate only. Further motion of the main flap away from the fore-flap produces motion of the aft or auxiliary flap segment. Fully extended, the total flap chord is about 150% greater than the chord in the stowed, flaps-up, position. Stowed chord of the inboard flap is 60 in. Average stowed chord of the outboard flap is 48 in. A side advantage to this type of motion is that, at large flap angles where drag changes rapidly, the rate of flap angle change is high.

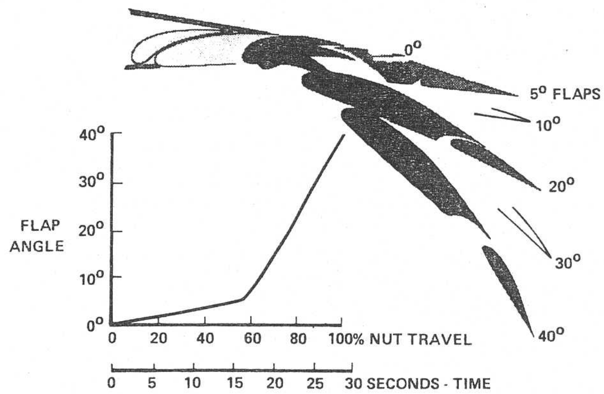


Figure 30.– Trailing Edge Flap Geometry

Leading edge (Krueger) flap and slat geometry is shown in Figure 31. As previously discussed, once the chord of the slat near the tip was chosen as large as possible, the key decision of leading edge design was made. This slat chord of 24 inches is about 25% tip chord. Moving inboard, the constant chord (24 inches) was maintained, because it met requirements and it allowed the use of common tracks. The large downward motion of the slat is believed to be unique. The Krueger flaps have a chord of 18 inches and extend to within 3 feet of the body. The Krueger flap combined with the large nose radius of the inboard airfoils provides the desired characteristics.

considerations shown on Figure 33. The starting point for these wing studies was the 720 wing which had a design cruise condition of Mach 0.83 at a CL of 0.4. In designing to the new performance requirements for the 727 a continuous effort was also made to improve basic stability characteristics. It was believed that improvements could be made in the inherent airplane stability which would minimize the amount of artificial augmentation required to achieve the desired handling qualities.

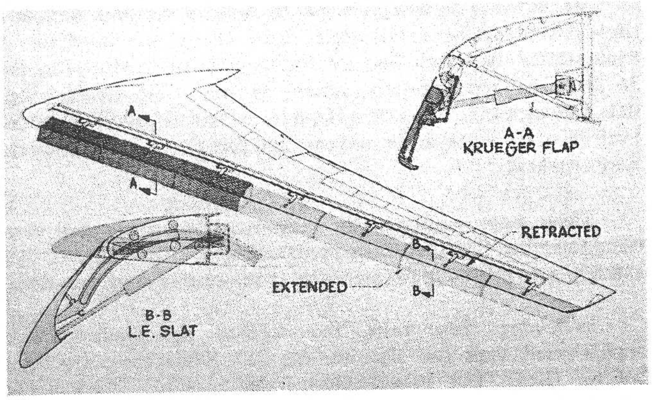


Figure 31.- L.E. Slat and Flap System

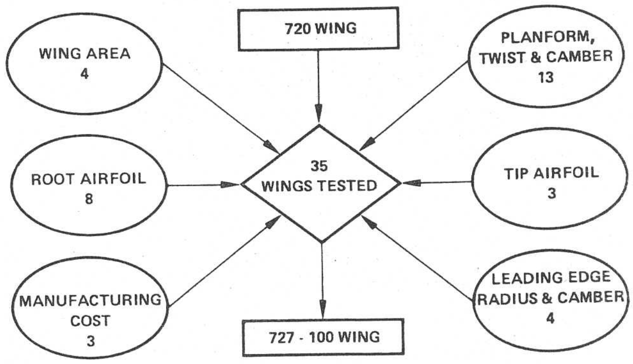


Figure 33.- 727-100 Wing Development

Transition Flap

With a flap system as powerful as that of the 727, consideration must be given to the transition from flaps-down flight to flaps up. At the 5 deg flap setting (55% screw travel) all leading edge devices (4 slats and 3 Kreuger flaps per side) are fully extended. The stall lift coefficient for 5 deg flaps is about 2.1, while $C_{L_{stall}}$ for flaps up is about 1.3. The significance of this large spread in C_L is shown in Figure 32 in terms of climb gradient versus velocity. Two cases are shown: a takeoff under normal conditions with all engines operating, and an extreme condition takeoff (high altitude, high temperature) with one engine out. The minimum speed for maneuvering is shown for each flap setting and the flap placard speed. To go directly from flaps 5 deg to flaps up, speed would have to be increased through a region of decreasing performance before "flaps up" could be selected. The use of the transition flap setting of 2 deg (25% screw travel) provides continuously increasing performance as speed is built up. Whe flaps are retracted from the 5 deg setting to 2 deg, all leading edge devices except the middle two slats on each side retract. This action is provided by hydraulic sequence values operated by trailing edge flap motion.

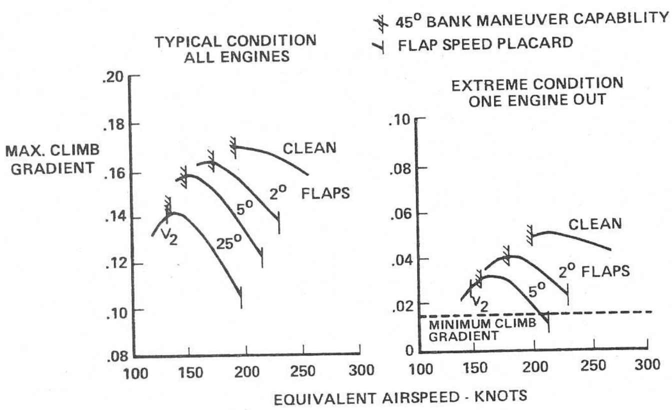


Figure 32.- Climb-out Performance

CRUISE CONFIGURATION DEVELOPMENT

The aerodynamic cruise characteristics center around the wing capabilities. A major part of the transonic wind tunnel testing involved the determination of the wing shape. Thirty-five wing variants were tested over a period of two years, with major

The general design direction was to hold thickness ratio, and to reduce sweep and camber while striving to hold Mach critical and increasing wing L/D. Typical technology curves available in 1960 indicating the trades on thickness ratio and sweep are shown on Figure 34. The general technology trend line for L/D shown on Figure 35 was used to compare the cruise performance efficiency of the airplane. This trend line is developed from a simplified form of drag which assumes at subsonic speed:

$$C_{D_{total}} = C_{D_{sym.}} + C_L{}^2/(\pi AR)$$

substituting and optimizing

$$(L/D)_{max.} = .886\sqrt{\frac{b^2 \cdot e}{A_w \cdot C_f}}$$

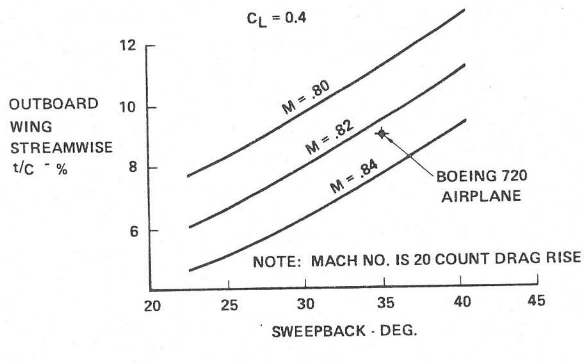


Figure 34.- Wing Sweep—Thickness Trades—1960

Wind tunnel data are shown on Figure 36 indicating that the final wing developed for the 727 has slightly less speed capability than the 720 but a gain in maximum L/D under cruising conditions. The choice of wing area and span were influenced to a major degree by landing approach speed and takeoff climb-out, and this high lift performance allowed greater freedom in optimizing wing area for cruise L/D. As the notes on Figure 33 suggest, there were questions as to the desired cruise speed, the wing sweep, the amount of camber required, and in wing changes affecting span loading. The wind tunnel studies of the wing also reflected considerations for fuel volume, structural modifications to the root airfoils, and design questions which were initiated by areas outside the aerodynamic staff. The integration of proper wing leading edge devices as well as trailing edge devices for flaps down flight was considered. An example of the "tailoring" of the flap track fairings is shown on the airplane photograph of Figure 37.

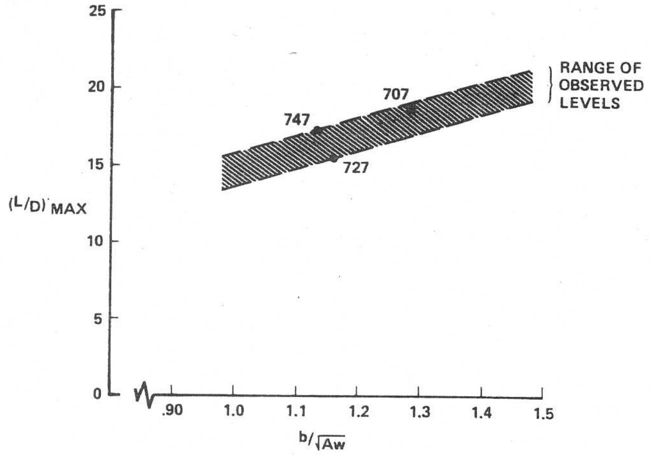


Figure 35.- Aerodynamic Cruise Efficiency

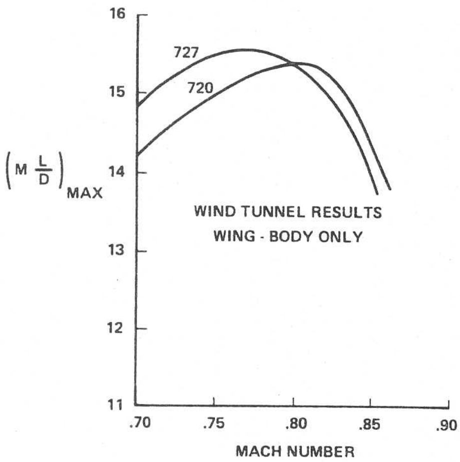


Figure 36.- Cruise L/D Comparison

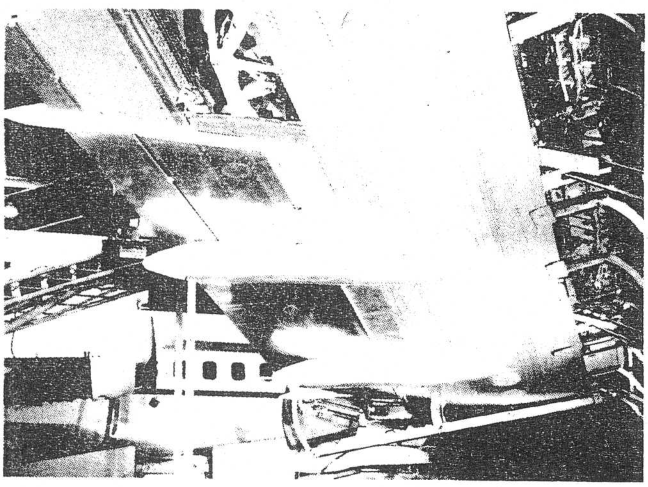


Figure 37.- Flap Track Fairings

The final wing design was chosen with a slightly less sweep for low speed performance on the quarter chord than the 720 wing, but with a similar inboard leading edge sweep extending out 30% of the span to improve the high speed characteristics. The 727-100 design cruise condition is Mach 0.82 and a CL of 0.30.

In addition to this wing development, other portions of the cruise configuration received considerable attention, both in the wind tunnel and on the drawing board. The sketch on Figure 38 summarizes the more important high speed tests performed to develop the aerodynamic design and acquire design data for other areas. The shape and location of the side nacelles were carefully tested in order to determine the optimum location and shape of these propulsion pods. Careful contouring of the nacelles was specified in spite of the demands from the project designers for "sewer pipe" symmetry for ease of production. Excrescence drag was controlled. Every effort was made to insist that all structural members remained inside of contour; only under great duress were items such as flap track fairings or any other proturbances allowed on the airplane, and they were then carefully shaped.

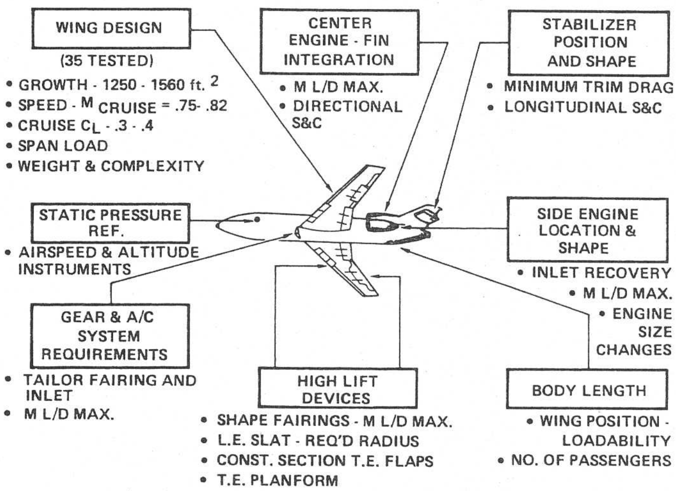


Figure 38.– Cruise Configuration Considerations - 727-100

The Environmental Control system (air conditioning) was carefully designed for the first time (compared to the 707) to provide maximum thrust recovery from cooling flow through heat exchangers. Both exits and inlets were provided with in-flight area control to reduce drag and match cooling requirements.

Configuration items impacting stability and control included the choice of vertical location of the horizontal tail and the lateral control devices. The wing spoilers are used for both lateral control and as speed brakes. Previous Boeing aircraft which had a body-mounted horizontal tail, experienced buffet produced by the wake of the wing spoilers. With the T-tail arrangement we recognized that greater use of these spoilers for vertical velocity control could be expected. Wind tunnel testing helped determine the proper gearing between the spoilers and the inboard aileron for lateral control. Extensive tests were also run to study the longitudinal stability characteristics, considering both the short period and long period stability of the airplane. The Mach tuck characteristics were predicted to be very mild (as proven in flight) and the short period handling qualities (elevator per g) were also predicted to be satisfactory.

Another area investigated was the Dutch roll characteristics, since experience had shown most jet aircraft had tendencies in this direction which require augmentation for a successful damping. As it turned out these characteristics are quite satisfactory but we could not successfully calculate the observed results. After analysis of all the flight data we still found it difficult to identify the exact value of the parameters which were most significant in lateral directional damping.

Some of the reasons for the choice of the T-tail were as follows:

Considering high speed flight,

- The pitching moments at extremely high speeds and high angles of attack tend to remain more linear since the horizontal stabilizer is farther from the wing wake. This allows for a smaller tail to provide the desired stability for the aft c.g. flight condition.
- With aft mounted engines, the "area distribution" of the aft part of the airplane is more even, providing better flow around the airplane at transonic speeds and therefore lower drag at high speeds.

For flaps down flight,

- Pitch-up due to the tail entering the wing wake is minimized since this does not occur in the normal flight envelope. (However, it was determined by wind tunnel tests that pitching moment characteristics prior to and at stall were sensitive to the placement of the engines on the aft body as well as the height of the horizontal stabilizer.)
- The stabilizer is moved away from potential destabilizing influences of the engine exhaust or, at takeoff rotation, from changing effectiveness when near the ground.

These general statements are true for any T-tail design but their relative importance may be different on another design.

This wind tunnel development of the high speed configuration was largely completed within a 20 month time span during 1960 and 1961. The resultant airplane design decisions were proven correct in that very few changes were developed from the flight test programs. The conservative performance predictions have been previously mentioned. The absolute wind tunnel level of drag of the complete model was not extrapolated to full scale to develop performance, but rather each incremental configurations item was assessed and compared to previous knowledge on such components. This method was successful on the 720 but led to a conservative drag build-up which was entirely unexpected for the 727. A photograph of the high speed wind tunnel model is shown on Figure 39.

FLIGHT TEST RESULTS

The aerodynamic flight test program on the 727 included an evaluation of cruise performance, low speed performance, and handling quality observations. The intensive wind tunnel test program and the flight testing of prototype hardware on 367-80 airplane proved its value by the completion of this aerodynamic flight testing in about 150 hours. There were only 8–1/2 months between the first flight of the first test airplane and the delivery of the first production airplane to an airline. During this critical time period the characteristics of the airplane had to be measured

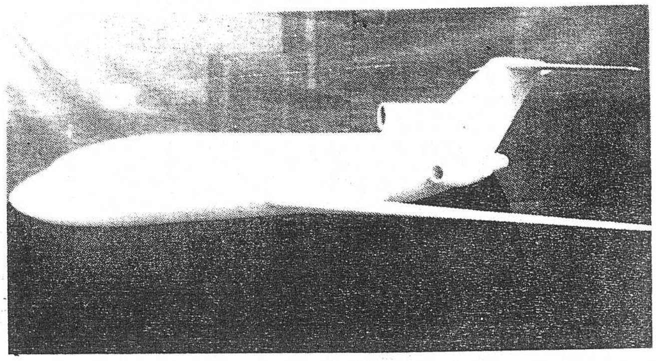


Figure 39.- High Speed Wind Tunnel Model

and any changes to the production hardware quickly determined, since the production line was building up at a rapid rate.

The most exciting result in the aerodynamic testing was the surprising cruise performance of the airplane. These showed up immediately when the range capability (miles per pound) were being recorded, as shown on Figure 40. The results indicated that the airplane could achieve up to 11% more range at a cruise speed of 0.8 Mach number than had been predicted from the wind tunnel data.

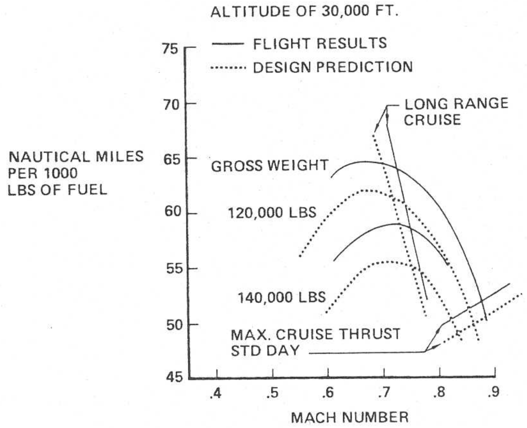


Figure 40.- Range Performance

In addition, the speed for both long range cruise and for maximum cruise thrust were increased significantly. These speed increments can be seen on Figures 40 and 41. A gain of about 10 knots in speed or an increase in altitude of up to 4000 feet is shown at a given weight. The task of identifying the source of positive performance increments is just as difficult as the search for causes of negative results although it is a much more satisfying assignment. In the case of the 727 it turned out that everything was working in a favorable direction. The engine manufacturer decided that the engine fuel consumption was better by about 2% than his original estimations. In addition the lower drag of the airplane resulted in cruise flight at lower thrusts and on a more favorable part of the thrust - TSFC curve. Furthermore, the engine installation losses due to bleed air to support auxiliary power turned out to be less than had been estimated. The resultant engine contribution to the improvement to miles per pound was on the order of 4%.

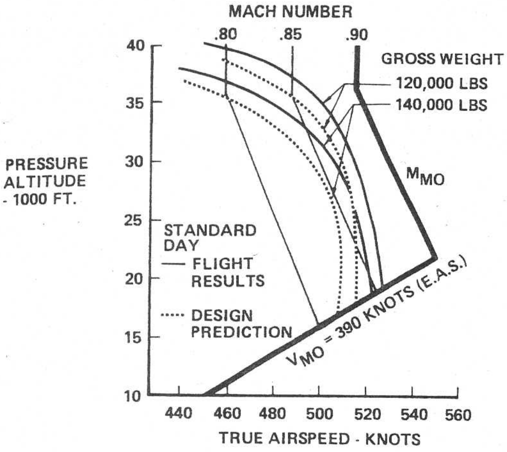


Figure 41.– Speed Performance

This left approximately a 4% to 7% conservatism in the airplane drag to analyze. In the 1950-1960 time period no manufacturer could make a drag prediction with a high degree of confidence to much better accuracy than ± 5%. In retrospect, our analysis of flight test and wind tunnel data reviewed all the elements applied to the prediction process. The novel arrangement of the nacelles eliminated the customary interference effect of the nacelles on the wing, and the T-tail also presented a new performance estimation situation. In the 727 design stage the aerodynamic staff established severe requirements to provide good seals and smoothness control of the entire airplane contour; as a result the airplane was built in a very clean condition-cleaner than our performance estimates assumed. Concern over leakage through the leading edge slats led to a performance allowance for mismatch of items on the airplane such as the leading edge slats, and the drag of other access doors had been included in the drag estimation. So a major factor in the good performance of the airplane was the attention to detail design and the aerodynamically clean condition that the production airplane did achieve. It is also true that the interpretations of the wind tunnel data were made on the conservative side. All of the items contributing to range performance and high speed performance of the airplane came out on the plus side.

The performance of the 727 high lift system was also very gratifying. All guarantees were exceeded. These include takeoff and landing distance, climb-limited weights (dependent on lift-drag ratio) and stall speed. In Figure 42, certification flight test results on stall lift coefficients are compared to guaranteed nominal level (predicted). The values shown for takeoff flap settings are at a typical takeoff weight and landing flap setting at a typical landing weight. For reference, landing $C_{L_{stall}}$ values for other Boeing Airplanes are shown.

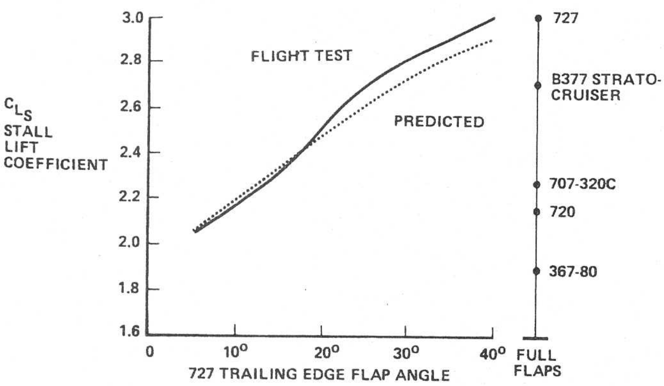


Figure 42.–Stall Lift Coefficient

Prior to flight testing, takeoff predictions had been based on using flap settings of 5, 10, and 20 deg. Flight test drag, flaps down, turned out so favorable that the airplane was certified using 5, 15, and 25 deg flaps for takeoff. This provided shorter field lengths while meeting climb limits.

One reference to use in assessing high-lift system performance is to compare flaps-down drag polars to an extended flaps-up polar. The flaps-up polar can be extended by fitting it with a theoretical induced drag polar at low angles of attack. This line then represents minimum drag or the least drag any flap system could produce at a given value of lift. The 727 flight drag polars are compared to such a line in Figure 43. Liftoff and landing approach values are shown where applicable. The resultant improvement in takeoff and landing performance is shown on Figure 44 and 45.

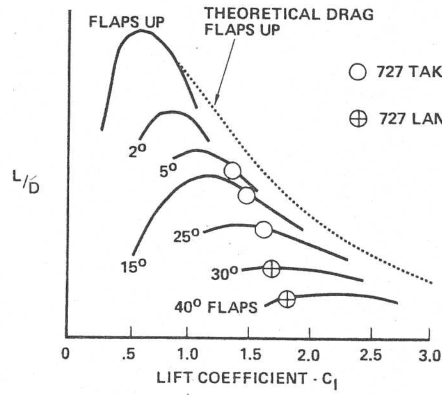


Figure 43.– Drag Polars

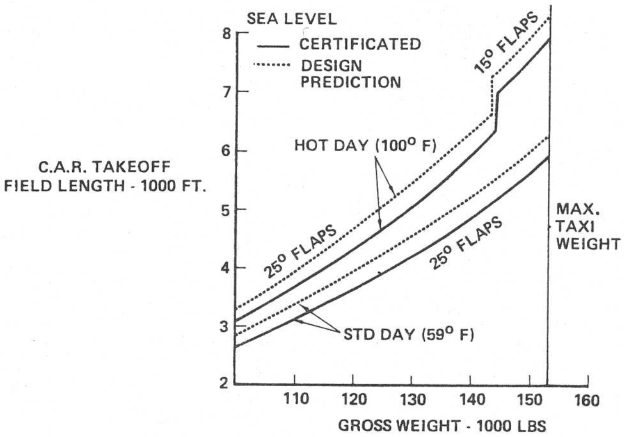


Figure 44.– Takeoff Performance

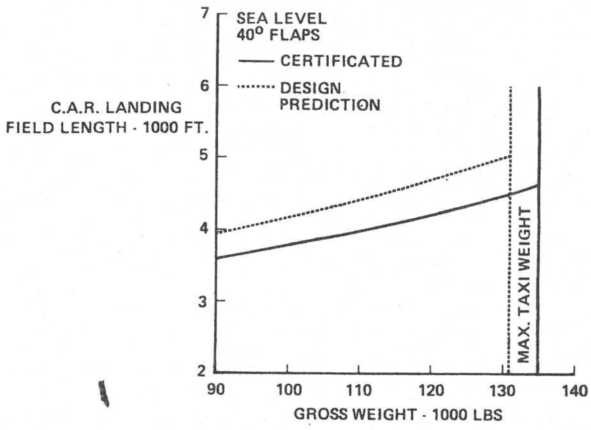


Figure 45.– Landing Performance

The reference speeds for this high lift system performance were determined by an evaluation of the stalling speed with flaps down and by extensive maximum attitude takeoff tests. Flight testing of the 727 required the conductance of over 700 stalls. In addition, the handling qualities during the stall approach and at the minimum speed were also important. Many of the stalls were flown at the most aft c.g. for which the airplane was to be certified. The stall characteristics were considered completely acceptable, with good stick forces during the approach, a slight roll-off tendency at the stall, especially with flaps up, and good recovery in the post stall maneuver. In order to provide a slight improvement in the flaps up stall maneuver, a small leading edge fence was added to the airplane during the flight testing. Several fence configurations had been evaluated in the wind tunnel and this flight test hardware was available. In the maximum landing flap configuration the natural wing buffeting prior to stall was not sufficient to satisfy Boeing pilots or to meet FAA regulations. A stick shaker was installed which actuates prior to the point of stall. Flight testing also revealed that in the landing flap configuration speed brakes shifted the position of the wing wash relative to the tail such that pitch up could be encountered with excessive use of up elevator at the stall. Since the 727 had sufficient drag with flaps and/or gear down, the use of speed brakes with flaps down was eliminated from the normal flight procedures.

Further comments noted during some of the early flight testing with respect to handling qualities are recorded in the following paragraph.

> "The initial evaluations showed that the airplane is smooth, responds readily to control motions, and has good control force characteristics. Trim change due to configuration changes are relatively small. The airplane is completely free of speed brake buffet or buffet due to flaps and slats in the normal flight regions. The airplane shows no unusual flight characteristics in the low speed flight regime. The elevator effectiveness and control forces are quite similar to pre-flight predictions and ground rig tests. Dutch roll is very well damped with the yaw dampers on, providing damping to half amplitude in one cycle and fulling damped in two to three cycles. With the yaw dampers off, the inherent damping is similar to the 707."

As the testing of the airplane continued many other items beyond the minimum certification requirements were evaluated. One of the more interesting developments in the performance area that the 727 pioneered was complete definition and demonstration of an operational wet runway landing field capability. This was performed in response to requirements of American Airlines, although some braking measurements had been made on wet runways on earlier airplanes. The 727 was the first airplane in which the approach conditions and landing conditions were put together in a way that satisfied this operational runway requirement. The technique is rather simple. It is necessary to have a runway which reflects what could be expected on a rainy day. This requirement is handled by having tanker trucks travel down the runway in successive passes, artificially providing a surface which meets the standard of a "wet, well soaked runway". The approach speed is increased somewhat to reflect operational conditions, and the flight path is specified, along with the condition of the tires and the manner in which the brakes are applied. The results of these tests showed that in addition to the superior performance of the 727 on dry runways, the airplane could safely land at normal landing weights on the same airports under rainy conditions. Other manufacturers have subsequently performed similar guarantee tests and it is interesting to note that although the airplane manufacturers and the airlines have agreed on such procedures, the industry is still working with the regulatory authorities to develop straight-forward definitions of such operational landing conditions.

