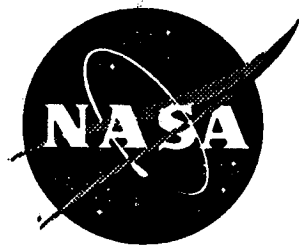


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NASA Technical Memorandum 109158



Why Do Airlines Want and Use Thrust Reversers?

A Compilation of Airline Industry Responses to a Survey Regarding the Use of Thrust Reversers on Commercial Transport Airplanes

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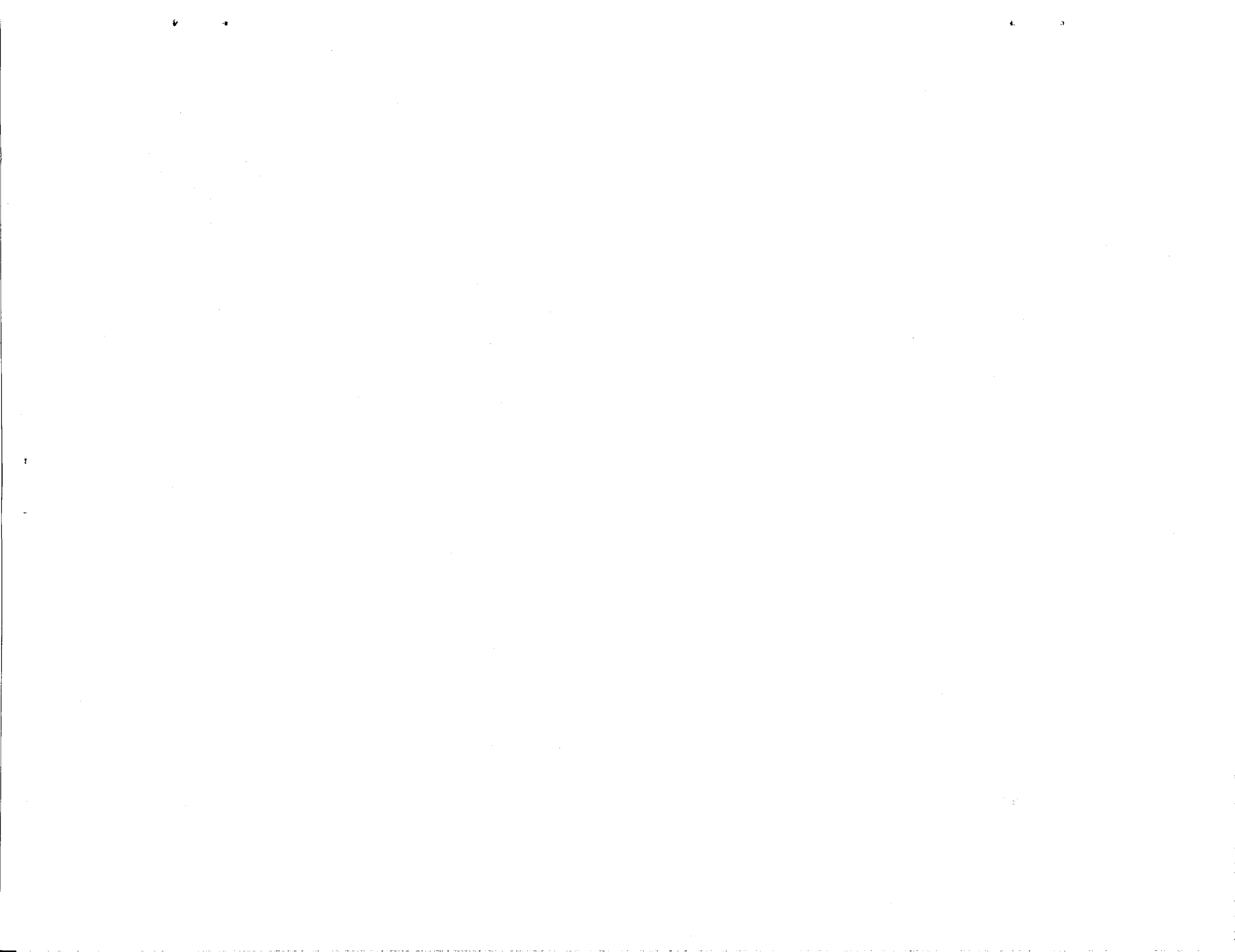
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SUMMARY

Although thrust reversers are used for only a fraction of the airplane operating time, their impact on nacelle design, weight, airplane cruise performance, and overall airplane operating and maintenance expenses is significant. Why then do the airlines want and use thrust reversers? In an effort to understand the airlines need for thrust reversers, the NASA Langley Aircraft Deceleration Study Group put together an airline questionnaire inquiring as to why and under what situations thrust reversers are currently used or thought to be needed. The survey was also intended to help establish the cost/benefits trades for the use of thrust reversers and airline opinion regarding alternative deceleration devices. A compilation and summary of the responses given by the airlines is presented.

INTRODUCTION

Aircraft deceleration systems for commercial transport airplanes have been identified by the commercial transport industry as an area in need of a "technology injection". The decelerating forces available on current commercial transports consist of wheel brakes, aerodynamic braking (such as flaps and speedbrakes) and thrust reversers. As shown in figure 1, the contribution of thrust reversers in terms of decreased stopping distance is small on a dry runway, but can be significant on contaminated runways when wheel braking effectiveness is greatly diminished.

Although the thrust reverser system is used for only a fraction of the airplane operating time, its impact on nacelle design, weight, airplane cruise performance, and overall operating and maintenance expenses is significant. Preliminary design studies conducted by General Electric Aircraft Engines indicate that the thrust reverser system accounts for more than 30 percent of the nacelle weight (not including engine) for an engine having a fan diameter in excess of 100 inches. This could be as much as 1500 lb for a GE 90 class engine. In addition, the installation of a thrust reverser system is estimated to increase the engine specific fuel consumption (SFC) by 0.5 to 1.0 percent as a result of leakage and pressure drops. The Boeing Commercial Airplane Company has estimated the total cost of using thrust reversers on a B-767 at about \$125,000 per airplane per year (includes amortization of initial costs). The savings associated with reduced brake wear due to the use of thrust reversers does not approach this expense. Thrust reversers are also noisy and have the potential for the reverser efflux to blow debris into the path of the airplane posing the risk of foreign object damage (FOD) and/or reduced visibility.

A deceleration system that employs engine power does offer some advantages over an aerodynamic braking system in that large retarding forces can be developed at low speeds when aerodynamic drag forces drop off significantly. However, due to reingestion concerns, thrust reversers are typically not used at speeds below about 60 knots. To achieve the greatest affect on deceleration, thrust reversers should be used at high speeds when the kinetic energy of the

airplane is greatest and braking/retarding forces are most effective at decelerating the airplane.

Thrust reverser systems represent a considerable cost to the commercial transport operator in terms of fuel burned and maintenance expenses for an item that is used only for a fraction of the total airplane operating time. Why then do the airlines want and use thrust reversers? Thrust reversers are not used during aircraft certification, nor are they required by FAA regulations. Thrust reversers are offered by the airframers as a backup to the airplane brake system and have become common place on nearly all turbofan powered commercial transport aircraft (one exception being the BAe 146). Although not required by regulation or for certification, the elimination of the thrust reversers would be difficult because of the added safety margins (albeit small) they provide in the event of an emergency.

In response to industry concerns about improving aircraft deceleration systems, the NASA Langley Research Center's Applied Aerodynamics Division formed the Aircraft Deceleration Study Group to address alternative ways of decelerating a commercial transport airplane during landing and refused takeoffs (RTO). Members of the working group included representatives from NASA, the FAA, airframe companies, engine companies, and thrust reverser manufacturers. In an effort to understand the need for thrust reversers, the study group put together an airline questionnaire to determine why airlines want thrust reversers and in what situations thrust reversers are currently used or thought to be needed. The survey was also intended to help establish the cost/benefits trades for the use of thrust reversers and to help establish the airline opinion regarding alternative deceleration devices. It was felt that since thrust reversers represent the state-of-the-art in supplemental stopping systems, a good understanding of how the airlines use thrust reversers would be useful in formulating aircraft deceleration requirements.

The questionnaire was sent to nearly all domestic airlines as well as major foreign airlines serving the United States. A list of the airlines surveyed is presented in Table I. A total of 64 questionnaires were sent out to the chief engineer of the domestic airlines or to the manager of the U. S. office of each foreign airline. A total of 22 airlines responded (34 percent) and are identified in Table I by boldface type. The titles and job functions of the respondents (those who completed the survey) are listed in Table II. The respondents represent a diverse cross-section of airline operating organizations, including engineering, maintenance, flight operations, and management. The airlines responding also provide a good representation of airline size and regions of the world.

A sample of the questionnaire sent to the airlines is presented in figure 2. The survey was organized into the following four parts:

- Thrust Reverser Utilization
- Economic Considerations
- Safety Considerations
- Alternative Concepts

This format was used to organize the questions around the three primary considerations for using thrust reversers and to seek initial reactions to alternative deceleration concepts. A "block" format was used in an effort to reduce the time required to complete the survey.

Compilations of the airline responses to each question are presented in figures 3 through 25. The responses have been tabulated without reference to the specific airline in an effort to keep the responses confidential. The actual airline responses are presented in quotations (i.e. " ... "). Editorial comments and explanations by the author are enclosed in brackets (i.e. [...]). The following discussion of the responses is organized according to the questionnaire format and the individual questions.

PART I - THRUST REVERSER UTILIZATION

The first section of the questionnaire addresses why and how the airlines use thrust reversers. The first question posed to the airlines was "why do we have thrust reversers?" (Question 1, see figure 3). The number one reason given by the airlines was to provide additional stopping forces in adverse weather conditions (i.e. on wet, slushy or slippery runways). The airlines also use thrust reversers to reduce brake wear and to provide directional control and additional safety margins during an aborted takeoff (RTO).

When the airlines were asked who they perceived as the principal organization behind the installation of thrust reversers on commercial transport aircraft (Question 2, see figure 4), the airlines responded that they were. That is, the aircraft manufacturers put the systems on board the airplanes because the airlines want them. The Federal Aviation Administration (FAA) does not require thrust reversers for airplane certification. The definition of certified landing distances per Federal Aviation Regulation (FAR) 25.125 is presented in figure 5.

Working group discussions suggested that there might be differences among the airlines as to how they instruct their pilots to use thrust reversers. The airlines were therefore asked to indicate their policy for using thrust reversers (Question 3, see figure 6). Most airlines deploy thrust reversers on every landing. The thrust reverser operating guidelines are well established and are typically based on inputs from the airframe manufacturer. Although most airlines deploy thrust reversers on every landing, the level of reverse thrust used is left to the pilots discretion. Most airlines instruct their pilots to put the reverser into idle reverse whether he intends to use the reverser or not.

It should be noted that most airlines recognize that since thrust reversers are available they should be used to reduce brake wear. Pilots are therefore instructed to use reverse thrust early in the landing sequence (high speed) so as to minimize the amount of wheel braking required.

It had been suggested that some airlines might have a policy of limiting the use of thrust reversers to emergencies only (Question 4, see figure 7). Of the

airlines responding, the policy of limiting the use of thrust reversers to "emergencies only" is not a common practice.

Regarding the use of reverse thrust (Question 5, see figure 8), pilots are instructed to deploy thrust reversers as soon as possible upon landing (after speedbrakes deploy). The airlines typically operate engines at 70 to 80 percent power with cutoff speeds between 60 and 80 knots to prevent problems associated with engine surge, reingestion and tail blanking. A sample engine operating line depicting thrust reverser usage is shown in figure 9. Examples of engine thrust limits and cutoff speeds used by various airlines are presented in figure 10. Weathervaning¹ in crosswinds can also affect the amount of reverser thrust used. Sample comments regarding the use of thrust reversers, extracted from the material provided by the airlines, are presented in Table III.

