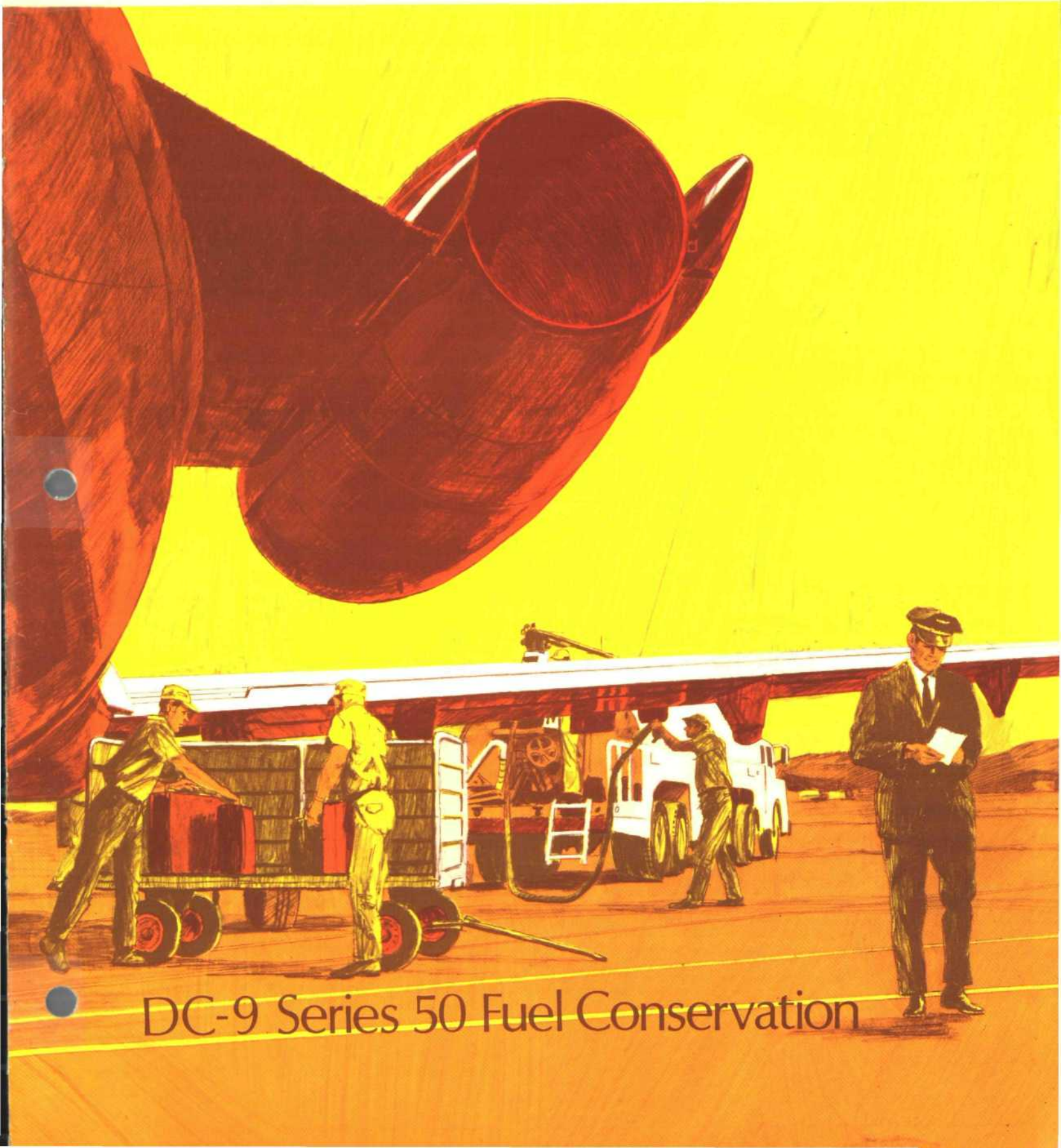
DOUGLAS SERVICE

VOLUME XXXVI

SPECIAL SUPPLEMENT

OCTOBER 1979



DC-9 Series 50 Fuel Conservation

DC-9 Series 50 Fuel Conservation

compiled by H. Tang
Commercial Customer Service, Douglas Aircraft Company

We want to express our appreciation to those who made contributions to this Special Supplement, especially: Douglas Program Engineering, Operational Engineering, Flight Operations, Aerodynamics, Environmental Engineering, Power Plant Engineering, Electrical Engineering, Product Support, and Pratt & Whitney Aircraft.

DOUGLAS SERVICE

VOLUME XXXVI SPECIAL SUPPLEMENT OCTOBER, 1979

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contents

Introduction 1
Aerodynamics 2
Flight Operations 16
Engines 38
Electrical Power 43
Environmental Control 52
Fuel Gage System 54
Performance Analysis 56

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INTRODUCTION

This Special Supplement was compiled in response to operators' requests for information that would help them reduce fuel costs.

Fuel costs presently represent about 35 percent of airlines direct operational costs and can be as high as $600,000,000 per year for some airlines.

In 1978, United States airlines spent approximately 4 billion dollars for nearly 10.5 billion U.S. gallons of turbine fuel. An average domestic trunk DC-9 consumed 3,080,160 gallons of fuel in 1978[1]. The average fuel cost per DC-9 aircraft for a 12 month period ending Dec. 31, 1978 was $1,171,102. Based on this expenditure, a one-cent per gallon increase in the cost of fuel would increase the annual fuel bill $30,801 for each aircraft. A one percent reduction in fuel consumption would mean a savings of over $11,711 per aircraft each year.

Even though the DC-9 consumes less fuel per passenger mile than most other commercial aircraft in service today, it is readily apparent that a fuel reduction of even one percent represents large savings. This means that operational policies, flight planning, and cockpit decisions must be made with regard to the most efficient use of fuel. Increased fuel consumption can result from specific operational practices as well as an operationally degraded aircraft.

This Supplement presents DC-9 Series 50 operational performance penalties and approximate fuel costs associated with various aerodynamic and aircraft system discrepancies. The subjects are placed in sections entitled, Aerodynamics, Flight Operations, Engines, Electrical Power, Environmental Control, Fuel Gage System and Performance Analysis. Throughout these sections, maintenance and operational procedures are provided to assist operational and maintenance personnel in restoring the airplane to the original configuration and to keep fuel consumption to a minimum. The importance of fuel conservation is obvious. A majority of the items that cause excessive fuel costs are not obvious. Each airline will have to assess the penalties shown and determine if the cost to correct them is worthwhile. The largest savings can be obtained by monitoring many small items, usually undetected, which add up to a considerable expense over a period of time.

[1] CAB Form 41 Uniform System of Accounts and Reports for a 12 month period ending December 31, 1978.

AERODYNAMICS

Aerodynamics is often said to be the study of drag, since even a barn door will generate lift, and, given enough power, can be made to fly as fast as desired. The key words are "given enough power," since aircraft power plants consume fuel at a rate that is roughly proportional to the power they produce. Thus, in order to minimize fuel consumption, the power required (i.e., drag) to perform a given mission must be the minimum possible.

During the initial design of an aircraft, the aerodynamicist's dream airplane is a perfectly smooth and continuous shape that incorporates state-of-the-art design philosophies. Unfortunately, when the dream airplane is actually built, real life intrudes in the form of external add-ons such as antennas, actuator fairings, external doublers, scuff plates; as well as various surface distortions or interruptions such as skin waviness, panel joints, control surface interfaces, and mismatch of doors, windows, access panels and rivets.

The drag penalties of such items are generally predictable from wind tunnel measurements or analytical techniques, and detailed trade-off studies are undertaken during initial design and development to arrive at the best compromise between aerodynamic cleanness, weight, minimum working clearances, cost, and tolerance buildup during assembly.

Once the final configuration is established, the basic drag level of the aircraft is essentially fixed, and during performance testing every reasonable effort is made to maintain the flight test aircraft to within published waviness, mismatch and rigging tolerances, so as to obtain data that fairly represent the true performance capability of the aircraft. However, most in-service aircraft experience normal wear and tear that result in degraded aerodynamic cleanness. This degradation usually causes no operational problems except for some increase in fuel flow.

Normal wear and tear over a period of time typically may include such things as external patches, chipped paint, mismatched doors, leaking seals, dents, substituted fasteners, and out-of-fair control surfaces. The amount of penalty actually arising from such items is, in part, a function of where they are located on the aircraft. This is because of such factors as boundary layer thickness, local flow velocities, and pressure gradients. Consideration of these factors leads to the classification of various regions on the aircraft according to their sensitivity to adverse aerodynamic effects, as shown in figure 1. Typically, Class I regions are highly sensitive, having high (possibly supersonic) local flow velocities, thin boundary layers, and adverse pressure gradients in some combination. Class III areas have relatively low sensitivity due to less severe local flow conditions. (It is interesting to note that it is often heard that small flow disturbances toward the aft end of the fuselage have little effect since they are "buried in the boundary layer." However, the flow velocity at a height above the surface corresponding to only one percent of the boundary layer thickness is more than half of the velocity existing at the outer edge of the boundary layer.)

There can be significant performance losses associated with certain types of in-service aerodynamic discrepancies that occur randomly within the fleet. As noted before, the general problem of aerodynamic cleanness degradation is that of gradual deterioration of various seals, rigging adjustments and skin surface smoothness. A review of audit data for the DC-9 fleet since initial delivery indicates that (if EPR to thrust relationship is assumed to remain unchanged) the average degradation of aerodynamic cleanness, i.e., drag increase, is less than one-half percent. While one-half percent may not appear to be significant, it represents approximately $5,000,000 in excessive DC-9 world-wide fleet annual fuel consumption.

One percent increase in drag represents approximately $300,000 in excessive annual fuel consumption for a fleet of 25 aircraft.

Since this average degradation necessarily includes aircraft that are either worse than, or better than, average, it is worthwhile to review some of the many conditions that can lead to degraded aerodynamic cleanness so that an assessment of cost-effectiveness of restoration can be made.

Usually, operational performance penalties are noted in the engineering terms of percent drag increase, or percent increase in fuel flow. While these are useful terms for the engineer, they may not satisfactorily convey the magnitude of penalties to less technically oriented personnel. Therefore, opportunity is taken to specify penalties for several conditions that adversely affect the aerodynamic cleanness of the DC-9, in terms of both engineering (percent increase in fuel flow) and general (gallons and dollars) units. The following illustrations summarize the approximate penalties associated with these several cleanness deviations. The fuel-used penalties given are based on an assumption of a flight average fuel flow of 950 gallons per hour and a 2,500-hour annual utilization. The cost penalties

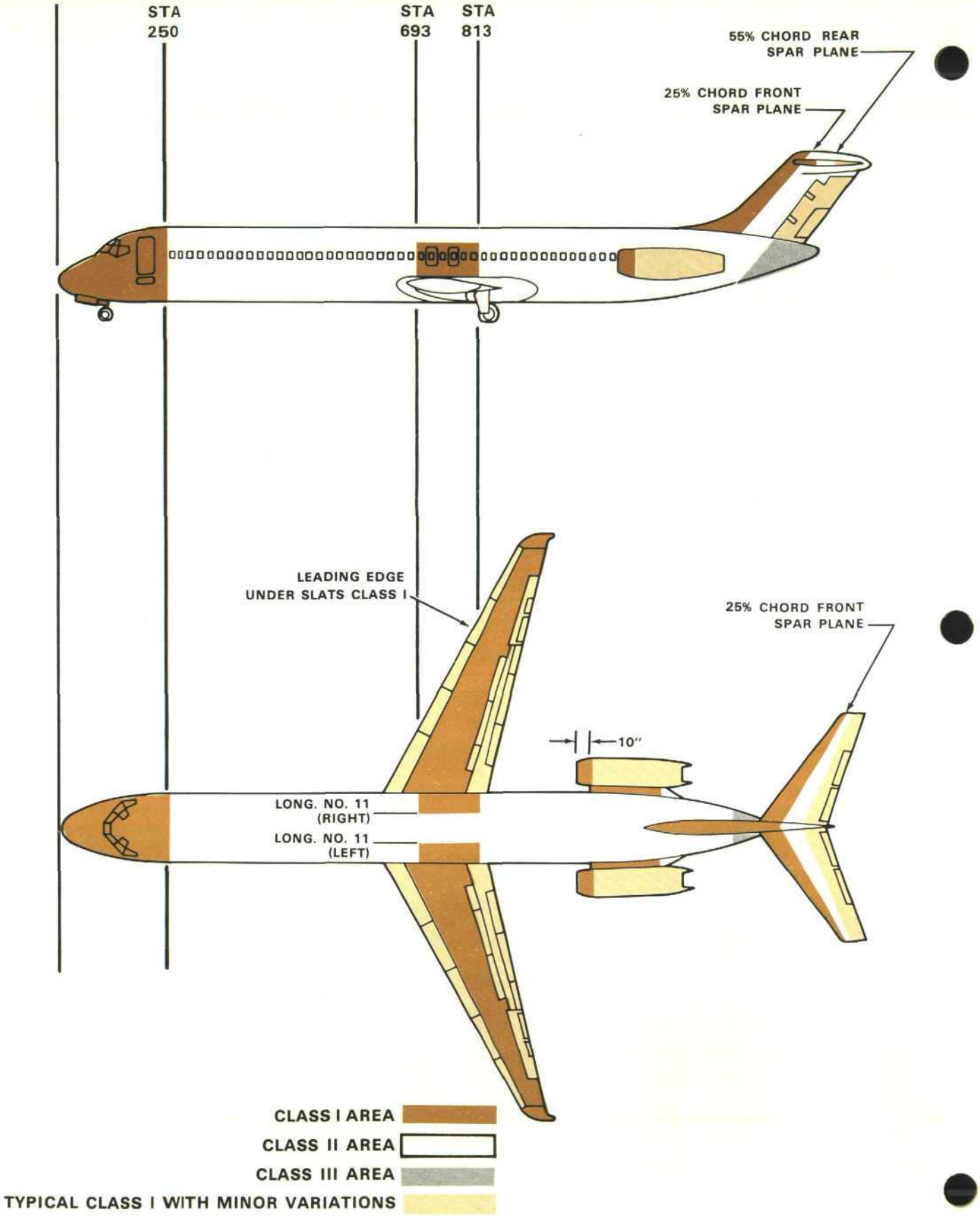


Figure 1. Boundary Locations and Class I, II, and III Areas

assume a fuel price of 50 cents per gallon. Since these values (particularly fuel cost) may vary significantly among individual operators, their approximate penalties can be derived as a direct ratio of the penalties noted herein.

The following figures and tables make no assumption as to the probability of a particular discrepancy, nor do they cover all possible combinations of improper maintenance or operational mishandling. Rather, the intent is to illustrate that seemingly minor discrepancies can result in a substantial increase in the fuel usage of a fleet of DC-9s.

Balancing the aircraft using aileron trim results in a moderate penalty since the spoilers are not affected by aileron trim. However, if the balance is maintained by manual or autopilot lateral input, the penalty increases since the spoilers begin to raise almost immediately as shown in figure 2.

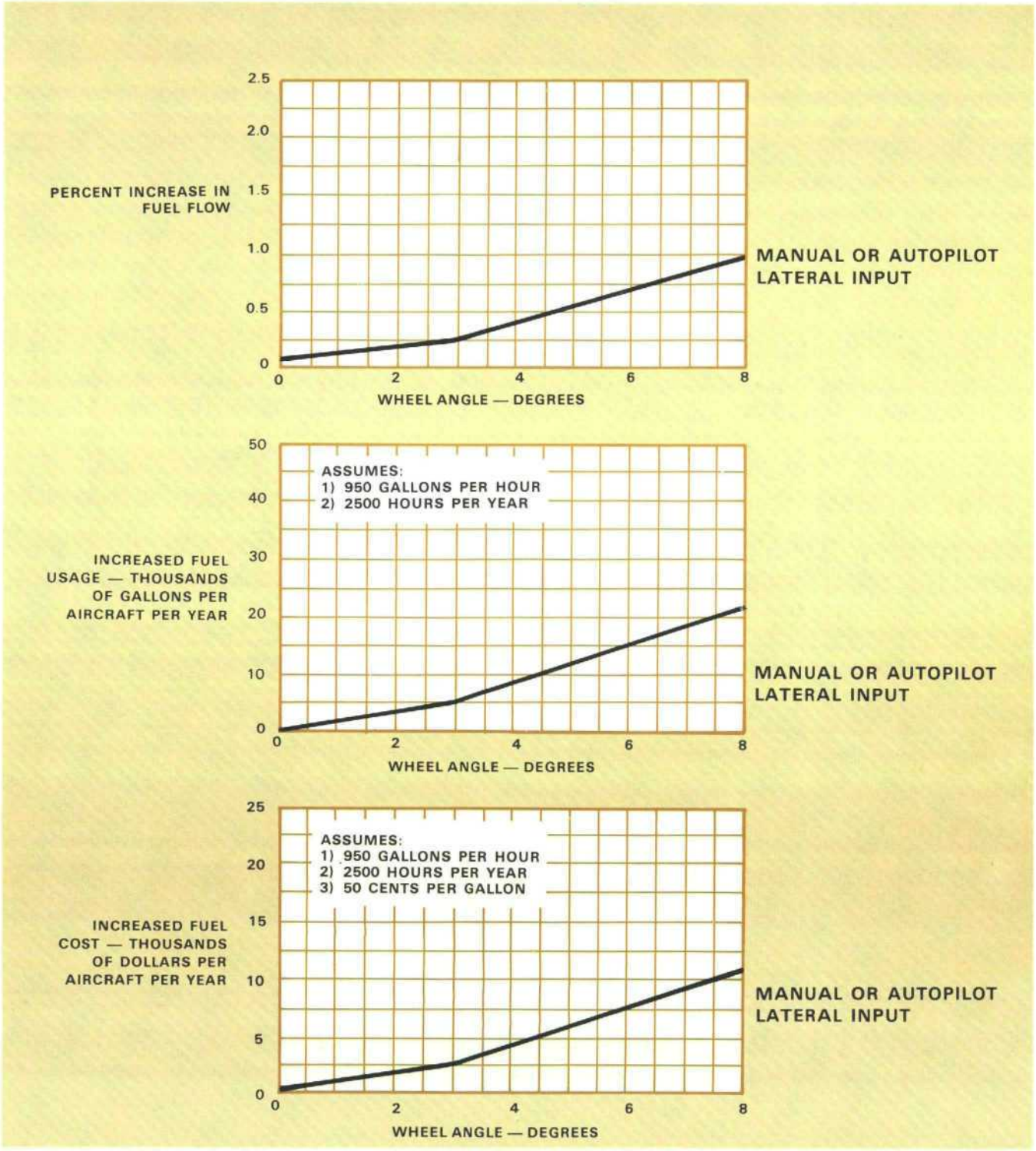


Figure 2. Approximate Penalties Associated with Insufficient Lateral Trim (Aircraft Balanced by Manual or Autopilot Lateral Input)

An aircraft with a misrigged rudder or biased gyro horizons (or turn-and-slip indicators) can also require excessive lateral and rudder trim in order to balance the aircraft into a steady heading sideslip. The penalties for the resulting cross-control situation are dependent upon how the lateral input is made, as shown in figure 3.

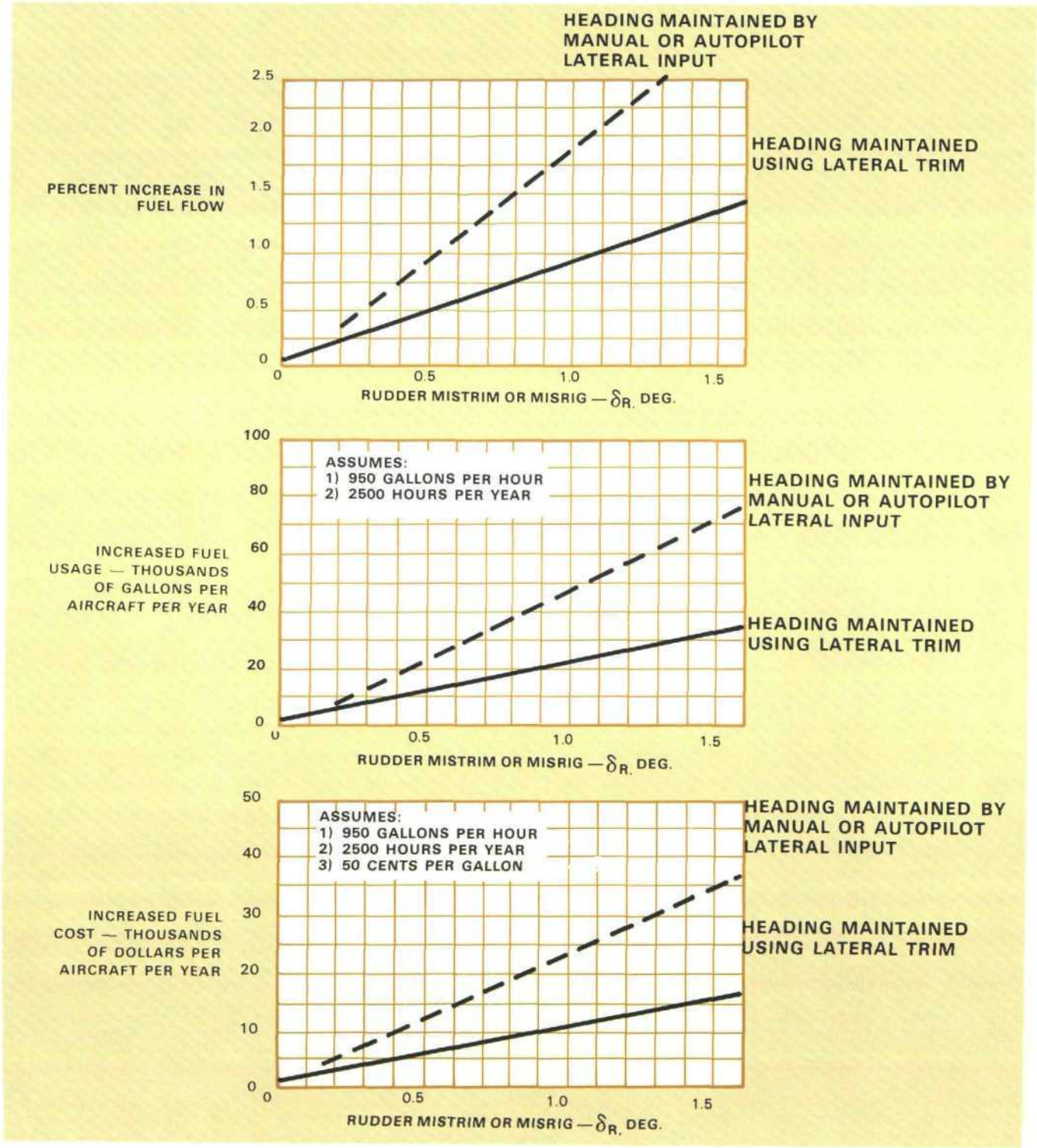


Figure 3. Approximate Penalties Associated with Mistrimmed or Misrigged Rudder (Aircraft Maintained in Steady Heading Sideslip using Lateral Input or Trim — "Crossed Controls")

Another sensitive interface, because of its location in the supersonic flow region near the wing leading edge, is the aft-facing step at the slat upper surface trailing edge. Figure 4 shows that small over-tolerances can have significant effect on performance.