In conclusion, the 727 flight test program was an exciting period and an amazing success even when re-examined 15 years later. The airplane exceeded its goals, particularly in the performance area. The stage was set for a successful production run of the 727-100. No one really dreamed the manner in which the airplane could support further development to the extent that became evident on the 727-200 series. Perhaps a fitting close of this section is a picture of the airplane (Figure 46) as it lifts off the ground in a maximum attitude takeoff test.

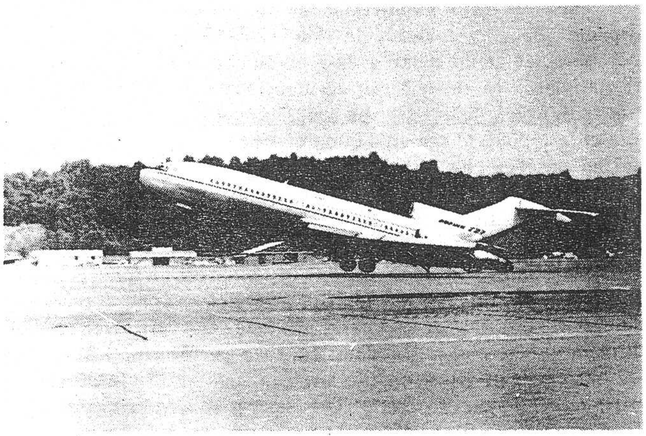


Figure 46.– Takeoff At Maximum Attitude

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6. "727 Flight Test", Boeing Airliner, March-April 1964
7. "727 Stall Characteristics", Boeing Airliner, November-December 1965
8. "Summary of 727 Flight Testing", First Report, February 18, 1963

DESIGN DEVELOPMENT OF THE 727-100

by
F.A. Maxam

Introduction

Translating the airplane design objectives and requirements, as outlined in previous presentations, into detailed hardware is the task of the Project Design engineer with the assistance of the Technology Staff engineer. Both types of specialists worked closely together in an interitive process. In addition, a configuration group of engineering specialists, who each seemed to be a favorable blend of Project Design and Technology Staff experience, greatly assisted in the melding process.

There were three distinct formal Engineering phases, following an informal series of concept studies, of this successful airplane program. Although these phases appeared to overlap and blend together this appearance was caused more by the individual scheduling of each element of the design than by the actual blending of the phases. The three phases are presented in Figure 1 together with partial lists of the activities taking place during each phase. The titles we elected to give each phase were:

- Preliminary Design Phase
- Design Development Phase
- Production Phase

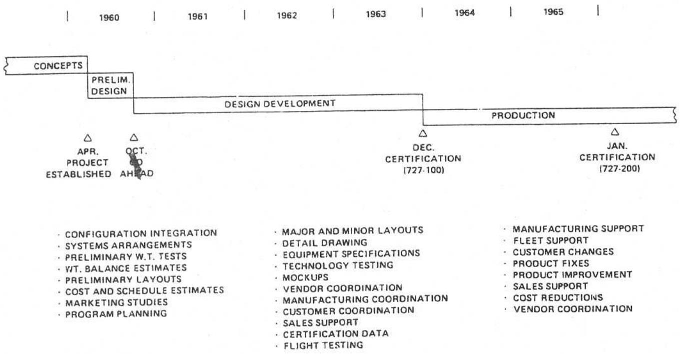


Figure 1.– Phases of Design Development

As the airplane design progressed through the three phases many changes in appearance, structural arrangement, and system configuration took place. In this section we have elected to reproduce and discuss the actual charts generated at the time the work was being performed, without editing. It is apparent the largest visible changes took place over the shortest time period during the Preliminary Design Phase. However, even after the Design Development Phase was underway for some time, the designer was still faced with many changes as more and more technical data was being generated, usually as the result of the testing process. It is also interesting to note that the Engineering schedules did not have the luxury of spare time, thus these late breaking changes had to be accommodated through overtime, work around, and a high dose of ingenuity of all concerned both inside and outside the Engineering organization.

General Configuration

During the evaluation of the general airplane configuration, many concept studies were conducted on two, three, and four engine versions. Generally the work tended to gravitate to a three-engine design. The economics of four engines was not as attractive as the three, for medium ranges, and the operational restrictions of the two appeared to limit the market. The operational restrictions of the twin were involved, *at that time*, in the twin requiring higher weather minimums for dispatch, terrain clearance problems with one engine out, limited range from higher altitude airports (such as Denver), and restricted length of flights over water.

The concept of the center engine in the aft body position, with an inlet near the lower forward fin area, was developed in preliminary design concept studies as early as 1956, some four years prior to the 727 becoming an identified project. This concept essentially installed the engine aft of all airplane structure on a rearward facing strut. Thus the experience gained by Boeing on the strut-mounted wing engines from a design and safety standpoint was directly applicable. Also, by mounting the engine in the frontal area shadow of the body, drag was reduced which more than compensated for the added skin friction of the "dog house" of the upper mounted inlet and the small losses of the S duct.

Placement of the remaining two engines then oscillated from wing mounting on forward or aft struts, and side aft body strut mounting. In the fall of 1959 the configuration of Figure 2 was favored. The aft body mounted engines were attractive because they allowed the smaller 727 to be considerably closer to the ground than wing mountings, provided better engine inlet protection from foreign object damage, and provided excellent internal noise levels. On this configuration the main landing gears were mounted in wing pods which seemed attractive since it allowed the gear to be further aft and at the same time did not reduce the cargo compartment volume necessary to balance the more forward payload center-of-gravity inherent in the aft body engine-mounted configuration. This general arrangement continued into early 1960 (Figure 3) with this main gear arrangement (Figure 4). A plaguing problem with the pod enclosed main gear arrangement was the inability to load the aft cargo compartment conveniently. The only place the compartment door could be located and provide an opening that would allow full access to the constant cross section was between the trailing edge of the wing and the side engine inlet. Tricks were played with the aft fairing of the landing gear pod (Figure 5) but airlines advised they did not believe loading clearance would be adequate.

In early 1960 the configuration was changed by adjustments to the wing location and sweep and integration of the main gear with the wing inboard trailing edge and the body, i.e., wheels housed in an unpressurized area similar to the 707 (Figure 6). This arrangement reduced the landing gear tread, which was of some concern relative to ground stability, but also substantially reduced the aft cargo compartment volume causing balance problems.

SECTION 3

DESIGN DEVELOPMENT OF THE 727-100

by
F.A. Maxam

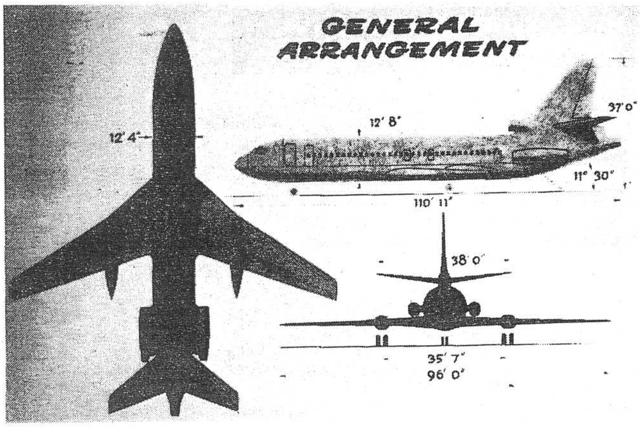


Figure 2.– General Arrangement

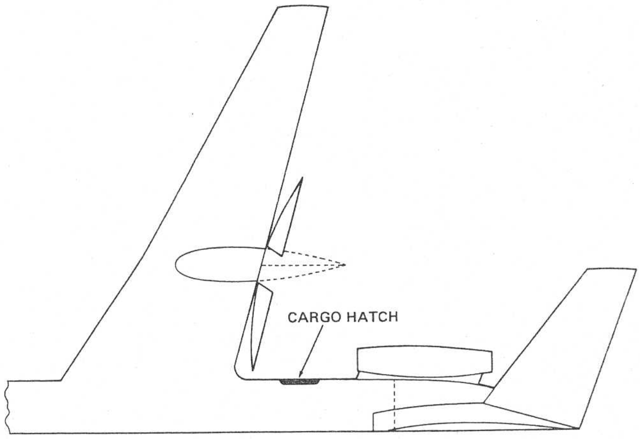


Figure 5. – Rear Cargo Access

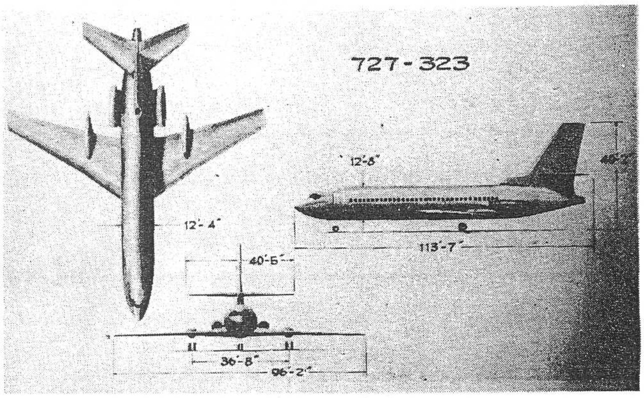


Figure 3.– General Arrangement

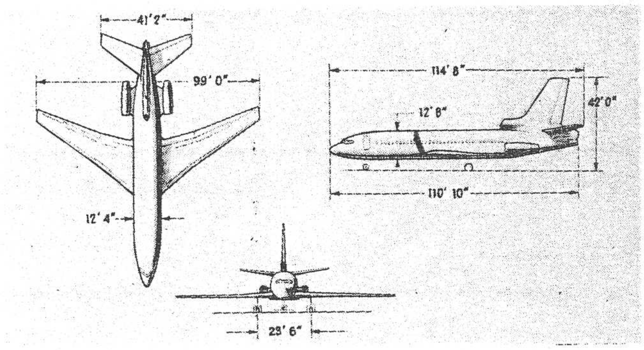


Figure 6. – General Arrangement 727-323

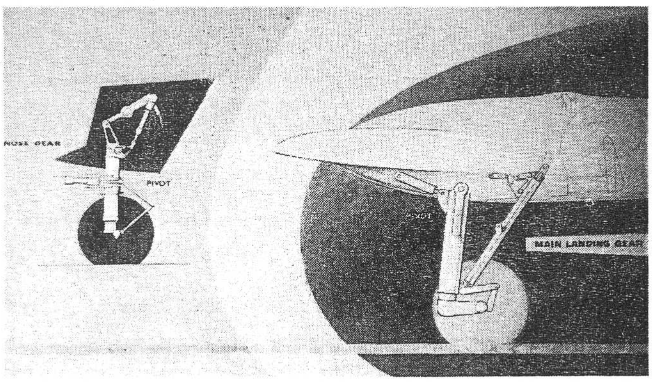


Figure 4. – Landing Gear System

During these early configurations the air conditioning equipment traveled forward and aft in the body trying to find a home within the minimum body contour. When aft it interfered with the aft stairway concept or reduced aft cargo volume. When forward it increased interior noise levels, had to be placed in the pressurized area which was a weight penalty, and required long duct runs from the aft engines which were inefficient from a weight and loss standpoint. There were some small balance benefits with the forward location.

By the fall of 1960, at program go-ahead, these problems had been generally solved. They were solved in the classic manner of airplane design, by compromises. Compromises are required in thousands of areas during design work but the successful designs are those wherein as many as possible of the compromises are synergistic. That is, through application of clever, innovative, and highly technically competent engineers and engineering managers many of the requirements can be brought together to compliment each other in the total design solution. Obviously the more the design is put together in this manner the more probable the overall success. In the material following, time after time it will be apparent that the excellent 727 design team was able to provide synergistic solutions to design problems and this capability was a prime factor in the long-term success of the product.

The configuration changes from Figure 7 to Figure 9 illustrate the above concept and may help to clue the reader in recognizing similar areas in reading the following material. The inboard wing trailing edge to body juncture point was pulled aft. This provided a thicker wing root section to house the landing gear strut in the retracted position and improved the landing gear trunnion location and geometry on the rear spar. An auxiliary beam was installed between the rear spar and the side-of-the-body which provided support to the landing gear trunnion on the aft end thus eliminating an undesirable cantilever support condition. It also provided a supporting means for the inboard trailing edge flaps. The effect of reduced cargo volume, from having the main gear wheels retract into the body was compensated for by increasing the depth of the aft body cross section. A fairing was then necessary under the wing to fair from the smaller cross section of the forward compartment to the larger cross section of the aft compartment.

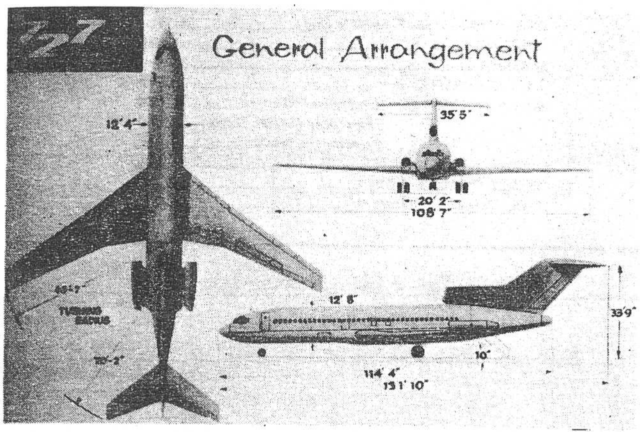


Figure 7.– General Arrangement

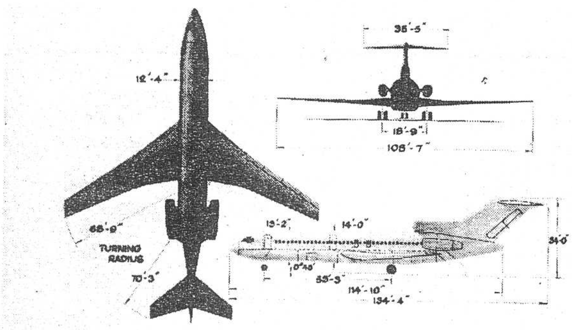


Figure 8.– General Arrangement

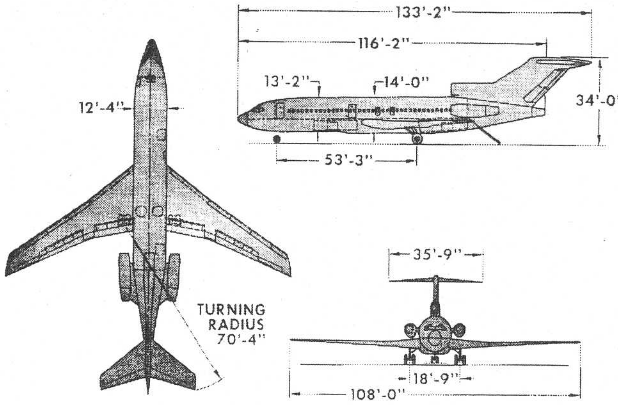


Figure 9.- General Arrangement

It was not desirable to increase the depth and consequently the cargo volume of the forward cargo compartment since the balance diagram begged for the largest aft compartment possible to compensate for the forward c.g. of the passenger payload. Added forward volume would only add structural weight and drag without allowing full loading of the volume. Since the fairing was required it was then shaped to allow incorporation of both airconditioning packs in the unpressurized area under the wing. This reduced the weight of the installation and shielded the aircycle machine noise from the passenger cabin by the mass of the wing center section. In addition, the fairing provided the opportunity to area rule the airplane and provide a more gentle slope to the airflow expansion as it goes from the relatively small cross section of the forward body past the wing to the larger cross section area of the side engine installation and the center engine inlet "dog house". While this was all going on we were trying to find a location for the installation of an auxiliary power unit (APU). With the center engine installation and the aft air stairs there was no space available without reducing the aft cargo compartment, a fatal defect to balance. Also we did not care for anymore weight aft for the same balance reasons. If the APU had to be installed in any external bump it had been determined that the added flight fuel consumption penalty would be considered excessive by the airlines and this most desirable item would probably be left off. It appeared from the economic trade studies that the airlines could accept the weight but not any drag. Although some airlines felt it might be desirable to be able to operate the APU in the air for short periods after takeoff or short periods prior to landing most felt there was not an absolute requirement for flight operation. With these design requirements in mind and still looking for a location for the APU, one late night on my way through the structures design group area to my car, I again passed the one-quarter scale mockup of the main landing gear and body cavity. Raising and lowering the gear a number of times disclosed a substantial unoccupied volume in the wheel well between the rear wing spar and the forward face of the main gear tires. The only problem was that the space was in two parts, left and right, because the keel beam that formed the only lower body structure tie, for the entire wheel well length, between the forward body sections and the aft body sections ran between the two sets of retracted wheels. Suddenly the light dawned. Would it be feasible to cut a large hole in the relatively lightly loaded keel beam webs, leaving the heavy lower chords intact, and mount the APU in this location by shoving it through the keel beam? At eight the next morning we had the structural and propulsion people around the one-quarter scale mockup and the concept was explained. No one voiced any strong objections and both groups got to work. By 4 PM the idea was pronounced acceptable and the synergistic design integration concept of the wing/body juncture, which included landing gears, airconditioning, APU, cargo compartments, fairings, and favorable effects on aerodynamics, weight, and balance, had all come together and been approved. It is unchanged in concept to this day!

The airplane's proposed characteristics, that accompanied each of the general airplane configurations discussed in the previous material, are shown in Figures 10 through 15. Initial takeoff gross weights were under 120,000 pounds, but grew to 160,000 pounds for the first production model. Similar changes took place in operating weight empty (67,000 lb. to 87,000 lb.), wing area (1300 sq. ft. to 1650 sq. ft.), engine thrust (11,350 lb. SLST to 14,000 lb. SLST), cargo volume (660 cu. ft. to 900 cu. ft.) fuel capacity (6,900 gal. to 7,680 gal.), and passenger capacity mixed class arrangements (88 pass. to 94 pass.). Substantial growth in all these areas continued during production and examples are illustrated in the later section under the Model 727-200 presentation.

	720 B	727-323	RATIO
TAKEOFF GROSS WEIGHT	221,000	118,000	53%
OPERATING WEIGHT EMPTY	110,000	67,000	61%
WING AREA	2433	1300	53%
PASSENGER CABIN LENGTH	96'	70'	73%
TOTAL ENGINE COST	812,000	480,000	59%

Figure 10.- Configuration Comparison

ENGINES	(3)ARB 963-1
THRUST/ENGINE (SLST)	11,350
WING AREA (SQ. FT.)	1,500
MAX. TAKEOFF WT. (LBS.)	128,000
MAX. LANDING WT. (LBS.)	112,500
OPERATING WT. (LBS.)	70,500
WEIGHT EMPTY (LBS.)	66,950
NO. of PASSENGERS: FIRST CLASS	68
ECONOMY	114
CARGO VOLUME* (CU. FT.)	660
DESIGN PAYLOAD (LBS.)	23,000
FUEL CAPACITY (GALS.)	6,900

* EXCLUDES CARRY ON LUGGAGE

Figure 11.- General Characteristics – 727-323

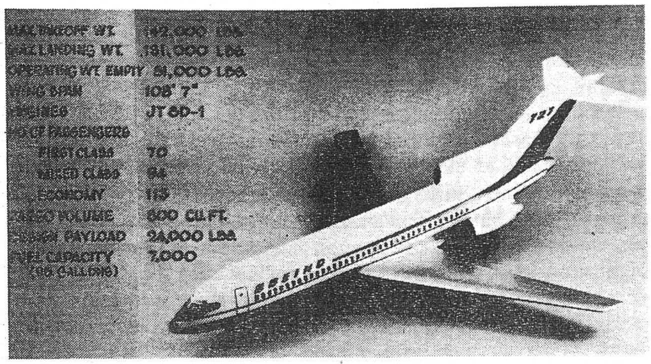
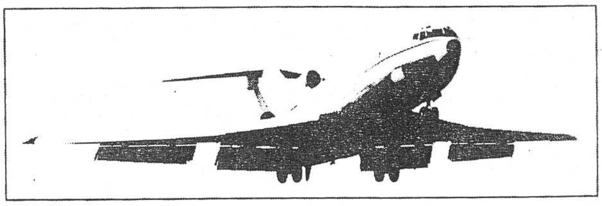


Figure 12.- General Characteristics

MAX. TAKEOFF WEIGHT (lbs.)	142.000
MAX. LANDING WEIGHT (lbs.)	131.000
OPERATING WEIGHT EMPTY (lbs.)	81.500
WING AREA (Sq ft.)	1.650
ENGINES	JT8D-1
THRUST/ENGINE (lbs.)	14.000
NO. OF PASSENGERS First class (38" pitch)	70
Mixed class (38"/36")(28/66)	94
Economy (36" pitch)	113
CARGO VOLUME (cu. ft.)	855
DESIGN PAYLOAD (lbs.)	24.000
FUEL CAPACITY (Gallons)	7.000

Figure 13.- Characteristics



MAX TAXI WEIGHT	161,000 LB
MAX TAKEOFF WEIGHT	160,000 LB
MAX LANDING WEIGHT	137,500 LB
ZERO FUEL WEIGHT	118,000 LB
OPERATING EMPTY WT	87,179 LB
ENGINES(3)	P&W-JT8D-7
MAX THRUST	14,000 LB

FUEL CAPACITY	7680 U.S. GAL
NO. OF PASSENGERS	
FIRST FLIGHT	28
TOURIST	66
TOTAL	94
CARGO VOLUME	900 CU FT

Figure 14.- Principal Characteristics

	BASIC	OPTION 3.1C.1
MAX TAXI WT, LB	161,000	170,000
MAX INFLIGHT WT, LB	160,000	169,000
MAX LANDING WT, LB		
@ 30° FLAPS	137,500	142,500
@ 40° FLAPS	137,500	137,500
MAX ZERO FUEL WT, LB	118,000	123,500
SPECIFICATION OEW	87,520	87,567
FORWARD CG LIMITS, PERCENT		
TAKEOFF	12	11
FLIGHT	11	10
LANDING	13	13
MAX OPERATING SPEED: V_{MO}, KTS EAS	390	390
M_{MO}	0.90	0.90
MAX OPERATING ALTITUDE, FT	42,000	42,000

' 142,500 LB OPTIONAL

Figure 15.- Principal Characteristics

General Arrangement

The clean lines of the 727-100 airplane are characterized by two prominent features; the aft mounted engines and the T tail. (Figure 9). Three Pratt & Whitney JT8D-7 turbofan engines are mounted in the tail section of the airplane; two pod-mounted opposite each other and the third located at the aft end of the fuselage, beneath the vertical stabilizer.

Selection of the T-shaped tail configuration gained the advantage of having no wing wake disturbance at normal operating angles-of-attack. This tail design also provides increased control effectiveness with associated smaller, low-drag control surfaces. Excellent handling characteristics have resulted.

The 727-100 wing displays an inboard leading edge sweep angle which is obviously greater than that of the outboard leading edge. This difference enables desired tailoring of the airfoil in the wing root area. Wing area has been intentionally kept relatively small to minimize cruise drag.

This configuration decreases airplane-mile costs and contributes to a smooth, comfortable ride for passengers and crew. The advanced system of high-lift devices gives the 727-100 excellent short field performance, low approach speed, and low-speed handling characteristics.

The simple tricycle landing gear uses dual wheels on each gear which provide adequate flotation characteristics and a short ground turning radius. The landing gear arrangement results in improved tire life through decreased scrubbing and simpler ground operations in crowded or small air terminals. The 727 has been demonstrated to be suitable for operation on gravel runways.

The ventral airstair and auxiliary power unit, items of standard equipment self-contained in all 727 airplanes, enhance the self-sufficiency of this airplane and provide significant savings in ground time.

Inboard Profile (Figure 16)

Efficient and convenient passenger enplaning and deplaning from the 727-100 is provided by two entry doors. The forward entry door is on the left-hand side of the fuselage and the aft entry door is on the cabin center-line opening to the aft airstair. Servicing of the passenger cabin is expedited through a separate mid-cabin galley service door on the right-hand side. Door-mounted escape slides are installed on the forward entry door and the galley service door. Two overwing exits, one Type III and one Type IV, are on each side of the fuselage.

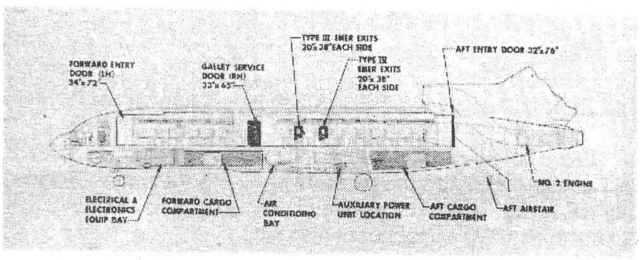


Figure 16. – 727-100 Inboard Profile

All electrical and electronics system components are shelf mounted by system in the lower forward compartment for centralized maintenance access. The compartment is accessible on the ground through a large door on the bottom of the fuselage and in flight through an access panel in the passenger cabin floor.

A 425 cubic foot cargo compartment is located ahead of the wing and a 475 cubic foot compartment is located aft of the main gear wheel well. Dual airconditioning packs are mounted under the wing center section. An auxiliary power unit, located in the main landing gear wheel well, provides ground electrical power and air for engine start and air conditioning, making the 727-100 independent of all ground servicing equipment during through-stop operation. The APU is not operable in flight.

STRUCTURES

Body Structural Features

Design Objectives

- Structural Integrity with Advanced Fatigue Life
- Minimum Maintenance and Adequate Access
- Adequate Corrosion Protection
- Safety, Adequate Size, and Ease of Operation of all Doors and Hatches

Configuration

The body is of semi-monocoque construction, similar to the 707/720 designs which proceeded it (Figure 17). Wing-body fairings are constructed of aluminum alloy for maximum fatigue life. Passenger floors were originally of corrugated, spot-welded aluminum for improved indentation resistance and longer floor life. With time, further life improvements were accomplished using sandwich construction with balsa core and aluminum or fiberglass face sheets; polyvinyl honeycomb core and aluminum face sheets; and nomex honeycomb core with either aluminum, fiberglass, or unidirectional fiberglass face sheets. The internal surfaces of the complete body structure are protected by Skydrol resistant finishes.

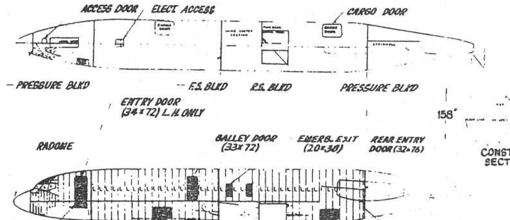


Figure 17.– Body Diagram

Doors and hatches are of the proven plug-type, similar to the 707/720 design. A large (33 x 72-inch) mid-cabin galley door is provided. The forward passenger entry door is identical to the 707/720 and is 34 x 72 inches in size. The rear passenger entry door is an inward-opening hinged door 32 x 76 inches in dimension. Four 20 x 38-inch overwing emergency exit hatches of the inward-opening plug-type identical to the 707/720 are provided.

Exceptionally large hinged doors are provided for the forward and aft cargo compartments. Larger than the 707/720, these 36 x 48 inch inward opening hinged doors are located near the centers of the cargo compartments for minimum baggage loading time and cargo accessibility. The use of hinged doors increases the useful cargo volume by 13 cubic feet per compartment. The clear vertical height of the door opening is 35 inches.