The working group was interested in how the use of thrust reversers might affect the set-up of the aircraft brake system (Question 6, see figure 12). The typical transport brake system consists of an anti-skid system and an autobrake system (ABS), each operating independent of the other. The function of the anti-skid system is to modulate the individual wheel brake pressure to achieve maximum braking effectiveness for the current runway condition. The anti-skid system senses wheel speed and adjusts brake pressure accordingly to prevent wheel lockup. The availability and/or use of thrust reversers has no impact at all on the design and function of the anti-skid system.

The autobrake system senses aircraft deceleration rate and modulates brake system pressure to maintain a constant preselected deceleration rate. The application of reverse thrust will result in reduced braking by the ABS system. The availability of the thrust reverser indirectly affects the use of the autobrake system in that the braking action required for a given deceleration rate is reduced when thrust reversers are used. To save on brake wear some airlines instruct their pilots not to use ABS except during adverse weather conditions. Examples of autobrake system settings are presented in figure 13.

As previously stated, the need for thrust reversers is most critical in adverse weather conditions. The airlines were asked how often they encounter "icy" conditions (Question 7, see figure 14). Airlines serving northern localities land on "icy" runways about 20% of the time while the typical airline operates in "icy" conditions about 2% to 5% of the time. Airlines divert to alternative airports less than 1% of the time as a result of poor weather. It should be noted that the wide variation in percentages given by the airlines is probably due to the definition of "icy" runway. Airlines use the term "slippery" for runway conditions that are worse than "wet". The definition of a slippery runway is - substantially covered with slush or with snow/ice and not sanded to provide satisfactory braking.

¹ Weathervaning (see figure 11) is defined as the condition where the reverse thrust side force component combines with the crosswind component to cause the airplane to yaw into the wind. This condition is alleviated by reducing the reverse thrust level and compensating with opposite rudder or differential braking.

Refused takeoffs (RTO's) were also identified as a primary reason for having thrust reversers on commercial transport aircraft. When asked how often RTO's are encountered (Question 8, see figure 15) the following conclusions were formed. The frequency of RTO's average about 2 per 10,000 takeoffs. The number of RTO's that occur on icy runways is probably about 1 per 100,000 takeoffs. As supporting data, Aviation Week (May, 12, 1992) estimated that by 1995 there will be about 6000 RTO's per year or an average of 16 per day. The average short haul pilot (short range flights, with numerous landings per day) is likely to make a RTO once every three years.

The airlines were asked about specific procedures for operating on "icy" runways (Question 9, see figure 16). Landing/takeoff on "icy" (e.g., unsanded) runways is often not permitted. Takeoffs on "slippery" runways require adjustments in gross weight and the RTO decision speed (V1) for a balanced field length. These adjustments take into account the availability of thrust reversers. Some airlines restrict operation on "slippery" runways if thrust reversers are inoperative.

The airlines were asked how often they encountered brake system failures (Question 10, see figure 17). The responses received ranged from none to as many as 83. The reason for this wide variation is that the term "brake failure" is subjective. Complete brake system failures are rare. Each airline operates according to an FAA approved Minimum Equipment List (MEL). As such, the airlines are allowed to operate with some portion (usually 1 or 2) of the individual wheel brakes inoperative (a partial failure). To do so, the airlines are required to make reductions to the airplane takeoff gross weight, V1, and increase the required runway landing length.

There appears to be no requirement for thrust reversers to be operational when a portion of the brake system is deactivated. During a follow up telephone conversation, one of the respondents suggested that if thrust reversers were not available (not installed on the airplane) then further weight reductions might be required.

Another reason often given for why thrust reversers are put on airplanes is for power back from the terminal gate. The airlines were asked to state their policy regarding the use of thrust reversers for power back (Question 11, see figure 18). The responses indicate that for reasons of ground safety, noise, and air pollution most airlines do not use thrust reversers for power back. A small minority of airlines do power back to minimize ground handling equipment and ground crew personnel requirements. In practice, power backs are typically limited to aircraft with relatively small (low thrust) tail mounted engines (B727, DC9, MD80, F100). Power back is not used on aircraft with the larger high bypass turbofans engines because of the large amount of air movement involved.

Airlines that do use thrust reversers for power back typically limit the engine power level used and require that all reversers be operational. For visibility concerns there must be no loose contaminants (i.e. snow) or heavy rain on the ramp. An additional issue regarding power back is a "tail tip". Brakes are never applied during the roll back and forward thrust is used to stop the airplane.

Since thrust reversers directly affect landing distances, the airlines were asked if field length was critical to their operations and route structure (Question 12, see figure 19). Field length is often critical to the airlines, particularly with larger aircraft, airports with short runways, and under adverse weather conditions.

Heavy braking (high deceleration rate) during landings often lead passengers to assume that the pilot is trying to make the first taxiway cutoff or to get to the terminal gate "on time". The airlines were asked whether or not "on-time arrival" had any affect on their policy for using thrust reversers (Question 13, see figure 20). The airlines do not promote the practice of a quick egress from the runway to meet scheduled arrival times. This practice would in fact be contrary to their desire to minimize brake wear. In practice however, air/ground controllers do request that the runway be cleared quickly during busy arrival/departure periods.

PART II - ECONOMIC CONSIDERATIONS

Working group discussions suggested that the use of thrust reversers increased the engine maintenance cost as a result of the increase in the number of operating cycles on the engine. The airlines were asked how the use of thrust reversers affected their engine maintenance schedules (Question 14, see figure 21). The responses and follow-up telephone conversations indicate that engine maintenance schedules are typically based on a combination of engine hours and cycles. In effect, the engine cycles per flight are factored into the flight hour referenced maintenance schedules for each aircraft type. Thrust reverser maintenance activities are performed along with routine (scheduled) engine and airframe inspections. The schedules used for typical pylon mounted thrust reversers (i.e. cascade reversers) for high bypass engines coincide with airframe inspections. The schedules used for engine mounted thrust reversers (i.e. clamshell reversers) coincide with engine inspections. Therefore, thrust reversers do not directly impact airframe or powerplant maintenance schedules.

It should also be noted that an engine cycle is defined as a flight cycle where a takeoff and landing (or RTO) was made. The deployment of the thrust reverser and a change in engine power setting during landing is not considered an additional engine cycle. An engine ground run-up for maintenance checkout would also not be counted as an engine cycle. This definition is used throughout the airline industry.

Engine cycles are important when it comes to the turbine disc and the number of mechanical cycles experienced. Turbine blade tip wear due to thermal cycles is critical to engine performance, not to mechanical reliability. Tip wear causes engine performance losses which show up as higher exhaust gas temperatures (and eventually an over temperature) when setting maximum power.

The airlines were asked what they consider the cost/benefits trades for thrust reversers to be (Question 15, see figure 22). The reduction in brake wear due to the use of thrust reversers is typically quoted at about 25 percent. Reductions in brake temperatures also impact aircraft ground turn around time. It is generally recognized that brake system costs are less than thrust reverser maintenance expenses. However, this trade is largely dependent on the aircraft type and age, and could affect the cost/benefits conclusions. Since the airlines consider thrust reversers necessary for safe airplane operation, they have not made a rigorous cost assessment.

During follow-up discussions, Airline 17 provided the following breakdown of brake system maintenance cost for their entire fleet and for two airplane types in particular:

Entire fleet (projected for 1992) = \$25 million

DC-10 = \$12.9 million (54 airplanes @ \$238,889 per airplane)

B-747 = \$3.1 million (52 airplanes @ \$59,615 per airplane)

Rest of fleet = \$9.0 million (382 airplanes @ \$23,560 per airplane)

These data show that the brake system costs vary significantly with airplane type.

An estimate of the savings in brake system costs attributable to the use of thrust reversers was made using the data above. A summary of the calculations and a breakdown of the cost per airplane is shown in Table IV. The first two columns represent the fleet make up of the airline. A duty factor (DF), defined as the number of flights per day per aircraft type, was assumed so that the total number of landings (sum of column 5) matched the number provided in Question 7 (see figure 14). The number of landings per airplane was then computed for each airplane type. Using the cost numbers given above for the DC-10 and B-747 an estimate of the brake system cost for the other airplane types was made. An initial estimate was made based on the landing kinetic energy corresponding to the published landing weights and landing speeds for each airplane type. The average brake cost per landing was then adjusted (considering airplane service age and relative size) until the total fleet brake costs matched the total given above. Although this approach is only a gross approximation, the relative magnitudes of the per airplane costs are thought to be representative and are in general agreement with the responses given to question 15. Using a brake savings factor of 25 percent, the savings in brake system costs due to the use of thrust reversers was estimated. The results show that the total yearly savings in brake system costs is about \$8.6 million, or an average of about \$17,700 per airplane for airline 17.

When asked if they thought that thrust reversers were cost effective (Question 16, see figure 23), the nearly unanimous airline response was yes. Due to the safety aspect and added margins when operating in adverse weather conditions thrust reversers are considered cost effective. There was also an implied consensus among the airlines that thrust reversers provided an adequate (though sometimes intangible) return on investment (ROI). Airline 17 also

provided an additional operating expense; the increase in fuel costs attributed to the weight of the thrust reverser averages about \$6,000 per year.

To settle the cost/benefits issue, the airlines were asked to provide estimates of what it costs to maintain thrust reversers (Question 17, see figure 24). As shown in the table below, the responses ranged from \$10,000 to \$187,000 per airplane per year, with an average cost was about \$53,000. The actual costs depend on the type of thrust reverser system (complexity) and age of the airplane.

Maintenance Cost per Airplane per Year

	<u>Brake System</u>	<u>Thrust Reversers</u>
Airline 3	n/a	\$100,000
Airline 4	\$29,500	\$31,000
Airline 7	n/a	\$30,000
Airline 9	n/a	\$20,000
Airline 11	\$33,000	n/a
Airline 12	n/a	\$40,000
Airline 13	n/a	\$187,000
Airline 16	n/a	\$27,500
Airline 17	\$53,000 est	\$12,000
Airline 22	n/a	\$27,000
	-----	-----
Average	\$38,500	\$53,000
Brake Wear Savings	\$12,800	

Estimates for brake system maintenance costs ranged from \$29,500 to \$53,000 per aircraft/year, with an average cost of about \$38,500 per airplane/year. On the basis of a 25 percent savings in brake system costs due to the use of thrust reversers, the total brake system costs without thrust reversers would have been about \$51,300 ($\$38,500/0.75$). This translates to a savings in brake system maintenance costs of about \$12,800 per airplane/year.

The thrust reverser maintenance costs are considerably larger than the costs associated with savings in brake wear. Comparing the average thrust reverser maintenance cost (\$53,000) to the average savings in brake system costs (\$12,800), thrust reversers maintenance costs are more than four times the savings in brake system costs. The use of thrust reversers solely on the basis of a perceived savings in brake system maintenance costs does not appear to be a valid justification.

PART III - SAFETY CONSIDERATIONS

The airlines were asked if thrust reversers were necessary for safe operation (Question 18, see figure 25). In general, the airlines feel that thrust reversers provide an added margin of safety for transport aircraft operations. Most airlines consider them essential to achieving the maximum level of operating safety.

When asked if thrust reversers have ever actually prevented an accident (question 19, see figure 26), the general implication was that any successful landing made using thrust reversers during adverse weather conditions demonstrates the benefits of thrust reversers. Most of the examples given indicated that thrust reversers were sometimes used to prevent accidents during ground operation. These examples emphasize a benefit of a powered reverser system.

The airlines were asked if any problems had ever been encountered in stopping an airplane after all thrust reversers had been locked out or made inoperative (Question 20, see figure 27). Operating with the thrust reversers locked out should not pose a problem for the safe operation of the airplane since it is certified without credit for thrust reversers. No problems with stopping the airplanes were reported. Typically, the MEL allows at least one thrust reverser to be locked out on a dry runway without adjustments to operating weights, speeds, etc.

It should be noted that during the period of time that the Boeing 767 thrust reversers were locked out by a FAA ruling, weight penalties were imposed on the airlines. For example, for a "cluttered" runway (1/2 inch of standing water - thunderstorm) an 11,000 lb gross weight penalty was imposed (~3%). This suggests that changes in the certification process might be required for large airplanes having no thrust reverser system.