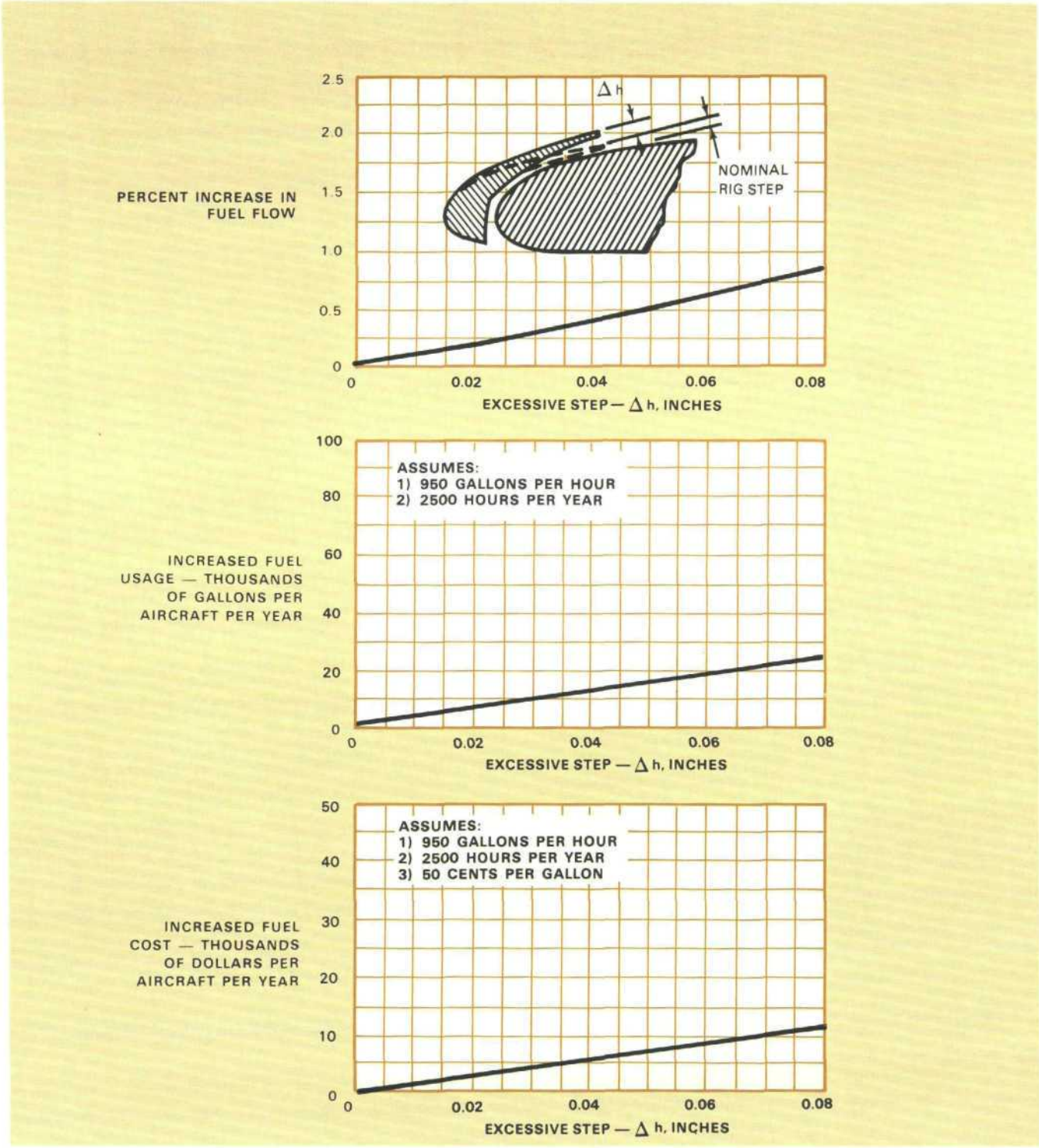


Figure 4. Approximate Penalties Associated with Excessive Step at the Slat Upper Surface Trailing Edge (All Slats Uniformly Raised)

Misrigging of the flaps, although not often encountered, can also adversely affect performance, as shown in figure 5. The penalties arise because of the unporting of flap hinge fairings and the BUTE (Bent Up Trailing Edge)-to-flap seals.

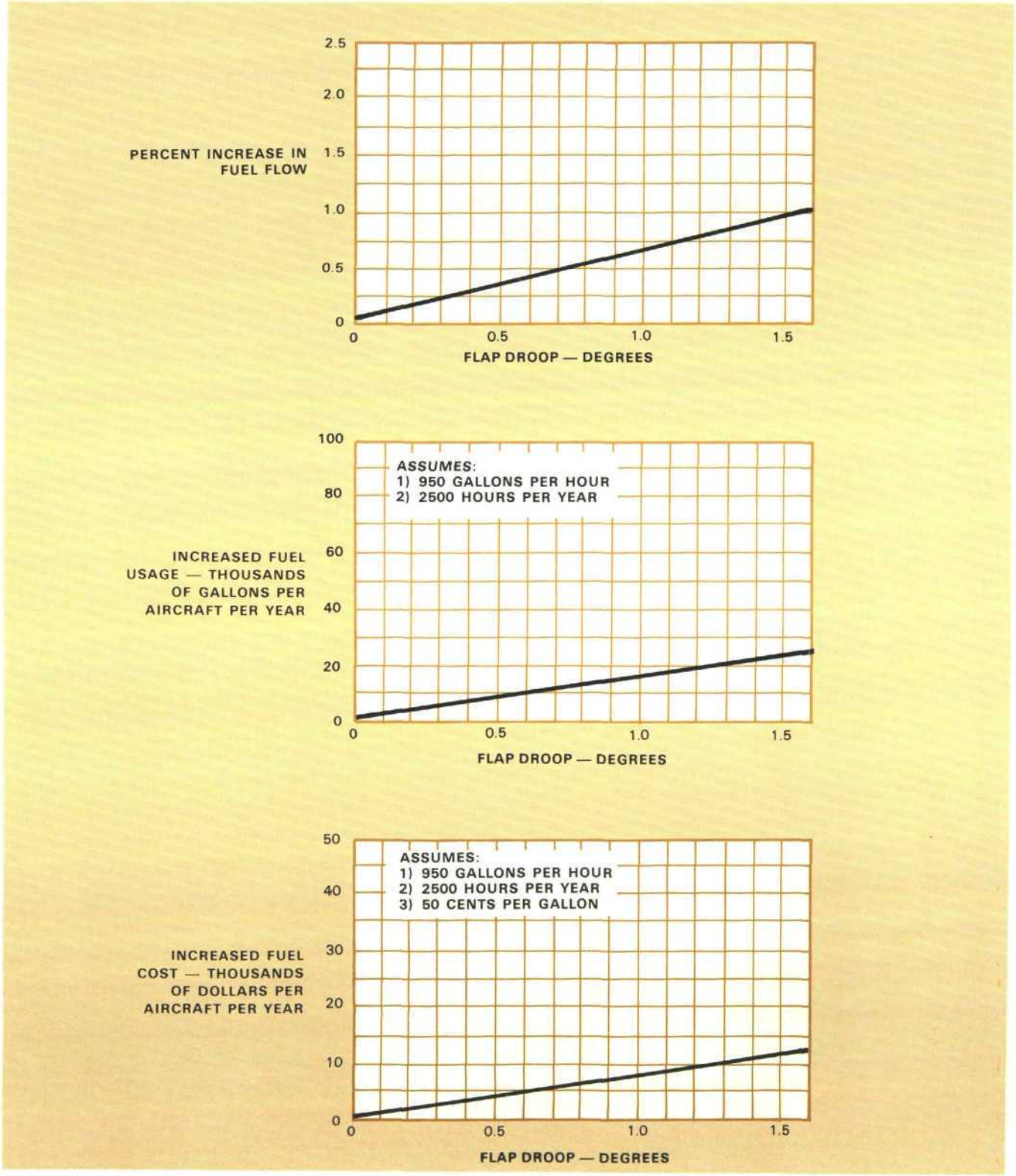


Figure 5. Approximate Penalties Due to Misrigged Wing Trailing Edge Flaps (Flaps Symmetrically Misrigged Down)

Misrigging of the elevator tabs affects the elevator neutral position, and leads to a comparatively small penalty that is due primarily to the drag difference between a symmetrical and a cambered airfoil at the same lift. See figure 6.

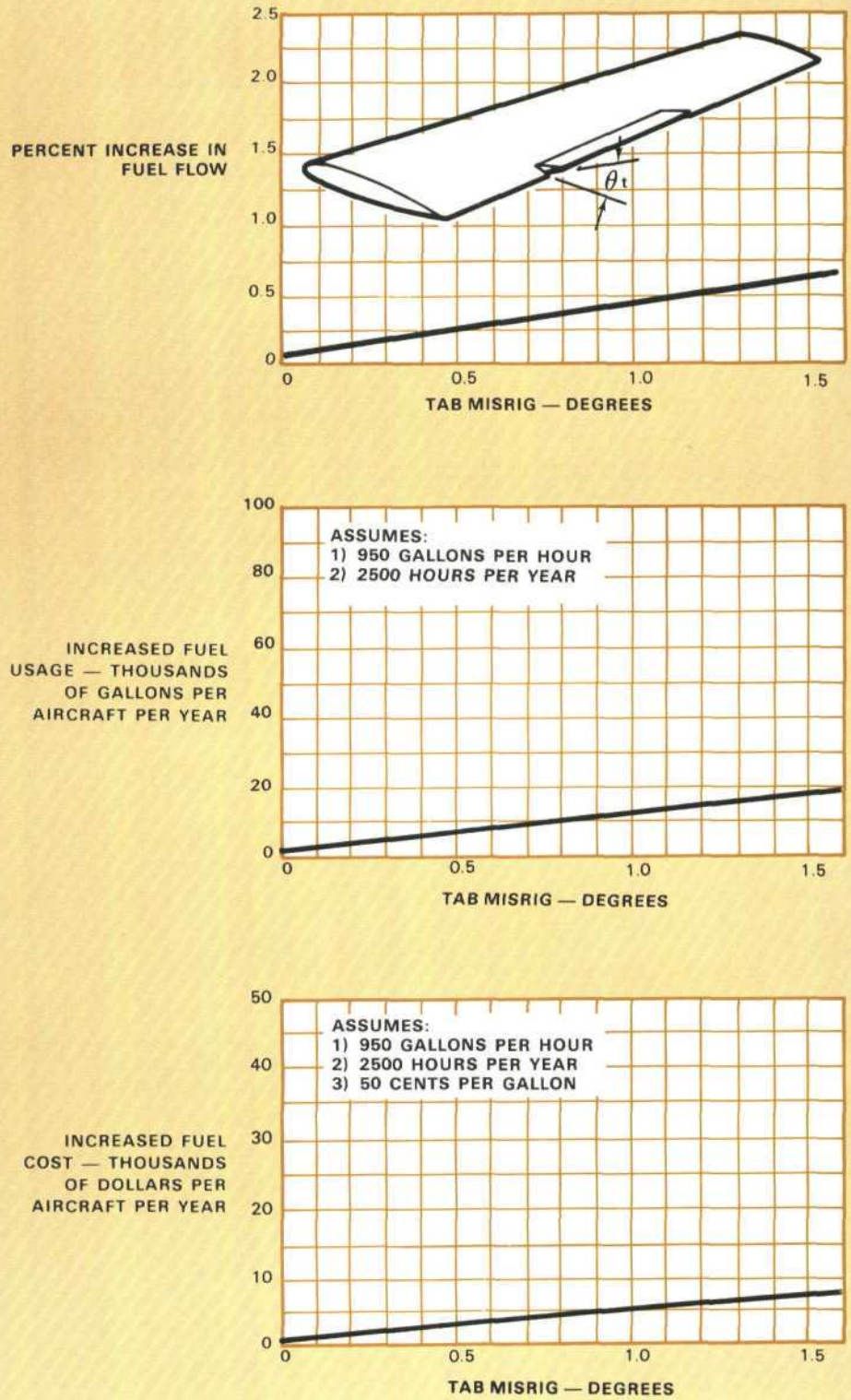


Figure 6. Approximate Penalties Due to Misrigged Elevator Tabs (Attitude Maintained Using Stabilizer Trim)

Drag increases with forward movement of the center of gravity due to the greater aerodynamic down load on the horizontal tail necessary to maintain longitudinal trim. As shown in figure 7, fuel expenditures are increased for procedures involving forward loading.

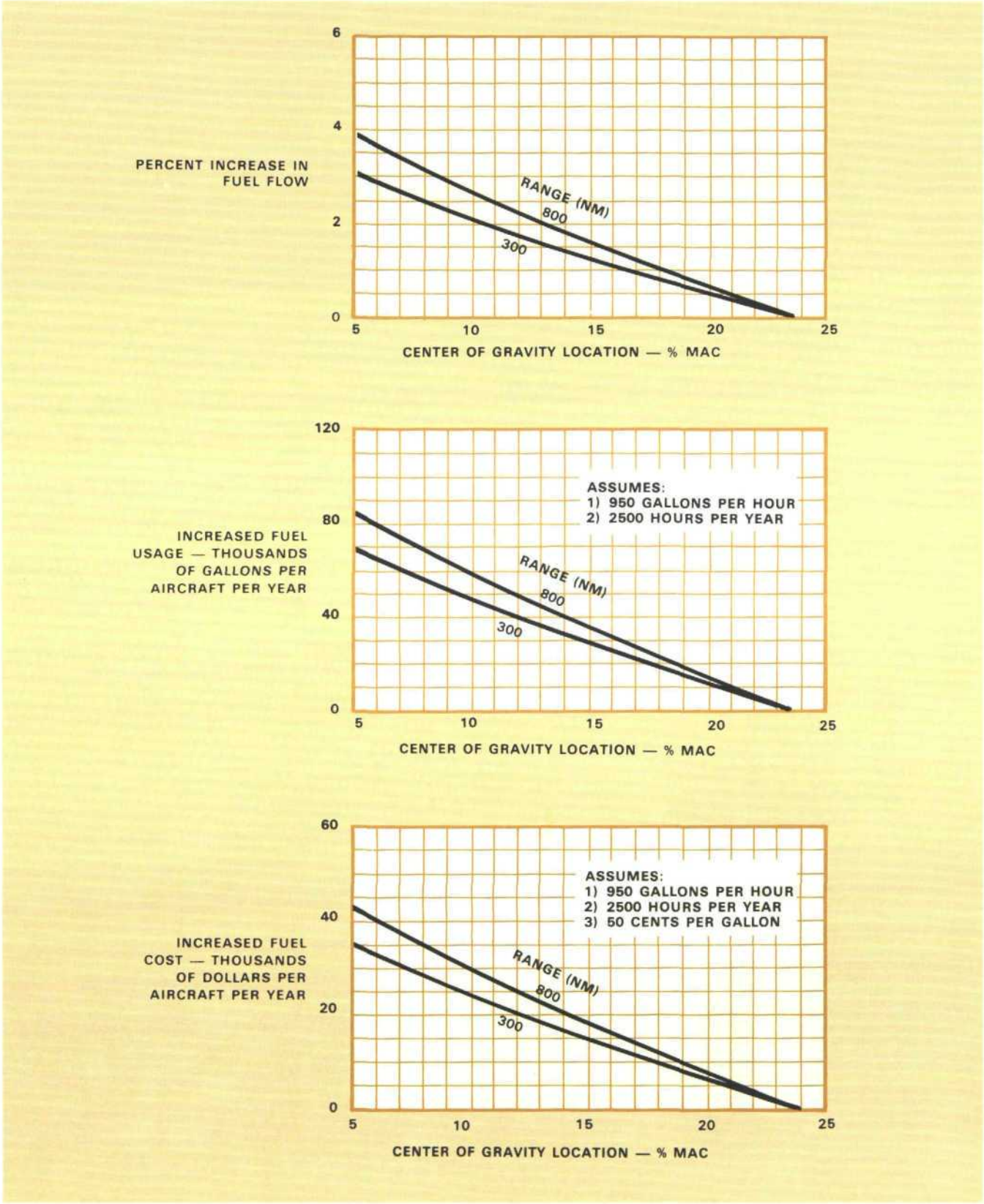


Figure 7. Approximate Penalties Associated with Trim Drag Variation Due to Movement of the Center of Gravity.

Significant penalties can be incurred by continued operation with various parts missing from the aircraft under the provisions of the Configuration Deviation List (CDL) as shown in table 1.

Table 1. Annual Cost Penalties Associated with Missing Parts (U.S. $/Year Per Aircraft)

MISSING PARTS	APPROXIMATE FUEL PENALTY U.S. $/YR	MAINT/REPAIR REFERENCE	EST MANHOURS TO CORRECT*	
			MEN	HRS
External Power Receptacle Door	$ 194	MM 24-40-0	1	0.5
Aft Waste Water Service Door	442	MM 38-30-0	1	0.5
Potable Water Service Door	442	MM 38-10-0	1	0.5
Conditioned Air Ground Connect Door	166	MM 21-20-8	1	0.5
Pylon Trailing Edge	28	SRM 54-02	1	3.0
Small Doors at Aileron Hinges (ea)	111	—	1	1.0
Inboard Flap Hinge Fairings	14,939	—	2	4.0
Outboard Flap Hinge Fairings	11,625	—	2	4.0
Bent-Up Trailing Edge Articulated Section	1,359	MM 57-20-3	2	3.0
Bent-Up Trailing Edge Ctr Articulated Section	4,004	MM 57-20-3	2	4.0
Bent-Up trailing Edge Ob'd Articulated Section	3,438	MM 57-20-3	2	4.0

*** The manhour estimate assumes that the aircraft has been placed in a maintenance status and does not include preparation or cure times.**

Mismatch of various doors can also accumulate to a sizable increase in fuel costs as shown in table 2. Similarly, non-flush or rough skin repairs can also add to fuel costs as shown in table 3.

Table 2. Approximate Annual Cost of Door Mismatches (U.S. $/Year Per Aircraft)

ITEM ➜ MISMATCH-INCHES** ➜	PENALTY (PER FOOT OF MISMATCH)				MAINT/REPAIR REFERENCE	EST MANHOURS TO CORRECT*	
	1/16"	1/8"	3/16"	1/4"		MEN	HRS
Nose Landing Gear Door	$30	$75	$129	$182	MM 32-22-1	2	5.0
Forward Passenger Door	25	58	99	141	MM 52-11-0	2	2.5
Forward Service Door	22	58	96	138	MM 52-41-0	2	2.5
Nose Radio Compartment Door	22	58	96	138	MM 52-42-0	1	1.0
Airstair Door	22	38	89	134	MM 52-62-0	2	2.0
Upper Cargo Door	17	38	66	96	MM 52-32-0	2	5.0
Main Landing Gear Door	13	36	58	86	MM 32-12-1	2	2.5
Overwing Emergency Exit Door	13	33	55	83	MM 52-21-0	1	2.0
Forward Cargo Door	13	33	55	80	MM 52-31-1	2	2.5
Aft Cargo Door	13	30	53	75	MM 52-31-1	2	2.5
APU Access Door	11	28	50	69	MM 52-44-0	1	2.0

* The man hour estimate assumes that the aircraft has been placed in a maintenance status and does not include preparation or cure times.

* * Door forward or aft edge, recessed or protruding.

Table 3. Approximate Annual Cost of Some Non-Flush Skin Repairs (U.S. $/Year Per Aircraft)

REPAIR ➜ EDGE TREATMENT ➜	BLUNT EDGES	CHAMFERED 8:1 TO .015" THICKNESS	MAINT/REPAIR REFERENCE	EST MANHOURS*	
				MEN	HRS
Patch on Wing Slat Leading Edge * * 10 Inches Spanwise x 4 Inches x 0.070 Inch Thick	$447	$94	SRM 57-09	2	50.0
Patch on Nacelle Inlet Cowl 10-Inch Circumference x 4 Inches x 0.063 Inch Thick	166	55	SRM 54-04	2	2.0
Patch on Fuselage Near the Nose 10 Inches Square x 0.10 Inch Thick	146	13	SRM 53-04	2	10.0
Rough Surfaced Fiberglass Panel Repair 1 Square Foot	—	166	SRM 51-70-1	1	4.0

* The manhour estimate assumes that the aircraft has been placed in a maintenance status and does not include preparation or cure times.

* * Blunt edge patches on wing slat leading edges may affect handling characteristics.

Typical fuel cost penalties due to dents and butt-joint gaps in the aircraft skin are shown in tables 4, 5, and 6. While joint gaps can increase fuel costs, overfilling the gaps is also undesirable, as shown in table 7. Penalties due to missing slat spanwise seals are shown in table 8.

Table 4. Approximate Annual Cost of Individual Dents in the Aircraft Skin (U.S. $/Year Per Aircraft)

DIAMETER — INCHES	DENT DEPTH — INCHES			
	1/8	1/4	1/2	3/4
1	$11	$11	$11	$11
2	37	46	46	46
4	12	149	180	180
6	NIL	119	407	407
8	NIL	49	597	746
10	NIL	30	587	1,085

NOTE: Penalty is for a dent in a Class II area. Multiply by 1.8 for Class I area, and by 0.4 for a Class III area.

Table 5. Approximate Annual Cost of Numerous Distributed Dents in the Wing Slat Leading Edges (U.S. $/Year Per Aircraft)

"SLIGHT" DAMAGE (DENTS = 0.02 INCH DEEP)	$10,350
"MODERATE" DAMAGE (DENTS = 0.04 INCH DEEP)	$22,770

NOTE: "Moderate" damage may adversely affect handling characteristics and anti-icing capability.

"Hail-type" damage, full span.

Table 6. Approximate Annual Cost of Unfilled Butt Joint Gaps in the Aircraft Skin (U.S. $/Year Per Aircraft)

DEPTH — INCHES	PENALTY (PER 10 FEET OF UNFILLED GAP) GAP WIDTH — INCHES		
	1/8	1/4	3/8
.040	$20	73	85
.060	17	57	111
.080	14	38	92
.100	13	34	73

NOTE: Penalty is for flow across a gap in a Class II area. Multiply by 1.8 for a Class I area, and by 0.4 for a Class III area. Multiply by 0.1 for flow parallel to gap.

Table 7. Approximate Annual Cost of Overfilled Skin Gaps (U.S. $/Year Per Aircraft)

SEALANT PROTRUDING 1/32-INCH	
CLASS AREA	PENALTY (PER 10 FEET OF SEALANT)
I	$76
II	32
III	23

NOTE: Penalty is for flow across filled gap. Multiply by 0.1 for flow parallel to filled gap.