The 10 x 14 inch passenger windows in each frame bay provide maximum seating flexibility and maximum visibility for all passengers. They are similar in construction to 707/720 design. Two structural panes - - an outer and a middle pane - - are provided, either of which can safely take the maximum cabin pressure differential load. A nonstructural inner pane is provided which serves as a dust and protective cover.

The control cabin windshields are of the V-type also identical to the 707/720 design. The forward and sliding windows are electrically heated for de-icing and de-fogging. These windows have been bird-tested with heat inoperative to establish safe limits of airplane operation. The remaining windows are electrically heated for de-fogging only.

Body Section 48

Design Objectives

- Structural integrity and adequate fatigue life.
- Ease of maintenance.
- Maximum stiffness.

Configuration

The aft body configuration is a skin, stringer, and frame design with the top cut out for the center engine duct and the bottom cut out for the aft airstairs (Figure 18). Upper and lower torque boxes are designed on either side of each cutout to carry the horizontal and vertical tail loads forward. The duct housing, forward of the front fin spar, is constructed of skin, stringer, and frames. The "in-spar" area of the duct housing is an extension of fin structure and is integral with the body section to minimize structural deflections. The fin structure is spliced integrally with the upper body torque box. Aft of the duct housing and fin rear spar, are the engine support structure and engine firewall (horizontal and vertical). Engine cowling and fairing complete the airplane aft body.

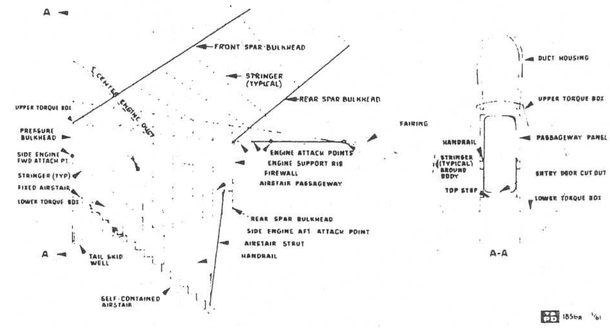


Figure 18.– Body Section 48

Vertical Fin

Design Objectives

The design of the fin "in-spar" structure shall incorporate:

- Service and fatigue life compatible with the short-haul requirements of the aircraft.
- Maximum serviceability and reliability.
- Maximum maintainability.

Configuration

The fin is of spar, skin stiffener and rib construction, similar to the wing, to provide a fail-safe, multi-load-path structure with maximum stiffness. (Figure 19). The stiffeners are not spliced from the upper body torque box to the fin tip.

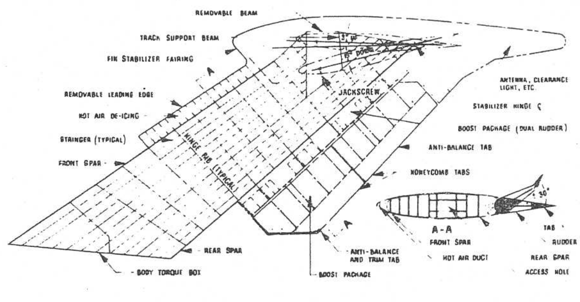


Figure 19.– Vertical Fin

Skin material is 2024 aluminum alloy. Stringers in the aft third of the in-spar area are fabricated of 7075 aluminum. Stringer material in the forward two thirds of the in-spar area is 2024 aluminum alloy for maximum fatigue life.

A hydraulically actuated upper and lower rudder are provided for fail safety. The structural configuration of each rudder is similar to 707/720 design.

Horizontal Stabilizer

Design Objectives

The design of the stabilizer inspar structure shall incorporate:

- Material and design to provide a service and fatigue life compatible with the short-haul requirements of the aircraft.
- Maximum service and reliability.
- Adequate access for maintenance and inspection.
- Adequate drainage.

Configuration

The stabilizer is similar in construction to the 707/720 design (Figure 20). It is an all-movable surface, with left and right sections connected by front and rear spars. The stabilizer is hinged about the rear spar of the horizontal and vertical surfaces by means of three bearings; the center bearing being included to make the design fail safe. It is actuated by a stabilized jack screw near the stabilizer front spar and fin mid spar.

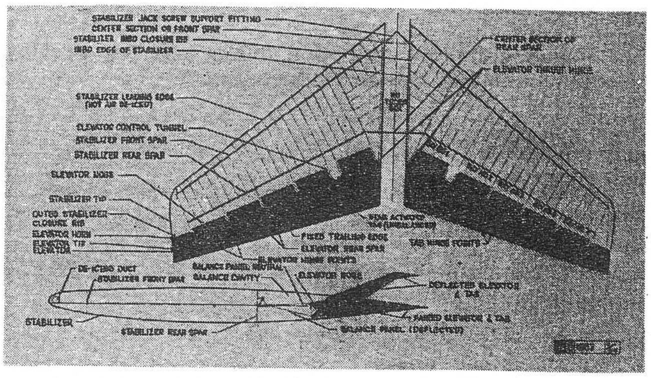


Figure 20.– Horizontal Stabilizer

The elevator balance system is simpler than the 707/720 design since it is designated for manual reversion.

Both spar center sections were originally 7079 forgings. (It was later determined that 7079 material was prone to stress corrosion and all such material was removed from the production airplanes and replaced with 7075. Many 7079 forgings on previously delivered airplanes have also been replaced by the airlines. This replacement, on older airplanes, is still continuing as stress corrosion prone parts are monitored through maintenance inspections). Outboard, the upper rear spar chords are fabricated of 2024 aluminum alloy and the lower spar chords of 7075. The in-spar area is fabricated of skin and ribs, with the optimum number of ribs for maximum structural efficiency. Skin material is 2024 aluminum alloy, with minimum splicing for maximum fatigue life.

Wing Primary Structure

Design Objectives

- Proved integral fuel tank design concepts.
- Material and design providing an airplane service fatigue life consistent with short-haul utilization of the airplane.
- Maximum serviceability, reliability.
- Maximum maintainability -- adequate access provisions.

Configuration

The wing box consists of two-spars with in-spar ribs spaced at approximately 27 inches (Figure 21).

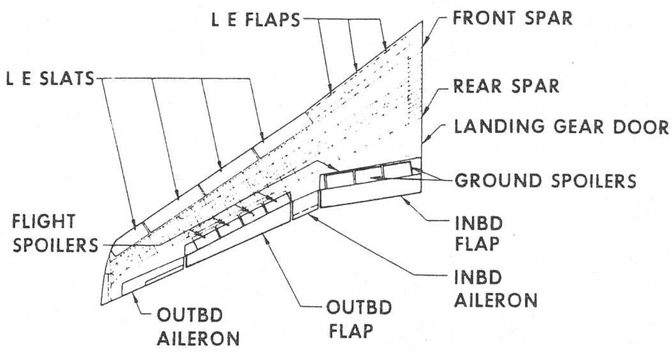


Figure 21.– Wing

The upper 7178S aluminum alloy skin-stringer assembly is fabricated with no joints from the wing tip to the side of the body. Wing joints occur at the top and side of the body only. Skin-stringer riveting is done with A2117S soft rivets. While the 707-type integral fuel tank is comparatively leak-free, the incorporation of these two features resulted in an even better 727 fuel tank configuration.

For maximum fatigue life, the lower surface 2024 aluminum alloy skin-stringer assemblies likewise are fabricated using continuous skin-stringer members from the wing tip to the side of the body. Extensive data gathered from actual fatigue tests dictated the use of 2024 aluminum alloy machined skin and stringers as well as elimination of joints as mentioned above. Attention to design details insured a wing fatigue life consistent with the service life expected of the Model 727. Here again, potential fuel leaks due to chordwise splices are eliminated.

Fatigue critical areas peculiar to the Model 727 design were proved by fatigue testing. Integral fuel tank access doors, proved on the Model 707, provide good access to the integral fuel tanks. Fuel tank sealant and application are identical to 707.

Leading Edge Flaps

Design Objective

Provide lightweight, high-lift leading edge devices for operation of the airplane from minimum-length runways.

Configuration

Krueger Leading Edge Flaps (Inboard Wing)(Figure 22).

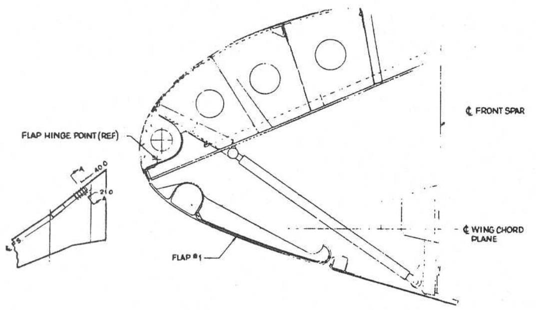


Figure 22.– Krueger Flap – Inboard

The inboard wing incorporates three leading edge flaps. Each flap has three hinges and a hydraulic actuator. The flaps are magnesium castings, similar to the 720 airplane. The fixed leading edge and the Krueger flaps are thermal anti-iced, in the inboard area only, for the purpose of eliminating ice ingestion by the engines. The fixed leading edge structure in the areas of the leading edge flaps is similar to the 720 airplane.

Leading Edge Slats

Configuration

Four wing leading edge slats are incorporated from the change in leading edge taper to the tip (Figure 23). Each slat incorporates two tracks and a hydraulic actuator. The actuator is a two-position actuator. with the slats either fully retracted or extended to a 55^{o} angle between the slat chord plane and the wing chord plane. The slats are constructed of aluminum. Steel tracks are used. The outer skin is designed for protection from hail damage and incorporates provisions for thermal anti-icing.

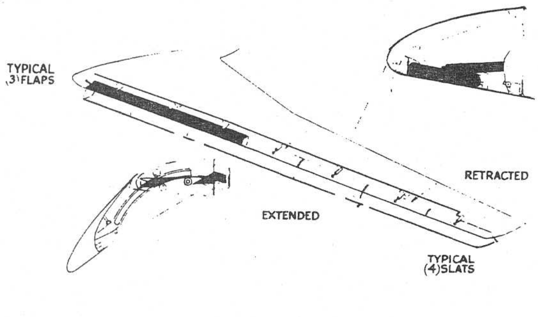


Figure 23.– L.E. Slat & Flap System

Provisions are also made for abrasion at the trailing edge of the slat in the form of a replaceable anti-friction material. The fixed leading edge structure is of conventional sheet metal design. Panels are provided on the lower surface for access to the structure and plumbing. Since the tracks and actuators protrude through the front spar with the slats retracted, fuel-tight chambers are provided for these members. Drainage is also provided. The fixed portion of the leading edge is broken into three sections, and each section is made independently removable by attaching with bolts and nuts.

Leading edge flaps and slats operate in conjunction with the trailing edge flaps to obtain the maximum lift for takeoff and landing.

Reliability and Maintainability

Due to the simplicity of design and good accessibility, the leading edge flaps and slats are easy to service.

Leading edge flaps, as well as leading edge slats are controlled by interchangeable components.

Triple Slotted Trailing Edge Flap

Design Objective

Provide a practical mechanical trailing edge flap providing very high lift for both takeoff and landing.

Configuration

The triple slotted flap is a segmented flap which expands its chord length as it is actuated to the landing position (Figure 24 and Figure 25). This provides greatly increased flap area, and the resultant slots forestall separation of the air flow over the flap surface.

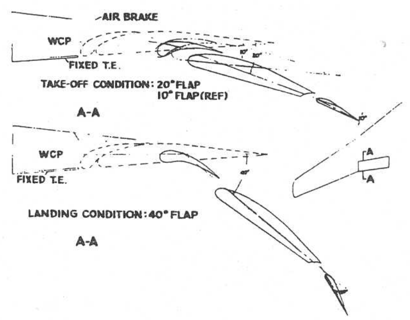


Figure 24.– Triple Slotted Flap – Inboard

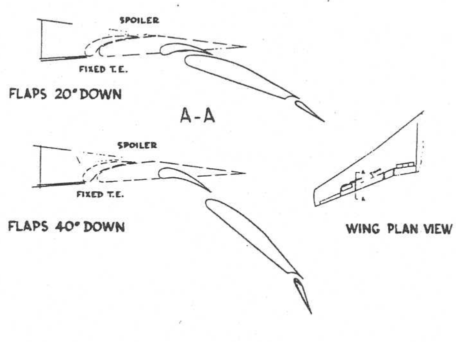


Figure 25.– Triple Slotted Flap – Outboard

The tracks which support the flaps are placed in a streamwise position (Figure 26). Placing the tracks parallel to the air flow presents minimum obstruction to the air flow over the flap. The streamwise-motion geometry is accomplished by a simple attachment between the flap and carriage consisting of a self-aligning bearing and a link.

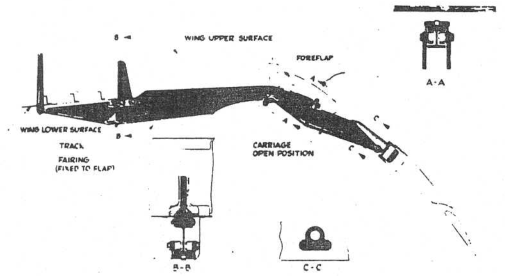


Figure 26. - Flap Support Structure

Reliability and Maintainability

The flap structure is designed in such a manner that a single failure of any structural member will not result in the loss of a flap surface. The design is made fail-safe by providing mechanical means to maintain flap symmetry and provide dual paths where practical.

The trailing edge flap system and all tracks, rollers, and carriages are readily accessible and are designed to require minimum maintenance. Replaceable wear strips are provided at all areas of contact between moving surfaces. The flap geometry is such that these contact areas are held to a minimum.

Summary

The flap system provides a very high lift, but does this with a practical mechanical flap system not dependent on boundary layer control nor auxiliary power sources such as bleed air (Figure 27 and Figure 28).

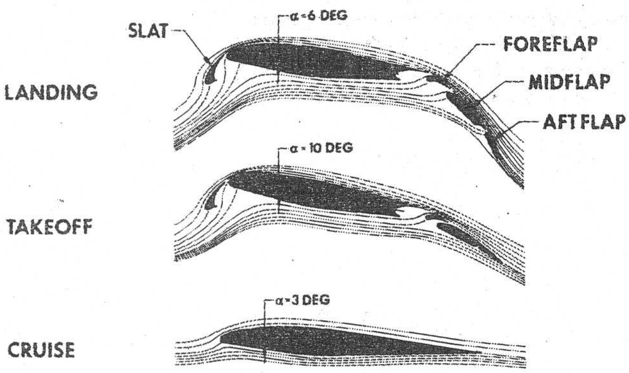


Figure 27.- High Lift System

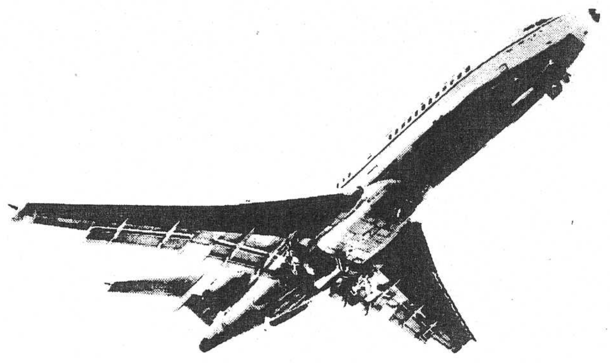


Figure 28.- High Lift System

Landing Gear

Design Objectives

- 60,000 Landings on all Primary Components
- 8,000 Landings on Replaceable Parts (Pins, Bushings, Etc.)
- 600 Normal Stops between Brake Replacements
- 10,000 Miles Roll Life for Wheels

Design Planning

The 727 landing gear is designed for basic structural and mechanical simplicity. Safe-life design concepts assure safety and dependability. At the same time, strong consideration was given to optimum servicing and maintenance by the operator. The 707/720 service experience was fully exploited to prevent possible areas of trouble and to improve the design.

The test program for the 727 landing gear consisted of component testing, photo stress analysis of a dummy gear, and complete fatigue testing of the actual gear.

Configuration

The main and nose landing gears are fully retractable, tricycle type, hydraulically operated units (Figure 29). The main gear is wing mounted and retracts to stow in body wheel wells aft of the rear spar under the main cabin floor (Figure 30). The nose gear retracts forward and stows in a wheel well under the control cabin floor (Figure 31).

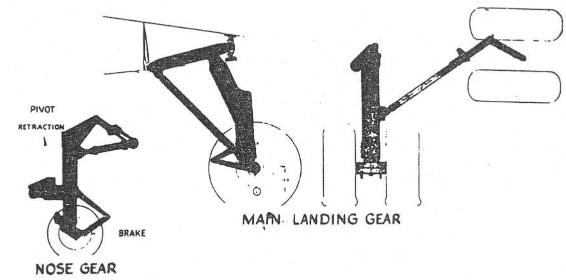


Figure 29.- Landing Gear

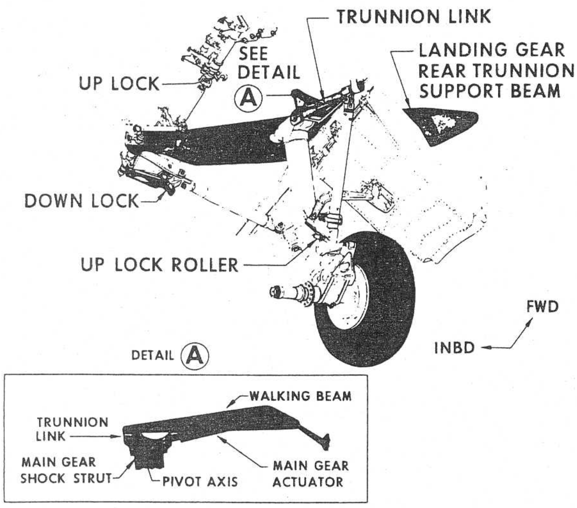


Figure 30.- Main Landing Gear

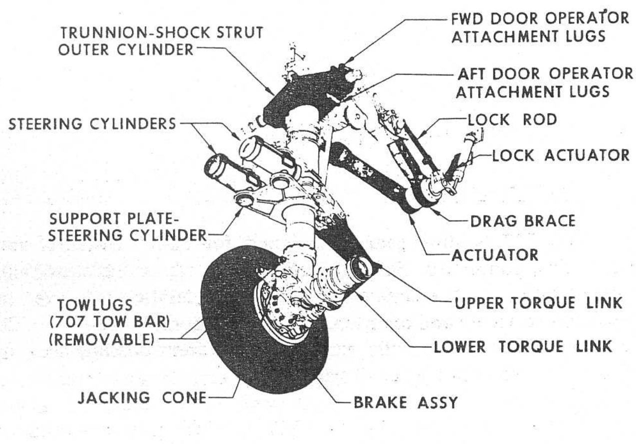


Figure 31.- Nose Landing Gear

Simple dual wheels provide for minimum tire scrubbing in taxi operation and minimum turn radius. A high maximum landing weight was chosen to allow versitile through-stop operation.

Main gear tread is 18 feet 9 inches. Wheel base between nose and main gears if 53 feet 3 inches. The main gear mounts 49 x 17 Type VII tires. 50 x 20 Type VII tires can be mounted as a special feature. Nose gear tires are 32 x 11.5-15 Type VIII.

Each gear features manual release for free fall extension by means of hand cranks operated through access doors in the control cabin floor.

Materials

The 727 landing gear is constructed of 4330 Modified Steel - Heat Treat 220,000 - 240,000 psi. Wheels are of forged aluminum alloy and of split rim construction. Rim halves are interchangeable.

Towing

The main gears have towing lugs on the bottom of each axle capable of handling a 36,000 pound load in the fore or aft direction. The nose gear has a lug on the forward face to lift a 707/720 type tow bar and sockets on the axle centerline to fit a UAL DC-8 type tow bar. The nose gear towing provisions are capable of handling 21,500 pounds towing load.

Disconnecting the torque links allow the nose gear to rotate 180 degrees.

PROPULSION

General

A very important customer design requirement is to have interchangeable engine assemblies for all three engine locations on the 727. The QEC (quick engine change) package is made up of the engine plus all of the wiring, tubing and accessories that are installed on the engine under the nacelle cowling. It would be very costly to stock three slightly different spare QEC assemblies at all of the customer's repair stations.

Normally, providing interchangeable QECs for all the engines on an airplane is not difficult especially if the engines are all mounted in the same manner, such as wing-mounted two and four engine transports.

In the 727 case, we have a left, right, and center nacelle each with a disconnect surface on different sides of the powerplant. A resolution to the problem was developed jointly with the engine manufacturer. Attachments to mount the engine were located on the top and both sides on all the engines even though for any 727 installation only selective ones were used, depending on intended installation. In other systems installations, full-scale nacelles mockup for all three nacelles were prepared to develop wire bundles, fuel controls, pneumatic and hydraulic tubing such that they could attach to the firewall disconnect; whether it be on top or the two sides. They were then supplied on the QEC with clips and brackets for each routing and the actual routing was accomplished during engine changes, after the nacelles selection had been made.

Power Plant

The 727 was initially powered by three Pratt & Whitney JT8D-1 long duct turbofan engines developing 14,000 pound SLST. All three engines are mounted outside the fuselage structure with the side engines enclosed in conventional nacelles and the center engine covered by hinged removable cowling which conforms to the fuselage fairing shape (Figure 32). Air is ducted to the center engine from an inlet on the top of the body (Figure 33).

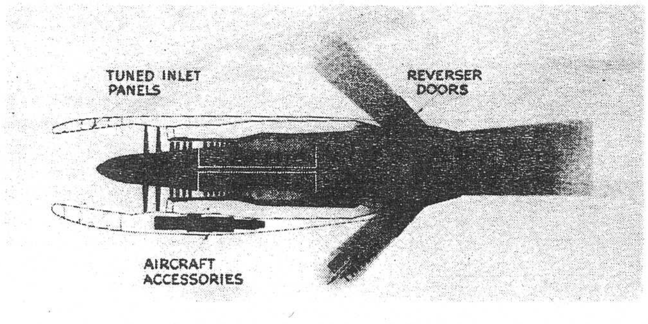


Figure 32. – Engine & Nacelle Cross Section

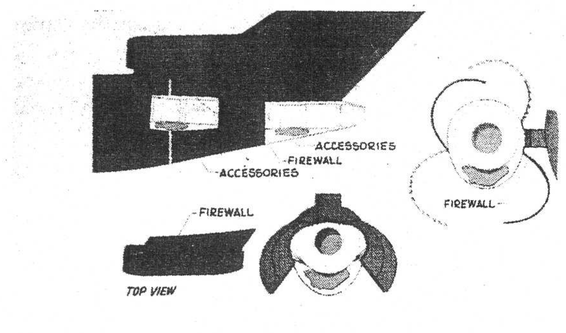


Figure 33.- Power Plant

The nacelles and cowling are designed for ease of engine access and maintenance. The upper and lower cowls on the side engines may be opened from either side. Nacelles and engine buildups are designed for maximum interchangeability between engine positions.

The power plant installation designs were established by wind tunnel tests and verified by flight tests on the aft body of the 707 prototype.

To reduce the engine noise level and noise transmission to the passenger cabin, acoustically tuned inlets and vibration isolator engine mounts are used (Figure 34).

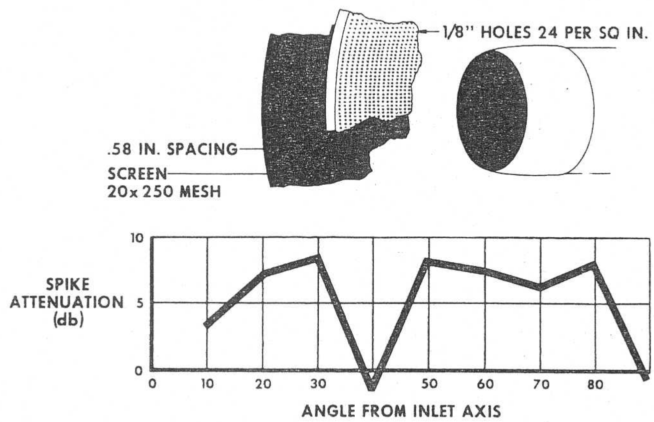


Figure 34.- Engine Inlet Noise Attenuation Panel

The related engine systems, such as the fuel supply system, have been designed so that the failure of a single engine will not affect the operation of any other.

Fire Protection

All engine compartments are isolated from adjacent body and/or strut areas by firewalls. The arrangement of the power plant and accessory systems provides the maximum possible separation of combustibles and ignition sources. All accessories and components comprising the power plant build-up are isolated from the engine hot section by the fan air duct.

Because of the fan air duct, the outer shell of the engine forward of the tailpipe mounting flange has a skin temperature that does not exceed 270°F, well below the ignition temperature of any combustible used in the airplane. In addition, this lower outer case temperature makes possible a reduction in nacelle ventilation which further inhibits a nacelle fire. Fire detectors are installed in each fire zone. Fire control is accomplished by air starvation and by a high-rate-of-discharge type extinguishing system capable of two separate discharges to any nacelle.

Drainage

The cowling is designed to ensure that the nacelles are drip free. While the airplane is on the ground, liquids are collected in the drainage tanks to be discharged overboard during flight. The design also prevents liquids from collecting in the cowling if a leak should develop in flight. If a leak should occur, the fluid would be siphoned overboard.

Flight Safety Aspects - Aft Engine Installation

The podded wing-mounted engine has established high safety standards. When a new engine location is proposed, it is necessary to compare its safety with that of the wing pod.

Engine malfunctions fall broadly into three categories: loss of thrust with no attendant physical damage, mechanical or structural failures of the engine or its installation causing airframe damage, and fire in the engine compartment. If adequate safety precautions are taken against each kind of failure, these same precautions will be effective in emergencies when combinations of these occur.

Asymmetrical thrust problems with an engine "out" are less for the aft body location, with the engines mounted near or on the centerline of the airplane, than they are with wing-mounted engines. The same is true when reverse thrust is lost on any single engine. During landing rollout on icy runways, directional control is more easily maintained despite the appreciably larger amount of reverse thrust available on the 727.

Turbine wheel burst is probably the most serious malfunction possible; however, a failure of this nature is extremely rare. Because of the potentially high energy level of the wheel pieces, absolute physical protection is very difficult to attain.

Protection is obtained by hiding fluid lines, electrical leads and control cables behind heavy structures. Maximum effectiveness is obtained by separation of these items, precluding the severing of both a primary and secondary flight control cable, or a fluid line plus an electrical lead, by a single fragment. The aft mounting is advantageous in that it places the plane of the turbine wheel far aft of the pressurized cabin and fuel tanks. Rupture of these portions of the airplane by a wheel fragment is not possible.

The engine fire problem, which hazard is very romote, is similar to wing pod engine installations except that the aft engine is farther from fuel tanks. The mechanical, control, performance, and balance of the airplane has been designed so that safe flight can be maintained in the event any single engine might depart the airplane in the extreme case of an uncontrolled fire or a violent engine seizure. Structurally and from a safety standpoint the center engine is supported by a rearward facing strut and is therefore strut-mounted following the same concept as the side engines or the 707/720 wing-mounted engines.

In light of these considerations, it is felt that the inherent safety of the aft engine installation is equal to that of wing-mounted pod engines.

JT8D-1 Engine

The JT8D-1 engine is a turbofan engine with a full length integral fan air duct (Figures 35 and 36). The fan air is mixed with the hot turbine discharge gases forward of the thrust reverser. The engine oil is cooled by engine fuel. The oil tank, fuel/oil heat exchanger, and supplementary fuel heater are furnished as integral parts of the engine.