Question 21 (figure 28) inquired about the types of problems typically encountered with thrust reverser systems. The types of problems identified by the respondents were:

- Indicator problems
- Inability to Deploy or Stow
- Mechanical failure: Actuator, Blockers, Linkages, Cascades
- Wear, Delamination of acoustic treatments
- Leaks

Although the failure rates provided by the respondents are difficult to quantify, they appear to be low, typically less than 3 per 1000 hours. The older the airplane or more complex the system, the higher the failure (squawk) rates.

PART IV - ALTERNATIVE CONCEPTS

The airlines were asked what they thought of eliminating thrust reversers from commercial transports (Question 22, see figure 29). The question stated that the replacement system would be cost effective and a safe alternative. It was implied that the alternative concept would have the same or better stopping effectiveness. In general the respondents were not opposed to alternative concepts. The airlines did indicate that such a system would have to provide for:

- Directional control at high and low speeds, on slippery runways and taxiways.
- Must be independent of runway friction
- Be flexible enough to be used at pilots discretion (for the unforeseen events)

Numerous airlines are concerned about the expense of retrofitting existing aircraft and were pessimistic about the likelihood of being able to develop an alternative system. Retrofit costs and certification costs should be included in any alternative system cost studies. [However, it was not the intent of the Working Group to imply that retrofit was a goal.]

The final question dealt with what type of alternative deceleration concept the airlines would be most interested in (Question 23, see figure 30). Of the alternative concepts offered, the airlines were most interested in the variable pitch fans. Reduced landing speeds via improved high lift systems was the second choice, followed by airframe mounted drag devices and systems that improved braking effectiveness. The airlines expressed little or no interest in off-airplane devices such as tail hooks, nets, or extended runway overruns.

The airlines were encouraged to make additional comments which might be pertinent to the survey. A summary of the specific comments received are presented in figure 31. The ideas expressed were included in the discussions above.

CONCLUSIONS

The following conclusions were formulated based on the airline responses to the questionnaire.

Thrust Reverser Utilization

Thrust reversers are used to provide an additional stopping force on wet and slippery runways.

Thrust reversers provide additional safety and control margins during aborted takeoffs, landings, and ground operations.

The airlines are the main driver behind the use of thrust reversers on commercial transport aircraft.

The airlines have specific guidelines as to how reversers should be used:

- Thrust reversers are usually deployed on every landing;
 - > Use of thrust reversers "in emergencies only" is not a common practice.
- For maximum effectiveness thrust reversers are deployed as soon as possible after touchdown.
- The amount of reverse thrust used is left to the pilots discretion;
 - > Most airlines use "normal" reverse thrust levels to reduce brake loads.
 - > Specific limits on the maximum thrust levels to be used do exist.

Thrust reverser cutoff speeds are based on engine surge, reingestion and tail blanking considerations.

The use of reverse thrust for quick egress from the runway is usually at the request of ground controllers and is not a typical airline operating policy.

The number of airlines using thrust reversers for power back is limited:

- Not used for reasons of ground crew safety, noise, and air pollution.
- Used only on aircraft with smaller engines (i.e. Thrust < 30,000 lb).
- Not likely to be used with larger high bypass turbofan engines.

The availability of thrust reversers has no bearing on the design and setup of aircraft brake systems (anti-skid & autobrakes):

- Anti-skid systems must be fully functional in adverse weather conditions per the minimum equipment lists (MEL).
- Thrust reversers reduce the amount of wheel braking performed when the autobrake system is active.
- Autobrake stopping performance is better than that achievable with manual braking.

In temperate climates, landings are made in "icy" conditions about 2% of the time and more than 20% of the time in more northern localities.

The frequency of refused takeoffs (RTO) is about 1 per 5000 takeoffs.

The frequency of refused takeoffs on "icy" runways is about 1 per 100,000 takeoffs.

Operation in adverse weather requires reductions in takeoff weight and the aborted takeoff decision speed (V1):

- All thrust reversers must be operational per the MEL.

Total brake system failures are rare.

Aircraft are typically allowed to operate with at least one wheel brake inoperable per the minimum equipment list:

- Adjustments to takeoff weight, V1 speed, and runway landing length are required.

When the B767 was operated with all thrust reversers locked out, operating weight penalties were imposed by FAA when operating on wet/slippery runways. This suggests that certification changes may be required for future airplanes built without thrust reversers.

Field lengths are often critical for heavy, long haul aircraft:

- Adverse weather creates additional critical field length situations.

Economic Considerations

Because of the added safety margins, the airlines consider thrust reversers to be cost effective.

The use of thrust reversers has little impact on airline maintenance schedules:

- Thrust reverser inspection/maintenance is typically performed as part of normally scheduled airframe and powerplant inspection and maintenance.
- Interim repairs are made on an as needed basis.

The use of thrust reversers reduces brake wear by about 25%.

The use of thrust reversers reduces brake temperatures and therefore aircraft turn-around time.

The cost of thrust reversers and brakes is largely dependent on aircraft type and age.

Cost trades do not benefit the use of thrust reversers:

- Thrust reverser costs average about \$53,000 per aircraft/year.
- Brake system costs average about \$39,000 per aircraft/year.
- The typical savings in brake system maintenance costs due to reduced brake wear (25%) is about \$12,800 per aircraft/year.

Estimated fuel cost to carry the additional weight of thrust reversers is about \$6,000 per aircraft/year.

Safety Considerations

The airlines consider thrust reversers essential to achieving the maximum level of aircraft operating safety.

Typical problems encountered with thrust reversers are sensor or indicator problems, inability to stow/deploy due to mechanical problems (valves, actuator, linkages), wear, leaks, and acoustic treatment delaminations:

- Problems occur at a rate of less than 3 per 1000 flight hours.

Examples were given of situations where the use of thrust reversers prevented an accident during ground operation (slippery taxiways). Concerns for aircraft controllability at low speeds and on slippery runways and taxiways were also expressed.

- This emphasizes the need/benefits for a powered thrust reverser system for optimum safety and operability.

Alternative Deceleration System Concepts

Alternative deceleration systems concepts might be considered as supplemental systems, rather than as replacements for thrust reversers.

Airlines expressed most interest in variable pitch fans, high lift systems which reduce landing speeds, and alternative high drag devices.

Little interest was expressed towards alternative methods of reversing engine thrust and ground based stopping systems.

Alternative deceleration systems must offer the same or higher levels of safety, reliability, and operational flexibility.

NASA Langley Research Center
Hampton, VA 23681-0001
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UNITED STATES

Air Wisconsin
Alaska Airlines
Aloha Airlines
American Airlines
America Trans Air
America West Airlines
Continental Airlines
Delta Airlines
Emory Worldwide
Federal Express
Hawaiian Airlines
Northwest Airlines
Southwest Airlines
Trans World Airlines
United Airlines
UPS of America
USAir

CANADA & MEXICO

Air Atlantic
Air Canada
Canadian Airlines Intl.
Aeromexico
Mexicana Airlines

ASIA & PACIFIC

Air India
Air New Zealand
All Nippon Airways
Ansett Australia
Australian Airlines LTD
Cathay Pacific Airways (H. K.)
China Airlines (Taiwan)
Japan Airlines
Korean Air
Qantas Airways (Australia)
Singapore Airlines
Thai Airways

MIDDLE EAST

Egyptair
El Al Israel Airlines Ltd
Kuwait Airways
Middle East Airlines
(Lebanon)
Royal Jordanian Airlines
Saudi Arabian Airlines

AFRICA

Ethiopian Airlines
Nigeria Airways
Royal Air Maroc (Morocco)
South African Airways
Zambia Airways

EUROPE

Aer Lingus (Ireland)
Air France
Alitalia (Italy)
Austrian Airlines
British Airways, PLC
Finnair
Iberia Airlines (Spain)
Icelandair
KLM - Royal Dutch Airlines
Lufthansa German Airlines
Olympic Airlines (Greece)
Sabena (Belgium)
SAS (Denmark, Norway, Sweden)
Swissair
Virgin Atlantic Airways (GB)

SOUTH AMERICA

Aerolineas Argentinas
Avianca (Colombia)
Ladeco Airlines (Chile)
LAN Chile Airlines
Varig Airlines (Brazil)

Table I. List of airlines surveyed and the airlines who responded (respondants in bold type).

Airline 1	Maintenance Prod. Manager
Airline 2	Manager Power Plant Engineering
Airline 3	(unknown)
Airline 4	Specialist Engineer - Powerplant Engineering
Airline 5	Manager Powerplant Engineering
Airline 6	General Manager - Performance & Products Engineering
Airline 7	V. P. Maintenance & Engineering
Airline 8	Project Engineer, Development & Operations Engineering
Airline 9	Manager Flight Ops Eng & Development,
Airline 10	Director of Flight Operations
Airline 11	Vice President, Engineering Department
Airline 12	V. P. Ground Services - The Americas
Airline 13	(unknown)
Airline 14	Asst Director of Flight Operations (Line Operations)
Airline 15	Technical Pilot, MD-11
Airline 16	Staff Vice President - Engineering & Quality Control
Airline 17	Director, Engineering Systems & Standards
Airline 18	Chief Pilot
Airline 19	Project & Development Manager
Airline 20	Technical and Air Safety Manager (Airline Captain)
Airline 21	Manager Powerplant Engineering
Airline 22	Operations Engineering Group

Table II. Position held by airline representatives answering survey.

The importance of establishing the desired reverse thrust level as soon as possible after touchdown, to minimize brake temperatures and tire and brake wear and to reduce stopping distances on very slippery runways, cannot be overemphasized. (Ref: 757/767 AOM)

The use of minimum reverse thrust significantly increases the brake energy requirements and can result in brake temperatures much higher than normal. (Ref: 737-300/500 Flight Manual)

The use of minimum reverse thrust will almost double the brake energy requirements and can result in brake temperatures much higher than normal. (Ref: A300 AOM)

No go-around after reverser deployed (reverser may not stow).

Crosswind landings can be aggravated by use of thrust reverser (weathervaning).

Pilots should use at least idle reverse on all landings. (Ref: MD80 AOM)

Adequate reverse thrust is generally recommended to minimize the use of brakes during the high speed portion of the landing roll.

When landing on long dry runways use reverse thrust as the primary method of slowing the airplane. Use manual braking in preference to the autobrake system. (Ref: B-747 Flight Manual)

If yaw develops (due to "tail blanking") which cannot be controlled by use of rudder, return to forward idle until directional control is regained. (Ref: MD80 AOM)

B727 EPR limits imposed by "tail blanking" and reingestion considerations.

For MD-11's, some airlines limits use of the thrust reverser on the no. 2 engine (center) to idle reverse under normal operating conditions.

Set normal reverse on contaminated runways (ref: MD-11 AOM)

Table III - Typical airline instructions regarding the use of thrust reversers.