Table 8. Approximate Annual Cost of Missing Slat Undersurface-to-Wing Seals (U.S. $/Year Per Aircraft)

PENALTY (PER FOOT OF MISSING SEAL)	
SLATS 1 THROUGH 5	$84

Table 9. Approximate Annual Cost of Excessive Inert Weight (U.S. $/Year Per Aircraft)

AVERAGE MISSION RANGE–NAUTICAL MILES	PENALTY (PER POUND)
200	$4.35
400	6.11
600	7.25
800	8.07

Table 10. Approximate Annual Cost of Leaking Door Seals in a Pressurized Area (U.S. $/Year Per Aircraft).

	PENALTY (PER INCH OF MISSING SEAL)	
	SIDES	TOP OR BOTTOM
PASSENGER DOOR	$311	162
CARGO DOOR	327	172

Excessive inert weight, due to dirt accumulation, carrying extra equipment, etc., also increases fuel expenditures as shown in table 9. Leaking door seals cost fuel as shown in table 10.

Although the examples given are not all-inclusive, it has been shown that the fuel penalties can range from small to substantial. Awareness of these penalties should make it clear that minimum fuel consumption is dependent, in part, upon maintaining the aerodynamic cleanness of the aircraft. However, since fuel penalties for various items do range from small to substantial, the cost effectivemenss of correcting (or maintaining) the various items should be reviewed in the context of each operator's requirements.

Finally, this entire section addresses excessive fuel expenditures due to degraded aerodynamic cleanness, involving one or more of the examples, that average less than one-half percent for the DC-9 fleet. It is therefore important to note that simply flying 2,000 feet below the optimum cruise altitude, or flying 0.01 mach number fast, will typically increase fuel expenditures in excess of one-half percent.

Flying off-optimum altitude or mach number can result in excessive fuel expenditures that are greater than those due to degraded aerodynamic cleanness.

It is therefore obvious that a coordinated program, involving all of the items discussed in this document, is necessary to be truly effective in minimizing fuel usage and expenditures.

FLIGHT OPERATIONS

The purpose of this Flight Operations section is to define the optimum flight profile in terms of fuel used and to present the penalties encountered when deviations are made from the optimum conditions. The information contained in this section is basic to the conduct of a trade-off study to arrive at a minimum cost operation, or to enable management to quantify fuel cost if a different operating formula should be adopted. This section, therefore, is written not as an operating manual, but as a guide for management to establish operating procedures.

Out on the line, air traffic control, weather, or other operational considerations may force a deviation from optimum performance. Knowledge of the "less than optimum" effects on fuel consumption will provide the flight crew with means to select the next most fuel-economic set of conditions. Fuel savings during ground operation can also be realized by procedural efficiencies.

A yearly cost penalty per airplane has been derived from a statistical average of all DC-9s currently in service, resulting in the following assumptions:

Total Trip Distance	**300 NM**	**800 NM**
Average utilization	2,500 hrs/yr	2,500 hrs/yr
Average flights per year	3000	1200
Average flight time/trip	0.83 hr	2.08 hrs
Average cruise time/trip	0.1 hr	1.18 hrs
Fuel price and density	$0.50/gal (U. S.) — 6.7 lbs/gal	

Specific subjects are presented in order by phase of flight. The principles of operation derived from these data will generally apply to all DC-9 models currently in service.

GENERAL CONSIDERATIONS

EXCESS WEIGHT

Substantial fuel savings are realized through careful planning by minimizing tankering reserve fuel or reducing basic aircraft weight. A flight dispatched with 5,000 pounds of surplus fuel (or excess weight) flying at FL350, long range cruise, will consume 4.2% (210 pounds) of the surplus fuel for a 300 NM flight or 9.2% (462 pounds) of the surplus fuel for an 800 NM flight. (See figure 1.)

5,000 pounds of excess weight equates to:
300 NM flight - **$15.67/flight or $47,010/year/aircraft**
800 NM flight - **$34.50/flight or $41,400/year/aircraft**

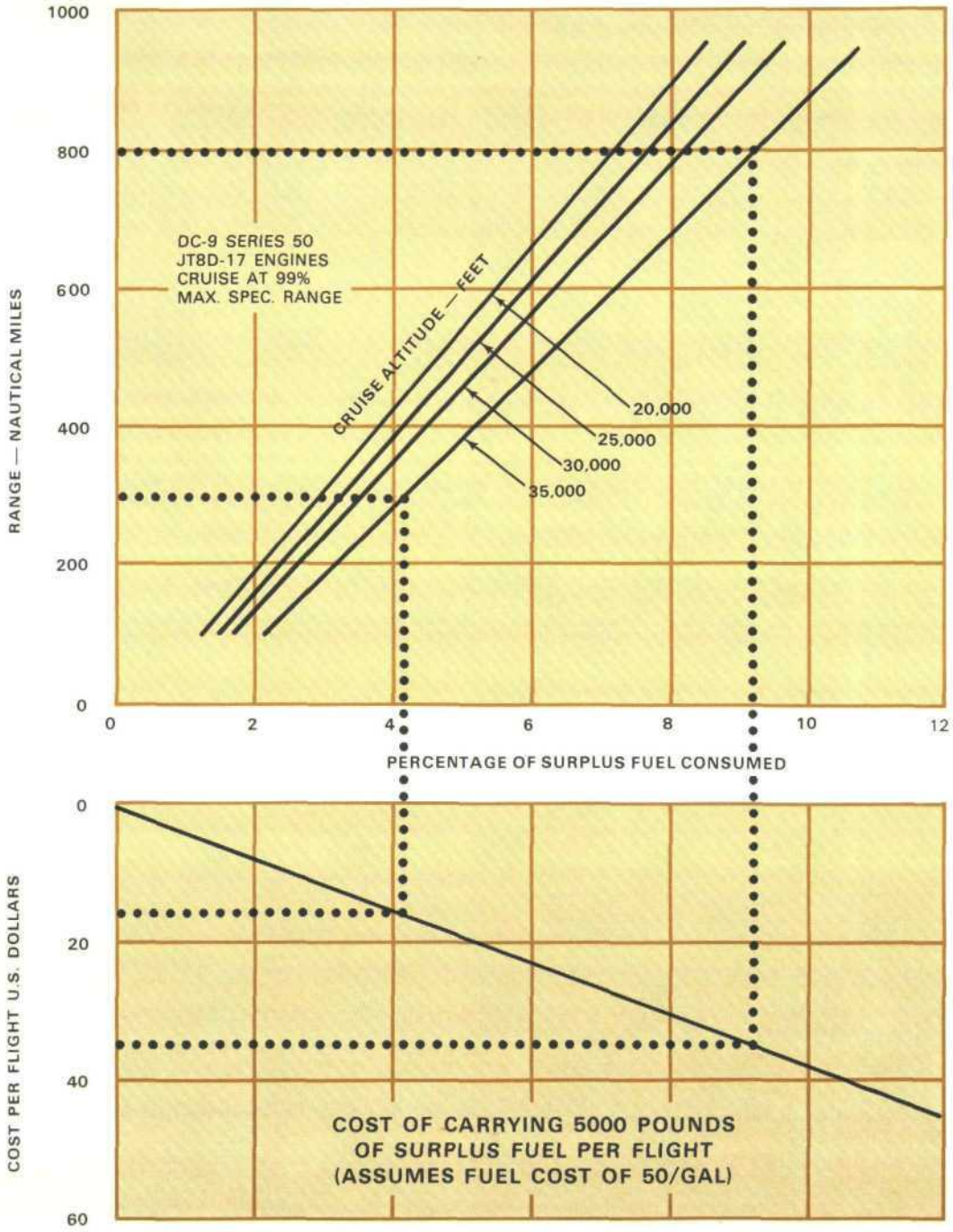


Figure 1. Cost of Carrying Surplus Fuel

CENTER OF GRAVITY

In cruise, the normal CG movement has minimal effect on fuel flow. However, the effect between the forward and aft limits can be as much as 5.6% for the 300 NM mission and 7.3% for the 800 NM mission. Figure 2 illustrates the incremental change in fuel flow, fuel used, and fuel costs as a function of CG for a typical DC-9 Series 50. This curve shows that it is beneficial to load the airplane toward the aft limit, which is true of all series DC-9 aircraft. At an aft CG, the amount of aerodynamic force required on the horizontal stabilizer to maintain proper longitudinal trim is reduced. Consequently, the required lift provided by the wing is reduced and the airplane flies at a lower angle of attack. Accordingly, the stabilizer setting will be near zero and drag at a minimum:

Aircraft loaded at full forward vs full aft CG limits results in following increase in fuel cost:

300 NM flight - $21.17/flight or $63,510/year/aircraft

800 NM flight - $64.83/flight or $77,796/year/aircraft

It is important to keep the CG as close to the aft CG limit as possible. Allowing the CG to travel forward increases fuel costs as shown below.

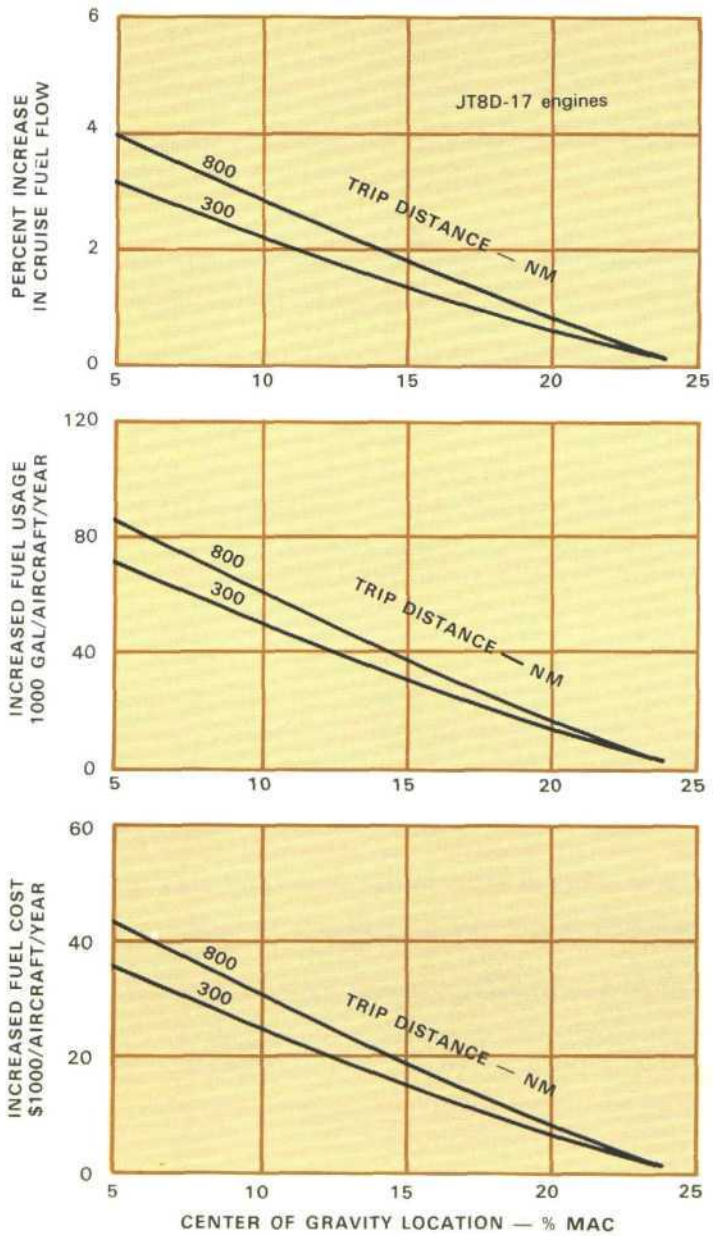


Figure 2. Approximate Penalties Associated with Trim Drag Variation Due to Center of Gravity Location.

AERODYNAMIC CLEANNESS

A preflight of the airplane should obviously include close scrutiny to confirm that all of the access panels, blow-out doors, service panel doors, slat seals, etc. are in place and correctly faired. (For specific cruise performance penalties due to the increased drag caused by these items, refer to the section on Aerodynamics.)

FLIGHT PLANNING

Modern airborne/ground navigation systems allow greater flexibility in route selection during preflight planning and while en route. When it is feasible to do so, an effort to shorten the route distance may result in minutes saved and dollars earned. The value of a minute is surprisingly high.

One (1) minute of cruise flight time saved per flight saves:

300 NM - $7.23/flight or 43,380 gal/year or $21,690/year/aircraft

800 NM - $7.40/flight or 17,754 gal/year or $8,877/year/aircraft

USE OF AUTOMATIC FLIGHT CONTROL SYSTEMS

The professional pilot sincerely believes he is able to coax a little more performance from the airplane than the autopilot can. This may be true over the short term (short first sector) but human fatigue usually degrades perfor-

mance more than automatic pilot tolerances over the long haul. For example, during a 20-minute climb to cruise altitude, the autopilot can maintain the desired airspeed within ± 5 knots or ± 0.015 Mach. While crew attention is temporarily diverted by ATC, departure procedures, or other cockpit duties, the automatic systems are continuously at work monitoring and correcting for changing conditions. Although deviations of ± 10 knots during climb will not result in significant fuel consumed increments, the goal of consistent optimum performance argues for maximum use of the automatic flight control system in the DC-9. Specific penalties will be discussed, where appropriate, by phase of flight.

GROUND OPERATION

APU OPERATION

The APU consumes 270-300 pounds per hour during ground operation. For flight crew consideration, the following provides the dual benefits of fuel savings and longer APU life: delaying start of the APU prior to departure when the airplane is powered by a ground power unit; and shutting the APU down as soon as possible after engine start when no longer needed.

Each extra minute of APU operation each flight at 300 pounds per hour F/F costs:

3,000 flights - 2,238 gal/year or $1,119/year

1,200 flights - 895 gal/year or $448/year

ENGINE START

The clearance to start engines is generally governed by traffic conditions. However, crew awareness of potential fuel savings may minimize early start times and long engine idle times through close communication with ATC and consideration of existing traffic conditions. A typical fuel flow for the Series 50 DC-9 during ground idle for two engines is 46 pounds per minute.

Each extra minute of running two engines at ground idle each flight costs:

3,000 flights - 20,597 gal/year or $10,299 /year

1,200 flights - 8,239 gal/year or $4,120 /year

TAKEOFF

GENERAL

During takeoff, the aircraft should be "cleaned up" as soon as possible consistent with other operational factors. The drag reduction by the early retraction of flaps, slats, and the landing gear will increase fuel economy.

DERATED TAKEOFF

Even though use of derated thrust results in small fuel penalties, long term benefits may be realized by the increase in engine life and the resulting lower rate at which specific fuel consumption deteriorates.

CLIMB

CLIMB SPEED COMPARISON

Fuel consumption for various climb profiles is shown in figures 3, 4, and 5 for various climb weights and ambient temperature conditions. Fuel consumption values include the fuel to climb, accelerate (or decelerate) to a cruise speed representing long range cruise, and then cruise to a common distance (300 NM).

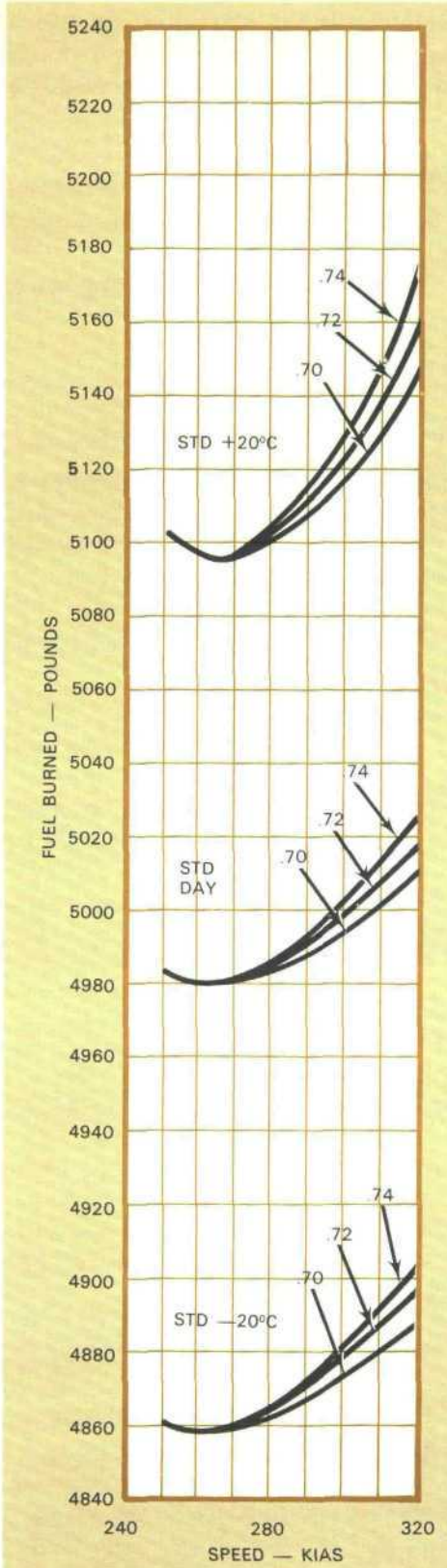
For purposes of direct comparison, Mach 0.76 was chosen for the cruise portion of the 300 NM segment. Thus, the climb speed schedule for minimum fuel burned can be found at the lowest point of the Mach number curve. For example, the climb speed schedule for a T.O.G.W. of 120,000 pounds (figure 5) should be 300 KIAS and Mach 0.72 to 31,000 feet and then accelerating to Mach 0.76, resulting in a total fuel burned of 6,515 pounds over the 300 NM distance. If a 290/0.74 schedule were used, the total fuel burned would be 6,520 pounds.

The data presented in figures 3, 4, and 5 are integrated into figure 6, Minimum Fuel Climb Speed Versus Weight. For DC-9 Series 50 powered by JT8D-17 engines, the speed profile is essentially independent of temperature. The long range speed schedule 250/290/0.72 is optimum for 110,000 pounds T.O.G.W: for lower weights, a lower speed should be used for higher weights, a higher speed should be used.

Table 1. Climb Schedules

LONG RANGE	HIGH SPEED
250/290/0.72	250/320/0.74

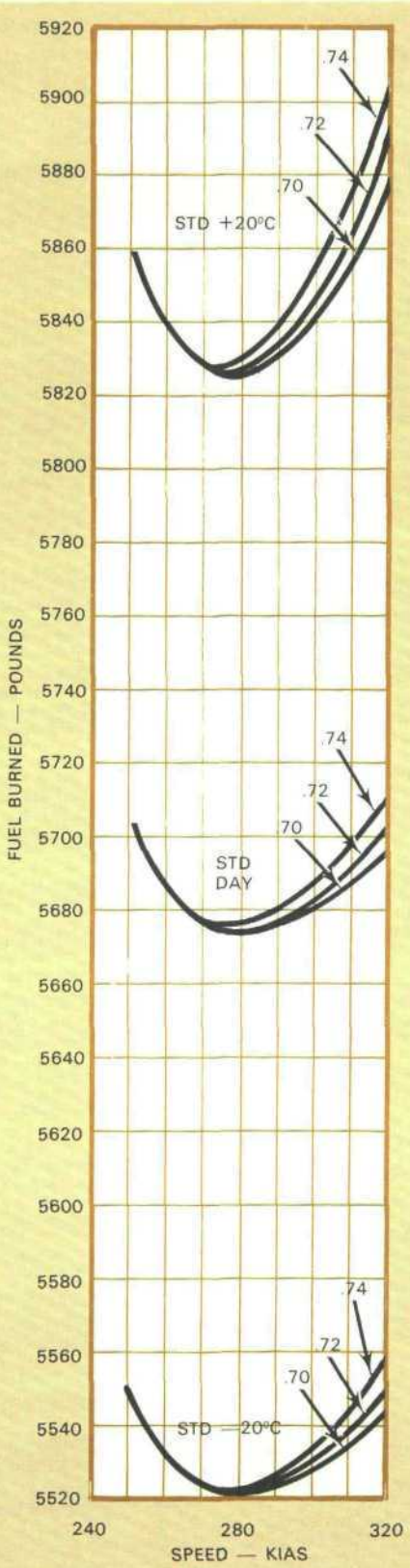
Table 2 shows the potential fuel savings associated with operating at the minimum fuel climb schedule versus the long range or high speed climb schedules.



NOTE:
CLIMB TO 31,000 FEET
ACCELERATE TO 0.76 M
THEN CRUISE TO 300 NAUTICAL MILES

LONG RANGE SCHEDULE
290 KIAS/0.72 M

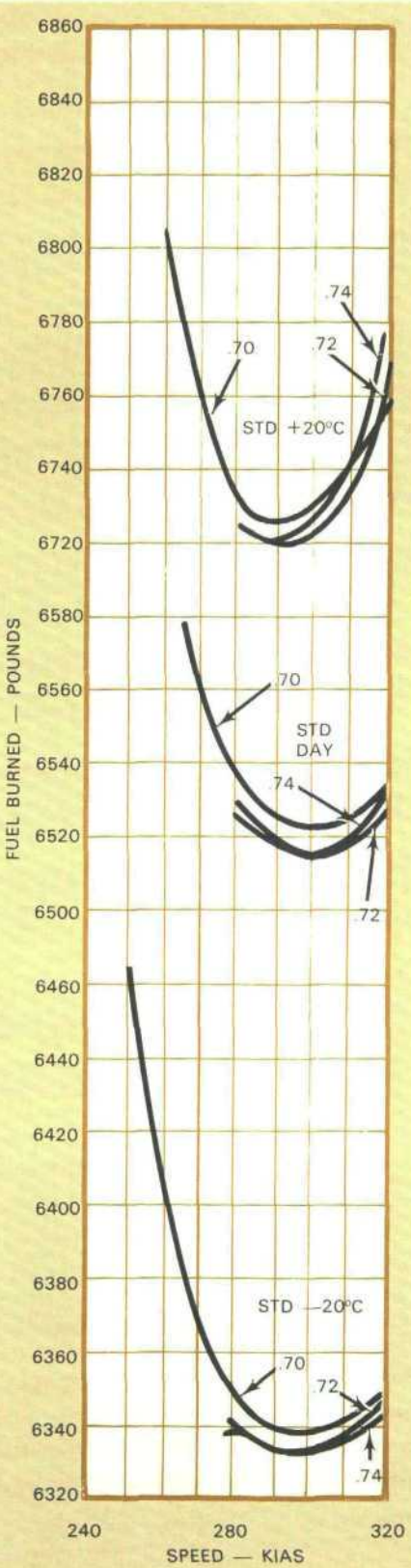
Figure 3. Climb Fuel Study — Fuel Burned Versus Speed (80,000 Pounds T.O.G.W.)