USES J52 PARTS
- Production proven
- Applied to two Airplanes & one missile

USES JT3D/JTF 10 FAN ENGINE TECHNOLOGY
- JT3D Has FAA Certificate
- JT3D Has logged over 100,000 hrs. on Boeing Airplanes

USES JT3D NOISE REDUCTION TECHNOLOGY
- Full scale research & development

JT8D PROTOTYPE DESIGN COMPLETED NOV. 1960
- First engine run. APRIL.1961
- Six engines have completed 1350 hours test time
- High time engine has completed 500 hours on same basic parts
- First endurance test of 150 hrs. successfully completed
- Engine durability has placed test time considerably ahead of sched.
- First flight test scheduled for JAN. 1962

Figure 35.- JT8D Engine - Jan. 1962

TAKEOFF THRUST	(S.L. Static)	14,000 lbs
	(S.L. 110 kts)	12,500 lbs
CRUISE THRUST		
25,000 ft.	(M.C.T. @ M.85)	4720
30,000 ft.	(M.C.T. @ M.82)	4115
SPECIFIC FUEL CONSUMPTION (lb/hr/lb)		
25,000 ft.	(M.C.T. @ M.85)	.838
30,000 ft.	(M.C.T. @ M.82)	.818
BYPASS RATIO		1.05
WEIGHT		3022

Figure 36.- Engine Characteristics

Major accessories provided are low pressure pneumatic starters, hydraulic pumps on engines numbers one and two, and 30 KVA brushless generators with constant speed drives. The constant speed drive is designed to operate a 40 KVA generator which is also available.

The accessory systems are simple and reliable. The constant speed drive oil is cooled by ram air in flight and by aspirated air on the ground. The generator is cooled by engine fan air. All accessory cooling is adequate for hot day conditions with no operating restrictions.

Engine Inlet

All engine inlet leading edges and the impact area of the center inlet duct are anti-iced with engine bleed air. The design of the engine inlets is the result of careful research using data from wind tunnel, hydraulic analogue, and full-scale static and flight tests. Studies were made of the fuselage boundary layer profile, the flow field at the inlet plane, the effect of flaps and of high angles-of-attack and yaw. Center engine inlet shape and duct contour influence on pressure recovery and distortion at the compressor face were determined, as well as the optimum inlet contraction and expansion ratios. Full-scale studies of the cente engine inlet duct were conducted using a JT4 engine as the ai mover. Flight tests were made on the 707 prototype airplan first with a JT3 engine installed in the 727 side position, followe by similar tests with a JT8D-1 engine.

Starting Systems

The 727 has a low pressure pneumatic starter system. Air fo operation is supplied through the air conditioning manifold fror either a pneumatic ground cart, an operating engine, or by th auxiliary power unit.

Electrical power may be supplied by a ground source or b the generator of an operating engine, or by the auxiliary powe unit.

The airplane is thus independent of pneumatic and electrica ground support by using the auxiliary power unit (APU) (Figur 41). Designed only for ground operation, it supplies air for th air-cycle air conditioning system, fulfills the pneumati requirements for starting and supplies up to 40 KVA for electrica services. Starting procedures using the APU are the same as fo the basic pneumatic starting system, but the air conditioning loa must be temporarily monitored.

Thrust Reverser

All three engines of the 727 employ identical thrust reversers (Figure 37). Their reliability was ensured by using the same o improved components used on the JT4 engine of the 707 "Intercontinental".

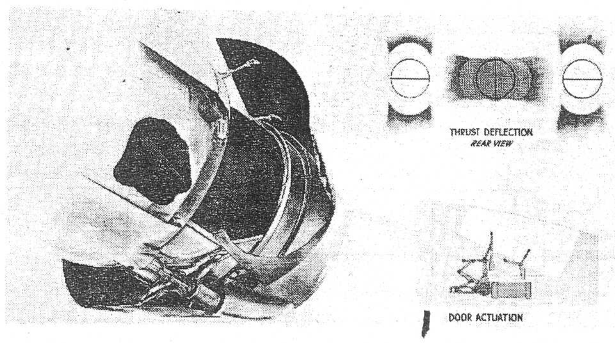


Figure 37.- Thrust Reverser

The thrust reversers can be actuated at any runway speed and to 100 percent engine power setting. Engine bleed air is used for actuator power; failure of the actuators leaves the reverser in the position at which failure occurs. No failure in the reverser or in the control system can cause inadvertent reverse thrust.

In the forward thrust position, the reverser outlets are covered by flush external doors forming a continuation of the engine cowling contour. These doors are linked pneumatically to the inner clamshell doors and act as final gas deflectors in the reverse thrust position (Figure 38). A later design removed the external deflector doors and added uncovered cascades as a design improvement in reliability and maintenance costs.

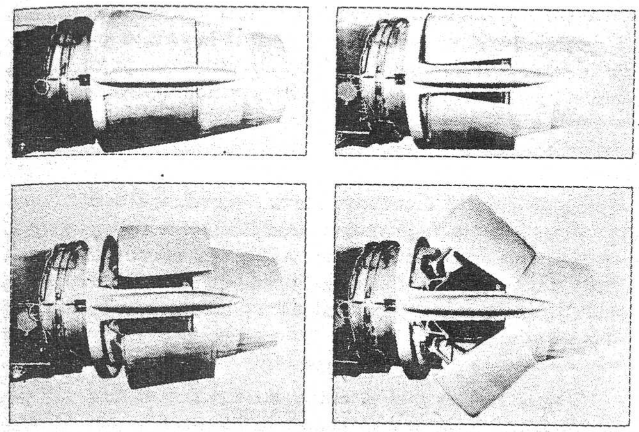


Figure 38. – Thrust Reverser

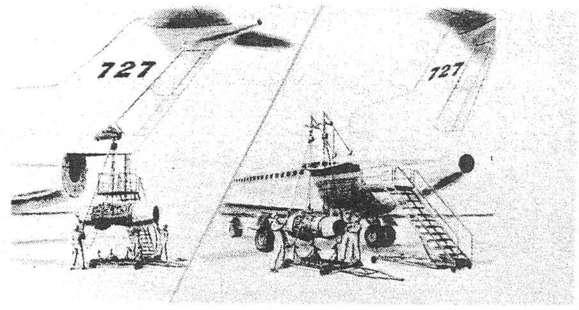


Figure 40. – Engine Support Equipment

Engine Mounts

The engines are supported at two points in front and a single point in the rear (Figure 39). The front mounts take all thrust loads, plus vertical and side loads, while the rear mount takes only vertical and side loads. Cone bolts are used at all three points and can be easily changed from the side engine configuration to that of the center engine.

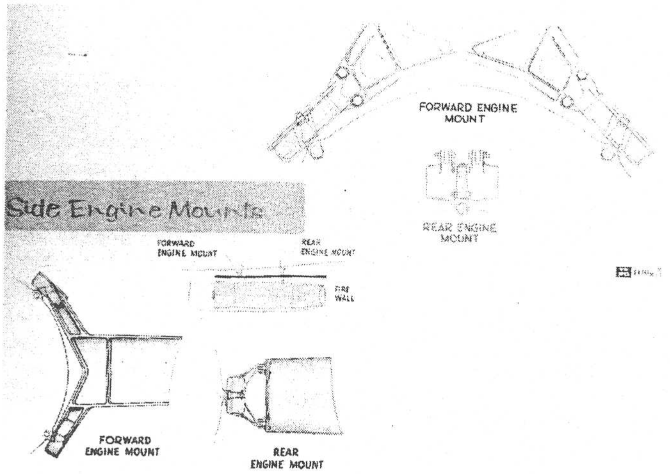


Figure 39. – Side Engine Mounts

In addition to thrust loads, the engine mounting systems are designed for a static forward load of 12 "Gs" (equivalent to approximately 25 "Gs" for a short duration).

Engine Support Equipment

The airframe fitting and hoist supports provided to facilitate engine changing are designed so that the same two hoists can be used for all three engines (Figure 40). When the center engine is to be removed, two beams are attached, one on each side of the engine, to receive the hoist hooks. Only one of the beams, fastened at the top of the engine, is needed to change the side engine. Adjustments are provided to compensate for the variation of engine center-of-gravity.

Side engine hoist trusswork is a quick disconnect pin jointed for ease of installation and removal, as well as for adaptation for right or left side use. Inboard and outboard movement is obtained by adjustments on the top of the truss.

Center engine hoist brackets attach to the sides of the lower fin. Fore and aft travel permits the engine nose dome to clear the air intake duct and body structure during engine installation and removal.

Auxiliary Power Unit

The auxiliary power unit (APU) is an AiResearch gas turbine engine located in a cutout in the keel beam between the main landing gear wheel wells (Figure 41). It may be operated from a control panel located on the third crewman's auxiliary panel or from a control panel located in the wheel well. The APU is designed to be operated only when the airplane is on the ground.

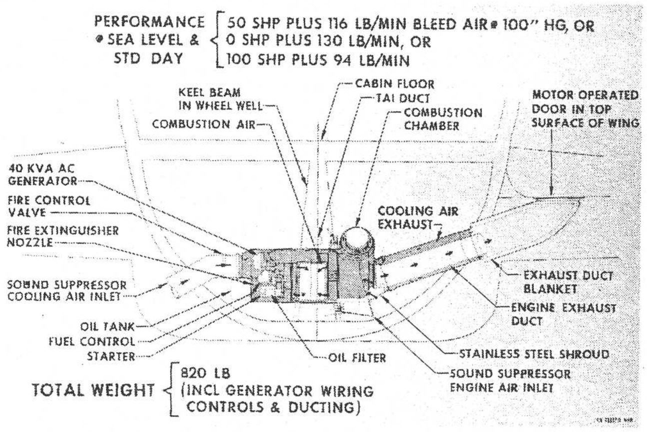


Figure 41.– Cross Section of Auxiliary Power Unit

Air intake for the APU is through the wheel well; exhaust was originally through a motor operated door in the top surface of the right wing root. A later redesign eliminated the movable door and provided a fixed set of louvers as a design improvement in reliability and maintenance costs. The APU is equipped with fire detection and fire extinguishing systems that are separate from the systems for the main engines.

The APU air output is connected to the airplane pneumatic system to provide both cabin air conditioning and engine start air. The unit is also equipped with a 40 KVA Westinghouse generator which can provide all ground electrical requirements, including the electric-driven hydraulic pumps.

Fuel System

A separate fuel tank is provided for each engine (Figure 42). All three tanks are located in the wing spar box. Numbers one and three are of integral tank construction. Tank number two is a combination of bladder cells and integral tank construction. (A later redesign removed the bladder cells and provided the second fuel barrier through the use of a "catalac" coating. This provided a substantial increase in fuel volume.) The bladder cell cavities are sealed, vented, and drained overboard. The drains are arranged so that the source of leakage can be identified.

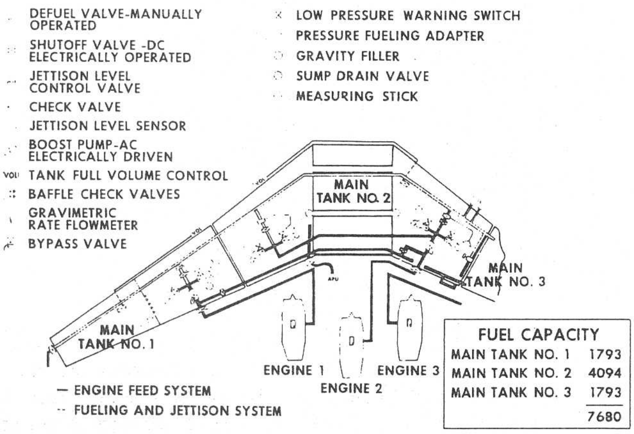


Figure 42.- Fuel System

Each tank contains AC-powered boost pumps to supply the feed and jettison systems. Each pump is capable of delivering fuel to its engine at the required pressure for all certificated operating conditions. With the boost pumps off, fuel is fed through a suction-operated bypass valve downstream of the pumps. This makes possible a single point inlet located to avoid air ingestion throughout the normal range of flight attitudes; it also reduces the pressure loss inherent in a pump-mounted bypass system. The crossfed manifold permits fuel from any tank to be delivered to any or all engines. Fuel routing is controlled by one crossfeed and one shut-off valve for each tank. Valves are installed directly on the tank wall. Tubing is routed inside of the tank to minimize external leakage. Fuel lines inside of the pressure section of the body run through the deck beams and consist of two concentric tubes; the outer is a pressure seal, and the inner carries fuel. The space between the tubes is vented and drained overboard.

The three tanks are filled equally until numbers one and three are full; if additional fuel is required, number two tank is filled further.

Takeoffs, climbs and landings are made with each tank supplying an engine. In cruise, when tank number two contains more fuel than numbers one or three, number two supplies all engines until its load equals that of numbers one and three.

A true mass-rate-of-flow meter is provided for each engine. A gage shows the temperature of the fuel in tank number one. Low pressure warning lights are provided for each boost pump. Transient lights, which indicate valve position change, for each crossfeed and engine shutoff valve are located on the third crewman's panel.

Engine shutoff, crossfeed, and the remotely selected dump control and pressure fueling valves use DC motors. Engine shutoff, crossfeed, and two dump control valves are operable from the battery. Fuel boost pumps, sump drain valves, measuring sticks, and DC electric motor operated valves may be replaced while fuel is in the tanks.

Pressure fueling rate is 600 gallons per minute, at 50 psi inlet pressure, through two nozzle receptacles at the fueling station (Figure 42). The fueling station is located in the leading edge of the right wing near the midspar point. The nozzle receptacles mate with airline standard MS 29520 nozzles and are connected to a common manifold running through the tanks, with branch lines for individual tank control. Valves are provided to permit partial and selective filling of tanks. The fueling station also has grounding jacks, individual tank quantity gages, valve control switches, valve transient lights, gage test switch, intercom jacks, and is lighted.

Automatic shutoff at the full level is provided for each tank. In the event a shutoff valve malfunction, the vents will carry off the fuel overflow preventing overpressurization of a tank. The structure will not be damaged, provided the nozzle pressure does not exceed 50 psi.

Tanks number one and three each have a three-inch filler cap for gravity filling.

Fuel Dumping

The capacity of the fuel boost pumps is greater than that required to supply the engines. This capacity is provided for fuel dumping (Figure 42). The fuel is pumped from the tanks into the pressure-fueling manifold and from there to the fixed nozzles near each wing tip. The dump flow is controlled by two tank valves in series for each pair of pumps and the nozzle valves. One tank valve maintains adequate pressure for engine operation; it also acts, through a pilot controlled system, as a minimum level shutoff. The other valve is the tank dump selector valve. This valve and the nozzle shutoff valve are DC operated, and they are controlled by switches on the third crewman's auxiliary panel. Valve transient lights provide an indication of system operation.

The dump rate is a minimum of one percent of the maximum takeoff gross weight per minute.

Defueling

Facilities are provided for complete defueling using boost pumps, crossfeed manifold valves and a manually operated valve in the crossfeed manifold (Figure 42). All defueling is accomplished through the fueling nozzles. The defueling rate is approximately 50 GPM per tank. Partial defueling may be accomplished using boost pumps and tank dump valves. Fuel may also be transferred from tank to tank on the ground by use of the dump valves and manual control valves in the pressure fueling system.

Fuel Tank Gaging System

A fuel quantity gage for each tank, showing pounds or kilograms remaining, is provided at the third crewman's station (Figure 43). In addition, repeater gages for each tank are located at the fueling station. A quantity measuring stick, operated from the lower surface of the wing, is installed in each tank. It shows the depth of the fluid in the tank. The 727 fuel quantity gaging electrical connectors employ crimp-type (soderless) pins. A junction box for gage wiring is used for each tank system to facilitate isolating system malfunctions and to permit bussing of tank units without splices.

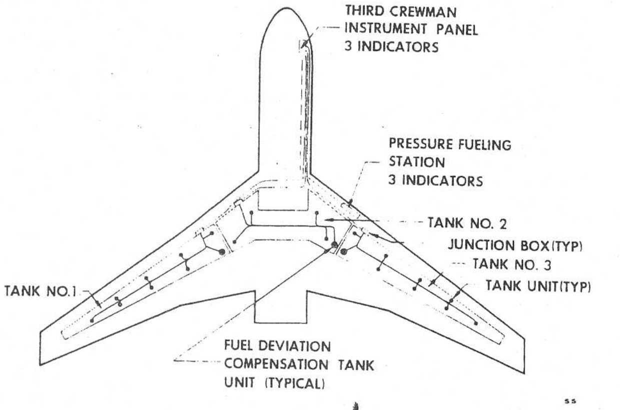


Figure 43.– Fuel Tank Gaging System

Fuel Tank Vent System

Each tank is vented through tubes and the upper wing surface stiffeners (Figure 44). The vents are essentially simple open tubes with no valves or mechanical devices which could malfunction and endanger the system. All vent lines terminate in a ramp-type, ice-free vent outlet on the underside of the wing near each wing tip. The vent lines are sized so that in the event of a control valve malfunction during pressure fueling, overflow occurs and the wing structure will not be pressurized beyond its structural limits.

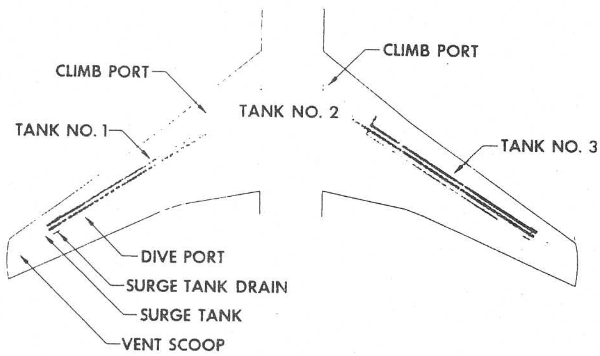


Figure 44.– Fuel Tank Vent System

Flight Controls

General

Flight control of the 727 in all three axes is fully powered with hydraulic servos (Figure 45). Pilot "feel" is supplied artificially. This provides control force levels and gradients which satisfy a rigid standard of acceptability. Integration of flight controls and automatic pilot is made by applying the autopilot signals directly to the same power control units which are used in pilot controlled flight. Safety and reliability are attained through good basic design and through redundancy with multiple power control units and multiple hydraulic pressure sources. In the unlikely event of complete loss of both main hydraulic power systems, aileron and elevator control will automatically revert to manual power by means of tabs. The lower rudder for this condition may then be powered by the standby hydraulic system. Reverting to manual operation places no speed restriction on the operation of the airplane.

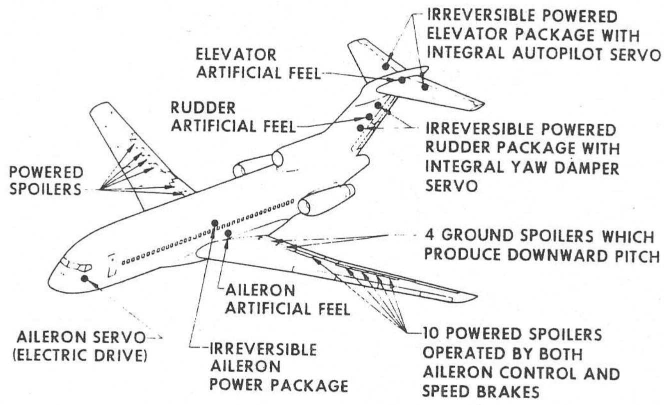


Figure 45.– Flight Controls

Lateral Control System

The lateral control system is designed for minimum breakout forces and smooth control force gradients up to a wheel force of twenty pounds at maximum throw (Figure 46). The system has the response and repeatability handling characteristics essential for operation with lower weather minimums.

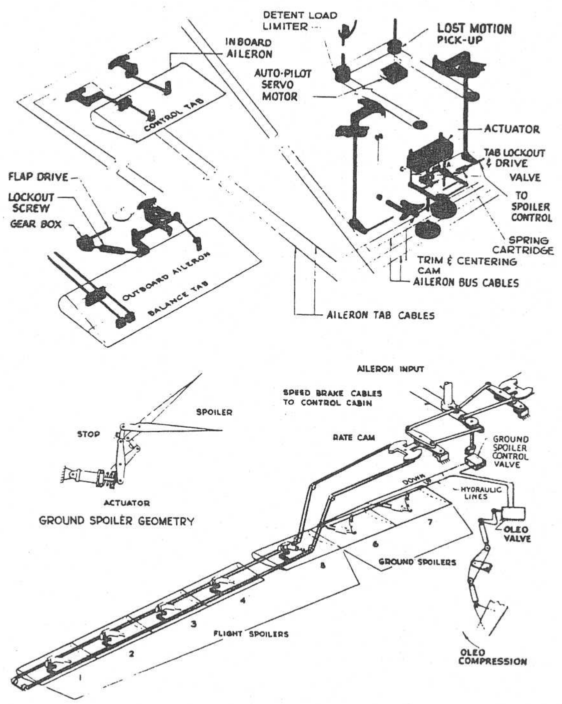


Figure 46.– Lateral Control System

If all hydraulic power were lost, the system automatically reverts to manually operated aerodynamic tabs. Full throw of the ailerons with manual tab control requires forces higher than those with power operation.

With flaps down, lateral control is maintained by both inboard and outboard ailerons and flight spoilers. With flaps up (high speed flight) the outboard aileron is locked out, in a manner similar to that of the 707, and only the inboard ailerons and flight spoilers are used for lateral control. All flight spoilers can be raised simultaneously to act as speed brakes for rapid descent. The flight spoilers are used for lateral control regardless of the position of the speed brake lever. For ground braking an additional set of spoilers is provided which work in conjunction with flight spoilers to reduce the stopping distance by disrupting the wing lift.

A dual hydraulic power package with two separate hydraulic sources is used in normal operation. The different banks of spoilers are powered by separate hydraulic systems.

The cable runs for the aileron bus system and the spoiler control cables are powered during normal operation. Pilot "feel" of control surface forces in powered operation is obtained from a simple spring.

All hydraulic components are readily accessible; the aileron power package is located in the main gear wheel well.

The ailerons are trimmed manually by cables from the pilot's control stand through a bias on the lateral control power package.

No gust snubbers, surface stops or control locks are required since the power packages perform these functions.

Loss of all hydraulic power engages the control tabs, converting the airplane to manual control without the use of any auxiliary levers and without requiring any special pilot action.

Longitudinal Control System

Longitudinal control is maintained by the elevators and the stabilizer (Figure 47 and 48). The stabilizer is movable, trim being accomplished as it is on the 707/720, by a ball-bearing jackscrew with an electromechanical drive. The jackscrew is connected by control cables to the pilot's trim wheel for manual trim. The elevators alone provide control for the extreme maneuvers required for training, FAA certification demonstrations, and stabilizer mistrim conditions, as well as for the normal maneuvers required for takeoff, cruise and landing.

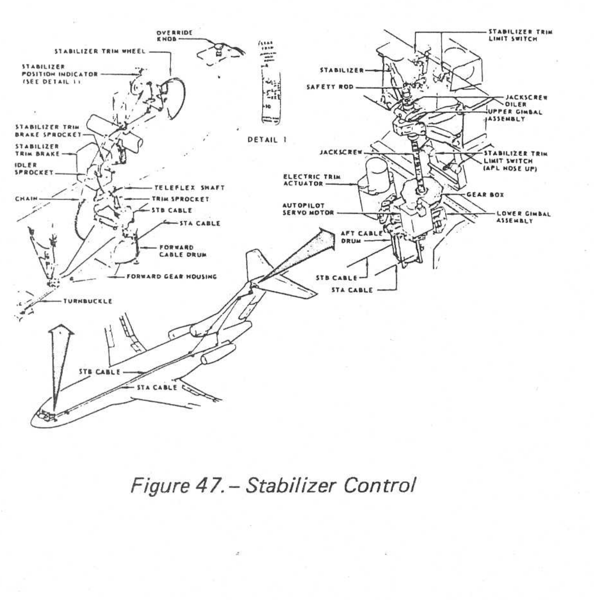


Figure 47.– Stabilizer Control

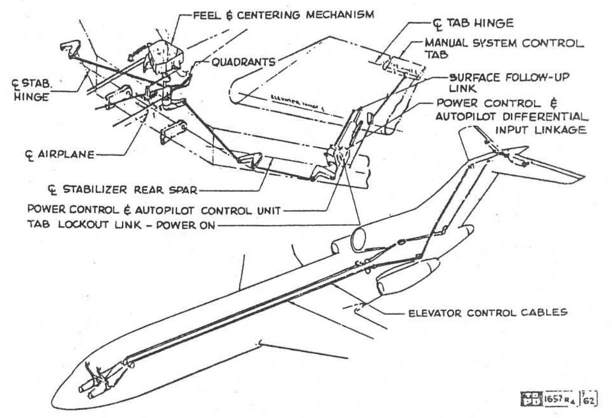


Figure 48.– Elevator Control System

In normal operation with the controls hydraulically powered stick forces are tailored to reflect center of gravity and aerodynami pressure variations.

System duplication removes any danger from a single syster failure. In normal operation, each elevator uses dual hydraulically powered servos. Autopilot electrical signals are fed directly int the servos.

Longitudinal trim is made by adjusting the stabilizer so n trim coordination problems exist. The power packages ar irreversible and will not move unless directed by pilot (or autopilot input. A mechanical brake prevents conflicting movements of th elevator and stabilizer. If the stabilizer is moving to trim th airplane, moving the elevators in the opposite directio automatically stops the stabilizer. No separate gust snubbers surface stops or control locks are needed since snubbing is bui into the power packages.

The system automatically reverts to manual tab contro upon the loss of all hydraulic pressure. As is true with the latera control system, no crew action is necessary to convert to manua operation. Aerodynamic balance minimizes floating tendencie in manual reversion.

Rudder Control System

The function of the rudder is to augment dynamic latera stability through aerodynamic damping, provide cross-win control for takeoff and landing and provide engine-out trir (Figure 49). To ensure full time yaw damping, the rudder ha been split into two segments, independently powered but normall operated in phase. The two segments are powered by separat hydraulic systems with the lower rudder supplied by a thir system through a separate actuator, for the improbab emergency of a double hydraulic failure. Dividing the rudder make it possible to use small power packages mounted between th rudder and the rear spar with good accessibility.

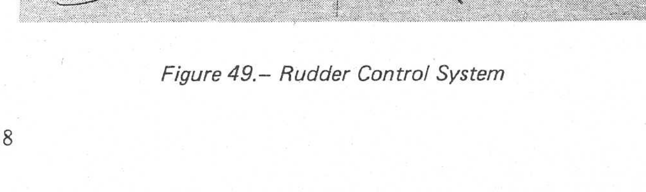


Figure 49.– Rudder Control System

The rudders are controlled from the flight station by a conventional cable system similar to that of the 707/720 in adjustment and travel. Pedal forces are generated by a spring centering unit at the aft cable quadrant. Uniform, low control forces are inherent. No pilot force restrictions on rudder operation is required since the structure is built to take the maximum loads under all conditions.

The system has a number of advantages. The use of two separately powered rudder segments with three hydraulic sources, plus positive lateral control from ailerons and spoilers, ensures the realiability of yaw control. The dual rudders also provide reliable yaw damping with the added safety provision that an erroneous hard-over signal to one rudder would automatically be compensated for by the other. If the airplane were being flown on only one yaw damper, even a hard-over fault would impose only half the yaw moment of a one-piece rudder.

Weight is saved by eliminating the conventional manual control tab, which, in turn, considerably reduces the amount of mass balance required on the rudder. Anti-balance tabs accomplish the desired control effectiveness with less surface area further reducing weight.

No gust snubbers, surface stops, flutter dampers, or ground locks are required since the irreversible servo package provides snubbing and rudder flutter damping with or without system pressure. No tab flutter dampers are necessary since rudder control tabs have been eliminated.

The power unit can be installed with only one adjustment because the servo and power package is an integral unit and all internal adjustments are made on the test bench. On the airplane, the only adjustments are those required to fair the surface.

Autopilot

The autopilot can be employed to maintain airplane pitch attitude, heading and altitude; and to provide such functions as VOR, ILS localizer, ILS glide slope and doppler heading control (Figure 50). The pilot can also use the autopilot for maneuvering in roll and pitch.