A/P Type	No. of A/P	Duty Factor (DF)	No. * DF	No. of Landings	Landings per A/P	Max Landing Weight (lb)	A/C Landing Speed (mph)	Maximum Kinetic Energy (ft-lb)	Brake Cost per Landing	Total Brake Cost	Brake Cost per Aircraft	Savings/AP Using 25 % Reduction in Brake Costs
B 727	115	5	575.0	236077	2053	148000	142	9.98E+07	\$14	\$3,305,073	\$28,740	\$9,579
B 737	196	5	980.0	402357	2053	130000	153	1.02E+08	\$10	\$4,023,567	\$20,528	\$6,842
B 747	52	1	52.0	21350	411	550000	160	4.71E+08	\$145	\$3,095,683	\$59,532	\$19,842
B 757	47	2.5	117.5	48242	1026	198000	152	1.53E+08	\$25	\$1,206,044	\$25,661	\$8,553
B 767	24	2.5	60.0	24634	1026	285000	157	2.35E+08	\$56	\$1,379,509	\$57,480	\$19,158
DC 10	54	2	108.0	44341	821	380000	160	3.25E+08	\$290	\$12,858,991	\$238,129	\$79,369
Totals	488		1892.5	777000						\$25,868,865		

Total Landings / (No. * DF) = 410.6

Cost Summary

Total Brake Cost = \$25,868,865

Average Brake Cost per Aircraft per Year = \$53,010

Total Savings at 25% of Brake Costs = \$8,622,093





Average Savings per Aircraft per Year = \$17,668

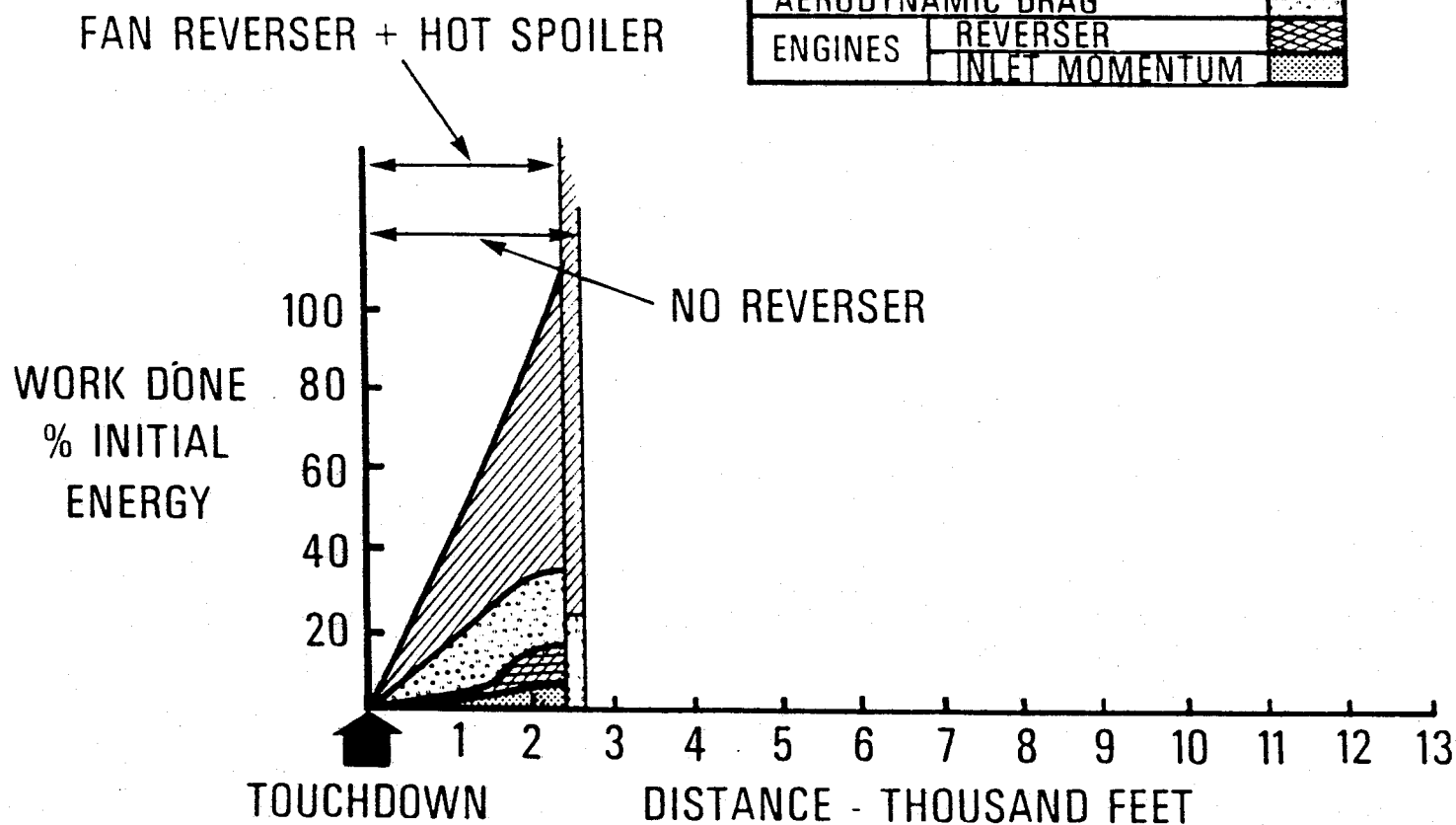
DF = Assumed duty factor (no. of flights per day)

Table IV. Estimate of brake system cost and savings on the basis of aircraft type.

Aircraft Landing on a Dry Runway

Source: General Electric Aircraft Engines

BRAKES		
AERODYNAMIC DRAG		
ENGINES	REVERSER	
	INLET MOMENTUM	

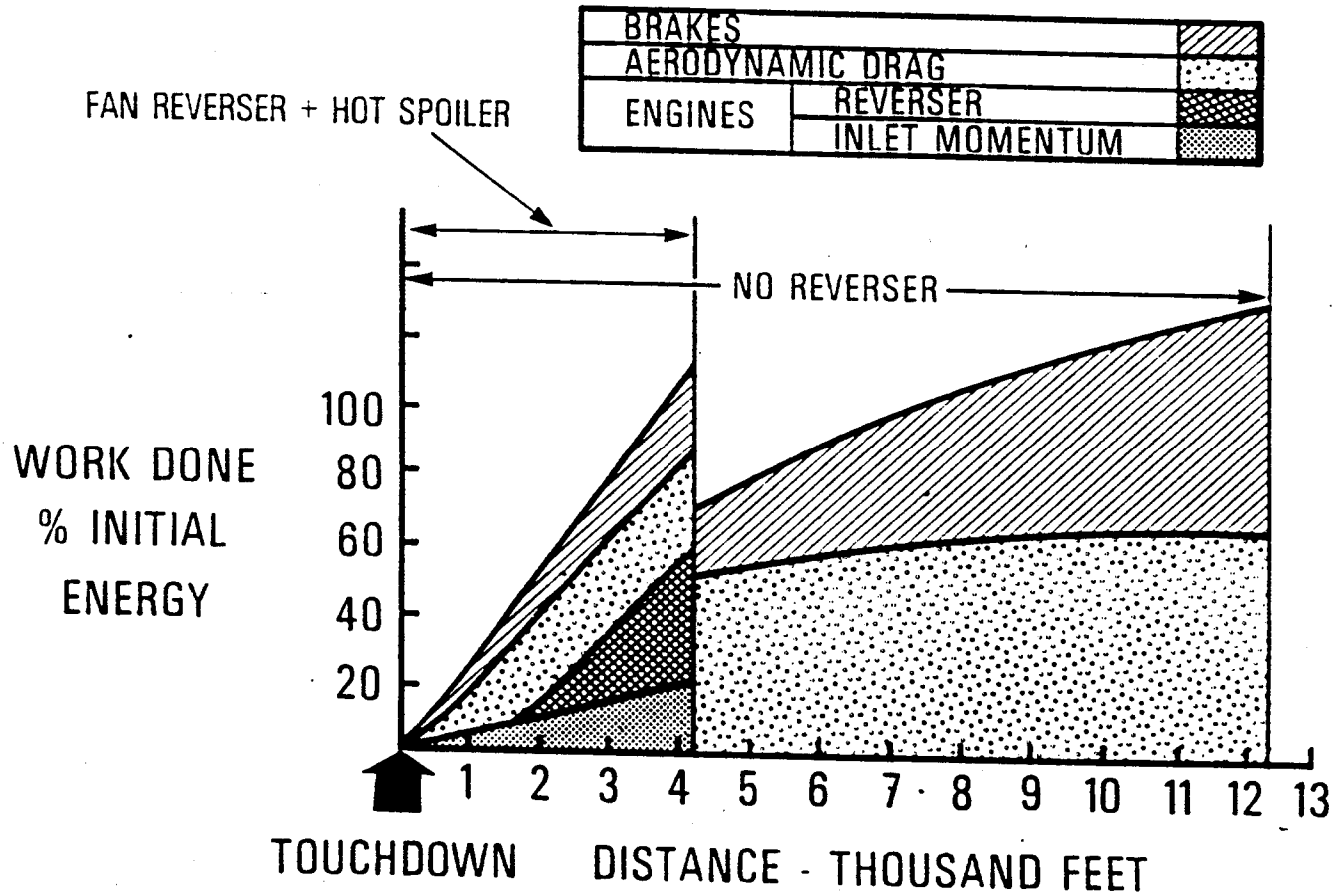


a. Dry runway.

Figure 1. Aircraft landing distances on dry and icy runways.

Aircraft Landing on a Icy Runway

Source: General Electric Aircraft Engines



b. Icy runway.

Figure 1. Concluded.

Commercial Transport Aircraft Thrust Reverser Questionnaire

Part I - Thrust Reverser Utilization

1. Why do you think thrust reversers are installed/required on commercial transport airplanes?

- To reduce brake wear.
- To reduce taxi distance.
- To reduce certified landing field lengths.
- To provide additional stopping force on wet, slushy and icy runways.
- For refused takeoffs (RTO).
- For taxiing on slushy and icy taxiways.
- For power back.
- Pilots want them.
- Other(s) _____

2. Who do you feel drives the need for thrust reversers on commercial transports?

- The airlines (i.e. for safety).
- The airframer (i.e. to meet field length specifications).
- The FAA (regulations).
- Other(s) _____

3. What is your airline's policy toward the use of thrust reversers?

- Use on every landing.
- Use at pilots discretion.
- Use only in emergency (RTO, landing hot/long).
- Other(s) _____

Do you have specific guidelines or "recommended operating procedures" for your pilots to follow? Yes No

Please attach an explanation or provide a copy of these guidelines if possible.

4. If your airline has a policy of not using thrust reversers except in emergencies, what are typical reasons for their use? _____

5. Do you have specific procedures for how thrust reversers should be operated (i.e. deployment sequence, power level, cutoff speed, etc)?

- Yes No

If yes, what are they? Maximum power _____ % N1
Cutoff Speed _____ knots
Other(s) _____

Please provide a copy of these procedures if possible.

Figure 2. Sample of questionnaire sent to the airlines.

Commercial Transport Aircraft Thrust Reverser Questionnaire (cont)

6. Is the availability and use of thrust reversers considered in the setup of the aircraft brake system antiskid features (i.e. maximum brake system pressure)? Do you have a recommended procedure for using "Autobrakes" during landing? Please explain: _____

7. Approximately how many landings does your fleet make each year? _____
How many of them are on "icy" runways? _____ How many are diversions to alternate airports? _____
8. On average, how many refused takeoffs (RTO) does your fleet encounter each year? _____ How many of those are on "icy" runways? _____
9. What are your operational procedures/restrictions for landing/takeoff on "icy" runways? _____

10. On average, how many occurrences of brake failure does your fleet encounter each year? _____
11. Does your airline use thrust reversers for power back?
 Yes No
If so, with what type of airplane(s)? _____

12. Is aircraft operational field length critical to your route structure? Please explain:

13. Does on-time arrival at a terminal gate have any impact on the airline instruction/pilot decision process on thrust reverser deployment to achieve quicker egress to the taxiway? Yes No

Part II - Economic Considerations

14. Is your engine maintenance/servicing schedule based on engine cycles, engine operating hours, or a combination of the two?
 Cycles Hours Combination
How does the use of thrust reversers affect your maintenance schedules?
Please explain: _____

Figure 2. Continued.

Commercial Transport Aircraft Thrust Reverser Questionnaire (cont)

15. Has your airline evaluated the costs/benefits of thrust reverser usage (i.e. savings in brake wear versus engine and reverser system maintenance, effect on engine/airplane cruise performance)?

Yes No

If yes, what are the trades as you see them? _____

16. Do you feel that thrust reversers are a cost effective means for aircraft deceleration? Do they provide an adequate return on investment (ROI)? Please explain: _____

17. What is your estimate of the yearly cost per airplane of maintaining thrust reversers for your fleet? _____

Part III - Safety Considerations

18. Do you feel that thrust reverser are necessary for safe aircraft operations? Please explain: _____

19. Are you aware of any instances where the use of thrust reversers prevented an accident? Please explain: _____

20. To your knowledge, has there ever been any instances where an RTO was made while an airplane's thrust reversers were inoperable or locked out?