NOTE:
CLIMB TO 31,000 FEET
ACCELERATE TO 0.76 M
THEN CRUISE TO 300 NAUTICAL MILES

LONG RANGE SCHEDULE
290 KIAS/0.72 M

Figure 4. Climb Fuel Study — Fuel Burned Versus Speed (100,000 Pounds T.O.G.W.)



NOTE:
CLIMB TO 31,000 FEET
ACCELERATE TO 0.76 M
THEN CRUISE TO 300 NAUTICAL MILES

LONG RANGE SCHEDULE
290 KIAS/0.72 M

Figure 5. Climb Fuel Study — Fuel Burned Versus Speed (120,000 Pounds T.O.G.W.)

Table 2. Yearly Increase Fuel Cost for Long Range or High Speed Climb Schedule Versus Minimum Fuel Climb Schedule

GROSS WT (1000 LB)	STD — 20°C				STD DAY				STD + 20°C			
	FUEL (GAL)		COST ($)		FUEL (GAL)		COST ($)		FUEL (GAL)		COST ($)	
	LR	HS	LR	HS	LR	HS	LR	HS	LR	HS	LR	HS
300 NM — 3000 FLTS												
80	4,925	28,208	2,463	14,104	4,478	21,045	2,239	10,522	6,940	35,821	3,470	17,910
100	1,343	16,119	672	8,060	895	16,791	448	8,395	3,582	35,821	1,791	17,910
120	895	6,716	448	3,358	1,791	8,060	896	4,030	0	25,298	0	12,649
800 NM — 1200 FLTS												
80	1,970	11,283	985	5,642	1,791	8,418	896	4,210	2,776	14,328	1,388	7,164
100	537	6,448	269	3,224	358	6,716	179	3,358	1,433	14,328	716	7,164
120	358	2,687	179	1,343	716	3,224	358	1,612	0	10,119	0	5,060

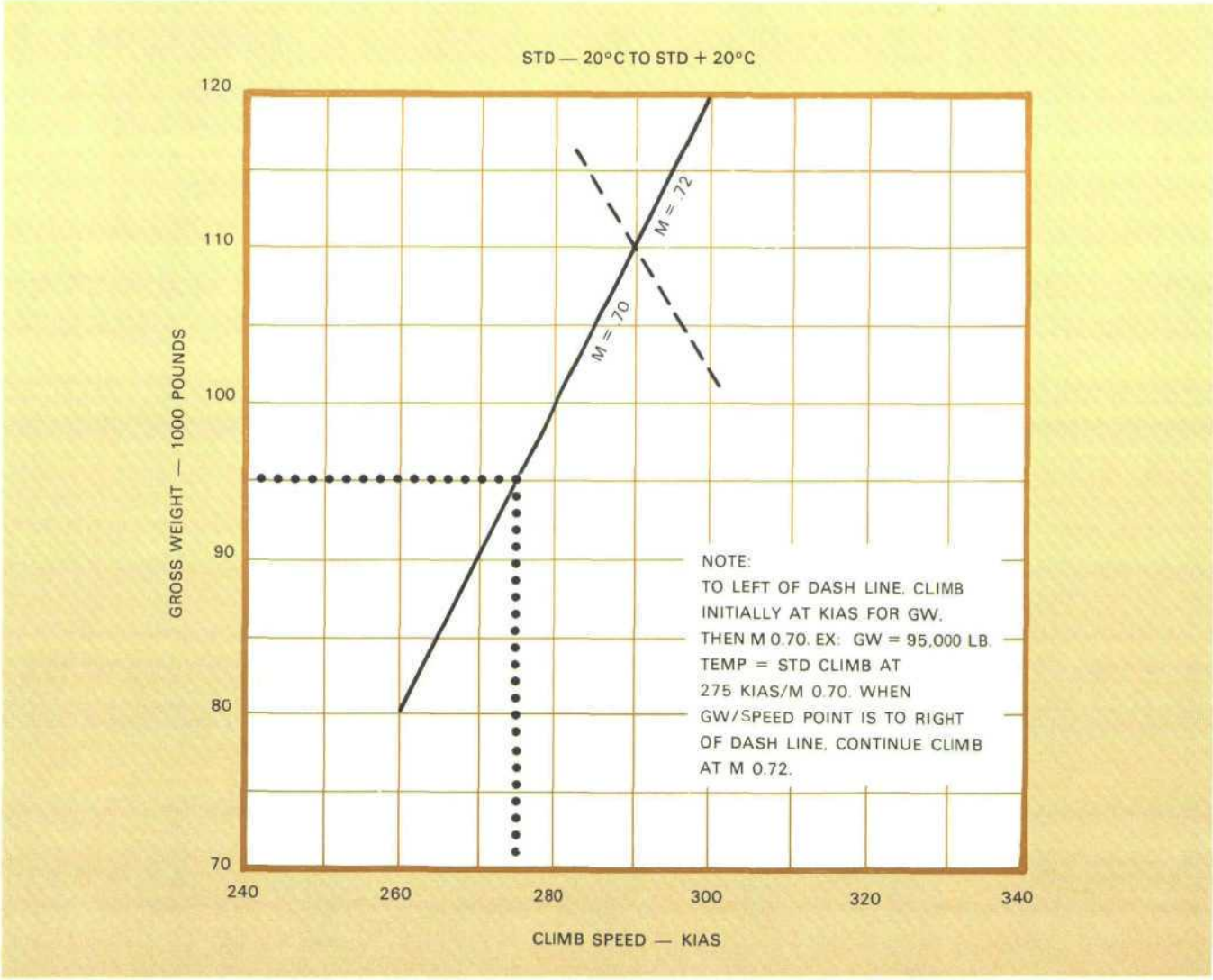


Figure 6. Minimum Fuel Climb Speed Versus Weight

EN ROUTE

The factors that influence fuel consumption during the en route portion of flight are discussed in this section. Although the actual percentage of fuel saved on a given flight may seem small, the total dollar value savings over a year can be substantial. Operational procedures that are based on fuel economy plus consistent adherence to them are the key elements in fuel conservation during cruise. The DC-9 aircraft can be flown in a wide range of operating conditions. For best fuel economy, however, en route Mach number and en route profiles must be optimized.

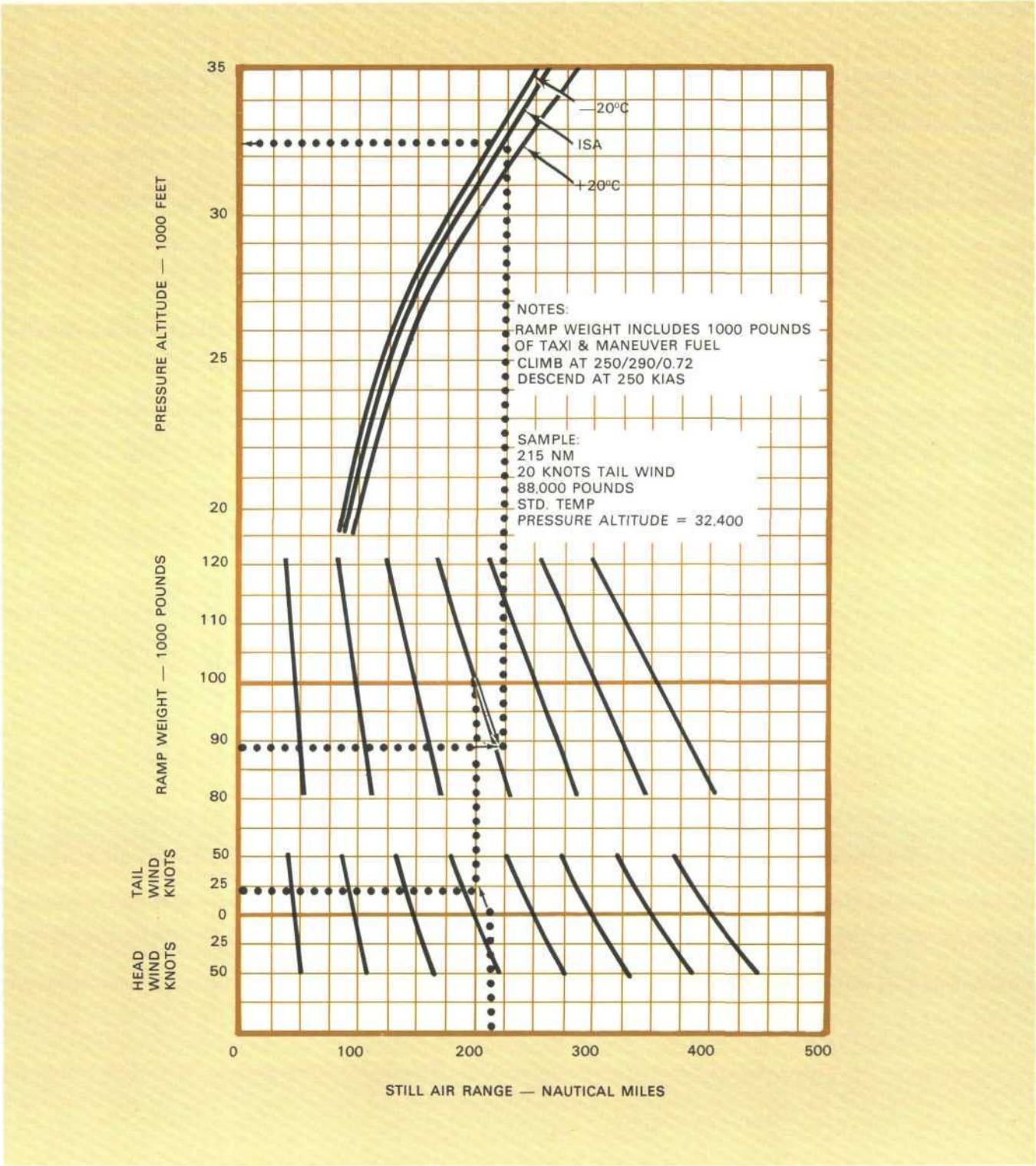
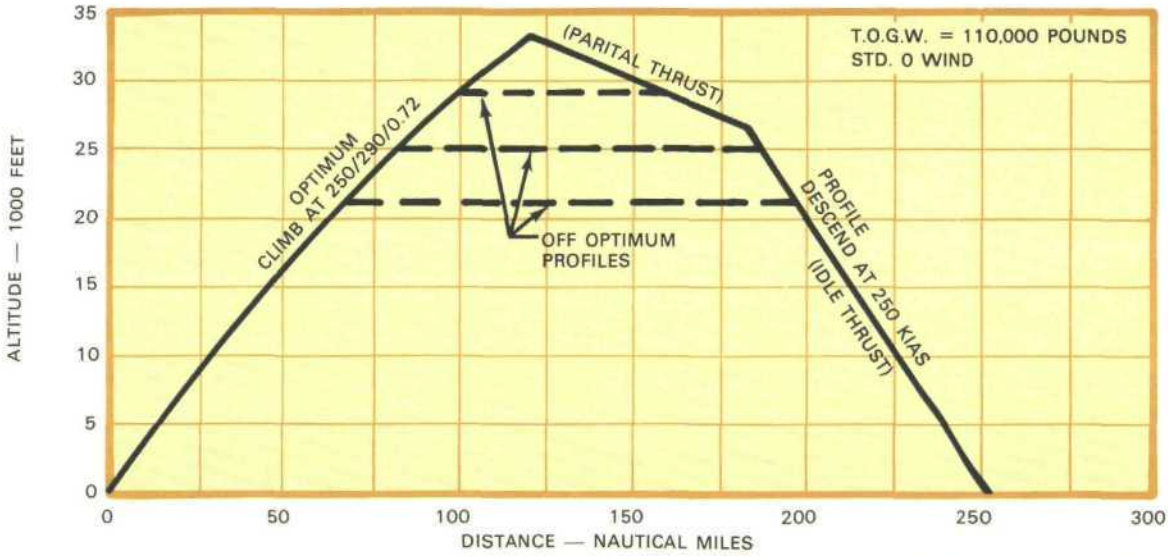


Figure 7. Highest Altitude Attained Versus Trip Distance For Minimum Trip Fuel

EN ROUTE PROFILE

The optimum en route profile for fuel conservation is to fly as high as possible. Except for maximum gross weight and hot day conditions, the DC-9 is capable of climbing directly to the maximum cruise altitude of 35,000 feet. The maximum cruise altitude, however, is also predicated on trip distance so that the optimum en route profile will be a climb to the highest altitude consistent with the trip distance followed by an immediate descent. For example (see figure 7), at a T.O.G.W. of 110,000 pounds and a trip distance of 210 NM with an average tail wind component of 25 knots, ISA plus 10 conditions, the airplane should be climbed to 29,000 feet and then descended on the optimum descent schedule (presented later in this section). Although operationally difficult to fly, such a profile would result in maximum fuel economy. The penalties for climbing to less than the peak altitude or maximum cruise altitude are presented in figure 8. The difference in trip time for the optimum profile versus flying at LRC at a lower altitude is less than a minute.



RANGE	4000 FEET BELOW OPTIMUM ALTITUDE			8000 FEET BELOW OPTIMUM ALTITUDE			12000 FEET BELOW OPTIMUM ALTITUDE		
	1 FLIGHT	3,000 FLIGHTS		1 FLIGHT	3,000 FLIGHTS		1 FLIGHT	3,000 FLIGHTS	
	ΔFUEL	ΔFUEL	Δ$	ΔFUEL	ΔFUEL	Δ$	ΔFUEL	ΔFUEL	Δ$
100 NM	24 LB	10,746 GAL	$5,373	77 LB	34,478 GAL	$17,239	170 LB	76,119 GAL	$38,060
200 NM	37 LB	16,567 GAL	$8,284	93 LB	41,642 GAL	$ 20,821	191 LB	85,522 GAL	$42,761

Figure 8. Penalties for Climbing to Less Than Peak or Maximum Cruise Altitude. (Trip Length Less Than 300 NM)

Table 3. Penalties for Cruising at Lower than Optimum Altitudes

800 NM TRIP				
ALTITUDE FT	LB/NM	% CHANGE LB/NM	CRUISE FUEL $ COST/ACFT/YR	INCREASED $ COST/ACFT/YR
OPT = 35,000	13.57	0	602,687	0
OPT − 4,000	14.07	3.7	624,725	22,038
OPT − 8,000	14.90	9.8	661,970	59,283
OPT −12,000	16.05	18.3	712,970	110,283

Based on 496 NM cruise distance at LRC at average GW of 104,200 lbs (landing weight 99,500 lbs) for 1200 flights.

300 NM TRIP				
ALTITUDE FT	LB/NM	% CHANGE LB/NM	CRUISE FUEL $ COST/ACFT/YR	INCREASED $ COST/ACFT/YR
OPT = 35,000	13.18	0	56,037	0
OPT − 4,000	13.77	4.5	58,590	2,553
OPT − 8,000	14.62	11.0	62,104	6,067
OPT −12,000	15.75	19.5	66,985	10,948

Based on 19 NM cruise distance at LRC at average GW of 100,900 lbs (landing weight 99,500 lbs) for 3000 flights.

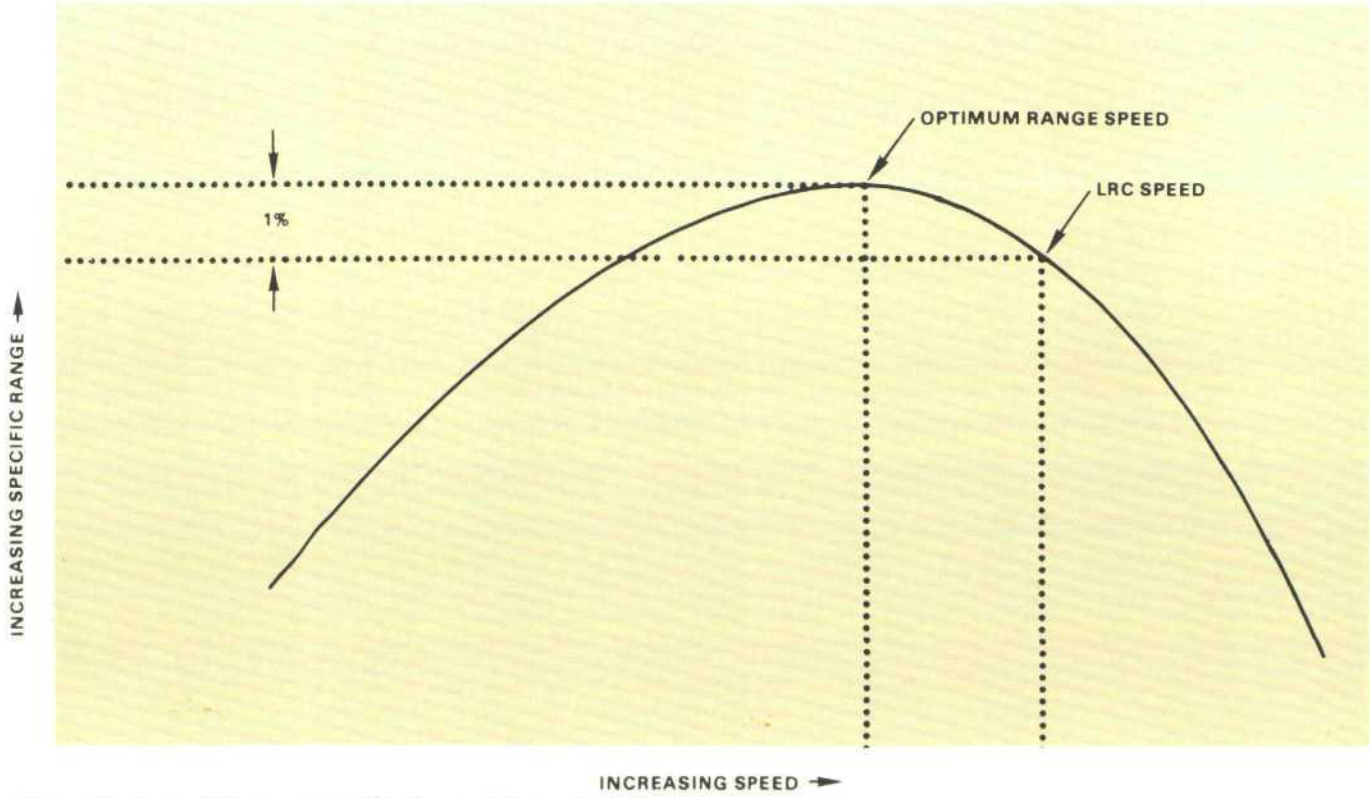


Figure 9. Speed Versus Specific Range Characteristics

PENALTIES FOR CRUISING LOWER THAN OPTIMUM ALTITUDE

For trip lengths greater than 300 NM, the optimum cruise altitude will normally be 35,000 feet. Table 3 presents comparative data with fuel and dollar penalties for cruising lower than the optimum altitude.

PENALTIES FOR NOT USING OPTIMUM SPEED

The optimum cruise speed for maximum range is at the peak of a typical speed versus specific range plot as shown in figure 9.

Operating on the peak of this curve, however, is not practical because constant thrust adjustments are necessary due to reduced speed stability at the peak of the curve. If atmospheric disturbances should occur at this speed, the airplane would be difficult to keep in equilibrium. Therefore, to achieve an optimum balance between fuel mileage and speed/thrust ability, a speed slightly greater than the optimum range speed called long range cruise has been adopted by the industry. Long range cruise speeds are typically 8 to 15 knots faster on the DC-9-50 than the theoretical maximum specific range which results in about one percent decrease in the fuel mileage.

The theoretical optimum specific range speed point on the DC-9 is aproximately 0.75 Mach and the LRC speed is about 0.76 Mach.

The penalty for flying faster than the theoretical optimum is shown in figure 10. The penalties for a DC-9 at 100,000 pounds gross weight, cruising at optimum altitude and standard day conditions are shown in table 4.

Table 4. DC-9 — 100,000 Pounds: Comparison of Theoretical Optimum Cruise with Higher Cruise Mach Numbers.

MACH NO.	LB/NM	% CHANGE	CRUISE FUEL $ COST/ACFT/YR*		INCREASED $ COST/ACFT/YR	
			300 NM	800 NM	300 NM	800 NM
0.75	12.90	0	54,873	572,991	0	0
0.77	13.16	2.0	55,979	584,539	1,106	11,548
0.79	14.28	10.7	60,743	634,287	5,870	61,296
0.80	15.38	19.2	65,422	683,147	10,549	110,156

* Based on cruise distance of 57,000 NM for a 300 NM trip distance and 595,200 NM for a 800 NM trip distance per year. This distance is the result of cruising 130 hours for 300 NM and 1360 hours for 800 NM flights at 438 TAS (0.76M), the practical long range cruise speed.

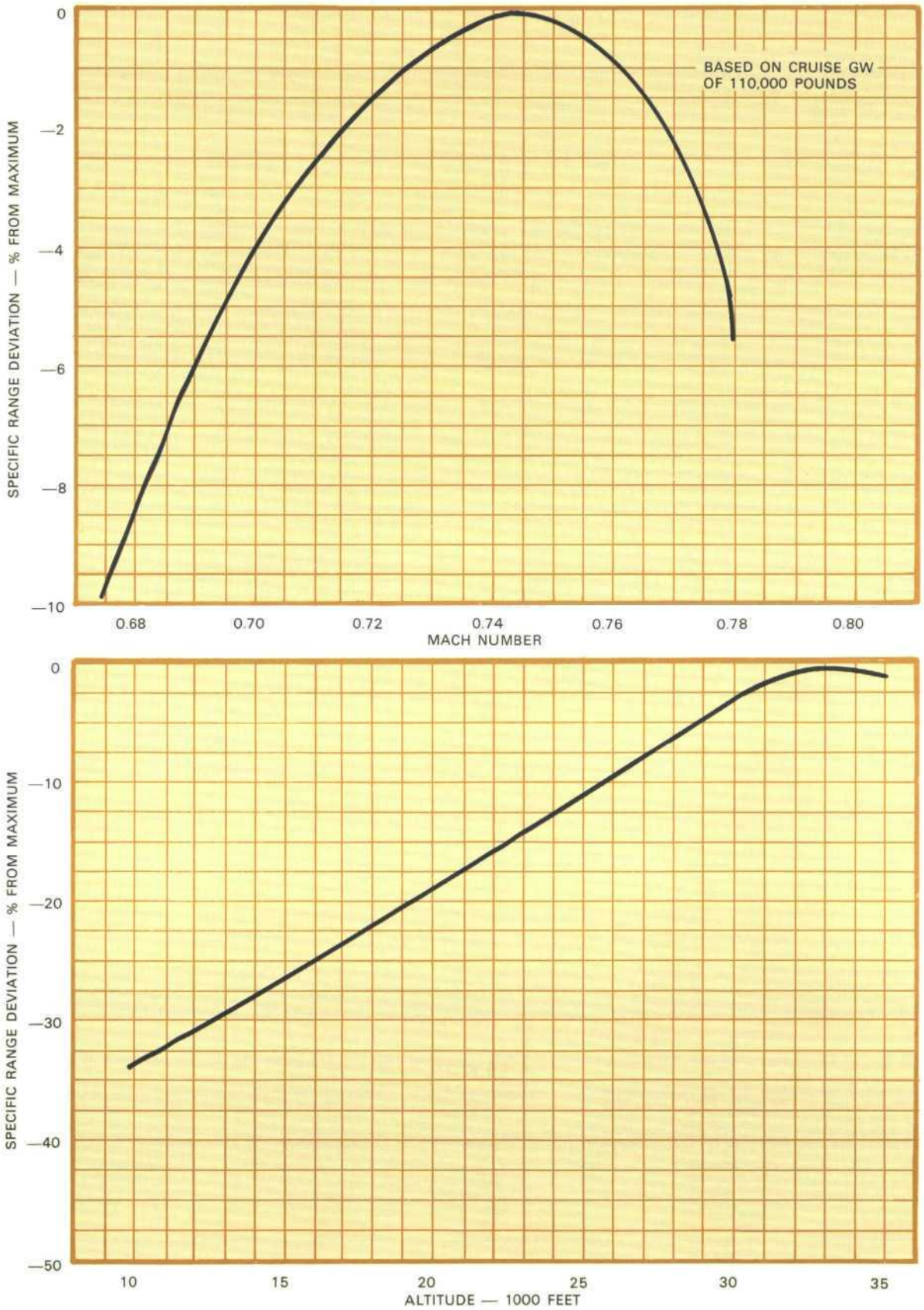


Figure 10. Effect of Speed and Cruise Altitude on Range Characteristics

CRUISE ALTITUDE COMPENSATION FOR HEADWINDS AND TAILWINDS

When operationally possible, the cruise altitude should be modified to achieve fuel savings as a function of wind component. Table 5 illustrates the decrease in headwind required to compensate for decreasing cruise altitude below the optimum. A DC-9 weighing 90,000 pounds cruising at 0.76 Mach at 35,000 feet is used as an example.