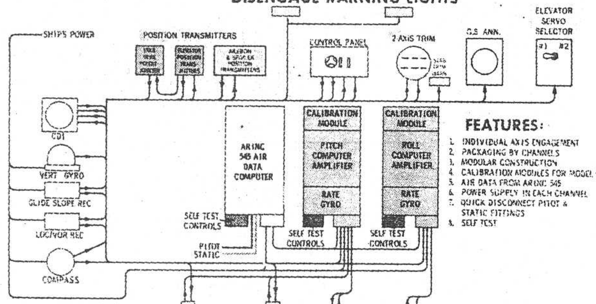


Figure 50. – Autopilot

Autopilot control of the elevator surfaces is accomplished through an electro-hydraulic servo fully integrated with the power actuator. Control of the aileron is accomplished by an electric servo motor operating on the control quadrant in the wheel well. The pilot can override the autopilot under any condition, and yet sufficient margin is provided to adequately handle the flight controls throughout the airplane's operating limits, including landing approach and flare.

The autopilot elevator control is coupled to the stabilizer trim system to provide automatic trim as required. Autopilot stabilizer trim is at a reduced rate so that a malfunction cannot produce excessive rate of maneuver.

The aileron and elevator channels may be engaged either separately or together. Interlocks prevent simultaneous engagement of incompatible controls, such as the altitude and glide slope controls. The pilot or copilot can disengage the autopilot by pressing the disconnect switch on his control wheel, by manually operating the engage switch, or by operating the manual trim control. Disengagement is indicated by warning lights located in prominent view of the pilots. The warning light reset button is on the control panel.

Packaging, including electrical connectors, case sizes, case mounting, and cooling conforms to ARINC specification 404. The control channels are functionally and, so far as practicable, physically separated. Power supplies, amplifiers, computers, gyros and interlocks for each channel are contained in each applicable channel box. The air data sensor unit consists of a power supply, an aneroid bellows, and a differential pressure bellows and provides outputs for altitude control and air speed gain compensation. All major components of the autopilot and yaw damper, including airframe furnished relays with connecting wire bundles, are mounted on a single removable shelf for easy maintenance.

Simple go—no-go test devices are employed on all major components. Quick disconnect attachments are used wherever practicable to facilitate component replacement. Readily accessible, rugged, screw-type junction terminals interconnecting components are provided to make system checking easier and simplify possible future changes.

The autopilot is designed for long life, with uniform performance. All components are derated, static switching is used, the circuits are simplified, and stabilization is accomplished by high feedback.

Yaw Damper

As described in the directional control section, each rudder has its own completely independent yaw damping control system, including transfer valve and electronic equipment (Figure 51). The system provides yaw stabilization with no forces or motions reflected in the pilot's rudder pedal.

Differential yaw damper control eliminates pedal motion and opposition to pilot inputs. Dual electronic yaw damper channels, interchangeable but functionally independent of each other and of the autopilot, operate separate rudder surfaces through electro-hydraulic servos fully integrated with their respective actuators. This redundancy provides a high degree of reliability. The electronic components are designed for long term operating stability, with simplified circuits and self-test devices.

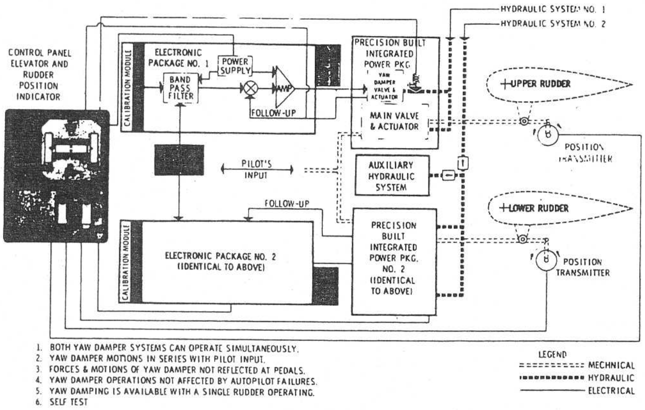


Figure 51.– Yaw Damper Diagram

Summary of Advantages of the 727 Control System

Dual hydraulic power to the primary flight controls provides redundancy and reliability. Since both systems are working in parallel, there would be no flight path deviation should one system fail.

With the tab control method of manual reversion on the aileron and elevator and with a third hydraulic system for the rudder, safe control of the aircraft is provided even if a failure of both primary hydraulic systems should occur. Full throw of the ailerons is available in manual reversion.

Demonstration of the manual reversion mode of operation for pilot training is easily accomplished through the hydraulic system shutoff controls.

The differential lever and tab lockout incorporated in the elevator controls provide a means of changing from power to aerodynamic boost with little flight path deviation. This is also a characteristic of the aileron boost system.

Artificial control stick "feel" forces, produced by a dual mechanism in the elevator control, provide a more uniform stick force with control deflection than is possible using the control surfaces as a source of feel. If a hydraulic system were to fail, there would be no change in stick forces.

By using full power control with simple aerodynamic balances on the elevator and rudder, manufacturing tolerance problems that affect aerodynamic performance are eliminated. With full power control of the elevators, full deflection of the surfaces is available during approach regardless of stabilizer trim position.

Control tabs and feel springs provide elevator control feel in manual reversion.

Hydraulics

General

The 727 was the first Boeing airplane which departed from the tradition that all the control surfaces must have manual (cable) backup capability in case of all-engine or power failure. The 727 aileron and elevators are hydraulic-boosted with manual backup, but the rudder is completely hydraulically-powered. The redundancy requirements of the flight controls were integrated with those of the leading-edge and trailing-edge, flap controls, brake systems, spoiler, main landing gear, etc., and an overall dual hydraulic system was developed with electrical backup, or in the case of the rudder, an electrically-powered third hydraulic system.

Much innovative design was applied to make the hydraulic system more reliable and leak proof (Figure 52). The installation was designed with long unbroken hydraulic lines running from the main landing gear wheel area to the nose gear wells and back to the body tail cone area, to eliminate all breaks in the pressurized area. Improved fittings were developed and extra filtering provision installed to insure trouble free operation. The hydraulic equipment was grouped into modular units to reduce the number of joints in the system increasing reliability and providing minimum maintenance.

1. Modular Packages Reduce Number Of Joints
2. Kellogg Pumps For Better Service Life
3. Seamless Steel Tubing To Reduce Tube Failures
4. More Extensive Filtering To Reduce Contamination Failures
5. For Reduced Fitting Failure Or Leakage
   a. Titanium Or Steel Fittings In Pressure Lines
   b. Improved Seals In Actuators
   c. Teflon Hoses With Swaged Fittings
   d. Elimination Of Banjo Fittings

Figure 52. - Hydraulic System Reliability Improvement Program

Hydraulic System

The 727 has three independent conventional 3,000 psi systems, designated "A", "B", and Standby (Figure 53). All three systems use variable displacement pumps, Systems "A" and "B" each having two and Standby, one. One of the System "A" pumps is driven by engine number one, the other by engine number two. The System "B" and Standby pumps are installed in the fuselage and are driven by AC electric motors. The power for the flight controls is supplied by Systems "A" and "B", operating simultaneously. The systems functions are shown schematically in Figures 53 and 54. The Standby system is used only if one or both primary systems should fail. Systems "A" and "B" are completely separated except for the ground interconnect and brake interconnect valves. The ground interconnect valve can only be operated when ground electrical power is available. The brake interconnect valve is used to supply hydraulic power to the brakes from System "A" whenever "B" system is inoperative and the brake system is intact.

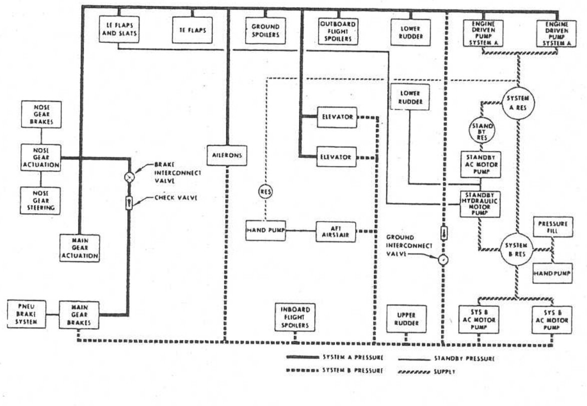


Figure 53. - Hydraulic System

Pressurization Control

The control cabin, passenger cabin, lower nose compartment and both cargo compartments are pressurized (Figure 79). The cargo compartments are the non-ventilated type, fitted with pressure equalization valves.

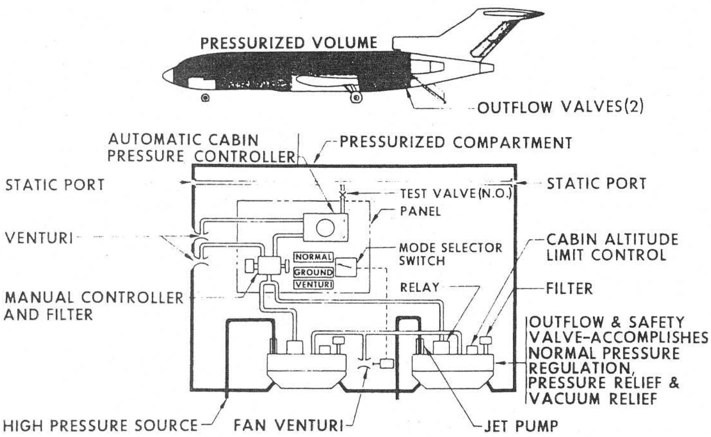


Figure 79.—Pressurization Control

The pressurization control system is completely pneumatic for in-flight operation, not dependent on electrical power. The major components consist of an automatic controller, a manual pressure control and two combination outflow safety valves. These components are the same type used on the 707/720 airplanes. For ground operation, an electric fan-venturi unit provides a means of opening the outflow valves to assure unpressurized operation without surges.

The automatic controller permits the selection of desired cabin altitude and rate of cabin altitude change, and limits the maximum pressure differential to 8.6 psi. The outflow valves respond to changing pressure signals from the controller. The outflow valves provide, as an independent function, positive pressure relief at 9.6 psi cabin pressure differential, negative pressure relief at .36 psi and limit the cabin altitude to 13,000 feet. An aural warning device, located in the control cabin, alerts the crew whenever cabin altitude exceeds 10,000 feet. The pneumatic manual override makes possible a wide range of cabin altitude change rates; the pressure relief and altitude limit functions of the outflow valves being the limiting factors.

The maximum pressure differential of 8.6 psi provides sea level cabin altitude up to 22,500 feet. At 35,000 feet, a cabin altitude of 5,200 feet is possible. Cabin altitude rates of change from 50 feet per minute up to 2,000 feet per minute can be obtained using the automatic controller. Adjustment to match field pressure altitude is facilitated by a barometric correction control on the automatic controller.

Dual reliability of control is assured by separation of the control tubing to each outflow valve, either of which has the capacity to provide normal pressure regulation. All sensitive control tubing is contained within the pressurized portion of the airplane providing protection against a depressurization signal in event of tubing leakage.

Ice Protection System (Figure 80)

Engine bleed air is used for anti-icing the wing leading edge surfaces and engine inlets. Electric heating is used for anti-icing, defrosting, and defogging the control cabin windshields and for anti-icing pitot heads, static ports, and water drain masts. The passenger cabin windows are designed to preclude formation of frost and fog.

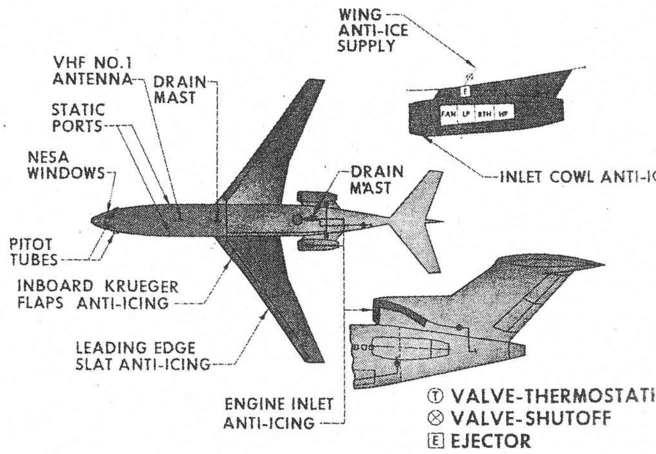


Figure 80.—Ice Protection System

Thermal anti-icing for the wing leading edges is provided in much the same manner as for the 707/720 wing. Engine bleed air is delivered to a common manifold from which it is distributed to the leading edge surfaces. Each wing leading edge slat on the outboard wing is anti-iced to maintain effective performance as a high-lift device. Critical portions of the inboard leading edge flap and the fixed wing surface in that area are anti-iced to prevent ice formations from shedding into the engine inlets. Control of the system is accomplished by actuation of a single switch to operate electric motor-driven shutoff valves. Automatic overheat protection is provided for ground checkout operation.

The wing anti-icing system does not require modulating control and functions with a minimum of attention from the crew. Because of its inherent simplicity, the system can be expected to have a high degree of maintenance-free operation.

Engine inlet guide vanes, the nose dome, the dorsal VHF antenna, the nose cowl on the side engines, and the air inlet duct to the center engine are also anti-iced by engine bleed air. A separate switch for each engine controls all anti-ice system shutoff valves for that engine. Panel lights are provided to indicate proper valve functioning.

PAYLOADS

Probably, the interior design gets more attention in the early stages of design than all the other systems put together. The 727 was approximately one half the size of its predecessor, the 707-320B. The 727 body design went through many iterations before gravitating to its present design. Some of the trades between drag, commonness, and passenger comfort have already been discussed. The 132-inch wide body shown in Figure 81 was a strong contender for a long period, but ultimately the benefits of common seats, common cockpit, and "wide body" of the 707 won out for the upper passenger cabin. Not so, however, for the cargo compartments; the economic trades indicated that a smaller (shallower) lower lobe resulting in reduced drag was the way to go (Figure 82). As in every other feature of the airplane, the cargo compartment went through a series of changes on a compromise of customer requirements, balance, and other system relationships (Figures 83 and 84).

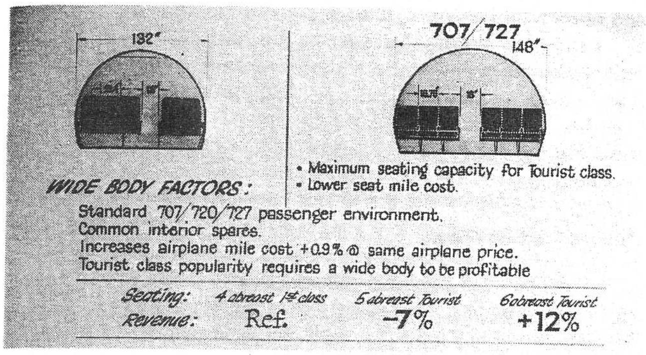


Figure 81. – Body Cross Section

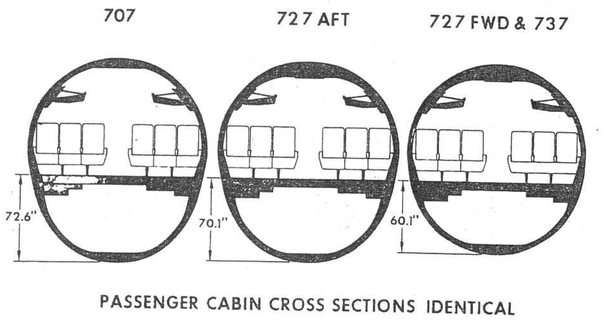


Figure 82. – Body Cross Section Comparison

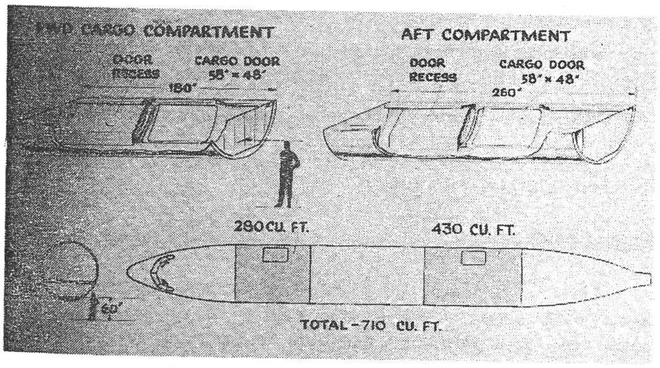


Figure 83. – Cargo Compartments

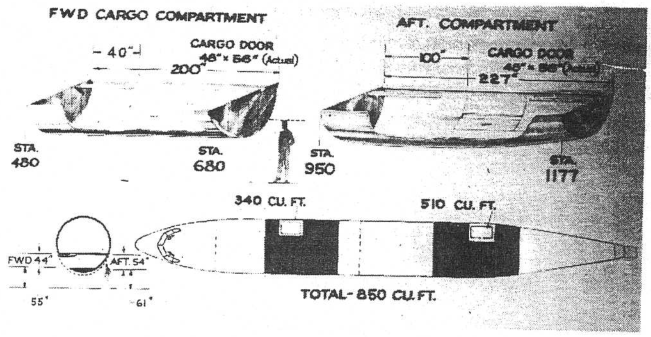


Figure 84. – Cargo Compartments

Loadability without restrictions is an important matter with the airlines. Many systems are affected to provide the well balanced airplane that was ultimately achieved for the 727. Many adjustments in the location of air conditioning equipment, electronic racks, and water tanks were made before a satisfactory balanced airplane was achieved. The galley location is an example of such a trade. Attempts to locate a galley in the rear of the cabin failed because there was insufficient room between the trailing edge of the wing and the side engine for a galley servicing truck. Alternatively, it was unacceptable to load the galley through the aft airstairs while boarding passengers. The galley originally, then, was located in the forward cabin (Figure 85 and Figure 86).

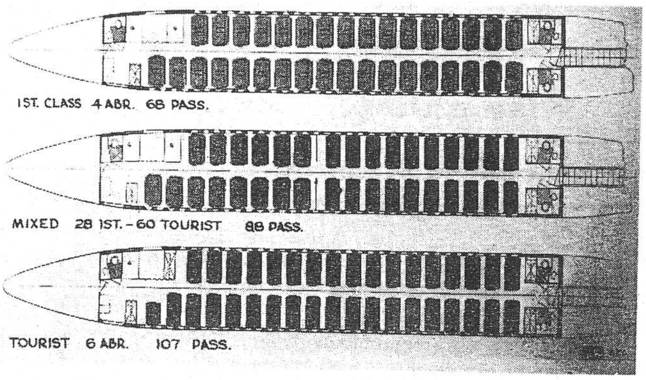


Figure 85. – Interior Arrangements

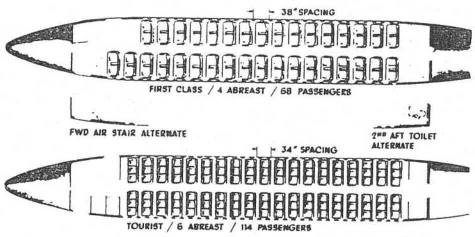


Figure 86. – Interior Arrangements

However, this was unacceptable to the airlines because all of the tourist passengers' food would have to be carried through the first class compartment. The compromise then was to place the galley in the middle of the cabin (Figures 87 and 88). This allowed a minimum crew with optimum flexibility.

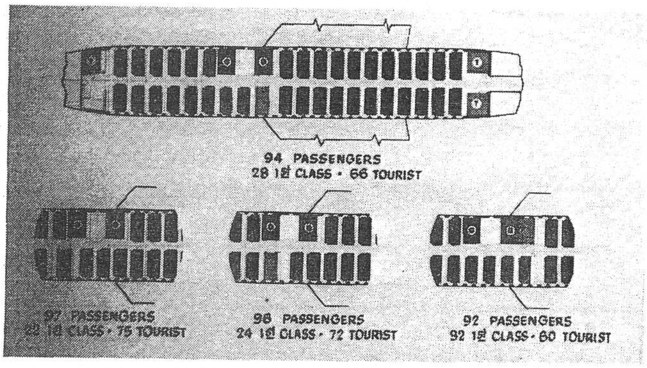


Figure 87. – Interior Arrangements

- Ease of loading galley
- Toilets & galleys separated
- Isolation of passengers from galley
- More Passengers
- Lower Weight
- Galleys located over air conditioning noise area
- Uses existing service equipment
- Less cabin attendants

Figure 88. – Mid-Cabin Galley Advantages

Ultimately all requirements were satisfied which resulted in a standard arrangement with the mid-galley better satisfying airplane balance, central serving station with minimum crew, and a high degree of loading flexibility (Figure 89).

- UNRESTRICTED PASSENGER SEATING
- BALANCE MAINTAINED WITH PASSENGER BAGGAGE ONLY
- 75% TO 100% OF AVAILABLE CARGO VOLUME LOADABLE UNDER ANY CONDITION
- LOADABILITY IS MAINTAINED WITH NORMAL EXPECTED ENGINE GROWTH
- EXCELLENT GROUND STABILITY

Figure 89. – Balance and Loadability

We were constantly reminded by the airlines of the goal for the 727 to be self-sufficient. The ventral air stair solution for passenger boarding seemed appropriate but it gave the structural engineer a few wakeful nights coming up with a solution for an overhead central duct, cut-out for air stair, and #1 and #3 engine mount and accessories inter-connect. All this must be accomplished while supporting a center engine, fin, and horizontal stabilizer. It wasn't an easy solution but ultimately a "wish-bone" front spar for the fin tied to the aft pressure bulkhead with a four torque box structural support for the aft spar, engine support, and tail skid provided the necessary structural strength, as well as, accommodate the large passageways for the third engine control duct, air stair, and side engine accessories.

Interior Arrangement

The 727-100 airplane is presented in a 28 first-class and 66 tourist-class passenger seating arrangement as shown in Figure 90. A typical 119 passenger, 6-abreast arrangement is also shown. Additional seating arrangements may be accommodated and are subject to negotiation with each customer.

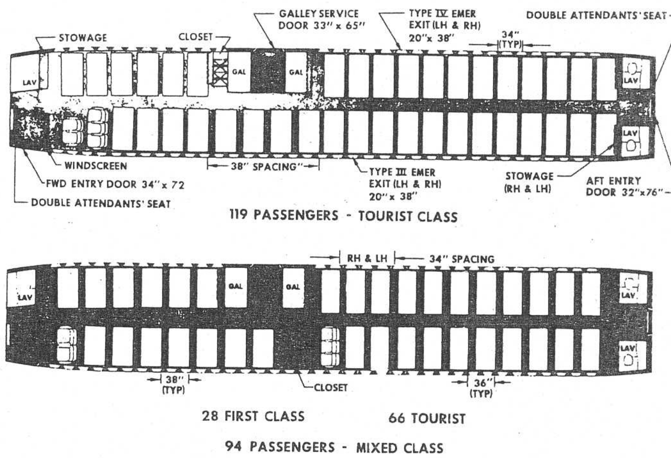


Figure 90. – Interior Arrangement

One externally-serviced lavatory is located opposite the front entry door and two more are located adjacent to the aft entry door. Stowage bustles on the outside of the lavatory walls hold magazines and miscellaneous passenger service items. Drinking fountains are provided outside the forward and the left aft lavatories.

Two large mid-cabin galley units with a 33- by 65-inch service door between them provide convenient service for both single and mixed-class arrangements.

Double attendants' seats which fold up out of the way are installed at the forward and aft entry doors.

Cargo Compartments

The 727-100 has two heated, illuminated, and pressurized lower deck cargo compartments with a total volume of 900 cubic feet, providing room for both baggage and revenue cargo (Figure 91). Centrally located 48- by 35-inch door openings and ample depth in the compartment permit fast and efficient cargo handling. The location and proportions of the doors permit either-hand loading from the ground or loading by a powered belt loader.

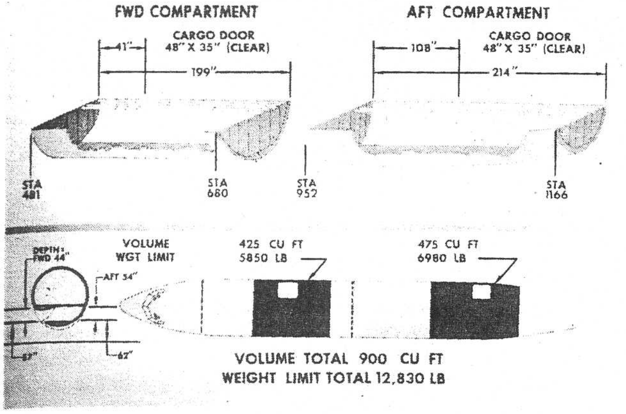


Figure 91.—Cargo Compartments

A highly damage-resistant, light-weight material is used for the compartment linings. Both compartments are provided with webbing compartment dividers and cargo restraints.

Airstair

The aft airstair enables the 727-100 airplane to be completely independent of terminal equipment for through-stop operations (Figure 92). The wide stairway is well illuminated, with individual light sources for each step.

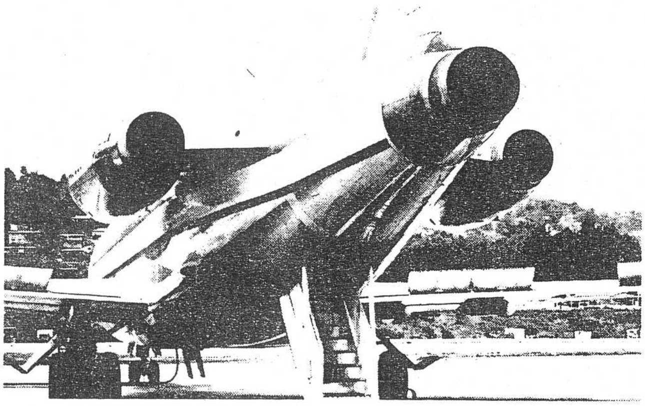


Figure 92.—Airstair

Treads of the stairway are covered with a medium grit, non-skid material as a traffic safety feature. The shelter provided by the fuselage overhead serves as a weather canopy.

Hydraulically actuated, the airstair in controlled from a position at the head of the stairs or from a service panel on the lower right side of the rear fuselage. Indicator lights notify the crew of the stairway position and also that it is locked down, ready for use. When no hydraulic power is available the airstair can be lowered by gravity and manually locked down or it can be locked down and retracted by means of a hand-operated hydraulic pump located at the lower service panel. A spring-loaded mechanical down-lock provides positive stability even if hydraulic pressure in the actuator should bleed off.

A forward airstair is available as an option (Figure 93). This stair is contained in a compartment in the top of the forward cargo compartment directly under the forward entry door.

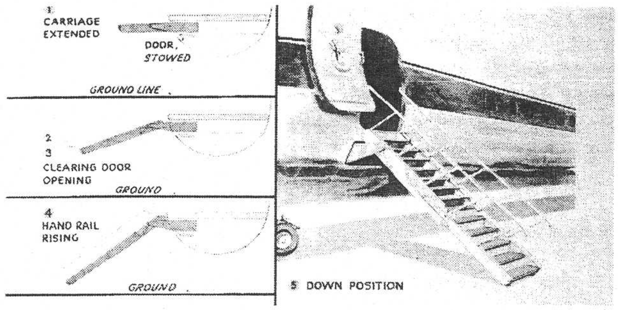


Figure 93.—Forward Airstair

Passenger Water System

The 727 passenger water system, utilizing a single storage tank mounted below deck, supplies water under pressure to the lavatories and galleys (Figure 94). An air head of 25 psi is maintained in the tank by air obtained from the air conditioning supply duct. For use on the ground and for standby pressure, a small auxiliary air compressor is supplied. The system is filled and drained in the conventional manner at an external service panel. Waste water from the wash basins in drained overboard through electrically heated drain masts. The drain masts also serve as toilet air exhaust vents so this continuous air flow tends to clear masts and lines of water. All components of the system are constructed of corrosion-resistant material and are suitable for use with superchlorinated water.