Yes No

If so, were any problems encountered with stopping the airplane? _____

21. What type of thrust reverser problems does your fleet typically encounter (i.e cascade failures, inability to stow, inadvertent deployment). How often (say in 1000 landings) do such problems occur. Please comment: _____

Figure 2. Continued.

Commercial Transport Aircraft Thrust Reverser Questionnaire (cont)

Part IV - Alternative Concepts

22. What is your opinion of removing thrust reversers from commercial transports, assuming a more cost effective and safe alternative is available? _____

23. In your opinion, which of the following potential alternatives to engine mounted thrust reversers are most worthy of study:

- Airframe mounted flap/thrust deflector system.
- Variable pitch fans.
- Reduce airplane landing speeds via improved high lift systems.
- Airframe mounted high drag devices (i.e. chutes, overextended flaps/spoilers, speed brakes).
- Off airframe drag devices (i.e. arresting hook, nets, pickup devices, other ground based systems).
- Concepts which improve brake effectiveness (i.e. friction coefficient).
- Runway solutions (i.e. soft extensions, overrun nets).
- Other(s) _____

Please provide the name and telephone number of a contact and add any additional comments below.

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1) Why do you think thrust reversers are installed/required on commercial transport airplanes?

- A To reduce brake wear.**
- B To reduce taxi distance.**
- C To reduce certified landing field lengths.**
- D To provide additional stopping force on wet, slushy and icy runways.**
- E For rejected takeoffs (RTO).**
- F For taxiing on slushy and icy taxiways.**
- G For power back.**
- H Pilots want them.**
- I Other(s)**

Airline 1	A, D
Airline 2	I; "They increase the safety factor on all airfield operations."
Airline 3	D, E
Airline 4	D, I; "To provide additional stopping force on dry runways."
Airline 5	D, H
Airline 6	A, D, E
Airline 7	C, D, E
Airline 8	A, D
Airline 9	D, F, I; "Directional steering on slippery taxiways and apron area."
Airline 10	D
Airline 11	A, D
Airline 12	A, D
Airline 13	A, G
Airline 14	A, D
Airline 15	A, D, E
Airline 16	A, D, E, I; "To reduce landing roll in all weather conditions."
Airline 17	D, I; "Add controllability margins. Allows safe completion of less than perfect landings, etc."
Airline 18	A, D, E, H
Airline 19	A, C, D
Airline 20	A, D, I; "And as a safety device."
Airline 21	A, D, E, H
Airline 22	D, E, H

Figure 3. Airline responses to question 1 (question in bold type).

2) Who do you feel drives the need for thrust reversers on commercial transports?

- A The airlines (i.e. for safety).**
- B The airframer (i.e. to meet field length specifications).**
- C The FAA (regulations).**
- D Other(s)]**

Airline 1	B
Airline 2	D; "Airframer wants T/R's but not for field length. They are not used for certified field lengths."
Airline 3	A
Airline 4	A, B; "While thrust reversers are not required by the FAR's some airlines (including Airline 4) have specified the use of reversers in stopping distances performance criteria."
Airline 5	A
Airline 6	A, B, C
Airline 7	B, C
Airline 8	A
Airline 9	A
Airline 10	A
Airline 11	A
Airline 12	A
Airline 13	D; "Conservatism"
Airline 14	B, C
Airline 15	A
Airline 16	A
Airline 17	A; "The airlines, increased safety margins since the FAA certifies aircraft operation without reversers. Side benefits in reduced brake costs. Brakes cost per landing are \$5 for the 737 and \$128 for the 747."
Airline 18	A
Airline 19	B, C
Airline 20	A
Airline 21	A
Airline 22	A

Figure 4. Airline responses to question 2 (question in bold type).

Reference: Federal Aviation Regulation (FAR) 25.125

Definition of Actual Demonstrated Landing Distance = Distance Required to Stop

- From 50 ft at $V_{app} = 1.3 V_s$
- Using maximum wheel braking and speedbrakes (without thrust reversers)
- On a dry runway

Built in Margins for "Minimum Landing Field Length" are:

FAR Dry Runway Landing Distance	= 1.67 x Actual Demonstrated Distance
FAR Wet Runway Landing Distance	= 1.15 x FAR Dry Runway Landing Distance
	= 1.92 x Actual Demonstrated Distance

Credit for thrust reversers is not given in the FAR landing distances.

These margins are imposed to account for operational variables such as:

- High touchdown speeds
- Long touchdown (i.e. high approach or extended flare)
- Worn brakes and tires

Figure 5. Definition of certified landing distances.

3) What is your airline's policy toward the use of thrust reversers?

- A Use on every landing.**
- B Use at pilots discretion.**
- C Use only in emergency (RTO, landing hot/long).**
- D Other(s)**

Do you have specific guidelines or "recommended operating procedures" for your pilots to follow? Please provide a copy of these guidelines if possible.

Airline 1	C; Yes
Airline 2	A; Yes
Airline 3	A; Yes; "We operate as per manufacturer's operating procedures (DC9-30/MD-80/MD-11/B747-200/A300 B6200)"
Airline 4	A; Yes; "Copies of Airline 4 operating procedures for each aircraft in our fleet are attached for your detailed review."
Airline 5	B; Yes
Airline 6	A, B; Yes
Airline 7	A; Yes; "Airplane Flight Manual"
Airline 8	A; [samples of Flight Operations Manuals provided]
Airline 9	A; "Activate on every landing and use power reverse at pilots discretion"; Yes; "Speed and EPR values to be used normally, not to use high EPR's on certain noise sensitive airports except in emergency, always use at least idle reverse and be prepared for power use."
Airline 10	A; Yes
Airline 11	A; Yes [page from 747-400 AOM attached]
Airline 12	A
Airline 13	A; Yes [page from MD-80 AOM attached]
Airline 14	A; Yes; "Max reverse thrust on landing. Initiate reduction at 80 KIAS to reach reverse idle by 60 KIAS. Return to forward thrust after engines have decelerated to reverse idle rpm."
Airline 15	A, B; Yes [guidelines for MD-11 provided]
Airline 16	A; Yes
Airline 17	A, "Normally on every landing but at pilots discretion." [sample procedures attached]
Airline 18	A; Yes; "Boeing and Douglas guidelines."
Airline 19	A; Yes; "Reverse 'idle' only in some situations."
Airline 20	A; Yes
Airline 21	A, B; Yes
Airline 22	A, B; "Variable from idle reverse to full reverse."

Figure 6. Airline responses to question 3 (question in bold type).

4) If your airline has a policy of not using thrust reversers except in emergencies, what are typical reasons for their use?

Airline 1	"Airline 1 only operates BAe 146-200 aircraft (no reverse capabilities) and DHC turboprops (with reverse pitch propellers). Icy ramp and runways conditions would be typical situations for reverse application."
Airline 2	n/a
Airline 3	n/a
Airline 4	"Question does not apply to Airline 4."
Airline 5	"Contaminated runways."
Airline 6	"Don't have such a policy."
Airline 7	"No"
Airline 8	n/a
Airline 9	[no response]
Airline 10	n/a
Airline 11	n/a
Airline 12	n/a
Airline 13	n/a
Airline 14	n/a
Airline 15	n/a
Airline 16	n/a
Airline 17	n/a
Airline 18	n/a
Airline 19	n/a
Airline 20	n/a
Airline 21	n/a
Airline 22	n/a

Figure 7. Airline responses to question 4 (question in bold type).

5) Do you have specific procedures for how thrust reversers should be operated (i.e. deployment sequence, power level, cutoff speed, etc)?

If yes, what are they? Maximum power _____ % N1
Cutoff Speed _____ knots
Other(s) _____

Please provide a copy of these procedures if possible.

Airline 1	No
Airline 2	Yes; ~ 70% N1; 60 - 70 knots, use all engines
Airline 3	Yes; "We operate as per manufacturer's operating procedures."
Airline 4	Yes; "Procedures vary by fleet type, please see the attached specific aircraft thrust reverser operating procedures for detail."
Airline 5	Yes; 60 knots
Airline 6	Yes; [no specifics provided]
Airline 7	Yes; 70% N1, reduce to 60% N1 at 40 knts (for 747, JT9D) [page from 747 AFM provided]
Airline 8	Yes [FOM's provided]
Airline 9	Yes; "Certain value up to max if needed"; 80 knots
Airline 10	Yes; "G/A" [ground accel]; 60 knots
Airline 11	Yes, [procedures provided]
Airline 12	Yes; 84% N1 (max available); 40 knots
Airline 13	Yes; 1.6 EPR, 60 knots
Airline 14	Yes; "See question 3"
Airline 15	Yes; [procedures for MD-11 attached]
Airline 16	Yes; "Varies by type"; "Generally 80 knots"
Airline 17	Yes [procedures provided]
Airline 18	Yes; "G/A"; "60/80 knots"; "Symmetric always / during RTO even with engine fire."
Airline 19	Yes; 70% N1, 60 knots
Airline 20	Yes; 100% N1, 70 knots
Airline 21	Yes; 1.6 EPR, 80 knots
Airline 22	Yes; [sample of B-767 AOM provided]

Figure 8. Airline responses to question 5 (question in bold type).

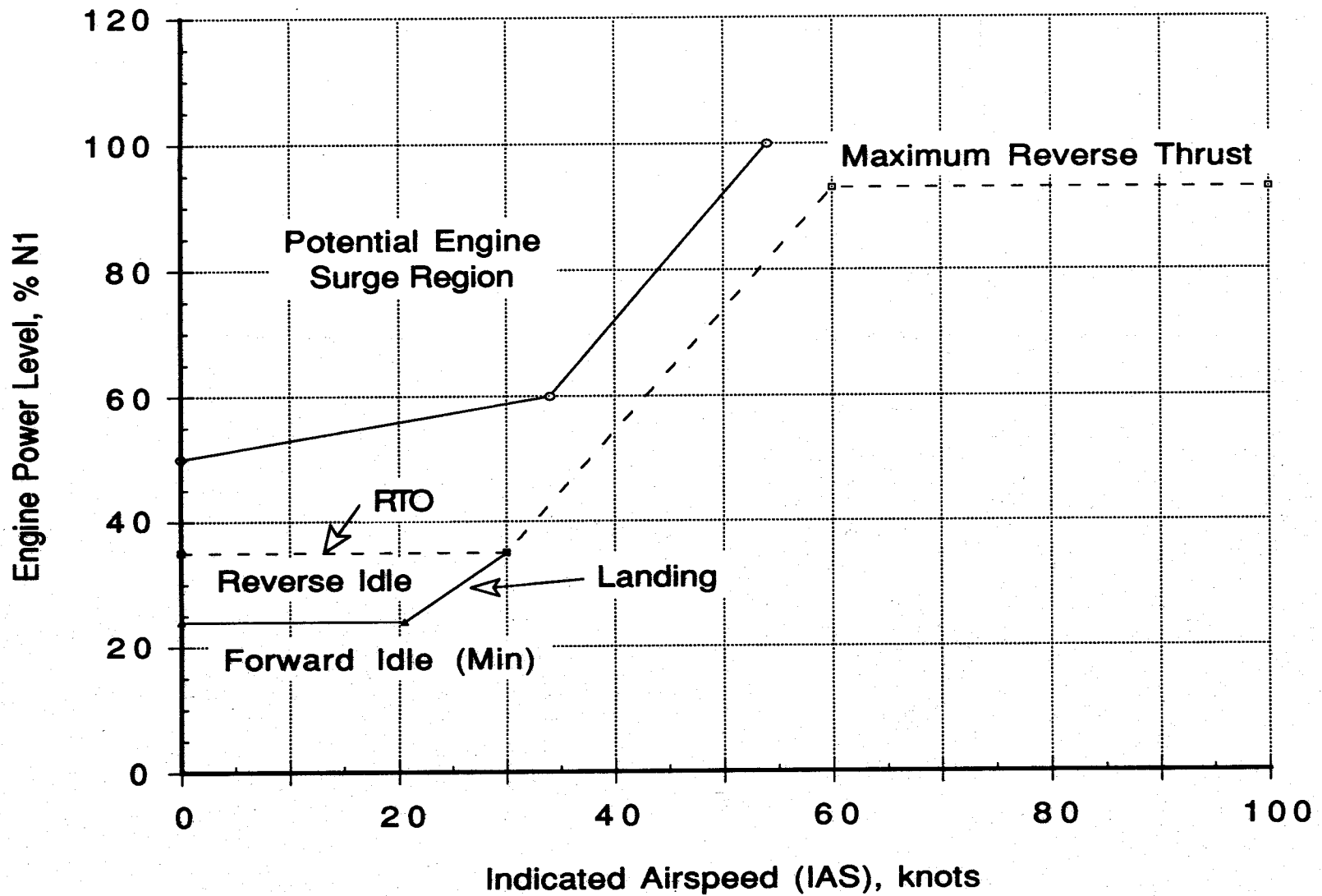


Figure 9. Typical engine operating levels and limitations during reverse thrust operation.