Table 5. Wind Altitude Trade

ALTITUDE BELOW OPTIMUM	WIND INCREMENT REQUIRED
1,000	3 knots
2,000	7 knots
4,000	20 knots
8,000	47 knots

For instance, flying the aircraft 4,000 feet below the optimum altitude requires a 20-knot increase in tailwind (or a decrease in headwind) to provide the same performance. A wind advantage greater than 20 knots would provide fuel savings at this lower altitude.

These fuel savings become measurable when the wind advantage is 20 knots or greater. A 20-knot wind advantage under the cruise conditions stated over a one hour cruise distance will equate to $21 savings in fuel.

Attempting to fly too high above the optimum cruise altitude in order to take advantage of winds is not practical because the airplane will be exceeding aircraft pressurization limits. Figures 11 and 12 give the wind/altitude trade for the DC-9 at Mach number 0.78 and also at Long Range Cruise.

THRUST SETTING TECHNIQUE

Improper level off and thrust setting in cruise will result in excessive fuel consumption. As the cruise altitude is attained, it is important that the aircraft speed not be permitted to drop below the target cruise speed. Regaining the target speed requires considerable thrust increase to overcome the drag resulting from the higher angle of attack at the lower speed and thus higher fuel flow.

As a general rule, accelerate to the cruise speed while maintaining climb thrust, then set the EPR values obtained from the cruise thrust tables when at or above the cruise speed. The speed should be allowed to stabilize (but not drop below target cruise speed) and incremental thrust adjustments made to arrive at the final thrust setting for the desired cruise speed. Assuming stable air conditions, subsequent thrust adjustments will be required approximately every 20 minutes to maintain the target speed.

The situation to avoid is a slow cyclic decrease, then increase (or increase then decrease) of speed which occurs when the initial and subsequent thrust settings are incorrect. Speed excursions that fall below optimum result in rapidly increasing drag and a requirement for a large thrust increase to correct. Speed excursions that drift above optimum will result in increased fuel consumption as previously discussed under penalties for not cruising at optimum speed.

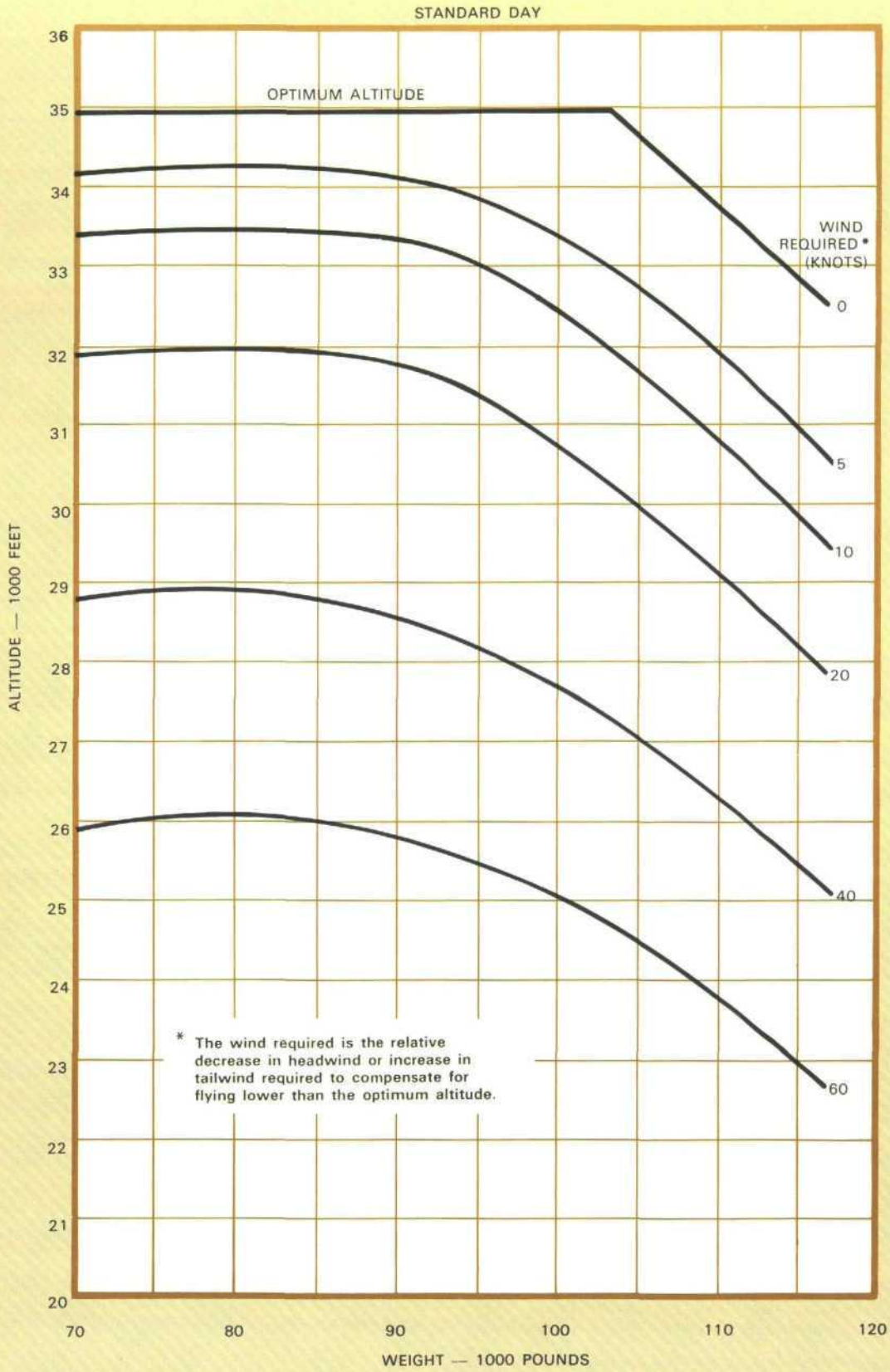
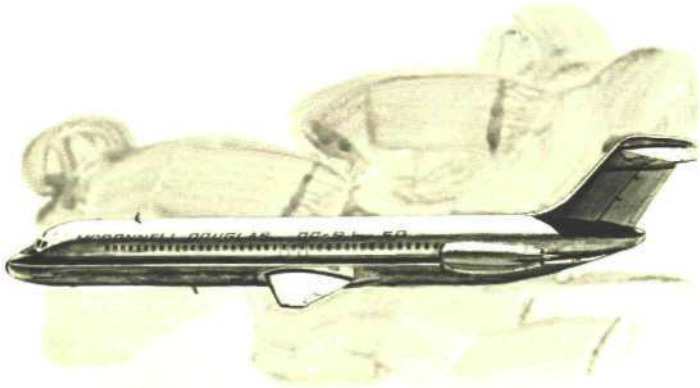


Figure 12. Wind and Altitude Trade for Constant Range at Long Range Cruise (99% Maximum NM Per Pound)



MISTRIM

Estimates run as high as $2,200 per year in wasted fuel for less than a half degree of aileron mistrim alone. The cost of one degree rudder mistrim is $10,-200 per year. A mistrimmed rudder can cause a mistrimmed aileron and vice versa compounding the problem.

The following technique should be used for trimming the aircraft in cruise: ensure that thrust is set symmetrically with the autopilot in altitude hold and the speed stabilized; and disconnect the autopilot and observe aircraft response. If the aircraft should slowly ascend or descend, trim the stabilizer to correct the mistrim. Next, fly the aircraft manually wings level and observe the position of the sideslip indicator (ball). Center the "ball" if it should be displaced, with the rudder trim while continuing to hold the aircraft wings level. After this is accomplished, trim the ailerons hands off as required to maintain a wings level attitude (zero bank angle). Check the correctness of the trim by observing that bank angle or heading changes do not occur. Repeat the procedure to refine the trim point if necessary. The effects of mistrim and misrigged surfaces are presented in table 6.

Table 6. Effects of Mistrimmed Surfaces

SURFACE	INCREASE IN FUEL FLOW	INCREASED FUEL USED GAL/DEG/ACFT/YR	INCREASED FUEL COST $/DEG/ACFT/YR
AILERONS			
Mistrimmed (Aircraft balanced by lateral input)	0.37%/degree (up to δa = 0.6 degree)	8,800	4,400
	0.90%/degree (over δa = 0.6 degree)	21,400	10,700
RUDDER			
Mistrimmed (Heading maintained with lateral trim)	.86%/degree	20,400	10,200
Mistrimmed (Heading maintained by manual or autopilot lateral input)	1.85%/degree	44,000	22,000

EFFECT OF INSTRUMENT ERRORS

A Mach meter that reads 0.01 low operating in the 0.76 Mach range can lead to 1.0 percent excess fuel consumption. For example; for a DC-9 weighing 101,000 pounds at 35,000 feet cruising at 0.76 Mach, this would amount to 2.54 pounds or $0.19 per flight. The annual penalty would be $570 when based on a 300 NM trip distance. Table 7 reflects the costs involved for other instrument errors and trip distances.

HOLDING

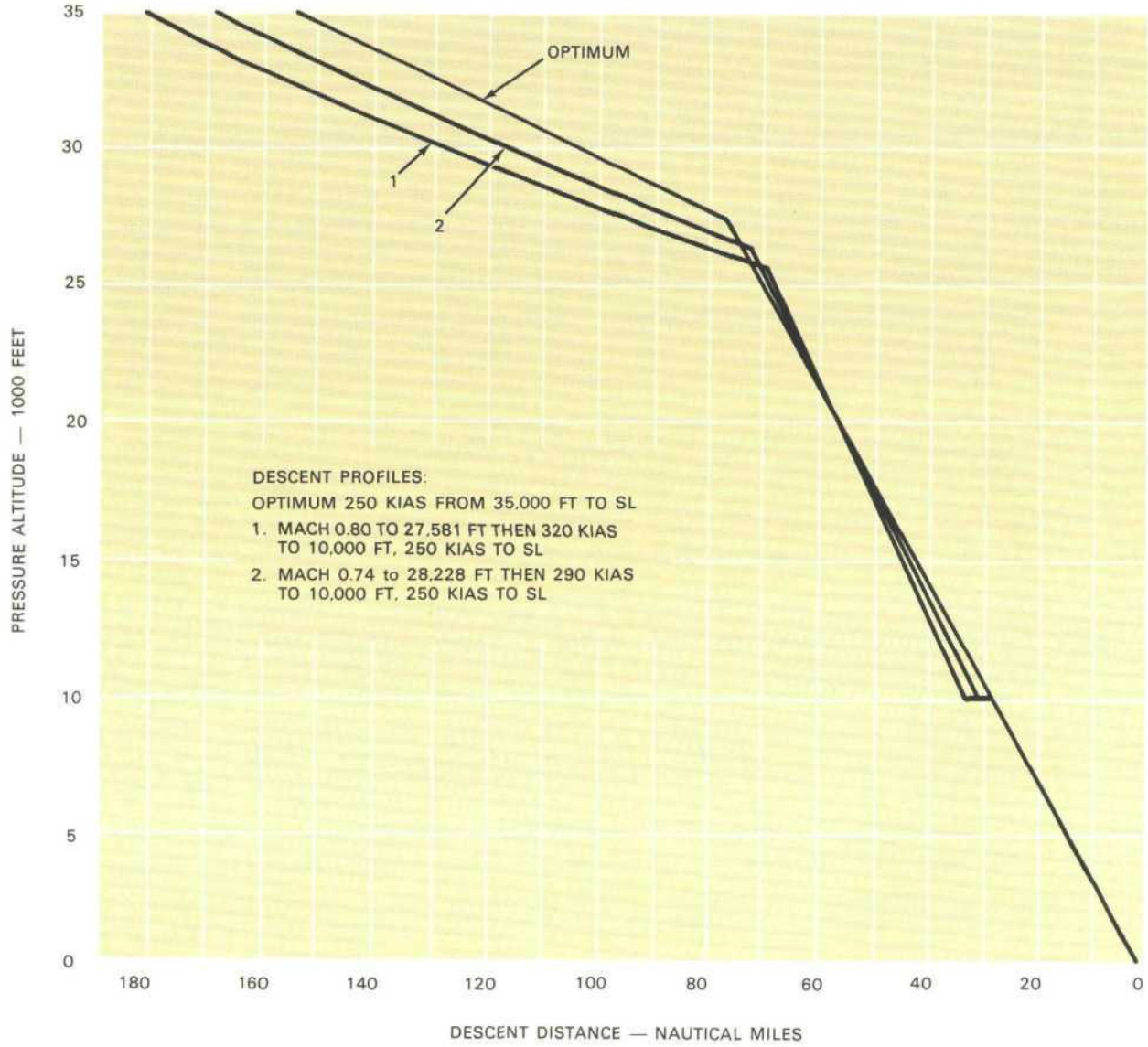
Holding maneuvers should be conducted at the highest possible altitude in the clean configuration with 1.5V_S minimum speed for reduced fuel consumption. This configuration provides approximately a 11 percent decrease in fuel consumption as compared to the slats extended configuration. This is equivalent to a 430- to 520-pound fuel savings per hour. Table 8 shows a comparison of holding fuel flows at various aircraft configurations.

Table 7. Effect of Instrument Errors

INSTRUMENT	ERROR	EXCESS FUEL		$ COST		$ COST/AC/YR	
		300 N MI	800 N MI	300 N MI	800 N MI	300 N MI	800 N MI
MACH METER	READS 0.01 LOW	2.50	87.78	0.19	6.55	570	7860
ALTIMETER	100 FT HIGH	0.20	6.0	0.018	0.449	54	539

Table 8. Comparison of Holding Fuel Flows

		INCREASE IN FUEL FLOW FROM CLEAN HOLDING CONFIGURATION (LB/HR)	
GROSS WEIGHT — LB	PRESSURE ALTITUDE — FT	GEAR EXTENDED	SLATS EXTENDED (GEAR UP)
90,000	5,000	2,111	1,038
	10,000	2,064	988
	15,000	2,120	1,030
	20,000	2,106	1,043
100,000	5,000	2,242	850
	10,000	2,358	940
	15,000	2,337	922
	20,000	2,388	971
110,000	5,000	3,417	1,407
	10,000	3,280	1,285
	15,000	3,246	1,286
	20,000	3,405	1,247



DESCENT PROFILE	DESCENT			ACCEL/DECL			CRUISE			TOTALS		COMMENTS
	TIME (MIN)	FUEL (LB)	DIST. (NM)	TIME (MIN)	FUEL (LB)	DIST. (NM)	TIME (MIN)	FUEL (LB)	DIST. (NM)	TIME (MIN)	FUEL (LB)	
1	26.65	1,952	180	2.10	83	14	26.08	1,499	106	54.83	3,534	0.80/320/250
2	26.65	1,552	168	.57	20	3	29.52	1,670	129	56.74	3,242	0.74/290/250
OPTIMUM	26.65	1,287	154	.22	8	15	31.79	1,857	131	58.66	3,152	250

Base Distance = 300 nautical miles
Standard day, zero wind
100,000 pounds
Descent from 35,000 feet

Figure 13. Descent Profile Fuel Comparison

DESCENT

PROFILE COMPARISON

The most important factor in the reduction of descent fuel is the use of idle thrust at a fixed speed. In comparison, the use of power to maintain a fixed descent rate at a fixed speed is much more costly in fuel consumption. The Descent Profile Fuel Comparison (figure 13) gives the speed schedules and distances for several descent profiles commonly used and compares them with the optimum profile for minimum fuel. The optimum descent for the DC-9 is constrained somewhat by cabin pressurization to maintain an average 300 feet per minute cabin rate of descent. Therefore, when descending from cruise altitudes above 26,000 feet, partial power is used to maintain 250 KIAS and an average 700 feet per minute descent down to 25,500 feet at which time descent is continued with idle thrust at 250 KIAS. This descent profile defines the optimum descent schedule and is the same as the LRC descent schedule contained in the DC-9 Flight Planning and Cruise Control Manual. Over a given base distance (example 300 NM), this descent consumes about 11 percent less fuel than the High Speed Descent.

DESCENT SPEED COMPARISON

Fuel burned during descent is shown in figure 14 over a fixed baseline distance as a function of descent speed/Mach number. These curves converge and show that minimum fuel consumption occurs at 250 KIAS. Descent at this optimum speed saves an average of 382 pounds of fuel over a high speed descent speed profile of 0.80/320/250.

The effect of speed increase on extra fuel burned is shown in figure 15.

A savings of about $85,523 per year per aircraft for 300 NM flights or $34,209 per year per aircraft for 800 NM flights can be realized when using descent at 250 KIAS in lieu of 0.80/320/250 descent profile.

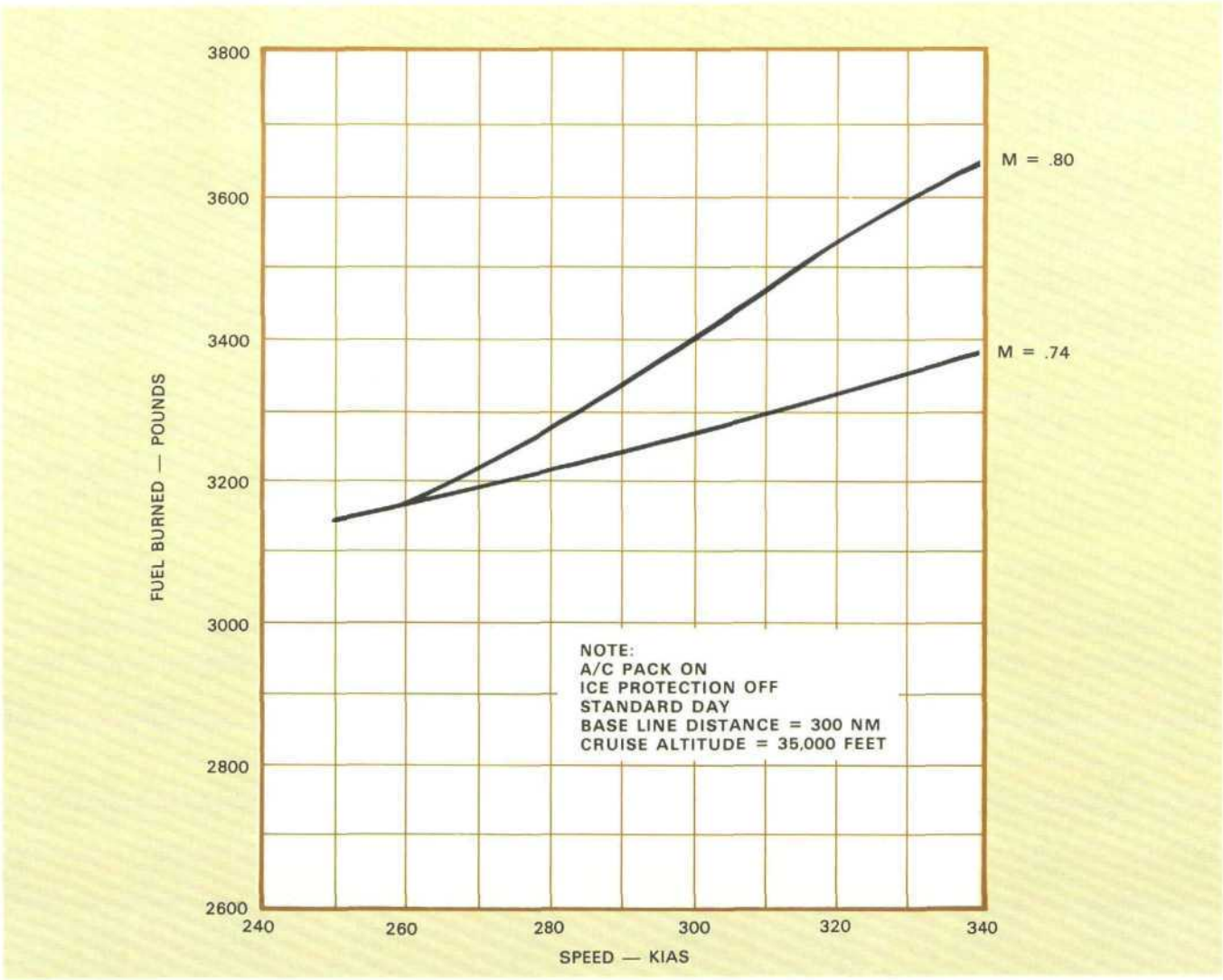
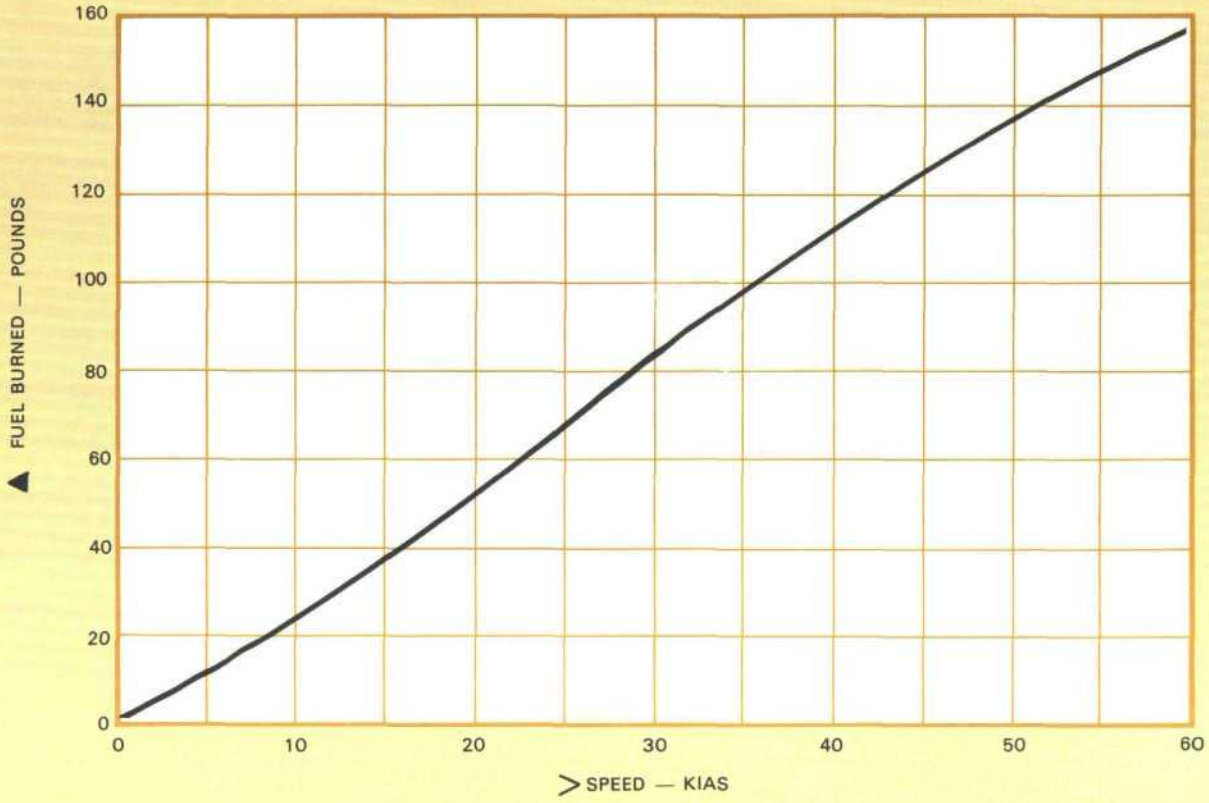


Figure 14. Fuel Burned Versus Descent Speed



INCREASE IN DESCENT SPEED ABOVE 250 KIAS	INCREASE IN FUEL BURNED (LBS)
10	23
20	50
30	83
40	110
50	135
60	155

Figure 15. Increase in Fuel Burned for Descent Speeds Over Optimum

EARLY DESCENT INITIATION

A fuel penalty is incurred for early initiation of the descent. For example: should the descent be started too soon so that the distance had to be recovered at 10,000 feet and 250 KIAS, the fuel penalty for a 10 nautical mile early descent would be 80 pounds. See figure 16.