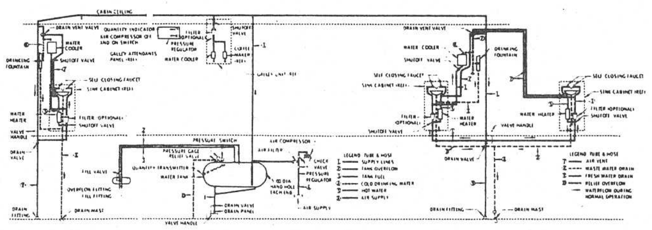


Figure 94.—Passenger Water System

The storage tank is of titanium, having a capacity of 40 gallons of water plus an air space. The overflow standpipe can be readily modified to limit the tank capacity to any lessor quantity. An electrical quantity gage is located on the water service panel outside the airplane. This permits easy determination of water requirements at intermediate stops.

All materials are selected for their resistance to corrosion and the components are placed to avoid freezing. A 1-1/2 quart water heater with an immersion element is installed at each wash basin. An activated charcoal water filter to provide drinking water when using superchlorinated water is optional.

Fountains are provided at both ends of the cabin. They consist of a paper cup dispenser, push-button faucet, drip pan, and a water-tight used cup container. When lavatory wash basins are equipped with filters, fountain water is obtained from this filtered supply.

SECTION 4

FLIGHT TEST RESULTS

by
S.L. Wallick

FLIGHT TEST RESULTS

by
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Introduction

Every airplane model intended for use as a commercial transport must show compliance with the requirements of the Federal Aviation Administration. The builder of such airplanes is thus required to conduct a flight test program, and that involves a detailed step-by-step planned process.

Depending on the scope of the certification effort and the uniqueness of the new model, the number of airplanes required to accomplish the necessary testing in the allocated flow time varies. The program must be carefully phased and scheduled to provide maximum utilization as the first airplanes become available off the production line. Two critical dates which influence the phasing are: the first flight date of the first airplane, and the promised delivery date of the first certified airplane to the first customer.

First the airplane is tested by the builder alone under an FAA experimental license. During these tests any parts of the model's design which require further development are evaluated and perhaps revised or improved.

Also the airplane's basic airworthiness, flying characteristics, and performance are evaluated. Upon reasonable assurance of certificability and freezing of the detail configuration, the FAA demonstrations with FAA personnel on board can begin.

To accomplish all of this, an appropriate and adequate data system must be created to provide the necessary records of information collected during the testing. Many months of planning and many manhours go into the creation, checkout, and operation of any up-to-date state-of-the-art data system.

After the crunch and emotional relief of certification accomplishment, the 727 model continued in a test phase with the objective of improving the design.

Flight Test Program Phasing

The flight test program for the 727 was the most intensive commercial certification program ever undertaken by Boeing. The goal was to certify the most completely tested airplane in aviation history, and naturally it had to be accomplished in the shortest possible calendar time. As a matter of record, the first 727 flight was made on February 9, 1963, and the Type Certificate was awarded on December 24, 1963, only 10-1/2 months later. Scheduled airline service was inaugurated on February 1, 1964, less than a year after the first flight.

To meet this tight schedule, the first four production airplanes were earmarked for flight test use. The No. 1 airplane was used primarily for aerodynamic testing, the No. 2 airplane for power plant and systems testing, the No. 3 airplane for flight load survey and systems testing, and the No. 4 airplane for F&R and systems testing. The first three airplanes were fully instrumented for their respective missions, with No. 2 also instrumented for aerodynamic testing as a backup for the No. 1 airplane.

The flight test program included design proving tests, developmental tests, FAA certification tests, and follow-on tests. All airplane systems, performance, and stability and control were to be evaluated during the design proving phase, as well as flutter clearance and flight load testing. Any deficiencies encountered during the design proving phase would be remedied during the developmental testing. Also scheduled for the developmental period was a comprehensive program to optimize the high lift devices to achieve the maximum takeoff, climb, and landing performance consistent with good flying qualities. These two test phases were to cover the first seven months of the program, with the final 3-1/2 months being used to demonstrate to the FAA satisfactory compliance with Civil Air Regulations (since then retitled Federal Aviation Regulations).

Figure 1 shows the overall flight test program, and the captions on the left-hand side include the number of flight hours expended by each airplane in accomplishing the program.

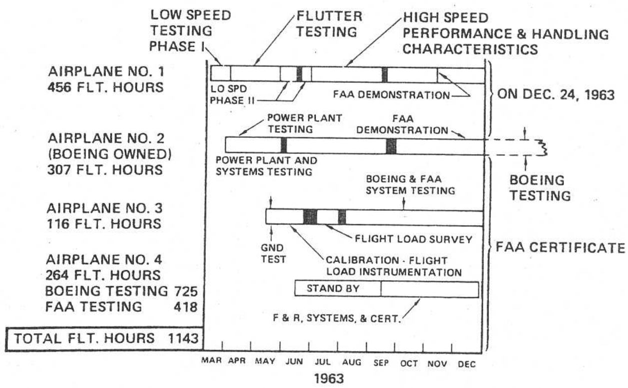


Figure 1.–Program Phasing Test Schedule

Design Development

Some early identified design development items which were of importance and were unique to the Model 727 were:

- A high lift wing configuration,
- The inclusion for the first time in a Boeing airplane of fully powered flight controls,
- The placing of the engines on the aft part of the fuselage on pods and with a center inlet,
- Larger landing gear, wheels, tires, and brakes to meet a design requirement of only four main gear.

Wing High Lift Configuration

One of the main factors in airplane performance is the stall speed. The stall speed has a critical effect on the approach and landing speed and, therefore, on the total landing distance from a 50-foot altitude to full stop.

Likewise, since the normal takeoff speed used in airline service is factored from the minimum unstick capability of the airplane, the wing configuration has a critical effect on that performance.

Low speed performance during the initial climb period and during the holding condition are also dependent upon the wing configuration.

Stall speeds are determined at forward center of gravity limits since this requires the largest tail load. Large tail loads represent reduced lifting capability, and the resulting stall speeds are, therefore, conservative.

Airplane stall characteristics must also meet FAA handling criteria, and stalls are demonstrated at the most aft center of gravity limit. The longitudinal stability of the airplane decreases as the center of gravity approaches the neutral point.

The wing trailing edge arrangement included triple-slotted flaps of the Fowler type on tracks which extend behind the wing. The flaps can be extended to six separate positions.

The leading edge arrangement consists of three Krueger type flaps along approximately one-third of the inboard span. During the test program the angle of rotation of these flaps was varied to positions of 76°, 86°, 91°, and 101°. The flaps were operated both individually and together to these various angles.

There were also four leading edge slats along the span of the wing outboard of the Krueger flaps, and the schedule of their extension in conjunction with the trailing edge flaps was varied.

Also, to help control air flow over the wing, several fence configurations were evaluated. The fences were made from one-quarter inch aluminum and were attached to the upper surface of the wing slat. Fence heights of 3, 5, and 8 inches were tested.

Three different fence locations were evaluated – at Wing Buttock Lines 341, 410, and 486. Flights were made with these fences installed separately and together.

Also, an attempt to improve airplane pitching characteristics during stall was made by installing a spoiler strip on the two inboard flaps. It was discarded, however, as it did not produce the desired results.

Vortex generators were attached to the upper surface of the wing in an attempt to improve the air flow pattern; however, these were also discarded.

Including the separate variations described, twenty-three different combinations of wing lift devices were tested.

The procedure was to determine the stall speed at the forward center of gravity. If the resulting stall speed appeared promising, then the stall characteristics were checked at the most aft center of gravity. When the characteristics at both extremes were satisfactory, the low speed drag was measured.

The final configuration selected as the best compromise for performance and flight characteristics was:

- Leading edge slats Nos. 2, 3, 6, and 7 extend when trailing edge flaps are in Position 2.
- The remaining slats and leading edge flaps extend when trailing edge flaps are in Position 5.
- Leading edge flaps and slats remain extended throughout further extension of the trailing edge flaps.

The final wing fence was constructed of fiberglass one-inch thick, five inches high, and positioned at Wing Buttock Line 341.

Figure 2 shows the various items in their general locations in relation to the final wing plan form.

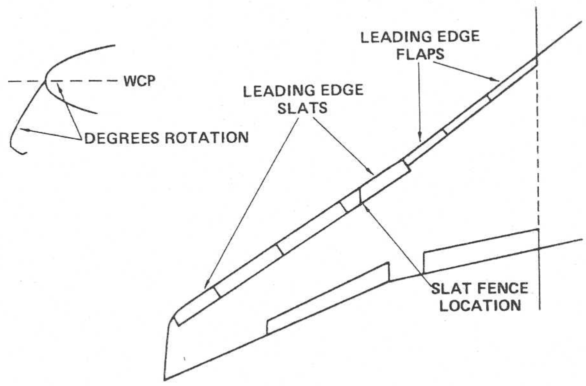


Figure 2.– Wing Leading Edge Configuration

In Figure 3, the wind tunnel tests performed before flight are compared with the flight test results. The varying symbols are different gross weights tested.

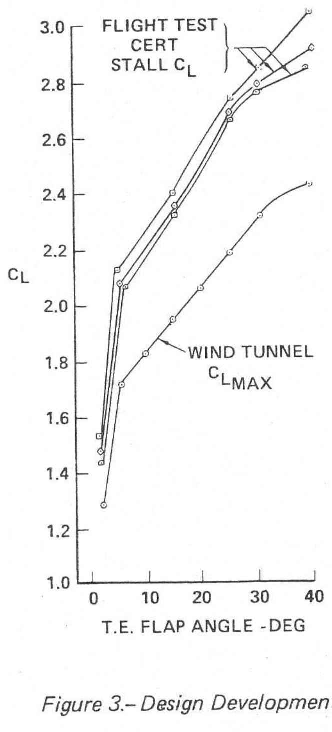


Figure 3.– Design Development

As is obvious, the actual results were very gratifying and resulted in considerable improvement over the predicted wind tunnel tests.

The C_L - C_D polars in Figures 4 and 5 show the drag improvement that resulted with the final configuration after testing the variety of other configurations.

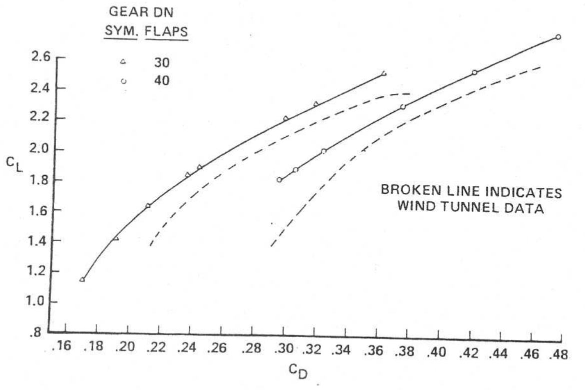


Figure 4.- Design Development

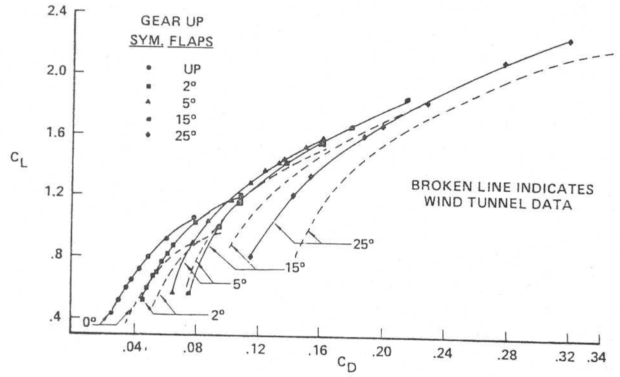


Figure 5.- Design Development

The benefit that was derived for the takeoff configuration was an ability to demonstrate very low minimum unstick speeds. This resulted in takeoff field lengths substantially shorter than predicted and provided the airplane with very good initial climb gradients.

The advantages derived for the landing configuration were low approach and touchdown speeds. With the fully modulated brake anti-skid system, nose wheel brakes, and ground spoilers, the airplane has excellent stopping capability.

No credit in the certification demonstrations is taken for the retarding effect of the thrust reversers.

Fully Powered Flight Controls

The 727 is the first Boeing airplane with fully powered flight controls.

The system was designed with redundancy, with the lateral and longitudinal systems powered by two separate hydraulic systems and with a manual reversion available to the ailerons and elevators. The rudder system has two hydraulic systems for the upper rudder and three hydraulic systems for the lower rudder.

With this fully powered flight control system, the airplane handling characteristics resulted in very precise trim capability with adequate travel for all flight conditions. With the powered systems turned off, the manual reversion was adequate over the full range required. One item that exceeded expectations was the control effectiveness in full-flap sideslip conditions.

The cross-wind capability exceeded the design requirements.

In testing the airplane in actual cross-winds, considerable research is done to find locations which could provide the required cross wind components and also provide adequate runway length. A tipoff as to probable cross-wind availability is an airport that has runways which cross each other. Two of our favorite locations were Great Falls, Montana, and Casper, Wyoming.

A wind watch is established, and when a good cross-wind condition appears to be developing in the morning weather reports, a test team and airplane is identified and prepares to go to the site, often on very short notice. Such was the case of the 727 at Casper, with a hurried effort to get the testing completed before the wind died. The result was good cross-wind capability demonstrated, but far too many hard braking stops using non-temperature-instrumented brakes. The blown tires and the airplane wheel rims slowly sinking into the asphalt runway added to the flight test romance of being away from home overnight, in a strange western town, in an orange flight suit, and no money. Needless to say, all's well that ends well.

Aft Fuselage Mounted Engines

The placement of the engines on the tail section of the fuselage was a new and unique item and presented new and different propulsion problems to be solved. The pod mounted configuration was first evaluated in the 707 prototype which provided early airflow and engine response characteristics for the pod location. However, the center engine inlet was not flight checked prior to the first flight of the 727. At the point of lift-off, the center engine produced a surge - - and the engine airflow development program was officially started.

The center engine was then instrumented to determine the magnitude of inlet total pressure recovery and the pressure distortion at the inlet guide vanes. Tufts installed in the inlet were observed and recorded by means of a closed circuit video system and a 16 mm motion picture camera.

The effects of airplane yaw, pitch, and flap and spoiler operation on engine operating characteristics were evaluated at different altitudes to develop a vortex generator configuration in the "S" duct which gave satisfactory results.

Landing Gear

Because the 727 main landing gear wheels, tires, and brakes were heavier than those of a 707, gear retraction was initially limited to lower airspeeds. Considerable aerodynamic testing of main gear strut mounted doors was conducted, and several hydraulic system changes were made before acceptable retraction was obtained.

A development program to modify main landing gear oleo rebound characteristics was conducted to optimize the landing distance.

Before first airplane roll-out, testing conducted on a Model 707-300 indicated a possibility that the Model 727 side-mounted engines would ingest water or slush when operating on wet and slushy runways. An extensive program consisting of many runs through water troughs at various speeds, flap and power settings during the 727 certification program confirmed that nose gear spray patterns did cause engine surges between 70 and 80 knots and some minor skin damage at 120 knots.

Chined nose gear tires were installed and all critical and marginal conditions were repeated with satisfactory results. Tests conducted later with slush on the runway further validated these results.

Airworthiness, Performance Verification, and FAA Certification

During the first hours of the test program, the airplane was flown through most low speed maneuvers which would reveal its handling qualities and general airworthiness.

The next and a very significant part of the test program was the structural dynamic damping evaluation, during which the maximum speed envelope was determined. In this testing the airplane was flown at the maximum operating speeds of V_{MO} and M_{MO} and to the structural design speed limits of V_D and M_D.

Test conditions involved stabilizing the airplane at a specified speed and altitude, applying abrupt manual control surface inputs or vibration inputs from vibrator units installed on a wing tip and stablilizer tip, then evaluating the damping characteristics obtained after the inputs. These test conditions provided telemetered data to ground station observers for analysis of the damping characteristics.

The speed limit lines are displayed in Figure 6.

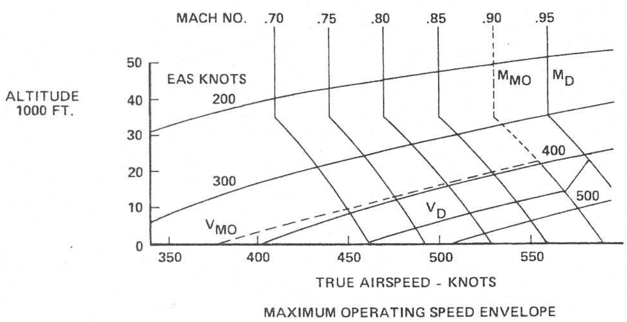


Figure 6.- Airworthiness and Performance Verification

One of the airplanes in the test program was extensively instrumented with strain gages and accelerometers, and calibrated in a structural test jig. The data system was designed to produce through a computer program the results in shear, bending moments, and torsion for flight maneuvers of roller coasters, wind-up turns, sideslip, etc.

This extensive structural load survey was not an FAA requirement for certification, but the Boeing Company considered it essential for providing a completely proved product to its customers.

With this survey the theoretical loadings were verified and the data obtained were then reflected in the static test and fatigue test programs.

The design performance objectives were to obtain results which would be cost effective in airline use after the FAA conservative factors are applied to the raw test results.

Our airplanes are normally taken to Edwards Air Force Base for a portion of the flight test program in order to use their very long runway (16,799 feet) for performance testing. On the first ferry flight down, while on the approach to the runway, the pilot requested to turn off on the first taxi strip. The tower operator assumed he meant the one at mid-field and approved, but was amazed when the 727 landed on the 1,650 foot paved overrun and taxied in on the first taxiway.

On the first landing at Renton Field, which is approximately 5,000 feet long, the airplane stopped before reaching mid-field.

Though there are no certification requirements for cruise performance testing, such testing was conducted and the data used to adjust estimated drag polars and fuel flow data to actual airplane performance. The drag polars and fuel flow data are used to prepare performance data for the Airplane Operations Manual and to show compliance with customer performance guarantees.

Landing tests were conducted to determine field length requirements and operational limitations. The tests must be completed using the same tires, wheels, and brakes, and the results must take into account any changes in configuration or test parameters, such as development of speed brakes, tail and head winds, etc. The 727 is currently scheduled into airports throughout the world, and some of them have runway lengths within the 5,000 foot design target.

Civil Air Regulations required that in addition to demonstrating performance, it must be shown with reasonable assurance that the airplane and all systems are reliable and function properly during a formal 300 hour Function and Reliability program. At least 150 hours must be flown on a designated "F & R" airplane which is maintained as close as possible to the current production configuration, including interior and seats. In addition, all systems must be exposed to an accelerated cycling program.

In fulfilling most of this requirement, the designated F & R airplane, No. 4, was sent on a demonstration tour covering the United States and a great many foreign countries. In many cases it stopped in cities in which were located the home offices of many of the world's airlines. The dispatch reliability in all weather and the almost complete lack of remedial maintenance drew considerable attention during the tours.

Figure 7 shows some facts about the tour.

DOMESTIC AND FOREIGN TOURS AND DEMONSTRATIONS

NO. 4 PRODUCTION AIRPLANE WAS USED. IT HAD A COMPLETE INTERIOR AND WAS MAINTAINED IN PRODUCTION CONFIGURATION AS NEARLY AS POSSIBLE.

DOMESTIC TOUR

- STARTED AUGUST 25, 1963
- VISITED 10 CITIES IN UNITED STATES AND CANADA
- FLEW 37 HOURS 5 MINUTES
- 14 FERRY FLIGHTS, 24 DEMONSTRATIONS
- TRAVELED 17,535 MILES IN 16 DAYS

FOREIGN TOUR

- STARTED SEPTEMBER 17, 1963
- CARRIED ONLY LIMITED SPARES
- VISITED 36 CITIES, 26 COUNTRIES
- FLEW 157 HOURS 11 MINUTES
- TRAVELED 76,943 MILES
- RETURNED NOVEMBER 3, 1963

TOUR RECORD

- NO MECHANICAL DELAYS
- TOTAL 94,478 MILES
- FLEW 194 HOURS 16 MINUTES
- OPERATED FROM FIELD ELEVATIONS FROM −13 FEET AT AMSTERDAM TO 5559 FEET AT JOHANNESBURG
- EXPERIENCED HEAT OF SAUDI ARABIA AND AUTUMN LOW ON NORTHERN EUROPE
- USED FIELD LENGTHS FROM 5,000 FEET TO 14,500 FEET

Figure 7.– Airworthiness, Performance Verification, and FAA Certification

Flight Test Data System Requirements and Composition

To accomplish such a complex and thorough flight test program in the time allotted required an instrumentation and data processing system which would yield data with a minimum of manual manipulation and provide short flow times for final test results. To this end, considerable reliance was put in an airborne magnetic tape data recording system and automatic data reduction methods. This was particularly true in the case of performance data required for expansion and presentation in the Airplane Flight Manual.

The magnetic tape recording systems installed in the first three airplanes - - pulse duration modulation (PDM) systems in the first two airplanes, and a narrow-band frequency modulation system (NBFM) in airplane No. 3 - - were utilized to the maximum extent because of their compatibility with modern digital computers. Oscillographs and photo-recorders were also installed in the test airplanes to meet the frequency response requirements of some test variables and allow visual monitoring of selected parameters, respectively.

The data from each of these recording systems were processed by ground station equipment and converted into a format compatible with automatic reduction in a digital computer. Further, by preparing special computer programs it was possible to integrate the output from all of the recording systems when inputs from each system were required to provide data in its final reduced form. This automatic data system had the capability to provide priority data in 24 hours. Forty-eight hours was the usual flow time for developmental and certification data during the active test program.

Flight Test Data System Performance

During the flight testing a total of 103,650,000 data points were reduced and distributed to the Technology Groups for analysis. The data reduction required 2100 hours of IBM 7094 computer time. In addition 80,000 manhours were expended in preparation of computer control decks and transducer calibrations, and in the manual data transcription of oscillograph records and theodolite film.

Flight test data reduction was organized around a 48-hour data reduction flow time. Computer programs automatically selected input data from the PDM and FM recordings, theodolite data, and a curve file tape as required. The data were calibrated, combined, and operated on as necessary to obtain final computed results such as drag, thrust, fuel specifics, and engine temperature. These results were printed out or plotted by the computer and associated peripheral equipment. The only manual operation was the physical control of the equipment.

The automatic computation of the required large volume of combined parameters (C_L, C_D, F_n, and Mi/lb.) significantly reduced the flow time and engineering manhours required to complete the final flight test analysis.

Follow-on Testing

Following certification of Model 727-100, there has been a continuous flight test program aimed at updating and improving the type. The No. 2 airplane was retained by The Boeing Company and was actively engaged in this work until just this past year.

In addition, there has usually been one and sometimes several other Model 727s involved in product development and certification testing. The highly successful Model 727-200, a stretched version, was one of the most noteworthy results of this effort. Another highlight was the -300 high performance wing, a development which did not go into production because of a bleak airline economic climate at the time.

Figure 8 lists some of the other many improvements which have involved flight testing.

TESTING CONTINUED FOR PRODUCT IMPROVEMENT

- PASSENGER/CARGO CONVERTIBLE AIRPLANE
- QUICK CHANGE CONVERTIBLE CARGO FEATURE
- MODIFICATIONS FOR UNIMPROVED RUNWAYS
- CERTIFICATION TO FAA NOISE STANDARDS
- ALTERNATE BRAKES (GREATER CAPACITY AND/OR ALTERNATE VENDOR)
- LIQUID COOLED BRAKES
- IMPROVED ANTI–SKID SYSTEM
- AUTO BRAKES
- AUTO SPOILERS
- AUTO THROTTLES
- AUTO POWER RESERVE & INCREASED THRUST FOR ENGINE FAILURE
- JET ASSIST TAKEOFF (JATO) FOR ENGINE FAILURE
- ADDITIONAL LANDING FLAP POSITION
- INCREASED GROSS WEIGHT
- INCREASED LANDING WEIGHT
- INCREASED FUEL CAPACITY
- SPERRY SP 150 DUAL AUTOPILOT
- CENTER ENGINE S–DUCT ANTI–ICE DELETION
- WINDSHIELD HEATING AND RAIN REMOVAL IMPROVEMENTS
- INERTIAL NAVIGATION
- AREA NAVIGATION
- GROUND PROXIMITY WARNING

Figure 8.– Design Improvement

SECTION 5

THE 727-200 DEVELOPMENT

by
M.C. Gregoire

THE 727-200 DEVELOPMENT

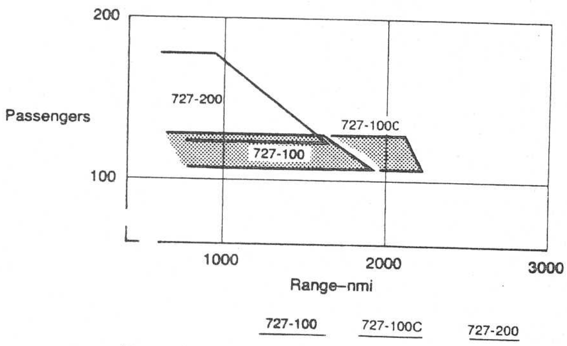
by
Mark C. Gregoire

"A stretch feels pretty good", and we've been feeling pretty good about the 727 stretch. We have been since the 1960's and will through the 1980's. Let me tell you about this, the most successful descendent of all commercial airplane programs - the 727-200, see Figure 1. At this reading we will have announced over 1,000 sales of 727-200's. In comparison, we have sold 571 of the Model 727-100 (short body) the last one was delivered in 1972.

Figure 1.

The original goal for the 727-200 was to satisfy a fast growing U.S. Domestic market with a more economical, larger payload. We set a minimum change design goal to (1) minimize the design (non-recurring), tooling, and certification costs, and (2) negate or minimize pilot and crew training, spares and maintenance costs to 727-100 operators. We were out to capitalize on a market that could not help but buy a "better mousetrap".

The original design requirement was aimed at the denser, short-range, medium and large city markets. This allowed us to trade maximum gross weight for more payload and sacrifice the range of the 727-100 as shown in Figure 2. Thus some were to know this aircraft as the "mini-airbus".



	727-100	727-100C	727-200
Factory rollout	11-27-62	11-12-65	6-29-67
First flight	2-9-63	12-30-65	7-27-67
Certification	12-24-63	1-13-66	11-29-67
First delivery	10-29-63	4-13-66	12-11-67
In service	2-1-64	4-23-66	12-14-67

Figure 2. – 727 Development

The go-ahead for the 727-200 was announced in August, 1965, as a simple variant of the 727-100. Little did we realize what the magnitude of this decision would mean to Boeing.

The 727-200 is a 727-100 stretched 20 feet, as shown in Figure 3, with 10 feet forward and 10 feet aft of the wing. The center engine inlet was changed from an oval to a circle with a modified duct to allow for the deeper boundary layer caused by the longer fuselage. A modified tail skid with a crushable cartridge and ablatable shoe was included - we felt that the tail skid would be struck more frequently. The galley was moved from the center of the 727-100 to the front and rear of the passenger cabin. Note the galley service doors just forward of the engine nacelle and opposite the main entry door. This arrangement clusters the service areas to either end or both ends of the passenger cabin and allows for flexibility in interior seating arrangement. Relocated and outward opening lower hold cargo doors were provided to accommodate containers and a container hoist system. Other changes included a modified air conditioning system and updated miscellaneous system, structural, and corrosion control revisions.