0%

30

	<u>Aircraft</u>	<u>Engine Limits</u>	<u>Cutoff Speeds (knots)</u>
Carrier A	All	70% N1	60-70
Carrier B	DC9	1.6 EPR	80, out by 60
	727	84% N1	80, Fwd Idle by 60
	757/767	EC limited ¹	Idle Rev by 80, Fwd Idle by 60
	DC-10-30	95% N1	Idle Rev by 80, Fwd Idle by 60
Carrier C	747	70% N1	60
		60% N1	40
Carrier D	727	1.6 EPR	80, Idle Rev by 60, Fwd Idle by 50
	747	70% N1	80, Idle Rev by 60, Fwd Idle by 50
	DC-10-30	95% N1	80, Idle Rev by 60, Fwd Idle by 50
Carrier E	727	1.8 EPR	80
	737-300/500	82% N1	80, @ Idle Rev by 60
	757/767	EC limited	80, @ Idle Rev by 60

Flagnote 1 - Engine controller (EC) limits engine power available.

Figure 10. Sample of engine power levels and cutoff speeds used by some airlines.

Source: B727 Operations Manual

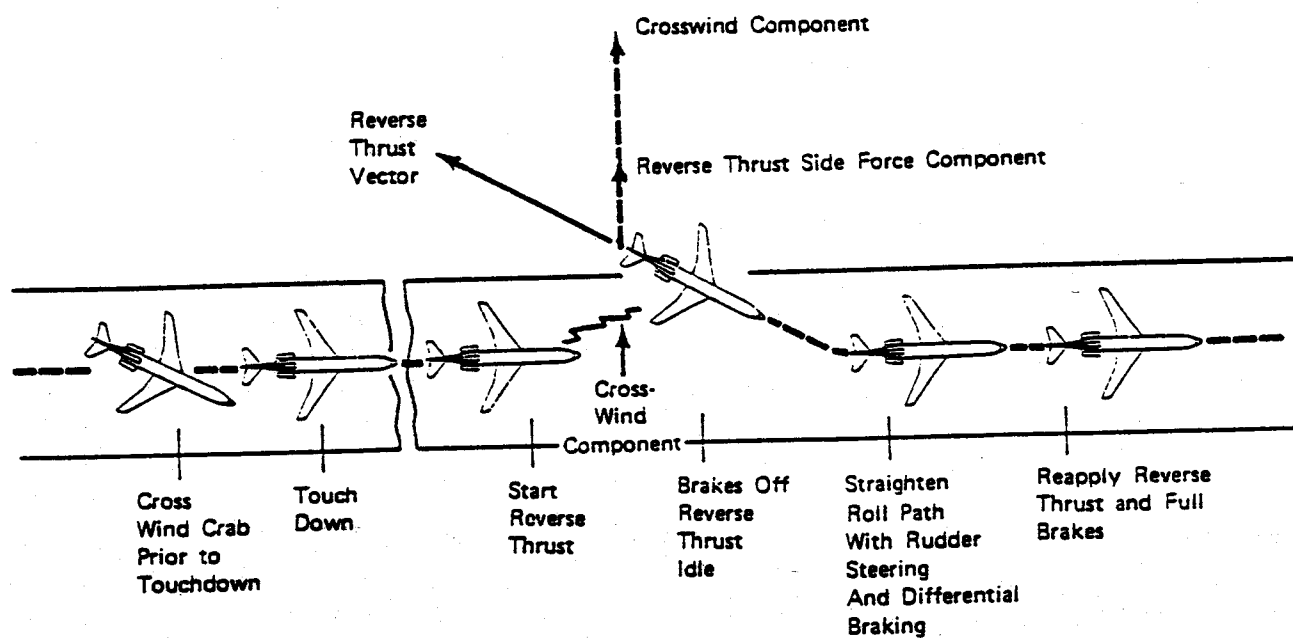


Figure 11. Weathervaning - Effect of reverse thrust on a slippery runway with a crosswind.

6) Is the availability and use of thrust reversers considered in the setup of the aircraft brake system antiskid features (i.e. maximum brake system pressure)? Do you have a recommended procedure for using "Autobrakes" during landing? Please explain:

- Airline 1 "Autobrake system deactivated on BAe-146 aircraft by manufactures service bulletin."
- Airline 2 "No - This is a design issue. The installation is done per the relevant airframer manual"
- Airline 3 "No (on brakes setup); Yes (for autobrakes procedure) for B747 and A300."
- Airline 4 "Yes, the availability and use of thrust reversers is considered. Autobraking systems are designed to provide the maximum stopping force in conjunction with all other devices used to decelerate the aircraft such that the total of autobrakes and reverse thrust combined provide deceleration at a maximum rate. The recommended procedure is specified in detail in the attached aircraft operating instructions."
- Airline 5 "No"
- Airline 6 "Normally on 'Auto' brake installations these are used."
- Airline 7 "Autobrake at 'minimum' setting is used every landing."
- Airline 8 "Condition of antiskid is NOT factor in use of T/R - T/R is recommended for each landing. See excerpts from DC-10 & MD-11 Flight Ops Manuals for relation between T/R and Autobrakes/Autospoiler."
- Airline 9 "First part we don't understand what you mean by the question. Second part, it is up to the pilots discretion."
- Airline 10 [no response]
- Airline 11 "Airline 11 believes that the availability and use of thrust reversers might have no relationship with aircraft brake system antiskid features. Airline 11 has no special recommended procedure for using 'Autobrakes'."
- Airline 12 "No - thrust reversers are not required for antiskid defects. Autobrakes are used on every landing."
- Airline 13 "On aircraft equipped with autobrakes, these shall be used on slippery runways."
- Airline 14 "Yes. Autobrakes are selected for all landings. MED or 3 settings are recommended for wet runways and on runway lengths of 9000 ft or less."
- Airline 15 [procedures attached]

Figure 12. Airline responses to question 6 (question in bold type).

- Airline 16 "Yes - Required on low visibility landings per certification/Ops Specs."
- Airline 17 "Not for anti-skid systems. Aircraft with accelerometer based autobrake systems, there are procedures to set the desired deceleration rate(s)."
- Airline 18 "No, Dry runway off, wet runway with field length restriction at Capt's discretion, most use it."
- Airline 19 "Normal operations - Dry runway = Min Autobrake,
- Wet runway = Med Autobrake."
- Airline 20 "The thrust reversers is not considered like a deceleration in any case of landing, then the thrust reversers will be always an additional source in the landing performance."
- Airline 21 [no response]
- Airline 22 "See page 02.36.02 from 767 AOM."

Figure 12. Concluded.

B757 & B767 AOM

- Level 1-2 - Minimum for braking on wet/slippy runway greater than 7000 feet or on dry runways.
- Level 3-4 - Medium when braking action is less than good or on wet/slippy runways 7000 feet or less in length.
- MAX - Maximum for Emergency braking.

ABS system is not required to be operational by Minimum Equipment List.

ABS system must be used (if operative) on wet/slippy runways when braking action is "less than good".

Whenever possible do not use brakes until below 100 knots - use manual braking.

MD11 AOM

- MIN - when available runway length is > 9750 ft
- MED - when available runway length is 7800 to 9750 ft
- MAX - when available runway length < 7800 ft

MAX mode is not recommended on dry runways.

The use of ABS is recommended for landing on wet, slippy and contaminated runways or runways close to minimum runway length.

B737-300/500 AOM

- Level 1 - Use when nominal deceleration rate is suitable in routine operations.
- Level 2 & 3 - Use when moderate deceleration rates are required for wet and slippy runways or when roll out distance is limited.
- Level MAX - Use when maximum deceleration rates are required. (Rate is less than full manual braking).

MD-80 AOM

To reduce brake wear autobrakes are only used when deemed necessary. LAND MAX not normally used on dry runways.

To achieve maximum brake effect for all runway conditions use autobrakes in LAND MAX.

When excessive runway length is available, delay brake action until speed is below 80 kts and do not use autobrakes (to save brakes and reduce load on landing gear).

Figure 13. Examples of typical autobrake system settings and pilot operating instructions.

7) Approximately how many landings does your fleet make each year? How many of them are on "icy" runways? How many are diversions to alternate airports?

Airline 1	42,000 cycles; 50%; 2.5%
Airline 2	120,000; < 1%; Almost none
Airline 3	500,000; "see item 9" [no data]; 1400 [0.3%]
Airline 4	"903,400 for 12 month period ending June 30, 1992."; "Quantity unknown."; "In the 12 month period ending June 30, 1992 we experienced a total of 3206 diversions [0.4%] to alternate airports out of the total 903,400 landings. Of the 3206 [diversions], 2463 [0.3%] were unplanned and of these, 1385 [0.2%] were weather related. Further breakdown by specific weather conditions is not available."
Airline 5	215,000; 20%; " ? " [unknown]
Airline 6	1,022,000; 1 - 2 %; 1 - 2 %
Airline 7	14,000; ~ 10%; ~0.1%
Airline 8	135,348; ~ 3.5%; ~ 10%
Airline 9	130,000; ~ 10,000 [8%]; 50 to 100 [0.1%]
Airline 10	12,000; ca 5%; > 1%
Airline 11	~110,000; "Unknown"; "Zero (Apr. '91 - Mar. '92)"
Airline 12	32,200; [no response]; 4 [< 0.1%]
Airline 13	220,000; 20%; < 5%
Airline 14	A310 ~ 25000, 747 ~ 20,000; [no response]; "Statistics not available."
Airline 15	250,000; ~ 5%; [no response]
Airline 16	338,000; " ? "; " ? "
Airline 17	"About 770,000 landings per year. About 800 [0.1%] of the landings are made on 'icy' runways during the winter season. There are about 1700 [0.2%] diversions per year to alternate airports."
Airline 18	160,000; 400 [0.3%]; 500 or less [[0.3%]
Airline 19	4800; 1 %; 0.5 %
Airline 20	91,419 [no responses to other parts of question]
Airline 21	~ 60,000; Unknown; Unknown
Airline 22	160,000; 500 - 1000; insignificant

Figure 14. Airline responses to question 7 (question in bold type).

8) On average, how many rejected takeoffs (RTO) does your fleet encounter each year? How many of those are on "icy" runways?

Airline 1	5 to 10; 3 [Percentage of RTO's = 0.02%]
Airline 2	10 max; Nil [0.01%]
Airline 3	27; "see item 9" [0.01%]
Airline 4	"Estimate 4 or 5 per year."; "Unknown." [< 0.01%]
Airline 5	[no response]
Airline 6	Few; None
Airline 7	5; Zero [0.04%]
Airline 8	"Unknown"; "Probably none"
Airline 9	5 to 10 max; 2 to 3 [0.01%]
Airline 10	1; Zero
Airline 11	8; "Unknown (Apr.'91 ~Mar.'92)" [0.01%]
Airline 12	16; [no response]
Airline 13	~10; < 5 [< 0.01%]
Airline 14	"Nine"; "No Statistics"
Airline 15	~30; "no info" [0.01%]
Airline 16	~12; "Almost none" [< 0.01%]
Airline 17	"Based on a recent 3 year period there was an average of 345 RTO's per year [0.04%]. There are no data on the number of RTO's on icy runways." [Airline 17 was asked why their RTO rate was higher than most of the other airlines responding. Their number is based on actual pilot incident reports and includes all aborted T/O's from low speed to V1. Airline 17 suggested that the definition used by other airlines used may be different.]
Airline 18	48; Nil [0.03%]
Airline 19	3; Nil
Airline 20	[no response]
Airline 21	~20; None
Airline 22	15 - 20; Maybe 1 or 2.