PROFILE DESCENT

Given the average wind during descent,the charts presented in figures 17 and 18 can be used to determine the distance to initiate a descent to any altitude from up to flight level 350 using minimum fuel. One chart is based on a descent speed of 250 KIAS and for operational reasons, if this speed should be too low, the other chart will show descent distances when descending at the high speed descent profile (0.8/320/250).

APPROACH AND LANDING

OPTIMIZED APPROACH MANEUVER

The same "fuel conservation" awareness and application of fuel economy measures taken during ground and inflight operations should be extended to the approach and landing. The approach intercept maneuver and point at which the landing configuration is established should be optimized. When it is possible, the approach intercept distances should be minimized and high drag configurations delayed as long as operationally feasible.

Each extra minute of flight with 15° flap/slats extended per trip costs 3,672 gallons ($1,836) per year for the 300 NM flights and 1,468 gallons ($734) per year for 800 NM flights.

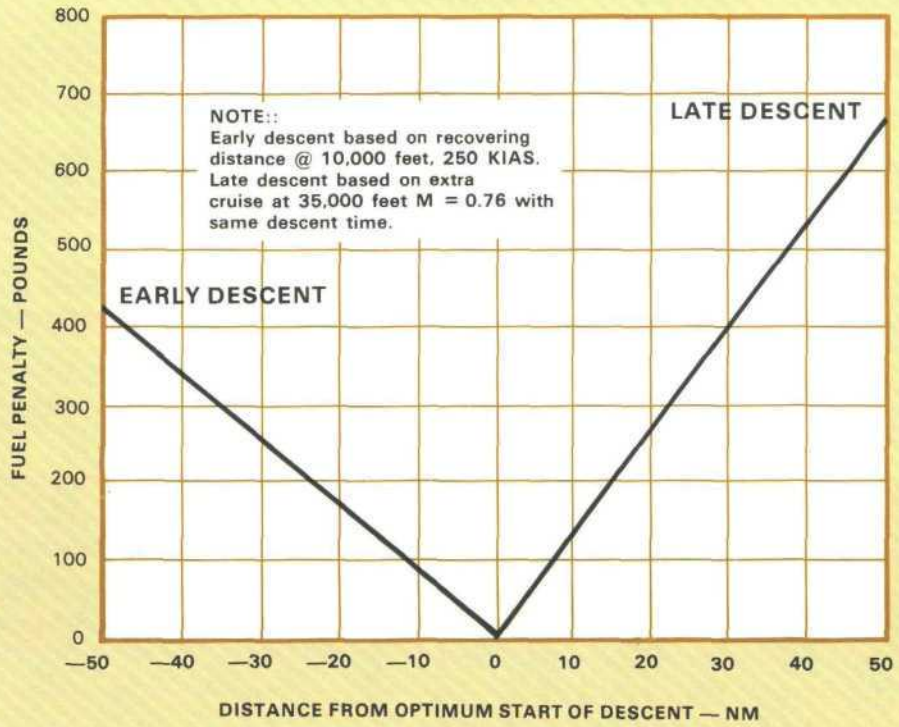


Figure 16. Fuel Penalty for Early/Late Descent — Typical Case

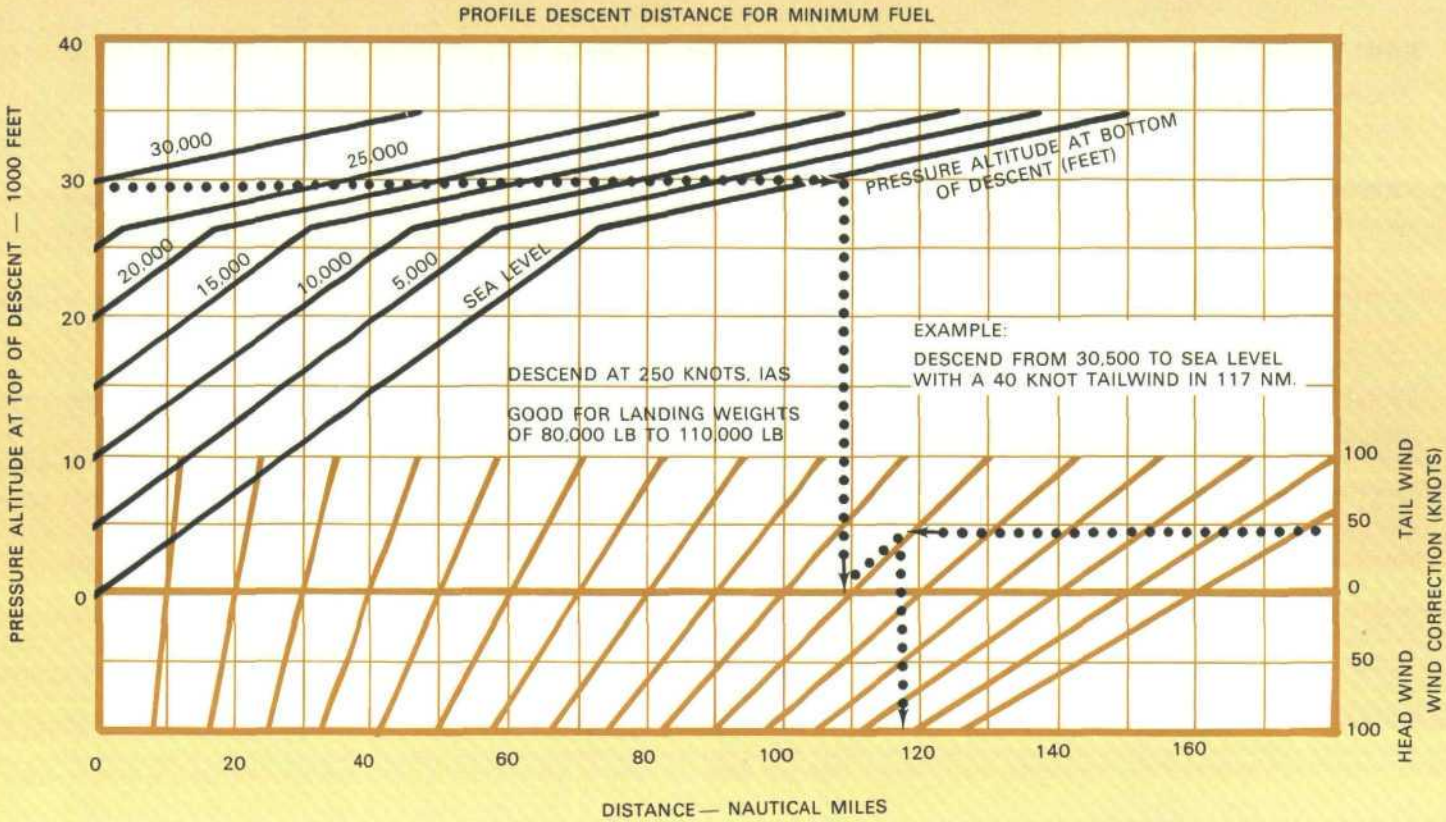


Figure 17. Distance to Descend — Minimum Fuel Profile — 250 KIAS

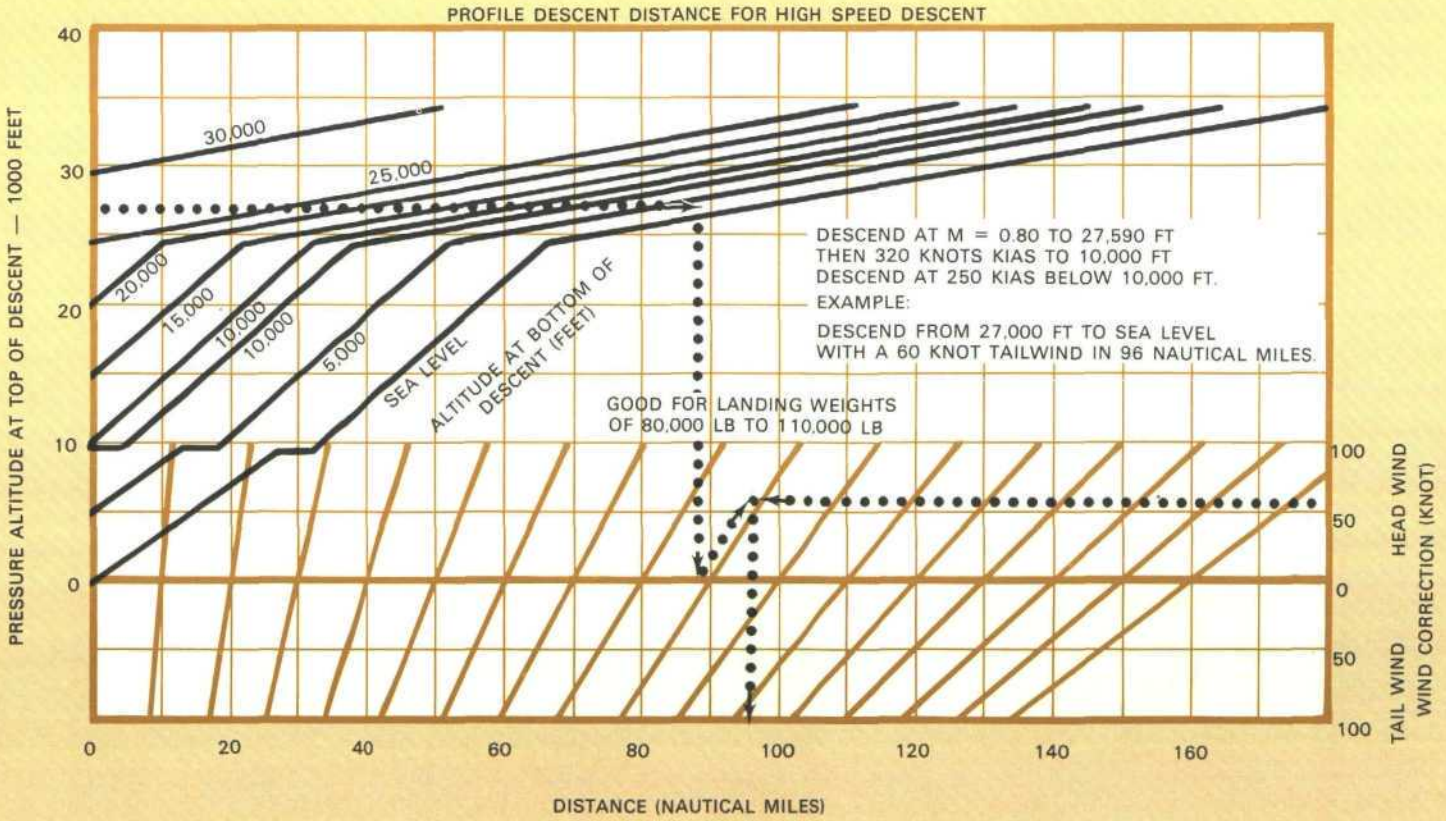


Figure 18. Distance to Descend — Descend at Mach 0.80 to 27,580 Feet, Then 320 KIAS to 10,000 Feet, Then 250 KIAS

USE OF AUTOMATICS

The automatic pilot and throttles should be used as much as possible. Performance and operation of the automatic systems over a period of time may contribute to fuel savings.

GROUND ROLLOUT AND TAXI

When possible, minimize ground rollout and taxi times consistent with the other factors involved.

Each extra minute of running two engines at ground idle each flight costs 20,597 gallons ($10,299) per year for the 300 NM flights and 8,239 gallons ($4,120) per year for the 800 NM flights.

SUMMARY

Awareness of fuel conservation principles and diligent application of fuel conservation procedures and techniques are the keys to reducing the fuel used. Each effort toward this goal by the flight crews, no matter how small, will pay off in dollars saved and vital resources conserved.

In the total operational picture, flying at optimum fuel flight profiles may not be practical as other economic considerations may be overriding. Each operator must select the suggestions made in this supplement which will fit into his operations. Table 9 is a checklist summarizing the key points for consideration, illustrated by potential annual savings. These savings are not necessarily cumulative but do indicate their relative importance as well as their potential effect on fuel economy.

Table 9. Checklist for Potential Yearly Fuel Savings — 300 NM Trip Distance

PROCEDURE OR TECHNIQUE	FUEL (GAL) PER AIRCRAFT	DOLLARS PER AIRCRAFT
Excess Weight — 5,000 LB. Reduction/Flt	94,020	47,010
Maintain Aft CG Loading	127,020	63,510
Aerodynamic Cleanness	N.D.	N.D.
Efficient Flt Planning Saving 1 Min/Flt	43,380	21,690
Use of Automatic Flight Control Systems	N.D.	N.D.
Reduce APU Operation 1 Min/Flt	2,238	1,119
Reduce 2 Engine Ground Idle 1 Min/Flt	20,597	0,299
Early Flap/Slat Retraction After T.O.	N.D.	N.D.
Optimum Climb vs Long Range Climb	896	448
Optimum Cruise Altitude vs 4000 Feet Off Optimum	5,106	2,553
Cruise — Effect of Wind vs Altitude	N.D.	N.D.
Cruise — Use of Step Climb	N.D.	N.D.
Mistrim — 1° of Rudder and Aileron	29,200	14,600
Effect of Instrument Errors Mach Meter .01 Error Altimeter 100 Feet High	 1,140 108	 570 54
Holding at High Alt. & Clean Configuration.	N.D.	N.D.
Descent at Optimum vs 0.80/320/250	171,046	85,523
Optimize Approach Maneuvering (1 Min Saved/Flt + 15° Flap/T. O. Extend)	3,672	1,836

N.D. = Not Defined

ENGINES*

GENERAL

JT8D engines typically are run until removal from the aircraft is forced due to being either exhaust gas temperature (EGT) limited or written up for stall. Repair action is then instituted to correct the problem and is usually accomplished through hot section inspection/repairs.

The cold section is not normally addressed unless foreign object damage (FOD) repairs demand cold section disassembly or the hardware reaches its cyclic limit. The hot section refurbishment procedure may be repeated until such time as the engine will not pass test cell acceptance limits for EGT or stall.

Complete hot section refurbishment with specific attention to the quality of the replacement hardware provides significant performance improvements, and when coupled with cold section management, will provide additional benefits in EGT and thrust specific fuel consumption (TSFC) as well as compressor stall margin improvements.

Table 1 identifies refurbishment recommendations pertinent to all JT8D engine models and provides Engine Manual references where the particular information may be found.

Cold section performance loss with time, particularly in the high pressure compressor, is a significant factor in (a) reduction of time between hot section repairs and (b) increased fuel consumption on-aircraft. The influence of the high pressure compressor is as great as that of the high pressure turbine in TSFC and EGT penalties for each percent loss in component efficiency.

A cold section management program with emphasis on periodic cold section attention (such as

*Data furnished by Pratt & Whitney Aircraft

cleaning) and refurbishment will yield improved compressor efficiencies with resultant decreases in fuel consumption and EGT. Increased hot section time and a reduction in the removal rate for compressor surge will be added benefits. A soft time of 8000 to 10,000 hours is recommended for cold section rework. The cost effectiveness of a cold section management program is dictated by individual fleet operations and engine condition.

JT8D engine cold section deterioration is primarily limited to three items:

1. Airfoil surface roughness - rotor and stator contamination
2. Blade leading edge erosion
3. Stator vane angle loss

AIRFOIL CONTAMINATION

Recommended blade cleaning is accomplished through the use of a vibrating abrasive media process. Similarly, stator vanes should be cleaned and maintained through the use of smooth sacrifical coatings such as those provided by the Sermetel 5375 process. Fleet average improvement of 1.0% fuel burn is being reported by one operator who has committed his entire JT8D fleet to Sermetel-coated stators.

Periodic water wash is recommended to maintain a smooth gas path.

BLADE EROSION

Compressor blade leading edge erosion is the primary area addressed in refurbishing JT8D compressors. Tip clearance does not generally become a problem since the blades seldom rub; however, abrasives in the air cause the blades to erode, with the majority of the erosion occurring at the tip. Control is maintained through the measurement of blade chord in the area of the blade tip.

The Engine Manual provides limits for blade chord that are based on structural integrity. Several operators have set revised minimum chord limits that are tighter than those given in the Engine Manual with the intent of limiting the performance loss due to erosion, with reported fleet wide improvements of 1.0% TSFC.

P&WA is currently working to define similar blade minimum chord limits which will be incorporated into the Engine Manual troubleshooting section. In the meantime, the operator developed limits are listed in table 1.

COMPRESSOR STATOR VANES

Stator vanes tend to erode with time similar to compressor blades. Erosion of both leading and trailing edges results in effective uncambering of the vanes with associated losses in performance and stall margin. Resetting vane A and H angles in accordance with the Engine Manual is recommended as part of the periodic compressor work to retain performance.

WATER WASH

Periodic water washing is recommended to minimize compressor contamination. There are documented cases of one-time water wash improvements in TSFC and EGT of 0.85% and 8°C respectively; however, experience indicates that water washing before the contaminants become set is more beneficial. One operator reports a fleet TSFC improvement of 1.0% utilizing engine water washes every three months. The recommended water wash interval is 1,000 to 1,200 hours commencing after a heavy maintenance.

P&WA estimates a reduction of 1.0% TSFC and 10°C EGT over a 6,000 hour period with regular water wash. Using this procedure, there may be no significant improvements noted after each wash since the interval selected was one which would ease contaminant removal rather than one which would result in a noticeable increase in TSFC and EGT prior to wash.

An additional benefit of water wash is the effect of reducing turbine sulphidation. P&WA tests have shown that compressor water wash removes water soluble substances applied to the turbine. A large domestic operator using water wash at 100- to 150-hour intervals with expanded repair limits has been successful in reducing turbine blade scrappage due to sulphidation damage at 6,200 hours from 100% to less than 5%.

It should be reiterated that water wash for sulphidation reduction requires much shorter time intervals between washes than those used for compressor cleaning.

TURBINE

A significant part of the inability to recover lost performance through turbine refurbishment has been isolated to the use of weld-repaired first turbine nozzle guide vanes. Rework without strict adherence to dimensional requirements can result in twisted vane platforms. Turbine cooling air leakage through the mismatched platforms creates an effectively large vane area and could induce reverse flow of hot gases into the vanes by reduction of the cooling air supply pressure thereby accelerating turbine vane deterioration (i.e., bowing, cracking and burning).

Tip clearance is a primary factor affecting turbine efficiency. The use of improved turbine outer airseals such as the 4-knife-edge seal or the filled honeycomb seal maintained to proper clearance is recommended.

Table 1. JT8D Refurbishment Recommendations

ITEM	REFERENCE	COMMENTS
A. FAN		
1. Restore leading edge.	72-33-01 Repair 8	Recommended for severely eroded 1st-stage blades — Improves TSFC.
2. Chamfer cut leading edge.	72-33-01 Repair 10 & 11	Recommended for 1st- and 2nd-stage blades not requiring leading edge restoration — Improves TSFC.
3. Restore S2 vane angle.	72-32	Recommended — Improves TSFC.
4. Clean airfoils.	—	Recommended — Shop SWECO cleaning.
B. LOW PRESSURE COMPRESSOR		
1. Control leading edge erosion.	—	Recommended minimum chord limits for performance.
		Stage / New Chord (In.) / Distance from Tip (In.)
		R3 / 1.277 / 0.400
		R4 / 1.276 / 0.340
		R5 / 1.234 / 0.340
		R6 / 1.225 / 0.315
		Improves stall margin.
2. Minimize blends.	72-32-01	Recommend maximum of 10% blended blades per stage.
3. Restore stator vane angles.	72-32-01	Recommended — Small TSFC improvement; primarily for stall margin.
4. Clean airfoils.	—	Recommended — Shop cleaning in vibratory abrasive media/on-aircraft water wash.
5. Eliminate excess 6th-stage bleed.		Recommended — Improves TSFC (+1% of core airflow, 0.8% TSFC and 15°C EGT).
C. HIGH PRESSURE COMPRESSOR		
1. Control leading edge erosion.	72-36-01	Recommended minimum chord limit for performance.
		Stage / Min Chord (In.) / Distance from Tip (In.)
		R7 / 1.4705 / 0.188
		R8 / 1.2066 / 0.188
		R9 / 1.0667 / 0.188
		R10 / 1.0174 / 0.188
		R11 / 0.8923 / 0.188
		R12 / 0.7258 / 0.188
		R13 / 0.7656 / 0.188
		Improves TSFC and EGT.