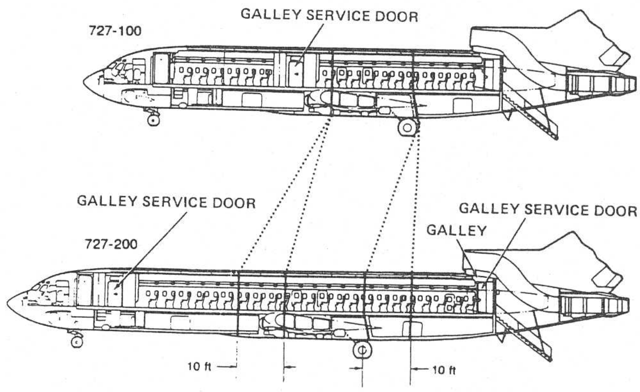


Figure 3. – 727 Development

This isn't quite the way the kickoff memo (signed by Jack Steiner in August, 1965) stated that the aircraft was to be. He stated that the 727 stretch was to be "and increased body length to be determined but equal to or less than 160 inches". The determining factor for the 160 inches was to allow a full payload to be carried from LaGuardia (a short runway on a hot day) to Chicago. We realized that to penalize the payload and economics for this one runway was wrong and in September, 1965, we committed to a 240 inch stretch.

In addition, this aircraft was being offered as a commuter (one class) interior for shorter ranges than it's parent 727-100. Airline desires were more for a mixed class interior for trunk line service and, therefore, required more galley service. Galleys are heavy and it requires a vast understanding of how to serve the passengers and how to service the galleys from the ground equipment efficiently and without damage to the aircraft. We relocated the galley from the mid-fuselage area to both or either end of the cabin as shown in Figures 4 and 5, a major undertaking but one that the airlines felt was absolutely necessary.

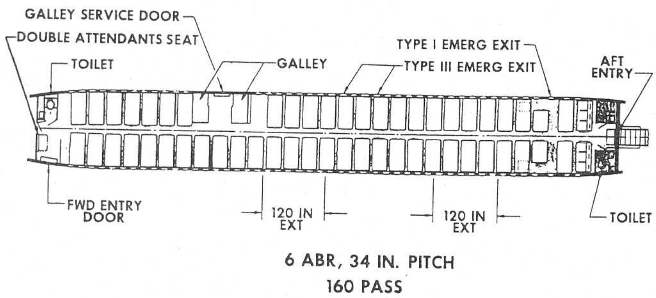


Figure 4.- 727-200 Interior Arrangement

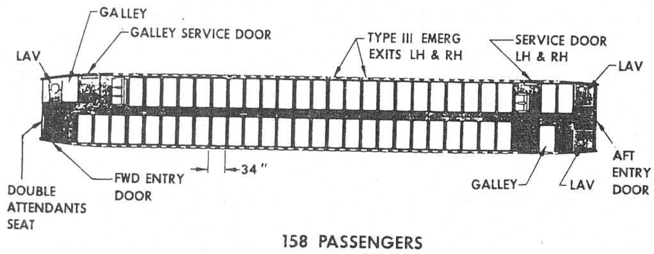


Figure 5.– 727-200 Interior Arrangement

At the time, the aircraft with competitive seat mile costs were the BAC-111, DC-9, and our own 737. Our objective was to come as close as possible to matching their seat mile costs but with a larger aircraft, and have the advantage of three-engine flexibility. The 727-200 has seat mile costs at least 20% lower than the 727-100. Figure 6 shows the, relationship between the aircraft costs but on an updated 1977 dollar basis.

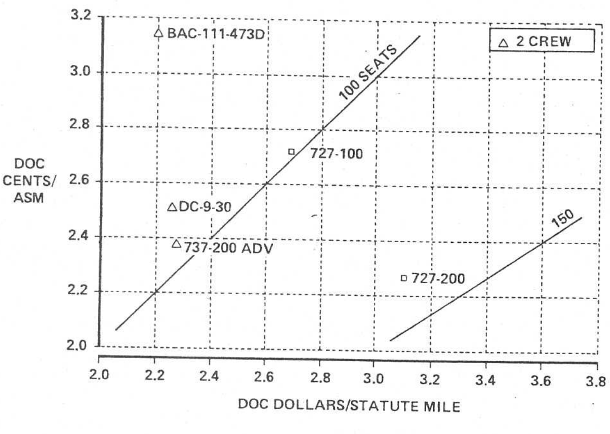


Figure 6.- Direct Operating Costs

The Wing

Wing changes for performance improvement could have been made, but were not, because they would have been minimal and would have lost parts commonality with the 727-100. The changes we had in mind were mainly leading and trailing edge slat and flap angle and gap scheduling. Wing loading did go up in relation to the earlier passenger 727-100 but not so relative to the later 727-100C. We used the same maximum takeoff weight, zero fuel weight, and landing weight as the 727-100C. Figure 7 shows a tabulated comparison.

	727	727 "C QC"	727 - 200
STRUCT. CRITERIA			
TAXI WT.	161,000	170,000	170,000
FLIGHT WT.	160,000	169,000	169,000
LANDING WT.	137,500	142,500	142,500
ZFW	118,000	132,000	132,000
OWE (SPEC. 6 ABREAST)	86,200	90,300/93,000	94,020
LANDING FLAPS, DEG.	40	30	40
DESIGN SPEED, KTS. (V_{MO})	390	350	390
POWER PLANT			
ENGINE MODEL	JT8D-1	JT8D-1	JT8D-7
TAKE OFF THRUST/TEMP. °F/°C	14,000/59/15	14,000/59/15	14,000/84/29

Figure 7.– 727-200 Characteristics

The JT8D Engine

The stretch of 240 inches was almost reduced by 40 inches because of one large customer's qualms about the aircraft turning into a "lead-sled". The resolution was to accelerate introduction of the Pratt & Whitney JT8D derivative engine called the -9 with 14,500 pounds of sea level static thrust. This is 500 pounds more thrust than the original JT8D-7 engine for the 727-200. This gave acceptable performance from LaGuardia even at 85% probability of occurrance of a hot summer day.

The JT8D-9 engine was also the first engine to have acoustical treatment to reduce community noise. This was developed to meet the American Airlines noise requirement for LaGuardia. The Port of New York has a noise limit of 112PNdB at a point 3 miles from brake release. The noise treatment finally developed by Pratt & Whitney was a liner of "feltmetal" on the inner wall of the engine by-pass duct as shown in Figure 8. This reduced takeoff and approach noise levels by 2 and 3 PNdB respectively. This in combination with a takeoff cutback procedure, allowed the 727-200 to demonstrate less noise than the LaGuardia noise requirement of 112 PNdB at maximum takeoff weight.

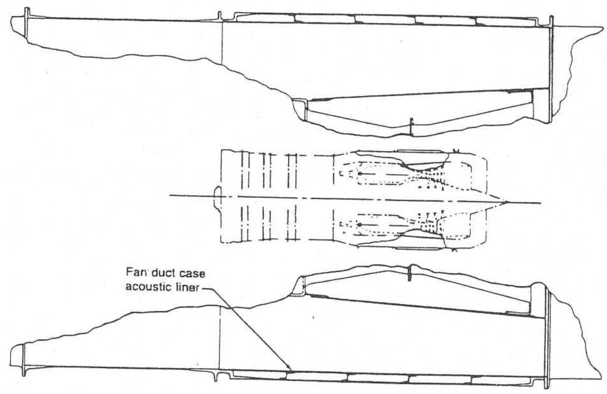


Figure 8.- P & W Sound Attenuation Configuration Feltmetal Liners

Center Engine Inlet

At first glance the center engine inlet of the 727-200 looks the same as the one on the 727-100 - but not quite. Look carefully at Figure 9 and you will notice that the 727-100 inlet shape is an oval and the 727-200 is a circle. The inlet lip is raised and recontoured as shown in Figure 10. The inlet duct is reshaped, see Figure 11, down through the first turn so that it can handle 4% more airflow with less diffusion. The forward intake duct cross-sectional area was constrained by the large forward fin spar opening shown in Figure 12, and the requirement to keep this large forging the same as in the 727-100.

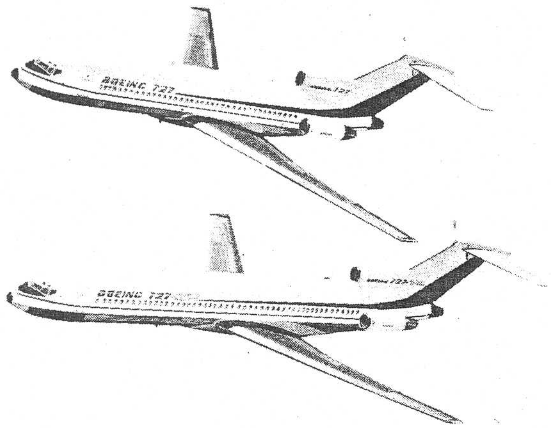


Figure 9.

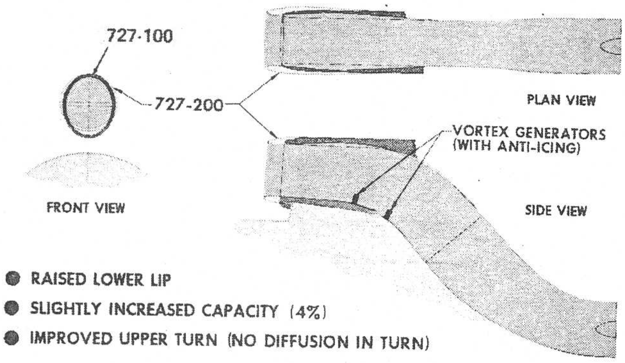


Figure 10. - 727-200 Center Duct Diagram

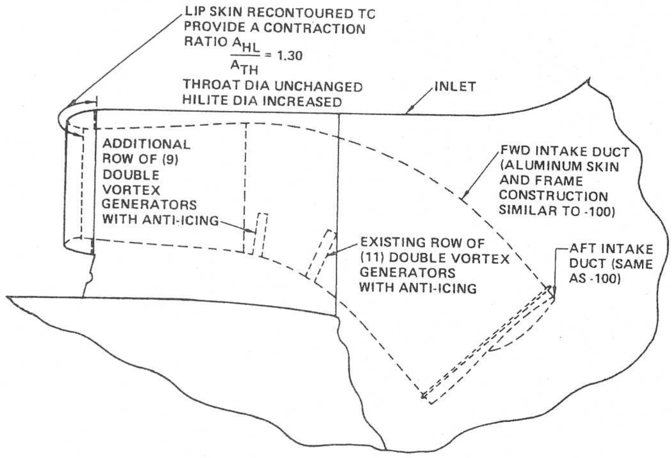


Figure 11.- 727-200 Center Engine Inlet Improvements

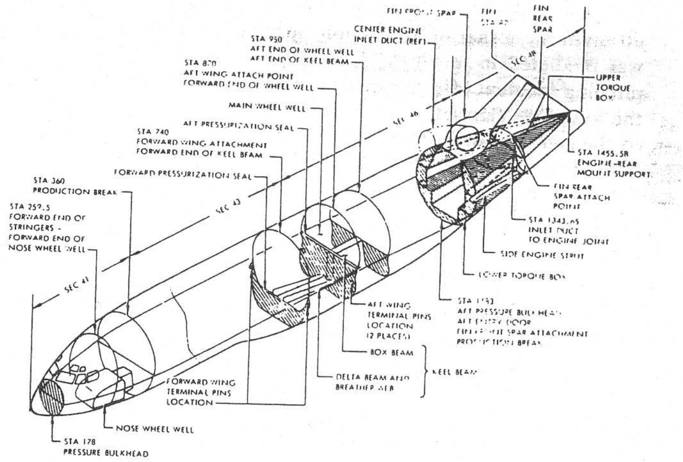


Figure 12.- Major Fuselage Components

The original construction material of the forward duct was aluminum honeycomb for reduced weight. The first completed sets were shipped to us from our Wichita Division with minor skin repairs which instantly fell out. Now would you like a piece of aluminum skin passing through a jet engine? An easy decision for Chief Project Engineer Bill Clay was to revert back to the same constuction as the 727-100; aluminum skin and frame construction.

Initial testing revealed that the center engine would surge with as little as 8 knots of crosswind. This problem was met by recontouring the inlet lip and adding an additional row of vortex generators in the duct. We also recommended a takoff procedure that increased thrust as airplane speed increased. This inlet has proved to be very workable with four higher thrust engines than the JT8D-9.

Drag Story

The airplane drag is an interesting two-part story. Cruise drag of the 727-200, due to increased body length, was estimated to be about 4% higher than the 727-100 drag and was confirmed by wind tunnel testing. A drag polar is shown in Figure 13. No attempt was made to estimate the effects of changes to the airplane area distribution. Flight testing proved our estimates were very accurate.

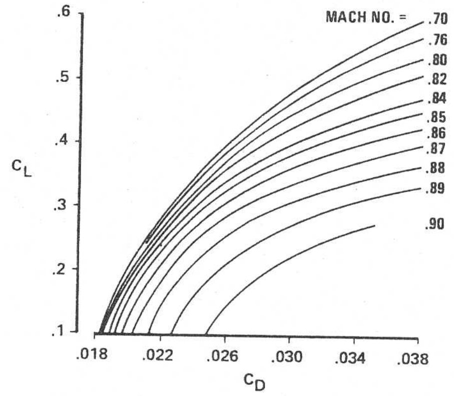


Figure 13.- High Speed Drag Polar

The flaps-down or low-speed drag story was somewhat different in terms of prediction accuracy. The flaps-down drag was predicted in much the same way as the cruise drag but with pitching moment effects included. When we flight tested we found the low-angle flap-setting drag was quite accurate but, as we went to the higher angle settings, we were pleasantly surprised by a much lower drag. The reason was that the 10 feet body extension aft of the wing kept the empennage and engine cluster further away from the effects of downwash from the more-powerful high-angle flap settings. This was a bigger bonus in takeoff and landing performance than we had anticipated. Since I was responsible for that prediction, I naturally lucked out - a hero instead of a pink slip!

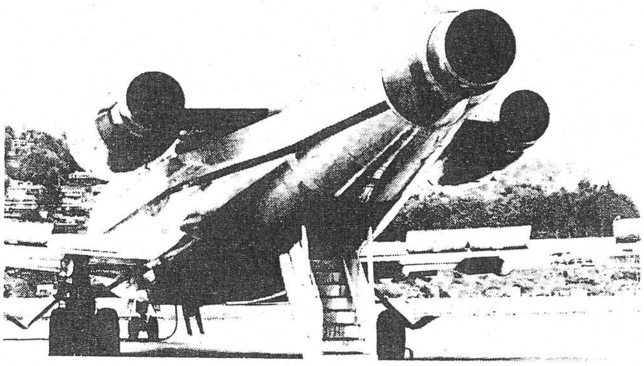


Figure 15.

Balance

As a typical of airplanes with aft mounted engines, about 2/3 of the fuselage is forward of the center of gravity (C.G.) and 1/3 aft. Loading the passengers, galleys, fuel, and cargo holds, as well as ground handling an empty aircraft, is a major balance concern. The additional 10 feet of fuselage forward and 10 feet aft of the wing was the best balance compromise for the loading extremes. The 727-200 has the largest center-of-gravity spread of any commercial aircraft. This gives us more loading flexibiliby but creates more demand on flight controls, structure, and load control. A loading diagram is shown in Figure 14.

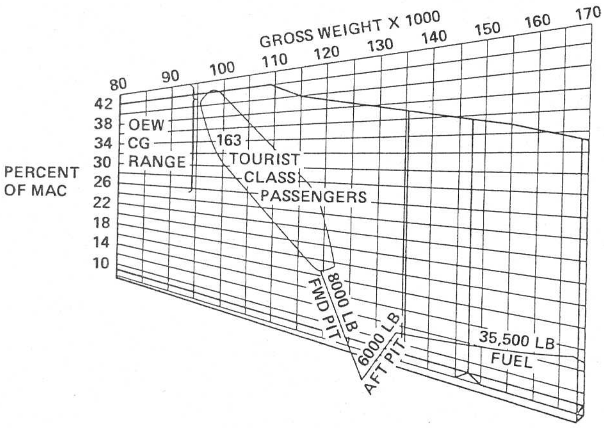


Figure 14.– Loading Flexibility

It is interesting to reflect on the reaction of Bill Clay, the 727-200 Chief Project Engineer, when the first National Airlines 727-200 was delivered to Miami. As it rolled to a stop near the National hangar, amid the expectant dignitaries, the pilot touched the brakes and the airplane nose went down and then recoiled up and lifted the nose gear off the concrete approximately 6 to 8 inches. The gasps in the crowd were heard 3,000 miles away in Seattle. Bill Clay put a team together and, armed with weight and balance data, toured the airlines outlining the entire spectrum of configuration control, ground handling, balasting, and precautionary measures from sloping ramps to heavy snow loads on the tail. As far as we know, no 727-200 has ever sat on its tail and maybe we over reacted to the National incident, but that's why, as shown in Figure 15, you will nearly always see a 727 with its rear airstairs down when it is parked. There are some rare cases where we attach lead to the radome bulkhead for extreme loading conditions.

Cargo Compartment

In stretching the fuselage 20 feet, we essentially stretched the cargo compartment 20 feet and thus gained an enormous increase in payload volume capacity. The 727-100 cargo compartment volume is 900 ft.^{3} and the 727-200 is 1,525 ft.^{3} At 10 pounds per cubic foot density this is a gain of 6,250 LB of payload. Since the 727-200 was originally designed as a commuter aircraft with fast turnaround service, the airlines pressed us for a container system to handle this magnitude of baggage and cargo in 30 minutes. We went through many variations of containers, cargo door locations, and door types, including some similiar to the bottom loading DC-8 type. Figures 16 through 20 show some of the configurations studied.

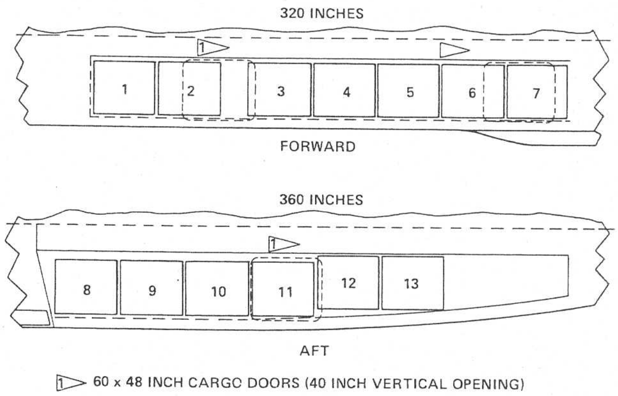


Figure 16.– 727-200 Cargo Container Location

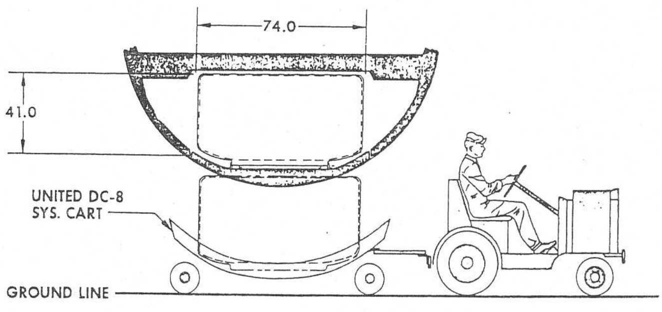


Figure 17.– 727-200 80" Door Width

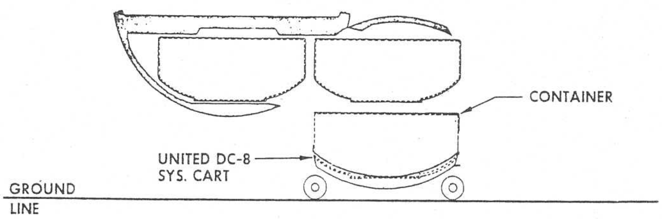


Figure 18.– 727-200 Side Loading

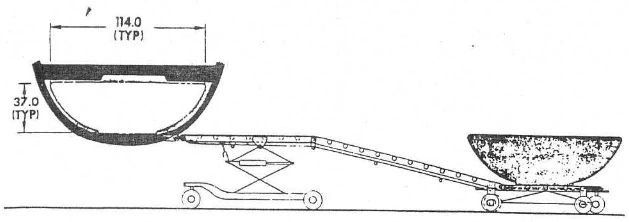


Figure 19.– 727-200 Side Loading

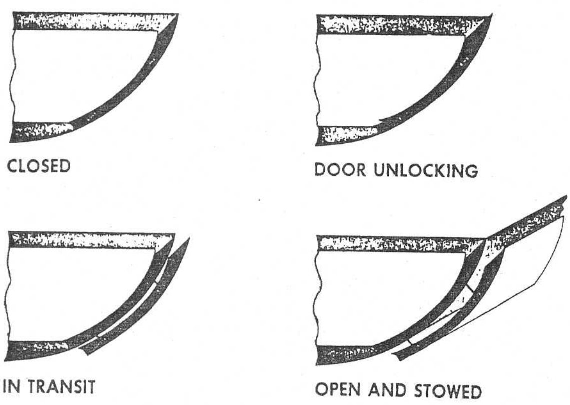


Figure 20.– 727-200 Cargo Door Movement

We finally ended up with the configuration shown in Figures 21 of cargo door location and outward opening doors, one forward and one aft, with an optional second aft cargo door for bulk loading cargo behind the containers. The final design included an optional container system shown in Figures 22 through 24 including a door hoist and a traverse system. This system can accommodate 7 containers in the forward hold and 4 in the aft hold.

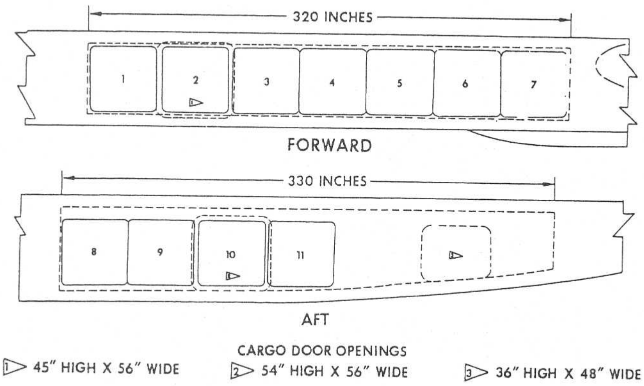


Figure 21.– 727-200 Cargo Container Location

The traverse system and hoist had many problems in airline operation due mainly to the caliber of personnel who operated it, but we should have designed it for that! After many attempts at redesign, we withdrew the option for the traverse and hoist and left the container roller system and ball mat in the floor. The airlines simply load the containers by ground lift systems and manhandle them. This way they are not hindered by delays due to mechanical or electrical breakdowns. We could have redesigned the system and made it work, but it would have been too expensive and we decided it was not cost effective.

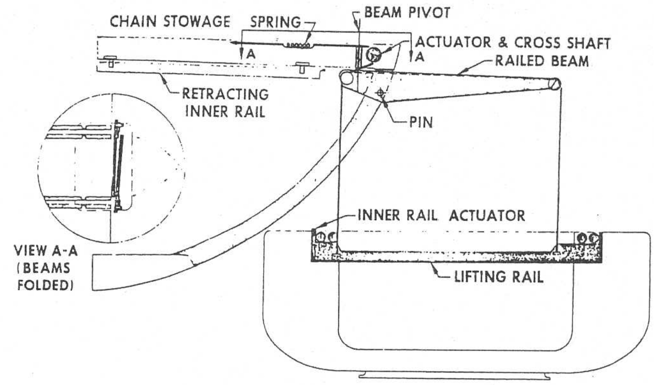


Figure 22.– 727 Lower Cargo Compartment Loader

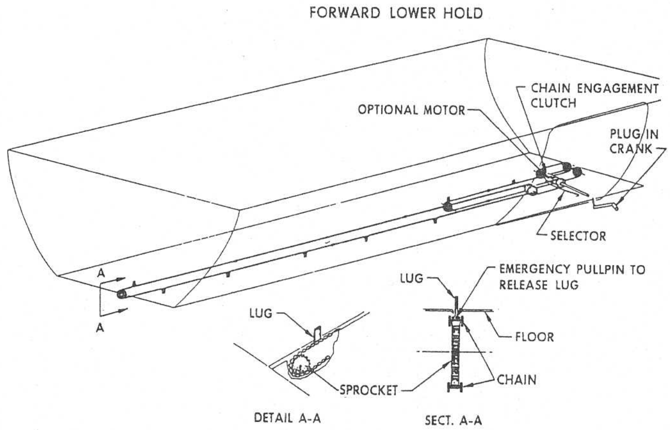
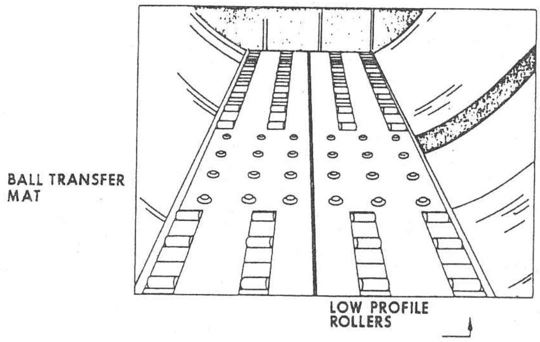


Figure 23.– 727-200 Container Traverse System



WEIGHT INCREMENT OVER BULK SYSTEM

FORWARD COMPARTMENT	130 LBS
AFT COMPARTMENT	80 LBS
	210 LBS

Figure 24.– 727-200 Container Conveyor System (Manual)

Objectives

How well did we meet our customer guarantees? We are proud to point out that we met every one and in many cases exceeded out performance goals and the customer received the bonus.

We also met our objective in maximum part commonness with the 727-100, as is shown by the "Part Number Comparison Chart" of Figure 25. The 727-100 and -200 have 58,000 (79%) of their parts that are common with 15,800 727-200 parts that are different from the 727-100, and 4,200 727-200 parts that are new or additive to a baseline 727-100. This results in a large saving for airline spare part inventories and in manpower.

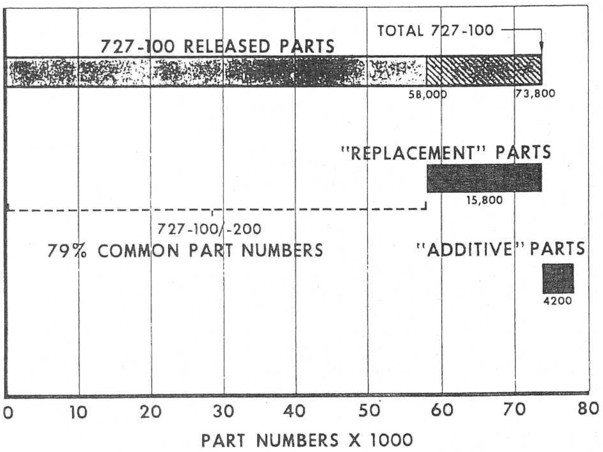


Figure 25.– 727-200 Part Number Comparison

We did not meet our originally planned certification and delivery dates by two months. However, because of the operational commoness with the 727-100 there was essentially no pilot flight training required - just a route proving check. This allowed the first in-service flight to operate only three days after the first delivery.

727-200 Development Costs

The 727-200 was designed, built, tested, and certified to the exact cost that had been estimated. I cannot give you the dollar number becaure it is proprietary, but that is not important. What is important is that we managed the program cost effectively and still delivered the most competitive commercial jet on the market.

Advanced 727-200

The wide-body era (747, DC-10 and L-1011) came in the late mid-1960's amidst an euphoric time of increased airline traffic. There was an ever widening group of enthusiasts for buying nothing but wide-bodies, or two aisle aircraft. They felt that the traveling businessman and tourist would abandon the single aisle aircraft if given the choice. Model 727-200 sales dropped and production in 1971 was down to two per month from a high of 14 per month in 1968. If you will recall, a recession also came about in 1969 which affected all aircraft sales, especially the larger aircraft such as 747, DC-10 and L-1011. The airlines were just then digesting their first large wide-body orders and postponing deliveries - it was a period of retrenchment. It was a period which we decided to capitalize on and started committing improvements to the 727-200 - later to be known as the Advanced 727-200. We are convinced that we had a uniquely sized aircraft with flexibility of performance and passenger interiors. It was a competition of frequency against size, service to more communities versus more congestion, and the bottom line - profit at lower risk.