Note: 0.01% = 1/10,000 takeoffs

Figure 15. Airline responses to question 8 (question in bold type).

9) What are your operational procedures/restrictions for landing/takeoff on "icy" runways?

- Airline 1 "Pilots discretion."
- Airline 2 "A 1.15 factor applied to landing runway length. Icy runway must be sanded prior to takeoff/landing. Reduced takeoff weights and V1 for icy runways."
- Airline 3 "We do not allow operations on icy runways when the friction coefficient is lower than 0.20. No statistics available."
- Airline 4 "Varies by fleet type - see attached operating procedures for fleet specific information."
- Airline 5 [no response]
- Airline 6 "'Icy' runway is a broad term. If a runway is 'icy' there are special runway weight numbers used."
- Airline 7 "D.D.P.G. inoperative T/R is not permitted on 'icy' runways."
- Airline 8 "See attachments" (727, 747, DC-10 & MD-11 FOM)
- Airline 9 "Weight corrections depending on friction coefficient, in T/O also V1 reductions, cross wind limitations."
- Airline 10 "Specific weight reduction from AOM, antiskid operating, reduced V1."
- Airline 11 "Landing/Takeoff performance on "ice" runway takes into account the reverser effect." (Plot of % N1 vs IAS attached).
- Airline 12 "Landing - Diversion should be considered if braking action is poor and crosswind exceeds 15 knts. Takeoff - Severe weight restrictions apply."
- Airline 13 "As long as the gross weight permits T/O or landing."
- Airline 14 "For T/O: 1. No reduced thrust, 2. no tail wind, 3. All reverses operational
For landing: 1. Flaps 30, 2. Autothrottles 3 or higher, 3. No overweight landing, 4. No tailwind
- Airline 15 [procedures attached]
- Airline 16 "Same as manufacturers recommendations."
- Airline 17 "See the attached pages from the 'Winter Operations Bulletin'."
- Airline 18 "Basically according to Douglas and Boeing recommendations; Max crosswind 10 knots; Reversers must be O.K."
- Airline 19 "V1 reduction. Weight (TOW) reduction. Limits on crosswind. OR Prohibit takeoff if conditions warrant."

Figure 16. Airline responses to question 9 (question in bold type).

- Airline 20** "The limitation for takeoff that we consider is 1/2 pg. [inch?] of sleet or the equivalent for dry snow. For a long landing the thrust reversers are used at pilot discretion with some knowledge about the care for use in slippery runway conditions [i.e. weather vaning]."
- Airline 21** "No takeoff or landings on icy runways (friction coefficient below 0.15)."
- Airline 22** "Variable. A320 requires operative thrust reversers if runway contaminated. DC-9 requires additional 500 feet over normal required landing distance if one reverser inoperative. In addition we limit cross wind as function of 'slipperiness'."

Figure 16. Concluded.

10) On average, how many occurrences of brake failure does your fleet encounter each year?

Airline 1	"Zero"
Airline 2	"Nil"
Airline 3	"83"
Airline 4	"No total failures (all brakes on one aircraft) but some failures of individual wheel brakes. The Minimum Equipment List (MEL) allows dispatch of an aircraft with one or more individual brakes inoperative. This varies by aircraft and is detailed in the attached MEL manual pages."
Airline 5	[no response]
Airline 6	"Few"
Airline 7	"Practically zero"
Airline 8	"See attached printouts for 1991"
Airline 9	"15 to 25"
Airline 10	">1"
Airline 11	"10 (steel brakes only)"
Airline 12	"Nil to date"
Airline 13	"< 5"
Airline 14	"Nil"
Airline 15	"Complete brake failures very seldom, we can recall 2 incidents in several years."
Airline 16	"8 to 10"
Airline 17	"None"
Airline 18	"5 considering one or other system, Nil both systems"
Airline 19	"Zero"
Airline 20	"Around five failures per year."
Airline 21	"None"
Airline 22	"Can only think of 2 or 3 in last 15 years."

Figure 17. Airline responses to question 10 (question in bold type).

11) Does your airline use thrust reversers for power back? If so, with what type of airplane(s)?

Airline 1	No "(only if absolutely no other option is available)"
Airline 2	No
Airline 3	No
Airline 4	Yes; "MD80, 727, F100. Power back is approved on the 757 aircraft but is not yet used."
Airline 5	No
Airline 6	No
Airline 7	No
Airline 8	No
Airline 9	No
Airline 10	No
Airline 11	No
Airline 12	No
Airline 13	"Formally allowed, but never used."
Airline 14	No
Airline 15	No
Airline 16	Yes "(limited)"; "DC9, MD80, 727"
Airline 17	"Thrust reversers can be used for power back. However, because of various economic and ground safety concerns, Airline 17 rarely uses the procedure."
Airline 18	No
Airline 19	No
Airline 20	No
Airline 21	No
Airline 22	No

Figure 18. Airline responses to question 11 (question in bold type).

12) Is aircraft operational field length critical to your route structure? Please explain.

- Airline 1 "Due to BAe-146 not having reversers, icy ramp and runway conditions must be handled cautiously."
- Airline 2 "Some routes takeoff distance governs weight for long haul."
- Airline 3 "Some airports in our network are critical from runway length standpoint."
- Airline 4 "No, we do not select an aircraft or city pair based on runway lengths or stopping performance."
- Airline 5 "We fly into many small airports where field length is critical."
- Airline 6 "In some cases - a very low percentage of the operation."
- Airline 7 "Most direct flights Israel to U.S. are field length limited!"
- Airline 8 "Yes. Our primary HUB is at an airport with relatively short runways which often limits our takeoff weights and therefore our payloads"
- Airline 9 "Yes, DC-10/MD-11 long flight at max. TOGW and hot airfields, some charter destinations with short fields."
- Airline 10 [no response]
- Airline 11 "Most airports we fly have enough field length for our flights on dry runway, but field length is critical on slippery runway."
- Airline 12 "Yes. A large percentage of operations are long haul sectors and optimum revenue/payload capability must be achieved."
- Airline 13 "On certain domestic flights, especially in Norway, during icy conditions with short runways."
- Airline 14 "Yes for long haul routes such as SIN-LHR."
- Airline 15 "No"
- Airline 16 "Yes at approximately 50% of airports."
- Airline 17 "Yes in some cases. The 747 is field length limited much of the time. The smaller 2-engine 737 tends to be landing weight limited frequently."
- Airline 18 "Low impact on payload/safety; 2% of all runways are less than 6500 feet long"
- Airline 19 "No (currently)"
- Airline 20 "Yes, about 20% of airports are class 6 according to I.C.A.O. classification."
- Airline 21 "Not always, very seldom."
- Airline 22 "No. Generally the airports we operate into have sufficient runway length."

Figure 19. Airline responses to question 12 (question in bold type).

13) Does on-time arrival at a terminal gate have any impact on the airline instruction/pilot decision process on thrust reverser deployment to achieve quicker egress to the taxiway?

Airline 1	No
Airline 2	No
Airline 3	No
Airline 4	No
Airline 5	No
Airline 6	No
Airline 7	No
Airline 8	Yes; "(Sometimes I am sure it does)"
Airline 9	Yes; "Some, but safety first."
Airline 10	No
Airline 11	Yes
Airline 12	No
Airline 13	No
Airline 14	No
Airline 15	No
Airline 16	No
Airline 17	"Probably. No quantitative data to substantiate, but observations indicate that this does happen frequently. Often, the airport tower will ask if a flight will expedite the egress from the runway."
Airline 18	No
Airline 19	No
Airline 20	No
Airline 21	No
Airline 22	No

Figure 20. Airline responses to question 13 (question in bold type).

14) Is your engine maintenance/servicing schedule based on engine cycles, engine operating hours, or a combination of the two? How does the use of thrust reversers affect your maintenance schedules? Please explain.

Airline 1	Cycles; n/a
Airline 2	Combination; "The scheduled overhauls of reversers is governed by a combination of hours/cycles which accounts for the fact that they are deployed on every landing."
Airline 3	Combination; [no explanation given]
Airline 4	Combination; "On engines which have thrust reversers attached to the engine, the reverser is maintained during normal engine shop visit. Reversers which are attached to aircraft pylon have set hour controlled scheduled maintenance which coincides with heavy aircraft visits to main base."
Airline 5	Combination; "Not much."
Airline 6	Combination; "Very little effect."
Airline 7	Hours
Airline 8	"Thrust reversers do not affect our engine maintenance schedules."
Airline 9	Combination
Airline 10	"Higher usage, more maintenance."
Airline 11	Combination; "As far as we experience the use of thrust reversers do not affect maintenance schedules."
Airline 12	Combination; "Reduced brake system requirements."
Airline 13	Hours; "Hard hour limit overhaul, maintenance actions based on checks. If wear appears, maintenance actions take place."
Airline 14	Combination; "Our maintenance schedules are based on our own experience as well as P&W recommended maintenance intervals."
Airline 15	Combination; "It does only if we have trouble with."
Airline 16	Does not affect, since we use reversers on 100% of landings."
Airline 17	Hours; "Reverser use is not considered in the maintenance schedule. Airline 17 uses sampling programs and reliability analyses to determine the engine maintenance schedule. The reverser system has its own program more closely tied to the aircraft maintenance program."
Airline 18	"No effect at all."
Airline 19	Hours
Airline 20	Cycles; "According with our maintenance area the reverser use does not affect the maintenance schedules."

Figure 21. Airline responses to question 14 (question in bold type).

Airline 21

Combination; "No affect."

Airline 22

Combination; "It creates scheduled maintenance. For aircraft like DC-8-73, which permits reverse in flight, a high flight idle situation in the past resulted in greater use of in-flight reverse with resulting maintenance costs. Reducing excessively high flight idle setting gave immediate reduction in reverser maintenance costs."

Figure 21. Concluded.

15) Has your airline evaluated the costs/benefits of thrust reverser usage (i.e. savings in brake wear versus engine and reverser system maintenance, effect on engine/airplane cruise performance)?

If yes, what are the trades as you see them?

- Airline 1 No
- Airline 2 "Early deployment of the reverser reduces brake wear as the reverser can remove large amounts of kinetic energy from the aircraft at high speeds."
- Airline 3 No
- Airline 4 "During 1992 Airline 4 will spend approximately equal amounts of money to maintain thrust reversers and brakes on our fleet and, based on the fact that thrust reversers supply only 20 to 25% of the total deceleration force, it is apparent that brake usage is more beneficial from a maintenance cost standpoint. However, it is widely recognized that brake wear increases significantly if reverse thrust is not used to decelerate the aircraft."
- Airline 5 Yes; "It is cheaper to use brakes - especially on A/C with carbon brakes where hard braking is not any harder on the pads than light braking."
- Airline 6 No
- Airline 7 No
- Airline 8 No
- Airline 9 "Fuel price dependent, efficiency of reverse thrust."
- Airline 10 No
- Airline 11 Yes; "We evaluated the brake wear and temperature with no reverser operation. Our evaluation shows the brake wear rate increase approximately 25 percent and additional stay time and/or ground equipment for brake cooling are required. Cost impact on our B747, 60 aircrafts, is over two million US dollars per year." [\$2 Million/60 AC = \$33,000 per AC per year. Interpreted this as a brake cost.]
- Airline 12 Yes; "Thrust reverser cost vs brake usage and shown to be cost effective. Brakes and landing gear are the most expensive maintenance cost apart from engines."
- Airline 13 No
- Airline 14 No
- Airline 15 No
- Airline 16 Yes; "Airline 16 philosophy has been to spend more on brake wear and cost to reduce reverser maintenance and cost - higher fuel cost of recent years enter into the decisions."

Figure 22. Airline responses to question 15 (question in bold type).