ITEM	REFERENCE	COMMENTS
2. Minimize blended blades.	72-36-01	Recommended — Maximum of 10% blended blades per stage.
3. Restore stator vane angle.	72-35-00	Recommended — Improves TSFC, off-idle stall margin.
4. Smooth airfoils.	—	Recommended — Shop cleaning in vibratory abrasive media for blades. Stator vane coating with smooth finish (Sermetel 5375) and on-aircraft water wash at 1,200-hour (maximum) intervals.
5. Eliminate excessive air bleed due to leakage.	—	Recommend periodic anti-surge bleed checks and air-conditioning bleed system pressure decay checks.
D. BURNER		
1. Control fuel nozzle coking.	73-13-01 All operator letter JT8D/ 73-13/PSE:JRC 8-9-15-1	Recommend shop cleaning of fuel nozzles and on-aircraft in-situ cleaning. Improves TSFC through reduction of turbine nozzle guide vane (NGV) deterioration due to hot spots.
2. Repair combustion chamber distress.	72-42	Recommended — Improves TSFC through reduction of T1 NGV distress due to distorted temperature profile.
3. Repair transition duct distortion.	72-46-02, 03	Same as 2.
E. TURBINE		
1. Maintain proper turbine nozzle guide vane area.	72-51-20, 23	Recommended — Improves TSFC through proper engine match.
2. Minimize surface erosion due to sulphidation.	—	Recommend water wash at 100- to 150-hr intervals.
3. Minimize T1 NGV dimension deviation of weld repair/ reairfoiled vanes.	—	Recommend 50/50 mix with new vanes.
4. Maintain tip clearance.	72-51-00	Recommend 4-knife-edge or filled honeycomb turbine outer airseals.

ELECTRICAL POWER

The amount of fuel used to propel aircraft is so enormous that fuel used to generate electricity is by comparison insignificant. There are many opportunities, however, to conserve fuel by reducing electrical loads or by using the most economical sources of electricity. This is especially true during ground operations.

The potential monetary savings are enough to warrant careful consideration of energy conservation policies and procedures. Let's examine the cost of fuel used to generate electrical power in flight and cost of electricity to support preflight, postflight, loading, unloading, cleaning, inspection, repairs, etc. In addition, a few helpful hints and procedures are offered that may lead to better electrical power management.

COST OF ELECTRICITY DURING FLIGHT

During flight, electricity is supplied normally by aircraft engine generators or, under some circumstances, by the auxilliary power unit (APU). The generation of electrical power depends upon energy supplied by the engine fuel. One gallon of jet fuel weighs 6.7 pounds, costs about 50 cents and contains 18,500 BTUs. One kwh is equivalent to 3,413 BTUs.

The cost of fuel used for converting to one kwh may be calculated by:

$$\text{COST} = \begin{cases} \text{(lbs fuel used) (cost per lb)} \\ \text{or} \\ \left(\dfrac{\text{BTUs/ kwh}}{\text{BTUs/lb (eff)}}\right)\left(\dfrac{\$/\text{gal}}{\text{lbs/gal}}\right) \end{cases}$$

where (eff) is the efficiency of conversion. By assigning efficiency values, based upon Douglas test data and calculations by engine manufacturers, to constand speed drive (CSD) 85%, generator 85% and other losses 50%, the formula becomes:

$$\text{COST} = \left(\frac{3413/\text{kwh}}{18{,}500/\text{lb}\ (.85)\ (.85)\ (.50)}\right)\left(\frac{.50}{6.7\ \text{lbs}}\right) = \$.038$$

The resulting calculated fuel cost of 4 cents per kwh may not be accurate for all engines and modes of operation, but the basic formula shows that some costs are involved and the condition of the generator drive function, including the load controller, plays an important part in these costs.

OPERATIONAL OPTIONS

Electrical use during flight is for the most part, dependent upon flight profiles and operational practices. There are, however, some "elective" loads that may be turned off when not needed. Examples of these include instrument lighting during daylight hours, galley area loads and cabin lighting. Galley power and cabin lighting management provides opportunities for flight attendants to contribute to fuel conservation. Savings during any single flight may be small, but savings could be significant for a fleet of airplanes operated over extended periods.

COST OF ELECTRICITY FOR GROUND SUPPORT

Most of the fuel required for aircraft ground activities is used for supporting aircraft preflight, postflight, loading, servicing, cleaning and repairing as well as for lighting, heating and cooling. Most of the energy consumed is in the form of electricity, except when pneumatic power is required for cabin air conditioning (heating or cooling).

AVAILABLE POWER SOURCES

Electricity may be purchased from a utility company or generated by ground power units (GPUs), aircraft engine generators, or aircraft auxiliary power units. The cost differences between these sources are significant and costs are often inversely proportional to convenience. For example, it is often more convenient to use an aircraft engine or the APU than it is to use a GPU.

Use of the aircraft engine or the APU is often an extremely costly convenience. For example, when operated solely to generate electricity, the APU runs less than 3 minutes on a gallon of fuel, whereas some GPUs will run for more than one-half hour on the same amount.

The APU uses 20 gallons of fuel per hour.

It should be noted that when the APU is being used to supply pneumatic power for air conditioning, the APU can concurrently drive the electric generator for a very modest additional cost in fuel consumption.

The typical electrical demand load for DC-9 ground support has been calculated and verified by observation to be about 20 kw.

Figure 1 graphically presents typical APU fuel consumption versus electrical power output. It should also be noted that if the APU is not being used for pneumatic power, the cost for electrical power is quite high.

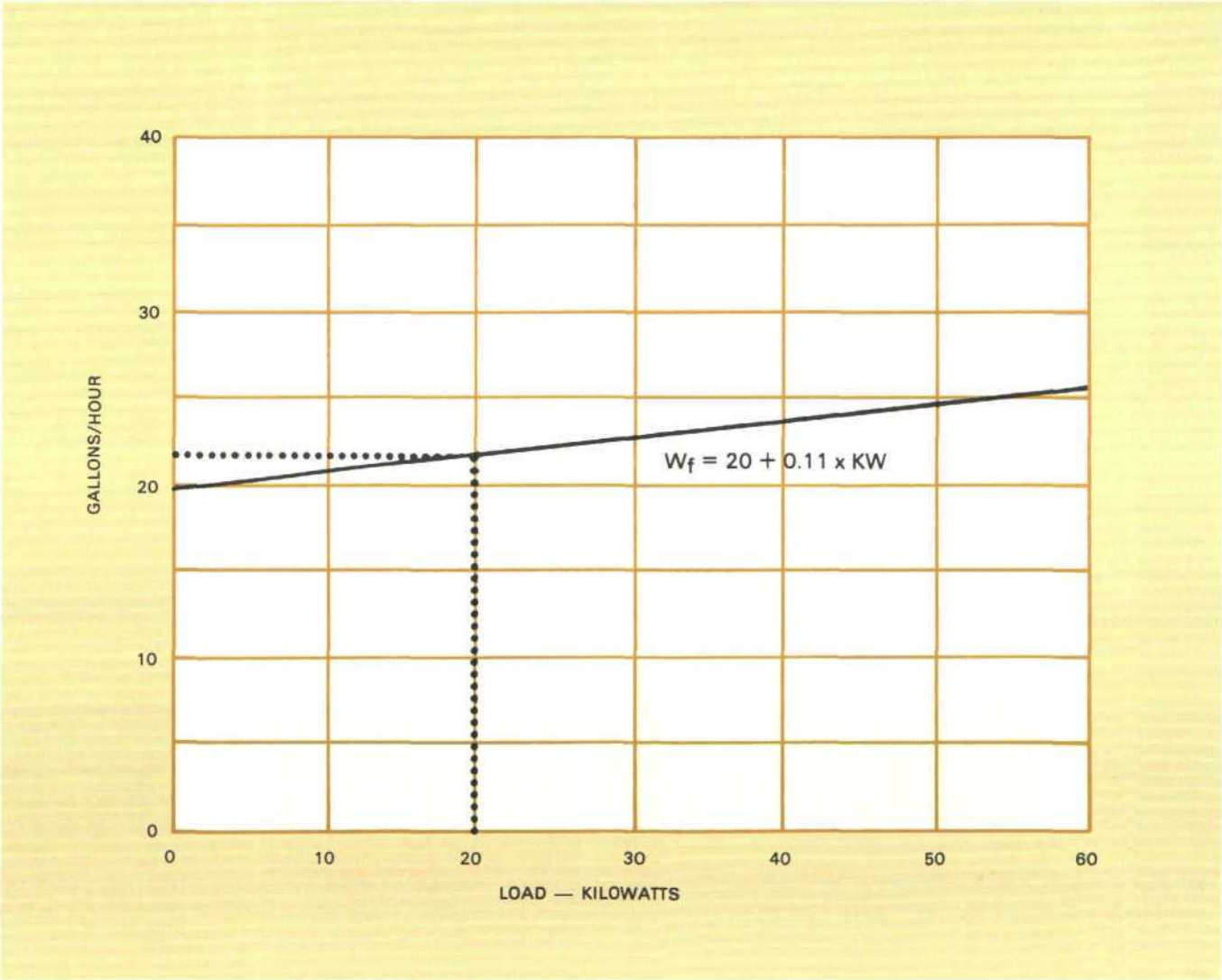


Figure 1. APU Fuel Consumption vs Electrical Load

Figure 2 shows the amounts of fuel used by typical GPUs. A comparison of figures 1 and 2 shows the disproportionate costs of running the different types of engines. Also illustrated is that once the cost of driving the prime mover is absorbed, the cost per kwh is reasonably constant over the range of the generator rating.

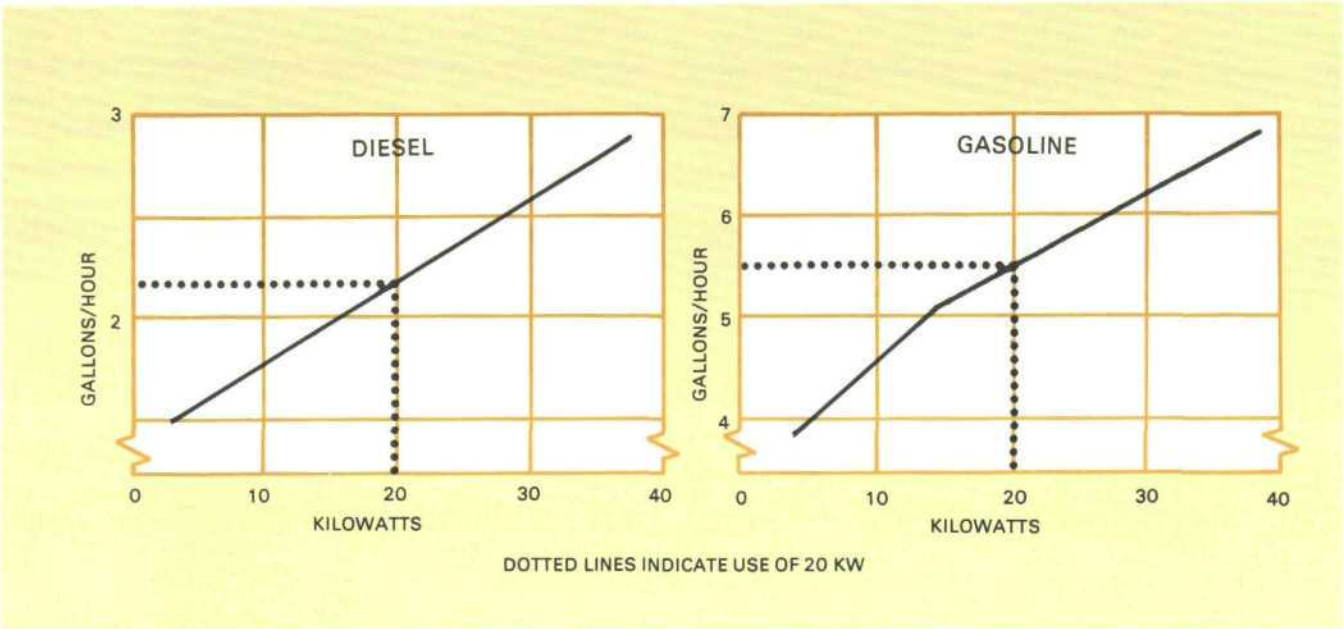


Figure 2. GPU Fuel Consumption

Costs per kwh for commercial electricity are generally less than costs of fuel for GPUs and APUs. The cost of turning commercial power turbines is prorated over such large bases that the allocation to each individual user is negligible.

COSTS COMPARED

Table 1 compares costs for DC-9 ground support electrical power based upon rates and fuel costs prevailing in the Los Angeles area in December 1978. The computations assume a demand load of 20 kilowatts.

Table 1. Ground Support Electricity

FUEL COSTS — ALTERNATE POWER SOURCES				
TYPE POWER	GALS.	$/GAL.	$/KWH	COST RATIO
Commercial Electricity	—	—	0.03	1.0
GPU (Diesel)	0.085	0.46	0.04	1.3
GPU (Gasoline)	0.197	0.60	0.12	4.0
APU (Electrical power only)	1.11	0.50	0.56	18.7
APU (Concurrent with pneumatic power)	0.11	0.50	0.06	2.0

OTHER "HIDDEN" COSTS

Fuel used to generate electricity is probably the least of the many costs involved in the generation and use of electricity. Some additional direct costs are capital investments for APUs and GPUs, salaries of operating and maintenance personnel, and expenditures for lubricating oils, anti-freezes and spare parts. Indirect costs include those associated with reduced "useful" life of light bulbs, unnecessary wear on motors and pumps, nonproductive powering of instruments and avionics equipment, and removal of unwanted heat.

Heat removal using the APU costs about 40 cents per minute for fuel.

Heat radiated (70,000 BTUs) into the aircraft by electrical equipment equals that of a furnace sized to heat an average two-bedroom home in the Los Angeles area. This heat can raise airplane cabin, flight deck and compartment temperatures above comfort levels for people and equipment. This heat must be either tolerated or removed. During a hot day, the APU will consume about 40 gallons of fuel per hour when used to air-condition the aircraft and to furnish electricity for ground operation.

WHAT TO DO

REDUCE POWER-ON TIME

Most aircraft spend more hours on the ground than in the air. During ground time, aircraft may sit idle with electrically powered equipment operating. Some aircraft have been observed, late at night, sitting in the docks with lights aglow and systems powered long after all scheduled tasks have been completed.

Through training, motivation and supervision, it may be possible to reduce the nonproductive power-on time. In some cases, it may also be practical to adjust servicing and maintenance schedules to permit all power to be removed from the aircraft for several additional hours each night.

USE MOST ECONOMICAL SOURCE

The greatest savings accrue from delaying the start of any aircraft engines until the last possible minute before departure, and shutting down engines as soon as possible after landing. Switching from APU to ground power sources can also reduce costs dramatically. Some operators start GPUs as airplanes approach the docks, while some leave them running between airplane departures and arrivals. Others start and stop as required. Since some GPUs can operate about 30 minutes on the fuel required by an APU for 1 minute, it may be appropriate to review the GPU availability and operational practices.

Some airlines have installed electrical outlets in aircraft parking areas. These are supplied from commercial electricity sources. While these represent considerable capital expenditures, some who have installed them claim to have recouped their investment in less than two years. Frequency of dock use, type of aircraft using dock, cost differences between commercial electricity and fuels, and capital costs are some of the most important factors to be considered.

REDUCE ELECTRICAL DEMAND LOAD

This is the least evident of the fuel cost considerations and is the one most often overlooked. At current fuel prices, even small electrical load reductions can result in sizable annual savings, especially for operators of large fleets. The most promising area for savings is in promoting the use of the ground service bus at every opportunity. This can leave unneeded electrical equipment unpowered and reduce the demand load by 16 kw. Resultant savings will probably average over fifty cents per hour. Electrical power management is discussed in detail in the following paragraphs.

ELECTRICAL POWER MANAGEMENT FOR GROUND SUPPORT, SERVICING AND MAINTENANCE

Figure 3 shows Flight Compartment power management switches in their usual positions for APU or external power in use and the resultant distribution of the typical 20 kw demand load between generator buses.

Note: Either configuration supplies power to both generator buses and the ground service bus through the Right Generator Bus.

These configurations are the ones most often used by flight crews during normal ground operations and are required for some maintenance and support functions. Switches are often left (as shown) by the aircrew when they park and leave the aircraft. This leaves power on both generator buses. Observation has shown that ground personnel seldom turn anything off until the aircraft is "buttoned up for the night."

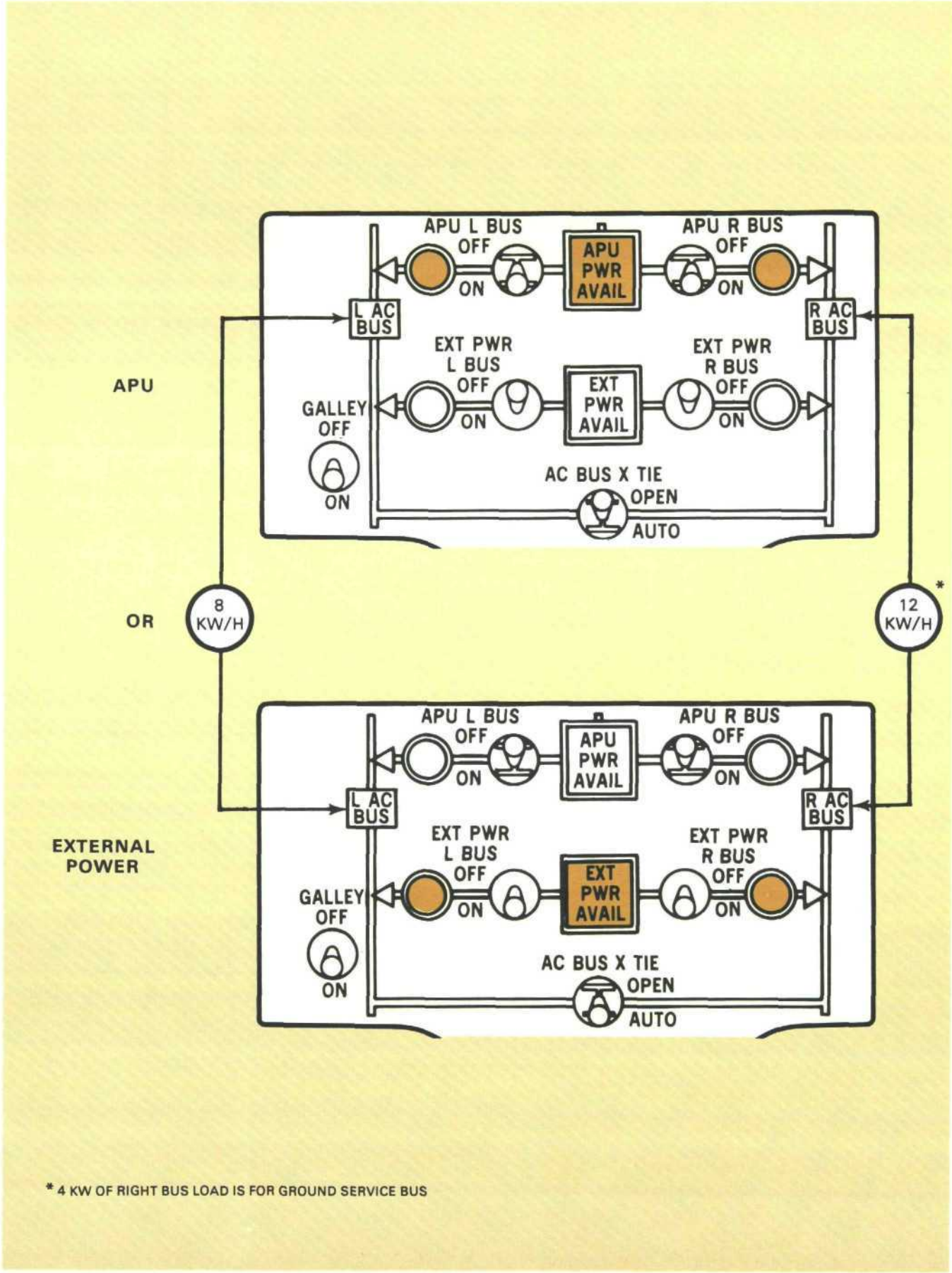


Figure 3. Flight Compartment Power Management and Load Distribution (Usual Configuration)

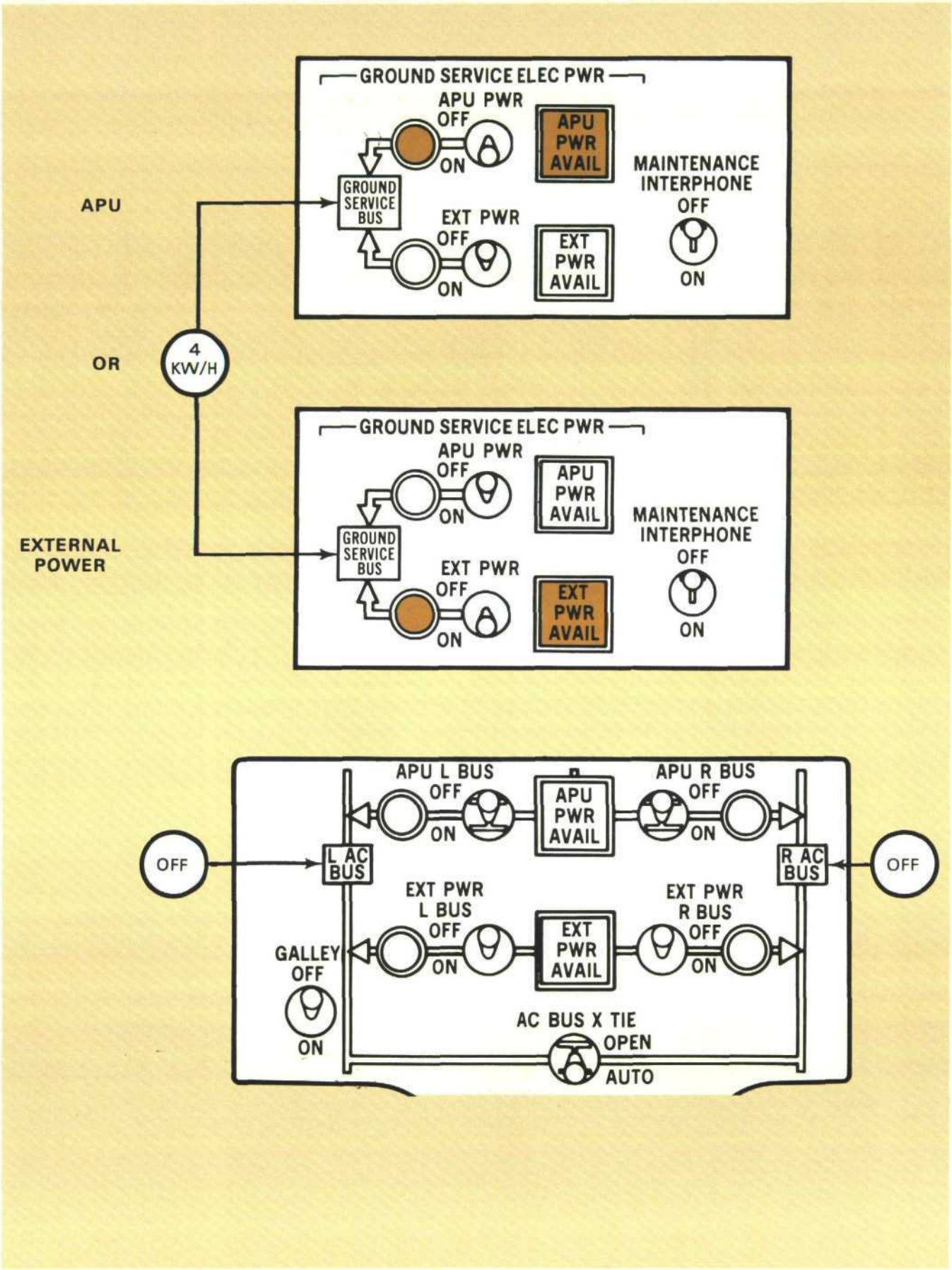


Figure 4. Ground Service Power Management

GROUND SERVICE BUS

To avoid the need to pull a large number of circuit breakers to power down the aircraft, the DC-9 has a "built-in" ground service bus feature. This feature provides an easy and effective means of removing power from the avionics equipment and other non-essential loads, while continuing to supply power to equipment required for servicing the airplane.