The Advanced 727-200 did prove to be the right answer as you can see by the U.S. Domestic Trunk Fleet Trend Chart of Figure 26. Since 1971, the number of 727-200s has steadily increased and the large wide-body airplanes have leveled off in quantity since inception of the airlines' initial large orders.

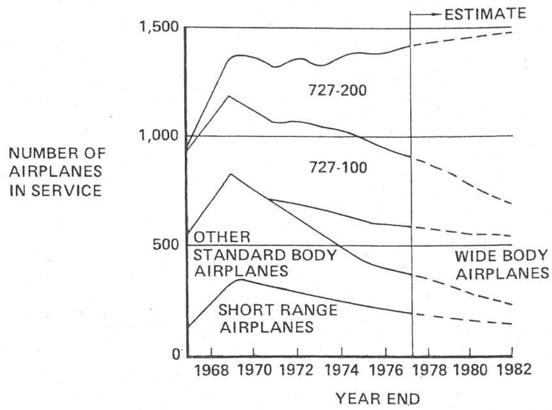


Figure 26.– Short/Intermediate Range Jet Airplanes U.S. Domestic Trunk Fleet Trends

I once had a Marketing Manager ask me, "What is there left for us to do on the 727-200?" My reply was that the opportunities were unlimited as long as we wanted to compete and airlines were willing to pay for improved technology. Presently, we are producing the Advanced 727-200 at a production rate of 12 per month and are sold out through 1980, and we have reserved options for 1981 and 1982. Those 148 airplanes delivered in 1980 will be flying into the late 1990s with the many improvements we are presently incorporating.

Now, that's a bit of marketing, but it is the basis for the commitment to the many improvements that have been made, and are still being made, with no end in sight.

Figure 27 shows a partial list of basic major features and options for Advanced 727-200s. The list is long and there is a story behind each one. Many more items never made the list. We don't have the time here for each of these items, so I would like to select a few that might prove to be interesting to you.

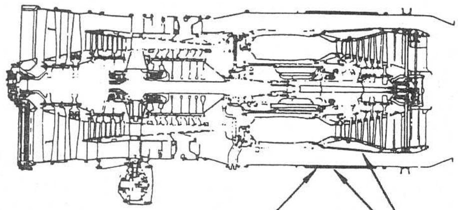
- Basic features
  - 185 800-lb maximum taxi weight
  - 154 500-lb landing weight
  - 138 000-lb zero fuel weight
  - Contemporary interior
  - Integral wing center section fuel
  - Automatic spoilers
  - Mark III brake antiskid system
  - Cascade vane thrust reverser
  - Automatic braking
  - Mark III ground proximity warning system
  - Quiet nacelles with polyimide treatment
  - 49 x 17 tires
  - JT8D-9A engines with full acoustical treatment
  - SP-150 (Mod Block V) advanced autopilot
  - Double louvered ceiling panels
  - Digital color weather radar
  - Performance data computer system (PDCS)
- Options and available features
  - 191 000-lb maximum taxi weight
  - 195 500-lb maximum taxi weight
  - 197 700-lb maximum taxi weight
  - 210 000-lb maximum taxi weight
  - Retrofit of increased gross weight
  - 161 000-lb landing weight
  - 141 000-lb zero fuel weight
  - 40° flap load limiter
  - 50 x 21 tires
  - JT8D-15 or -17 engines with full acoustical treatment
  - JT8D-17R engine with APR
  - Supplementary fuel up to 2480 gal
  - Third cargo door
  - Containerized baggage system
  - Lowered landing minimums – Cat IIIa with 50-ft decision height
  - Area navigation (RNAV)
  - OMEGA navigation system (Marconi)
  - Digital TAT/EPRL system
  - Forward airstairs
  - Carry-all overhead stowage compartments
  - Lower tire pressure
  - Speed command/autothrottle
  - Inertial navigation system (INS)
  - Single louvered ceiling panels
  - Executive interiors with new ceilings and sidewall treatment
  - Systron-Donner fire detector

Figure 27.– Features and Options

Community Noise

The early Federal Community Noise Rule was called the "Parent Rule" because it astablished a baseline airplane in a model. The manufacturer could not increase gross weight or thrust if it increased noise above that baseline (parent) airplane. This tended to inhibit simple growth versions of an aircraft and forced the manufacturer into noise suppression devices - which seemed impossible at the time.

Pratt & Whitney and Boeing further developed the noise attenuation treatment in the JT8D engine. The treatment covered both sides of the bypass duct, which further reduced the takeoff and approach noise of the 727-200 by 1 PndB. See Figure 28. This was modest but instrumental in allowing simple growth versions of the 727-200.



Estimated Noise Reduction

Condition	Single Treatment	Double Treatment
Approach	3 PNdB	4 PNdB
Cutback Take-Off	2 PNdB	3 PNdB
Take-Off	0 PNdB	0 PNdB

Figure 28. – JT8D Noise Attenuation Treatment

The parent noise rule was later superseded by the "New Airplane Noise Regulation" known as FAR Part 36, Appendix C. This rule was primarily developed for new design aircraft. However, Boeing acoustical development engineers had produced a device called the "quiet nacelle", as shown in Figure 29 that enabled the 727-200 to be the first commercial jet to meet the "New Airplane Noise Regulation".

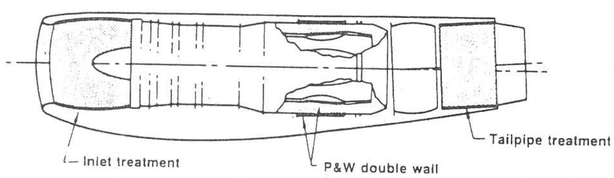


Figure 29. – 727 Nacelle Configuration

We met this regulation at increased gross weights, landing weights, and higher thrust engines. The quiet nacelle consists of inlet noise treatment in the two side engines. Pratt & Whitney fan duct treatment in all three engines, and tail pipe treatment in all three engines. We decided that the long center engine duct is a good inlet noise silencer. There are no measurable thrust or fuel flow losses due to this treatment, but it increased the total airplane weight by 416 pounds.

It is noteworthy that the 727 enjoys a wing blanking effect of the engine noise emanating from the inlet. This effect is worth 2-3 PNdB that was not anticipated but was just a blessing in disguise.

The 727-200 can also meet the "New Airplane Noise Regulation" with the Pratt & Whitney double wall engine treatment, but at the limited takeoff gross weight of 179,000 LB and the JT8D-9 model engine.

The acoustical treatments were once options that airline operators could choose, but since so many were selecting the option we have made it a basic piece of equipment. It is interesting that some areas of the world, such as the emerging nations, think jet noise is "macho" and would rather not have the quiet nacelle - you can't win them all!

New "Wide-Body" Look Interiors

We took a look at the inside of our cabin and decided to restyle it completely by making the inside look wider, lighter, and adding overhead storage bins. We attained acceptance by the airlines and sold not only the new production aircraft with this option, but many hundreds of kits for redoing the older 727s.

This decision to invest in a new interior with a wide-body look was difficult because it was hard to quantify the benefits. It came down to gut feel of how long our 727 product would last against wide-body aircraft if we didn't have the new look. The decision was somewhat easier to make due to the fact that we could offer this same interior on our 707 and 737 aircraft since they have the same body width and windows. This allowed us to prorate the tooling and other costs over a wider base. However, the many hundreds of variations between cargo and passenger aircraft of a given model gave us added expense and customer cost.

Introduction of the new interior was made in early 1971 (see Figure 30). Six years later we introduced the carry-all stowage bin as shown in Figure 31 - a bin that was twice the capacity of the former overhead bin and was 60 inches long instead of 40 inches. Its design was dictated by a garment bag, a new trend especially for the businessman who wants to carry a few overnight articles and does not want to wait in the terminal baggage areas or have baggage damaged or lost.

Figure 30.

Figure 31.

Performance Improvements

As Figure 32 dramatizes, we started making major improvements in 1970 for gross weight, fuel capacity, and thrust. Each of these steps was created to meet a specific market requirement, such as our best selling gross weight of 191,000 LB. This was to meet All Nippon's 2000 Nautical Air Mile (NAM) range requirement of Tokyo to Hong Kong with 140 passengers and a very high fuel reserve. This new weight required major wing, body and landing gear structural changes. We also committed a two auxiliary fuel tank configuration and the JT8D-15 engine with the quiet nacelle for the All Nippon order.

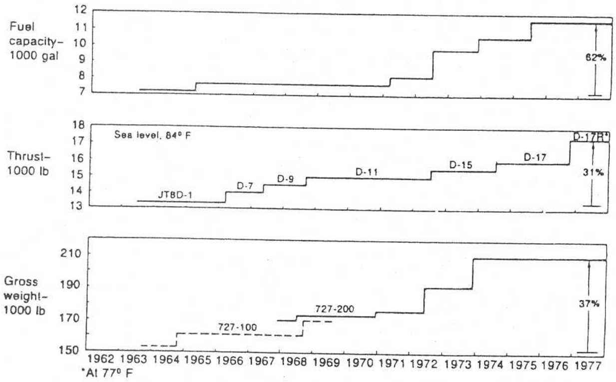
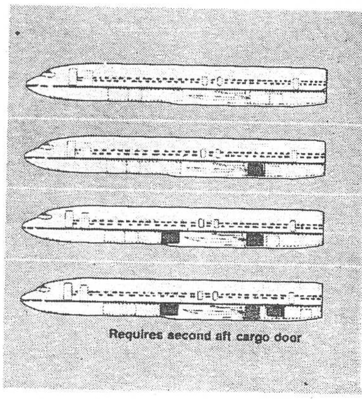


Figure 32.– 727 Development

The current maximum gross weight version was developed for Sterling Airways (the world's largest charter airline) to achieve a 2,500 NAM range allowing the Stockholm-Las Palmas route to be flown non-stop with 187 passengers and 5,000 LB of saleables. Here the criterion was to certify to the ICAO noise rules which are slightly more relaxed than the FAR 36 noise rules, thus allowing a 14,500 LB increase in gross weight. We also engineered for Sterling an additional or third auxiliary fuel tank which is located in the aft cargo compartment as shown in Figure 33.



Additional fuel– U.S. gal	Total fuel– U.S. gal **	Cargo volume– cu ft
0	8,090	710 fwd 815 aft 1,525 *
1 tank 860	8,950	710 610 1,320 *
2 tanks 860 810 1,670	9,760	520 610 1,130 *
3 tanks 860 810 810 2,480	10,570	520 290 810

*Subtract 70 cu ft with second aft cargo door
**Assumes basic wing

Figure 33.– Additional Fuel Options

This payload range chart, Figure 34, shows the numerous choices available in gross weight, fuel, and engine. All this flexibility came into being because the airline requirements were met by an organization that had a can-do attitude. This flexibility has a domino effect on satisfying more airline customers requirements. It allows the aircraft to expand service to more communities, and to replace older, less-efficient aircraft thus allowing one airplane type to do a job that 2 or 3 types did before.

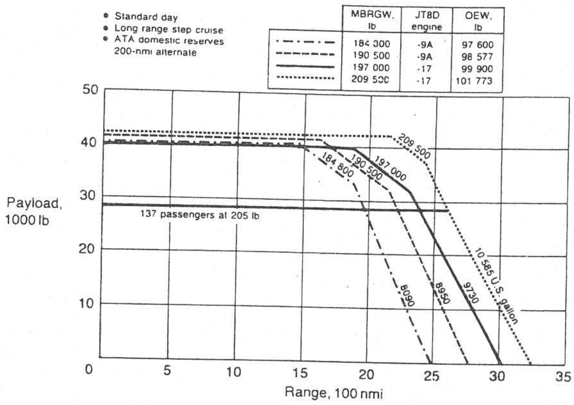


Figure 34.– Payload–Range (Advanced 727-200)

The JT8D-17 engine, at 16,000 LB of sea level static thrust, came into production just six months after Sterling received their first 727-200. All subsequent Sterling deliveries were taken with the JT8D-17 engine. This engine was created for a number of important sales campaigns that were for high altitude and short field takeoff requirements.

In late 1974 Boeing engineered a new technology system that automatically set thrust 1,000 LB higher than normal takeoff thrust in the event of an engine failure on takeoff. The system was a marriage of two ideas: (1) using some of the extended life of a modern jet engine at a critical time, and (2) reduce pilot work load by using a proven automatic engine-failure-sensing system, the 727-200 autobleed shutoff system. See Figure 35. However, the probability of jet engine failure on takeoff is now so remote that the system may rarely be used. This system is called the Automatic Performance Reserve (APR) System and the newest JT8D engine - the 17R - was specially designed to mate with it.

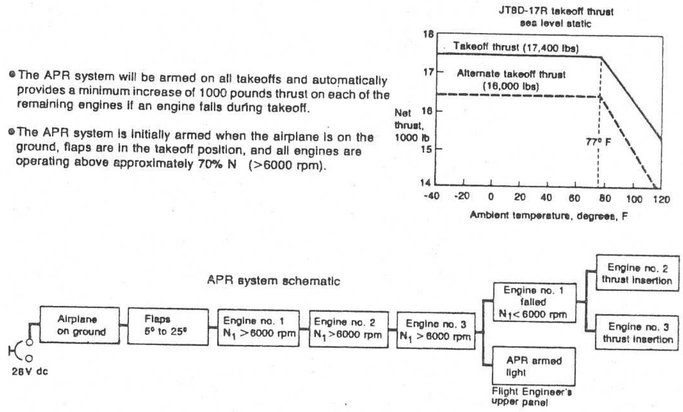


Figure 35.– Automatic Performance Reserve (APR)

As fuel prices increased we accelerated development of an electronic device that monitored and programmed an optimum flight path for the 727-200. The philosophy behind the design of the Performance Data Computer System (PDCS) was relatively simple. It is computer programmed with all of the aircraft's basic performance data or, in effect, an electronic flight manual. With the few pieces of operational data, such as temperature, weight, etc., it runs through stored routines and calculates engine control data, airplane speed, and automatically displays this data on the engine, airspeed indicators, and control display unit. See Figure 36.

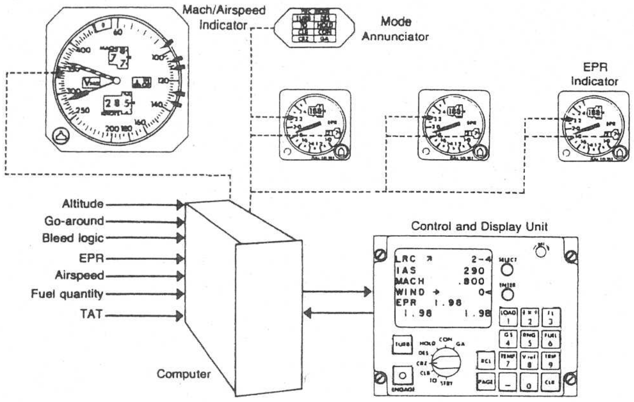


Figure 36. - Airborne Performance Computer System

By flying an optimum flight path for the existing conditions instead of a few standard routine flight paths, this system has demonstrated fuel savings of 4 to 5 percent. One airline flying this system is showing a 7% fuel savings.

It also reduces crew work load when responding to Air Traffic Control instructions, by providing more precise operational data control, and by having immediate availability of performance data. This is the first step in a true Flight Management System with the second step being the development of a full-flight-regime autothrottle. This is just one of the more-updated electronic cockpit system applications that the 727-200 is moving ahead with, but also is a good example of a coordinated challenge met by airplane manufacturer, component vendor, and engine manufacture.

All these advancements on engines and aircraft have definitely sold more of the product. Boeing has passed the milestone of selling their 1500th 727 and last June we ordered the 10,000th JT8D engine. This engine will be mounted on a 727 (727-200) and rightly so because that's where the first JT8D engine was installed.

It is no doubt enlightening to the casual observer that an aircraft like the 727-200 can be changed (improved) piece by piece until it has very few of its original parts in a current production aircraft. There has been a great deal of engineering, development, testing, and coordination over the years since the original model was delivered. The following chart, Figure 37, shows the engineering manpower for the entire 727 program. I would like to point out that the engineering manpower at the present is more than 60% of the level that we had when we designed the 727-100.

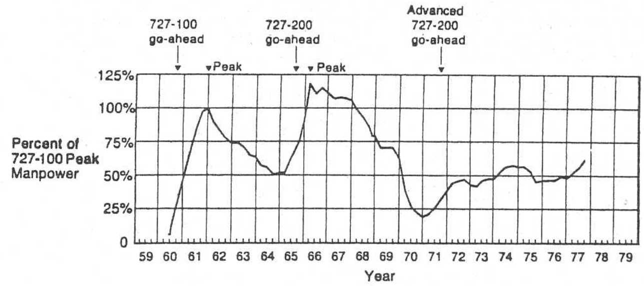


Figure 37. - Engineering Manpower (727 Program)

Not only is this creative work going on in Seattle at the "Big B", but hundreds of subcontractors are doing the same all over the United States and in many foreign countries. I think this does prove that there is a need for a creative work force over a long period of time. Some of us have spent almost our entire career on the 727 program and it has been very rewarding.

The Future

There are a number of study or development projects in various stages of approval and covering almost all technology disciplines. Some of these are:

- Advanced composite material for secondary structure
- Full regime autothrottle
- New technology auxiliary power unit
- Aerodynamic fairing improvement
- Engine noise suppression
- 727-200 freighter or convertible
- Flight managment system.

Many of these will be approved, some rejected, and some postponed until the market is ready, but, whatever the reason, the usual tough, cost-effective, decision-making process will be applied to each. The work done on the 727-200 impacts more units and more airlines than any other commercial aircraft. We have been selling over 100 units per year in recent years and anticipate selling these improved 727-200s into the 1980s for use through the 1990s and century 21.

SECTION 6

CONCLUDING REMARKS

by
J.E. Steiner

CONCLUDING REMARKS

by
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It is appropriate that we conclude this case study discussion of the 727 with a brief coverage of "lessons learned". I'm sure that my list of eight is not the only list which could be constructed, and that the other program participants might have other items of equal or greater importance.

The 727 succeeded in part, because of its quality - - but also in part, because it has never had a strong direct competitor. As I compare our forecasts at the time we first presented the program to the Board of Directors, two factors emerge: (1) we predicted the total market for this class of airplane with reasonable accuracy over a rather long time period and (2) we actually obtained a much greater percentage of the market than we had predicted. I believe this leads into the first of the "lessons learned", which is shown on Figure 1.

1. THE MOST IMPORTANT SINGLE ELEMENT OF SUCCESS IS TO LISTEN CLOSELY TO WHAT THE CUSTOMER PERCEIVES AS HIS REQUIREMENTS AND TO HAVE THE WILL AND ABILITY TO BE RESPONSIVE.
2. AN AIRLINE AIRPLANE IS ONLY AS GOOD AS ITS ECONOMICS – ITS COST PER SEAT MILE, ITS APPEAL TO ITS PASSENGERS AND RESULTANT LOAD FACTOR BENEFIT, ITS RETURN ON INVESTMENT TO ITS AIRLINE OWNER.

Figure 1.—Lessons Learned

I will cover these lessons by referring to similar abbreviated titles.

1. <u>Customer Requirements</u>

Perhaps one of the greatest problems in developing both commercial and military programs is that of adequately placing ourselves in our customer's position and really understanding what he perceives his requirements to be. I mentioned earlier that Douglas had sold a miniaturized, four-engine DC8 (which they called the DC9) to United Airlines subject to the condition that they had to get another major customer before the program proceeded. The 727 thus entered a market which was already spoken for. Perhaps the only reason the 727 succeeded and the competitive program died was that we were able to find a compromise through what was then a very unpopular configuration - namely, a three-engine airplane. Otherwise, there would have been no 727 program at all. Similarly, the British deHavilland Trident program was initiated before the 727. The Trident was, and is, a sound aircraft, designed by a competent design team. However, it had the misfortune of being oriented toward a specific single airline desiring an extremely tight body cross-section, the likes of which had already failed in the American market place during the DC8-707 competition. Because of its body cross-section, we never expected the Trident to make significant U.S. sales.

Another customer requirement related example in the 727 program was the choice of engine. Boeing's choice was the Rolls-Royce ARB963. One of the customers would not accept either the long supply line across the Atlantic, or the designated licensee that Rolls had selected. The path was open, I believe, for Rolls to succeed, but they did not, and perhaps could not, follow that path.

The lesson then is that program success or failure may hang by the slender thread of responding to what the customer perceives as his requirement. History is full of magnificent non-programs that offered exactly the "right" vehicle or system but not the one that the customer perceived that he wanted.

2. <u>Economics</u>

In the U.S., the economics of the vehicle and that of the system are almost totally governing. Even in foreign countries, where many of the airlines are government-owned, they are run on much the same principles as a private company. Their profit or budget performance is closely watched and repetitive poor performance will bring the management down.

As the design progresses and solidifies therefore, all the factors affecting economics must be considered. The most difficult of that consideration for the designer is putting the economic evaluation into a basis that is credible to the customer. I wish that I had a nickel for every time I've heard "Of course the airline is using some unrealistic inputs and gets a different number, but this is the way our economics really compare to our competition." The only problem is that "this way" does not present the data on which the <u>decision</u> is made. So, how the customer perceives his economics is as significant as how he perceives his requirements.

One must also remember that economics is a relative thing. The vehicle has to be economically viable in the environment and for the time period that is relevant. The industry constantly seeks to improve the economic viability of its products, and this of course, guides such derivatives as the 727-200 with respect to the original 727-100.

3. <u>Technology</u>

Technology is always important both to the initial sales and to the continued success of the program as shown in Figure 2.

As noted, it is the aggregate level of technology that is important - the compilation of all of the various parts of technology.

3. SMALL ELEMENTS OF TECHNICAL SUPERIORITY ARE IMPORTANT IF, IN AGGREGATE, THEY ADD UP TO WINNING (VS. LOSING) A SALE – AS THEY FREQUENTLY WILL.
4. TECHNICAL SUPERIORITY NEED NOT MEAN HIGHER COST. IN FACT, IT MAY MEAN JUST THE OPPOSITE, I.E., LOWER COST.
5. AS MUCH EFFORT IS NECESSARY IN ACHIEVING LOWER COST MANUFACTURING AS IN ACHIEVING A SUPERIOR TECHNICAL DESIGN. A VERY CLOSE WORKING RELATIONSHIP BETWEEN ENGINEERING AND MANUFACTURING IS ESSENTIAL.

Figure 2.—Lessons Learned

It is true that airline or government purchase decisions frequently are made without giving what the designer perceives as adequate credit to more refined or improved technological levels. However, if in fact those technological levels result in genuine benefits to the customer, then the reward will come through added program life.

Generally, one should adopt the latest technology that has a reasonable chance of being accepted by the customer - even though such adoption means that there will be an occasional case where the older technology would have been safer.

I have seen horrible examples of the failures of new and unproven technology, for instance, in the use of certain aluminum alloys and bonding processes. Yet, if I had the decisions to make over again, I would still make them in favor of the latest technology, because I think these instances are the exceptions rather than the rule.

4. Technical Superiority Versus Cost

As noted, it is my belief that technical superiority may sometimes reduce cost rather than increase it. This is not simply based on the idea that technical superiority makes the program last longer. The attainment of technical superiority generally means iterating the design; and in this process, weight can go down, part counts can be reduced, and the total cost lowered - even though the technological level is being improved. Engineering is often called "the science of doing things over again". The main lesson perhaps, is that as much as possible of this iteration must take place before final go-ahead, and the rest should continue in a cost-conscious, controlled environment.

5. Engineering/Manufacturing Relationship

In any commercial airplane program, most of the money is spent in manufacturing. The cost of engineering is relatively small. Of course, the engineering effects on manufacturing can build up the total cost.

The engineering and manufacturing teams should be selected well in advance of go-ahead and should practice working together for at least one year. There should be enough intertwining of objectives and communication so that the total engineering/manufacturing team acts as a unit. The results can be truly astonishing.

6. Goals

Figure 3 continues the statement of "lessons learned".

6. A WINNING PROGRAM WILL HAVE TECHNICAL AND ECONOMIC GOALS BARELY WITHIN REACH AND REQUIRING ENGINEERING CREATIVITY TO ACHIEVE.

7. A SUBSTANTIAL CONTINUOUS PRODUCT IMPROVEMENT PROGRAM PROVIDING FOR IMPROVED AIRPLANE RELIABILITY, FLIGHT CHARACTERISTICS, PERFORMANCE, OPERATING ECONOMICS, ROI, NOISE CHARACTERISTICS, AND SIMILAR BENEFITS IS ESSENTIAL TO ACHIEVING LONG TERM PROGRAM SUCCESS.

8. SIGNIFICANT, OR EVEN MAJOR, DERIVATIVES MUST BE CONTINUOUSLY CONSIDERED FROM PROGRAM INITIATION, AND A CONSTANT CUSTOMER DIALOG MAINTAINED, NOT AVOIDED.

Figure 3.—Lessons Learned

Any new airplane program is a balance between opportunity and risk. From a technical standpoint the 727 program must be classed as a very "risky" program, because the goals were known to be barely attainable - if attainable at all.

However, the 727 program benefited by having a competent total team, and by having a relatively long pre-go-ahead period for that team to interface internally. In addition, Boeing had developed, as had NACA, a sizable storehouse of unapplied technological improvements.

The subject is highly argumentative, but I believe that engineering/manufacturing teams are capable of far greater accomplishments if they are stimulated by goals that they recognize as almost unachievable.

7. Continuous Improvement Program

A balance, of course, must be struck between the customer's desire for as few changes between his successive airplanes as possible and the program's desire that the airplane be continuously improved. As noted earlier, we have followed a practice of maintaining a very large sustaining engineering team, and of adopting constant improvements in all of our product lines. This is not necessarily desired by all of the customers, but one must recognize that occasions will arise when a previous design or piece of equipment must be installed, probably out of sequence, in order to give an earlier customer another airplane exactly like the earlier ones he is operating. However, I have found this to be the exception rather than the rule, and have generally insisted on contracts which did not prevent improvement changes between airplanes.

Military contracts frequently are written to prevent any change whatsoever. On occasion this is a valid position, but I believe each element of the airplane must be analyzed separately to make sure that such a requirement is sound.

8. Derivatives

I believe one must constantly try to obsolete one's own product and that major airlines or government agencies are sophisticated enough to carry on a dialog on this subject without killing near-terms sales. It is only through such a continued dialog that the really correct derivatives will make their appearance.

The 727 has been continuously improved and today's version which is being increased to a 12 per month production rate has relatively little commonality with its original ancestor. In addition, there has been a continuous program to bring out derivatives far superior to the airplanes currently being built.

As an illustration of this, the first "wide-body 727" was laid out in late 1970. A cabin mockup was build in 1971 (retaining cockpit, wing, gear, and partial tail) and we almost sold a seven-abreast 727 in 1972. That program was known by various names, possibly the most frequently used one being the 727-XX.

In the first quarter of 1973, we initiated a less ambitious improvement derivative program called the 727-300, which raised gross weight, installed a more powerful engine and lengthened the body still further. This version lasted until about September 1974, when major airline customers decided that the advanced version of the present JT8D engine then being considered constituted a significant noise risk. We then shifted to consideration of other engines, including the JT8 refan and the CFM-56 (which had been used in some versions of the 727-XX).

Many millions of dollars were spent on attempting to launch the 727-300 program. But it was not until late September 1975 that we finally concluded we could not sell it.

From then on, 727 derivatives contained two critical elements: (1) a new high technology wing and (2) two high bypass ratio engines. That program has had several names including the 7N7 and now the 757.

Thus, the 727 Case Study is open-ended. We do not really know how many airplanes called 727's will eventually be built. In addition, we do not know how many of our new airplanes will be of partial 727 ancestry.

Ladies and Gentlemen: It has been a privilege for our team to have had the opportunity of presenting the 727 Case Study to you this morning. On behalf of the team, I would like to thank you for this opportunity.