The exclusive use of the ground service bus during ground operation will extend the life of avionics equipment, increase the life of manual and remote control circuit breakers, and conserve fuel.

Electrical demand load on the ground service bus under normal conditions is approximatley 4 kw.

Ground service bus supplies power to:

- Battery charger
- Cabin overhead lights
- Entrance lights
- Coatroom lights
- Galley area lights
- Lavatory lights
- Cargo compartment lights
- Wheelwell lights
- Position lights
- Water quantity indicating system
- Toilet flushing
- Pressurized fresh water service panel lights
- Lavatory waste service panel light
- Circuit breaker panel floodlights
- Electrical/Electronic compartment lights
- Forward accessory compartment lights
- Aft accessory compartment lights
- Electrical power center service lights
- Flight compartment floor lights
- Ground floodlights
- Leading edge floodlights
- Nacelle floodlights
- Upper sidewall lights
- Lower sidewall lights
- 115 VAC utility lights
- Right TR #2

GROUND SERVICE BUS CONTROL

When power is not required for maintenance, but is necessary or desirable for lighting or other servicing functions, the demand load may be reduced by 16 kw by turning AC bus power off and energizing only the ground service bus. Figure 4 shows the switch positions to power the ground service bus from either the APU or external power. These configurations do not provide all power necessary for maintenance, but will support most servicing and cleaning operations. Potential savings may well offset the supervisory effort necessary to schedule and manage switching configurations to support specific maintenance tasks.

POTENTIAL SAVINGS

The Douglas Aircraft Company conducted a study to determine potential savings through improved ground support power management. Although this survey was focused primarily on DC-10 operations, the conclusions are applicable to many DC-9 operations. This survey revealed that aircraft were electrified on the ground approximately 12 hours each day. Monitoring of aircraft at specific ramp and maintenance facility locations showed several instances where power could have been turned off between scheduled servicing and maintenance operations. Observations revealed that numerous opportunities existed for substituting idle GPUs for APUs, but would have required moving the GPUs or the airplanes. Instances were also observed where aircraft could have been moved to locations where commercial power was available.

Conclusions based upon the survey were:

Opportunities for implementing savings vary with operators, schedules, type of ground facilities available, geographical locations, weather and other factors.

Savings of approximately 20% can be achieved by most operators through training and motivation.

Savings of an additional 10% can be achieved by some operators through revision of ground servicing and maintenance schedules (compression).

Savings of up to 25% can be achieved by some operators through capital expenditure for more efficient GPUs and installation of commercial power outlets at ramp, dock and hangar locations.

Table 2 provides potential savings for different size fleets. Information in the table is based on the following assumptions. Adjustments must be made for variations applicable to each operator.

ASSUMPTIONS: (each aircraft)

Ground electricity in use	12 hours per day
Average electrical demand load	15 kw
APU as source	6 hours per day, $50.40
GPU (Diesel) as source	2 hours per day, $1.20
GPU (Gasoline) as source	3 hours per day, $5.40
Commercial electricity	1 hour per day, $0.45
Average cost per day per aircraft	$57.45
Average cost per year per aircraft	$20,969.25

Table 2. Estimated Savings

POTENTIAL SAVINGS — FLEET PER YEAR				
FLEET SIZE	TRAINING & MOTIVATION 20%	SCHEDULE COMPRESSION 10%	CAPITAL EXPENDITURE 25%	TOTAL
1	$ 4,193.85	$ 2,096.93	$ 5,242.31	$ 11,533.09
5	20,969.25	10,484.63	26,211.56	57,665.44
10	41,938.50	20,969.25	52,423.13	115,330.88
25	104,846.25	52,423.13	131,057.81	288,327.19
50	209,692.50	104,846.25	262,115.63	576,654.38

ENVIRONMENTAL CONTROL

FUEL PENALTY FROM FUSELAGE LEAKAGE

The fuel penalty due to the loss of thrust recovery of the air leaking out of the pressurized compartments of the airplane is given in figure 1. The fuselage leakage is shown in terms of the cabin differential pressure decay time established by the test in Maintenance Manual Chapter 21-00.

The fuel penalty shown is based on an average mission which consists of a trip leg of 300 miles and a total of 3000 trips per year. The cost of fuel was assumed to be fifty cents per gallon.

It should be noted that overboard leakage of cabin pressurization air can disrupt the external airflow, leading to higher fuel penalties than presented in figure 1. However, no generalization of this additional penalty is possible due to the many variables involved.

A major cause of pressurized compartment air leakage is damaged door seals. Seals on all pressurized doors eventually require repair or replacement during the life of an aircraft. Occasionally these seals become abraded to the point that excessive cabin air leakage is experienced.

The approximate annual cost of leaking door seals in a pressurized area is given in table 1.

To alleviate this cost, the condition of the seals on all pressurized doors should be checked periodically for conformity and repaired or replaced as necessary. Refer to the DC-9 Structural Repair Manual (52-04, pages 1 through 8) for repair of damaged seals.

SINGLE AIR-CONDITIONING PACK OPERATION DURING CLIMB OR CRUISE

When the passenger load is light, the fuel saved by turning off one air-conditioning pack during climb and cruise is significant. For example, a DC-9-50 would obtain a fuel saving of $3,000 a year if operated for an average mission. (The criteria for an average mission consist of 3,000 flights per year, 300-mile trip, and a trip duration of 0.8 hour.) Also, if the trips are longer, the savings will be greater.

EXCESSIVE USE OF RADIO RACK VENTURI

Presently the radio rack fan switch position is optional for airplanes without cargo heaters. Some operators elect to use the radio rack venturi not knowing the full economic impact. For example, using the radio rack venturi may cost the operator as much as $1760.00 a year due to the loss of thrust recovery of air being bled overboard. Therefore, it is recommended that the venturi be used only during an emergency or to dispatch the aircraft with the radio rack fan inoperative.

Table 1. Approximate Annual Cost of Leaking Door Seals in a Pressurized Area (U.S. $/Year Per Aircraft)

LOCATION OF LEAKING DOOR SEAL	PENALTY (PER INCH OF MISSING SEAL)	
	SIDES	TOP OR BOTTOM
Passenger Doors	$300.00	$157.00
Cargo Doors	$316.00	$166.00

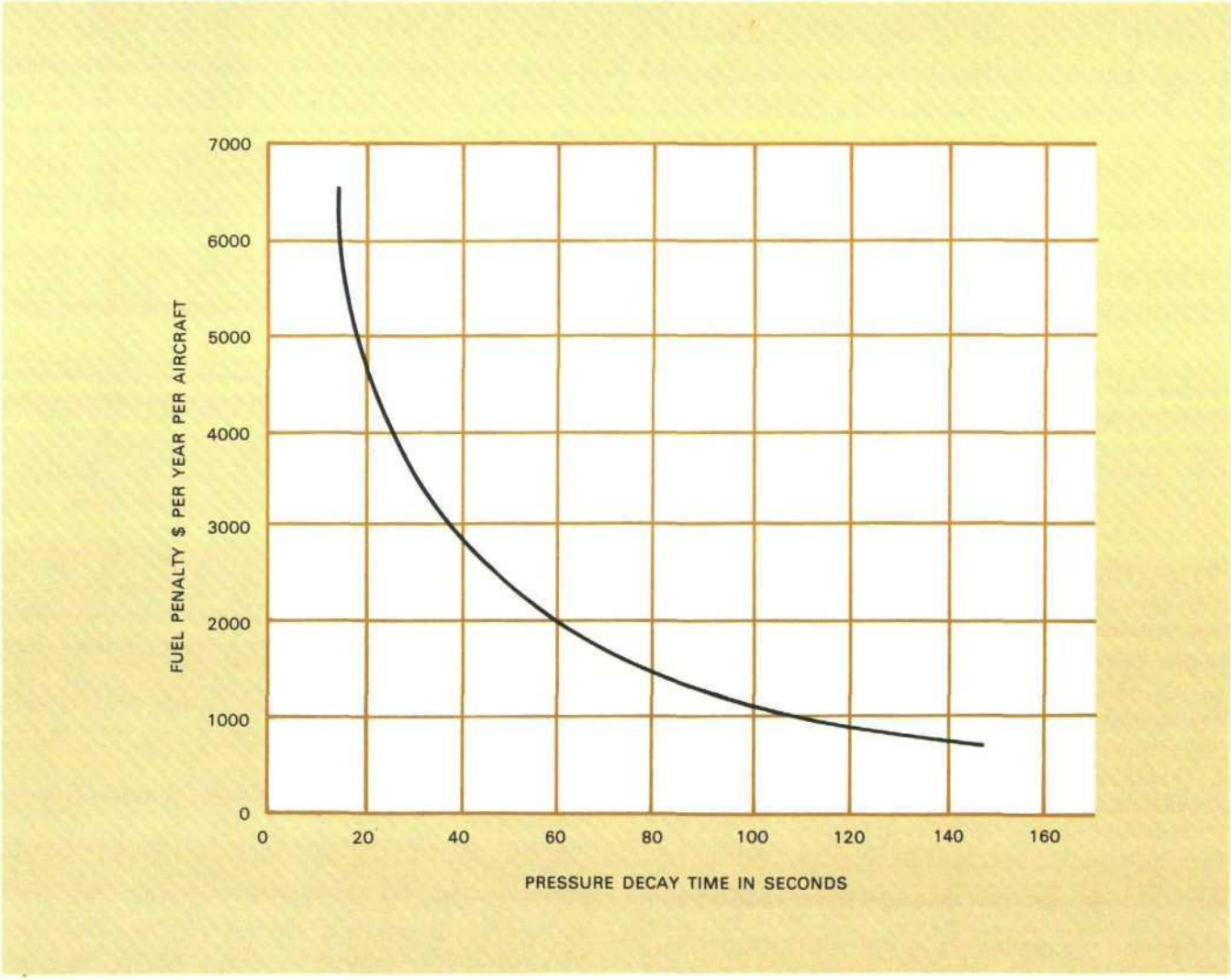


Figure 1. Fuel Penalty Versus Decay Time — DC-9 Series 50

FUEL GAGE SYSTEM

More fuel is consumed as an airplane's gross weight is increased, whether with added payload or excess fuel. Added payload can mean increased revenue, but in the case of excess fuel, added weight means an erosion of profits and an unnecessary waste of natural resources. The amount of excess fuel burned may be expressed in "percent" of excess fuel carried. For ranges up to 2000 nautical miles, the additional fuel consumed would be on the order of 10 to 12 percent of the excess fuel at takeoff.

The DC-9 fuel gage system was designed to provide maximum accuracy to reduce, as much as possible, the need of carrying excess fuel for a given flight. This was accomplished by reducing component tolerances and providing additional features previously not available:

1. Tank unit tolerances were held to ± 1/2 percent of tank unit reading or less — a substantial improvement over earlier systems.

2. The indicator tolerances were reduced to the smallest practical increment:

   (a) Individual tank indicators: ± 50 pounds.

   (b) Totalizer indicator: ± 150 pounds as compared to the sum of master tank indicator readings.

3. Douglas experience indicates an accuracy of full tank shut-off within ± 100 pounds.

4. Automatic shut-off capability was incorporated for partial fuel loading of tanks. The accuracy of the fuel load preselect is ± 50 pounds.

Calibration data shows that the DC-9 fuel gage system for each tank is accurate to within 250 pounds at ground refueling attitudes. To assure this performance, operators must properly maintain the system. We believe that using a properly operating system to determine the fuel load will help the operators avoid carrying excess fuel due to the larger variations associated with dipsticks or supply flowmeters.

As a means of rapid cross checking and troubleshooting of the system, Douglas recommends the use of a GTF Fuel Gage System Test Set developed by Gull Airborne Instruments Inc., 55 Engineers Road, Smith House, New York 11787. A description of this test set was published in the May/June 1977 issue of the Douglas Service magazine.

PERFORMANCE ANALYSIS

Investigating an airplane with poor performance requires some method for determining the most likely areas for corrective action. The following provides a general approach for an investigation. The first part of this approach compares the indicated performance level against a reference. This considers possible instrumentation problems as well as the airplane's configuration compared to that used for the referenced performance level.

The next step is an assessment of the contributions of the two major subsystems of the airplane to the poor performance. That is, we look at the engine and the airframe performance levels

Following this assessment, the investigation can now work on the most probable areas for correction. For the airframe, the most productive areas are the external control surfaces. In-flight checks of the trim of the airplane can give definite clues as to problem areas. The next area considers external surfaces followed by internal systems.

INSTRUMENTATION CONSIDERATIONS

There are flight parameters which are the key to accurate establishment of the performance level of the DC-9. These include airspeed or Mach number, pressure altitude, total air temperature, airplane gross weight and engine fuel flow. From these parameters, the overall performance parameter of range constant or specific range is determined. Specific range is nautical miles per pound of fuel and range constant is specific range divided by the gross weight of the aircraft to give a generalized specific range.

To assess the contribution of the airframe or the engine to the overall performance deviation from a given level, engine parameters are also required. These include EPR and engine fuel flow. When used with the other parameters, an approximation of the airframe performance and the engine performance can be determined.

For the DC-9, the airspeed, altitude and Mach number can be cross-checked as the captain's and pilot's panel display these parameters from separate sensing systems. The static pressure for the altitude is sensed from separate ports; however, the ports can be in the same static plate on the side of the fuselage. Differences in these readings require that consideration be given to determining which of the two is correct.

On some configurations, the total air temperature (TAT) can be cross-checked with the outside air temperature (OAT). However, this is not a separate system since the OAT is derived from the TAT. The OAT can be cross-checked with ambient conditions but keep in mind there are radiation effects when the airplane is on the ground.

Engine fuel flow is probably the most sensitive parameter other than the Mach number. With a properly maintained system, the accuracy of the fuel flow indication should be within ± 1.25% in the normal cruise region. Some operators check the accuracy of the fuel used counters by comparing the fuel uplifted against the fuel used over a number of flights. This gives a good check as the volume of fuel used is sizable.

Airplane gross weight is a key parameter in performance. Weight errors are directly proportional to the performance at the instantaneous weight. A 1,000 pound error at takeoff becomes a higher percentage as the weight decreases prior to landing.

GENERAL INSTRUMENTATION CHECKS

1. Check condition of static plates and pitot heads. Undesirable conditions can be plugged pitot heads or drilled out drain holes, warped or damaged static plates with plugged holes.
2. Cross-check of airspeed, altitude and Mach number between captain's and pilot's instrumentation. Calibration of key instruments might be considered.
3. Review engine parameters. Relationships between the two engines and other engines in the fleet — generalized fuel flow and EGT.

   Consider cross-checking fuel used from fuel uplifted for several flights.

   Consider calibration of instrumentation.
4. Review of method for determination of aircraft gross weight.

   Check operating weight empty (OWE), accountability of passengers, cargo, fuel quantity system.

   Consider weighing aircraft.

CONSIDERATION OF MISSING PARTS

Prior to comparison of the performance level of aircraft to the Flight Planning & Cruise Control Manual, adjustment should be made for any deviation in the configuration of the aircraft. These items are listed in table 1 of the Aerodynamic section.

ASSESSING ENGINE AND AIRFRAME CONTRIBUTIONS

In evaluating the performance of a DC-9, three generalized parameters are generally used to assess the performance level of the aircraft and its two major subsystems. The overall performance of the airplane engine is evaluated by Specific Range (SR). Specific Range at a given gross weight is defined by true airspeed (V_T) divided by total fuel flow (W_F):

$$\frac{V_T}{W_F}$$

This generalization is used with the Mach number (M) and the airplanes gross weight divided by the atmospheric pressure ratio (W/δ). Thus the performance of the airplane for all altitudes and temperatures can be defined.

The assessment of the contribution of the airframe deterioration is made by using the percentage deviation in EPR at the given specific condition. The engine subsystem is assessed using a percentage deviation in engine fuel flow required for an EPR at a specific condition. In making these assessments, we have assumed EPR represents thrust; however, engine tolerances and deterioration may affect this assumption. Defining this actual relationship may require running engines in a test cell and accurately defining the thrust and fuel flow parameters as a function of EPR.

AIRFRAME

The following checks are suggested as an approach to investigating the airframe contribution to poor performance.

FLIGHT CONTROL TRIM CHECKS

Excessive trim may be an indication of problems with movable surfaces. For example, excessive aileron trim could result from spoilers being up or an indication of asymmetric flaps. Excessive rudder trim requirements could be an indication of misrigged trim tabs.

- Review pilot trim control positions.
- Have an in-flight look at the external surfaces visible from the cabin.
- Verify spoilers, flaps, slats and aileron positions.
- Ground check rigging of systems suspected.

EXTERNAL SURFACES CONDITION CHECKS

- Wing Leading Edge
- Fuselage Fillets
- Misrigged Doors
- Mismatched Panels
- Missing Access Panels, Doors & Plates

INTERNAL SYSTEMS CONDITION CHECKS

- Pneumatic Leakage
- Leaking Door Seals

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contents

Introduction 1
Aerodynamics 2
Flight Operations 16
Engines 38
Electrical Power 43
Environmental Control 52
Fuel Gage System 54
Performance Analysis 56

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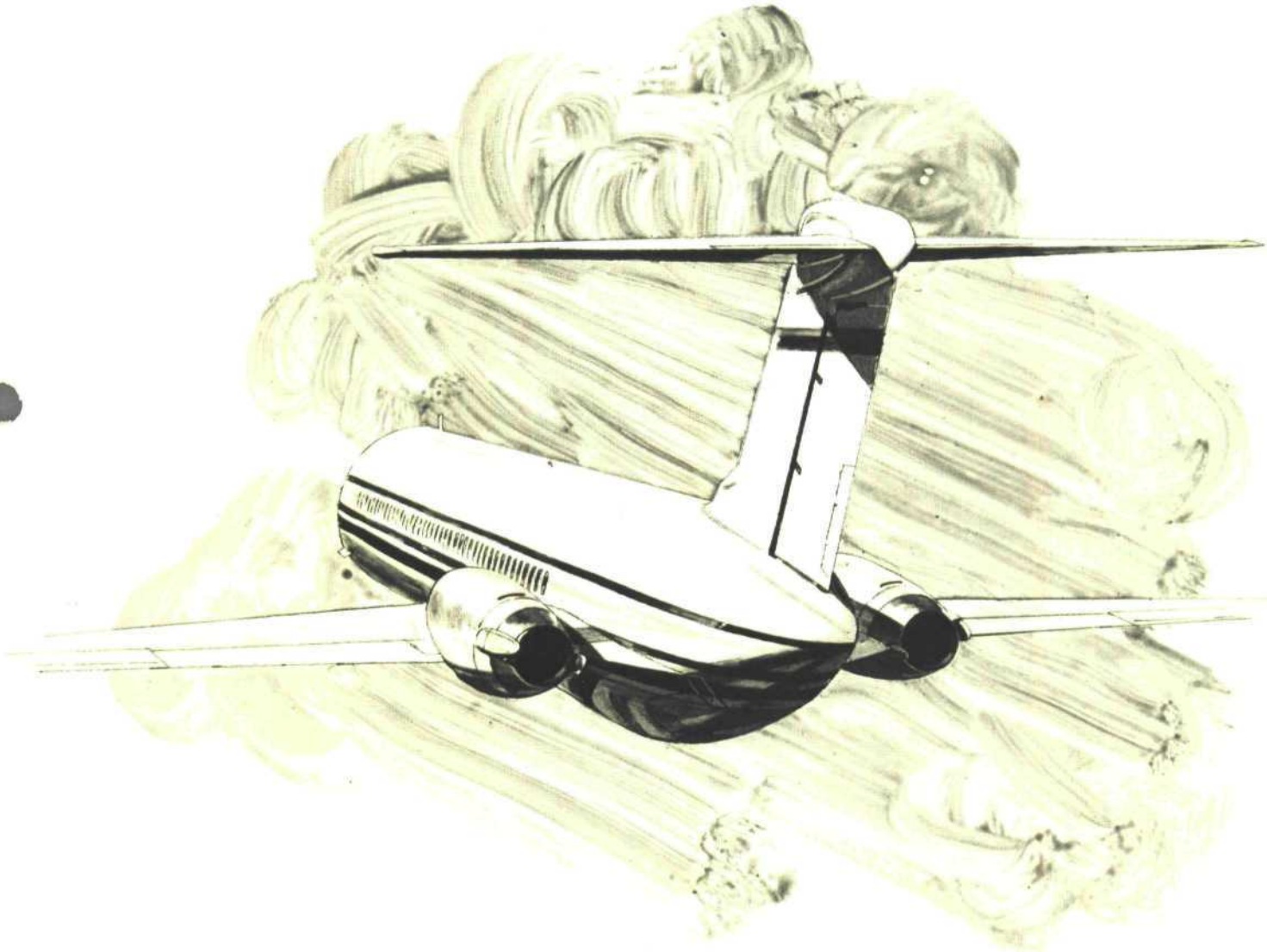

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