Airline 17	"Yes. Weight of the reverser system = increased fuel burn/loss of potential payload. Reverser maintenance cost vs brake wear cost."
Airline 18	No; "Anyway consistent less brake wear."
Airline 19	No
Airline 20	No
Airline 21	No
Airline 22	No

Figure 22. Concluded.

16) Do you feel that thrust reversers are a cost effective means for aircraft deceleration? Do they provide an adequate return on investment (ROI)? Please explain.

- Airline 1 "Yes. In our northern environment, I would definitely consider them a cost effective system."
- Airline 2 "Yes. Due the increased safety factor."
- Airline 3 "Yes. The T/R is an effective means for A/C deceleration but we do not think is offering adequate ROI since it is very expensive equipment with low reliability (see final comments)."
- Airline 4 "Given that there are no alternatives to thrust reversers it is difficult to say reverser ROI is or is not adequate but it is fair to say that reverser ROI is much less than brake ROI when comparing the amount of deceleration force provided by each systems."
- Airline 5 "Not cost effective at major airports, required at northern bases."
- Airline 6 "Difficult to measure."
- Airline 7 "Unknown."
- Airline 8 "We don't pay extra for thrust reversers, so an 'ROI' has never been considered. As long as they are used judiciously (i.e. don't overboost the engine or allow debris to be re-ingested) so as not to harm the engines while reducing brake wear. This has not been quantified."
- Airline 9 "Not very effective and very costly, but necessary."
- Airline 10 "No. Too complex, heavy, noisy."
- Airline 11 "We feel that thrust reversers are a cost effective means for brake consumption."
- Airline 12 "Yes, since they are cheaper than brakes and require less servicing as regards off-time, and do not use any consumable material."
- Airline 13 "Yes, as we can use them formally when we calculate T/O weights and landing weights on slippery runways. Operation would not be possible without reversers on existing aircraft fleet."
- Airline 14 "No. The reversers are heavy to carry around, and it contributes little to aircraft deceleration except only on contaminated runways. However, we recognise its contribution to safety."
- Airline 15 "No, but improves safety margin."
- Airline 16 "As mentioned in question 15 above, the management of reversers vs. brakes is always a factor in the overall economics of aircraft stopping decisions. Reversers in conjunction with brakes, are effective."

Figure 23. Airline responses to question 16 (question in bold type).

- Airline 17** "It costs Airline 17 Airlines in excess of \$3 million annually in fuel to carry thrust reversers on over 500 aircraft. [\$6,000 per AC] Considering the added ground control and stopping capability provided under varying runway surface conditions for the flight crew, this 'insurance policy' will return the cost to carry on a single incident. Yes, it is felt they do provide an adequate return on investment."
- Airline 18** "Yes. No detailed data but definitely maintenance costs are well below brake wear associated costs."
- Airline 19** "No. Fan rub increase, turbine life reduction, compressor rub. All shorten on-wing life of engine."
- Airline 20** "As a safety device all the operations have benefits and the cost is considered."
- Airline 21** "Yes, reduces brake wear."
- Airline 22** "Don't know. Have not costed the alternatives."

Figure 23. Concluded.

17) What is your estimate of the yearly cost per airplane of maintaining thrust reversers for your fleet?

Airline 1	n/a
Airline 2	"Not known."
Airline 3	"Around \$100,000 per A/C."
Airline 4	"Approximately \$31,000 per aircraft or \$21 million for fleet in 1992. This, of course, varies with age and type of reverser. The DC10 reversers are most expensive to maintain while MD11 and F100 reversers are currently the least expensive to maintain (these are newest aircraft in fleet). "In addition to thrust reverser maintenance costs, Airline 4 will spend approximately \$20 million during 1992 to maintain the brakes and related systems on our fleet. Brake maintenance cost varies by fleet and by the type of brake, steel or carbon. Carbon brakes offer significant weight savings which translates into more payload, however, they have the disadvantage of being much more costly to maintain. Brake maintenance costs are expected to increase as new aircraft with carbon brakes enter service in our fleet while older aircraft with steel brakes are retired from service."
Airline 5	[no response]
Airline 6	"Unknown."
Airline 7	"For a 747, \$30,000 per airplane per year."
Airline 8	"A cost breakdown at this level is NOT made."
Airline 9	"\$20,000/airplane, but big variation between airplane."
Airline 10	n/a
Airline 11	"It is difficult to estimate the yearly cost (maintenance cost of thrust reverser is not traced separately from total maintenance cost)."
Airline 12	"\$100/flight approximately or \$40,000/year."
Airline 13	"Approx. \$20 mill" [assume total fleet cost for 107 AC, \$187,000/AC/year]
Airline 14	"Study has not been conducted."
Airline 15	[no response]
Airline 16	"\$10,000 to \$45,000 per year [average = \$27,500] depending on type of aircraft."
Airline 17	"\$12,000/aircraft/year annual cost. Includes on-aircraft checks/repairs (annual) and shop overhaul once every 6-8 years averaged into the annual expense."

Figure 24. Airline responses to question 17 (question in bold type).

Airline 18	n/a
Airline 19	[no response]
Airline 20	"DC-10: \$550,000, B-727: \$220,000." [very high, relative to other airlines]
Airline 21	[no response]
Airline 22	"Total cost is about \$2,700,000. We have about 100 aircraft. Therefore yearly cost per aircraft = \$27,000. However, B-767 is much higher than others."

Figure 24. Concluded.

18) Do you feel that thrust reversers are necessary for safe aircraft operations? Please explain.

- Airline 1 "No" [this airline operates airplanes without thrust reversers]
- Airline 2 "Yes - They provide a positive and independent means of stopping the aircraft."
- Airline 3 "Yes (see item 1 and 2)."
- Airline 4 "Yes, without them brakes-only stopping performance margins are not adequate to provide the degree of safety desired by operators. Also, reversers are very important for directional control on icy runways."
"On the other hand it should be noted that on twin engine aircraft which have wing mounted high bypass ratio engines the hazard of an in-flight reverser deployment which may severely compromise flight safety far outweighs any benefit from increased landing stopping margins or better directional control on icy runways. Also, triple redundancy of systems to prevent in-flight reverser deployment will cause departure delays which will exceed stopping value."
- Airline 5 "Yes, in some instances. Especially in the north where ice and snow are present 6 months of the year."
- Airline 6 "Yes - just puts on added stopping factor."
- Airline 7 "Yes. T/R provides redundancy braking on: 1/ wet and icy runways, 2/ brake and/or tire failure, 3/ refused takeoff."
- Airline 8 "No."
- Airline 9 "In slippery conditions they are the only means to produce forces for aircraft steering."
- Airline 10 "Any means of quick deceleration is necessary for safe operations."
- Airline 11 "Thrust reverser is necessary for takeoff/landing on slippery runway."
- Airline 12 "They are redundant system but are certainly valued."
- Airline 13 "Today it is on existing aircraft fleet."
- Airline 14 "Yes, for operations on runways where the braking coefficient have been reduced by natural forces."
- Airline 15 "Yes, it is an additional safety margin, since reverse is not included in calculation for takeoff abortion."
- Airline 16 "ABSOLUTELY ! - provide additional margin of safety."

Figure 25. Airline responses to question 18 (question in bold type).

- Airline 17 "The aircraft is certified for field length and 'safe' operation without the reversers. See the attached copy of the FAA Advisory Circular dealing with aircraft certification. Reversers do make operations 'safer' by giving the flight crews more options. Without them or something equivalent, there probably would be more restrictions on operations on wet runways, etc.
- Airline 18 "Yes, additional and efficient stopping power."
- Airline 19 "Perhaps not necessary. But they do provide a greater safety margin."
- Airline 20 "Yes, because the reverser system provides an important deceleration without contact with the ground, it means the reverser deceleration will not be affected by runway conditions like water, ice or rubber contamination."
- Airline 21 "No"
- Airline 22 "Yes. Existing retardation systems apart from thrust reversers are not adequate for slippery runway operations which are relatively common in Canada during winter months."

Figure 25. Concluded.

19) Are you aware of any instances where the use of thrust reversers prevented an accident? Please explain.

- Airline 1 "Yes. A DHC-8 taxied to terminal in high winds and icy ramp. Reverse application prevented aircraft from colliding with boarding ramp."
- Airline 2 "Yes" [no explanation given]
- Airline 3 "We experienced cases where during a landing an overrun was avoided and during taxi a collision prevented by use of reverse thrust in condition of unreported slippery surfaces."
- Airline 4 "Yes, many incidents of using reversers to help stop an aircraft in runway overrun situations where it is believed that not using reversers would have led to much more aircraft damage and possible passenger injury."
- Airline 5 [no response]
- Airline 6 "No"
- Airline 7 "Yes! In all last year 5 RTO stops. T/R was used and in all cases airplane came to rest in last 300 feet of runway."
- Airline 8 "No"
- Airline 9 "Many, mostly veerooffs from runway or taxiways."
- Airline 10 "No"
- Airline 11 "No such instances have been recorded."
- Airline 12 "Not within our operations."
- Airline 13 "Every landing on runways with poor braking action."
- Airline 14 "No. Since it is our policy to use reverse thrust at all times, we are unable to comment on whether the non use of reverse thrust would have caused an accident/incident."
- Airline 15 "No"
- Airline 16 "Yes - on many instances with slick runways and taxiways."
- Airline 17 "There were '2' instances of hydroplaning in the past year. The use of reversers prevented the airplane from leaving the runway."
- Airline 18 "A/C was oriented to hold on mid-runway loop. On a different language [the tower cleared another A/C for takeoff. Wing tip collision was imminent. Avoided by our Capt's decision to power back ~4 meters (B737-200, 1992)"]
- Airline 19 [no response]
- Airline 20 "In some instances, contaminated runways, reversers have been used as a last resort to stop."

Figure 26. Airline responses to question 19 (question in bold type).

Airline 21

[no response]

Airline 22

"There are many occasions when most of the runway is used even though full reverse is used. If reverse had not been used the airplane would have gone off the runway. Do you consider this an instance?"

Figure 26. Concluded.

20) To your knowledge, has there ever been any instances where an RTO was made while an airplane's thrust reversers were inoperable or locked out? If so, were any problems encountered with stopping the airplane?

Airline 1	No
Airline 2	"We do not operate with more than one reverser locked out."
Airline 3	No
Airline 4	"Don't know of any instances, however, MEL allows no more than one reverser to be inoperative or locked out so any given aircraft would have one or more reversers operable at all times."
Airline 5	Yes; "No"
Airline 6	No
Airline 7	No
Airline 8	"No one can recall such an event."
Airline 9	"Don't know, but probably on dry runways and from lower speeds."
Airline 10	No
Airline 11	No
Airline 12	Yes; "No problems since a maximum of 1 reverser can be locked out and power/reverse thrust is applied symmetrically."
Airline 13	No
Airline 14	No
Airline 15	No
Airline 16	Yes; "No - because aircraft is certified to stop without credit for thrust reversers."
Airline 17	No
Airline 18	Yes; "No - at least two incidents at slippery & wet runways where reversers played major part at stopping A/C"
Airline 19	No; "Not all thrust reversers."
Airline 20	No
Airline 21	No
Airline 22	No

Figure 27. Airline responses to question 20 (question in bold type).

21) What type of thrust reverser problems does your fleet typically encounter (i.e cascade failures, inability to stow, inadvertent deployment). How often (say in 1000 landings) do such problems occur?

- Airline 1 n/a
- Airline 2 737-200 = 2/Khr, 737-300 = 0.3/Khr, 747-100 = 10.7/Khr;
Hours/Cycle Ratio: 737 = 1:1, 747 = 3.2:1 [assume cycle = landing]
- Airline 3 "Around 0.07 x 1000 landings we encounter problems such as inability to deploy or inability to stow. Another problem of the modern sound suppressed T/R is the delamination or disbonding of the honeycomb panels."
- Airline 4 "Cascade failures and inadvertent deployment are very rare in our fleet. Inability to stow occurs occasionally on our DC10 fleet and when it involves number 2 engine we experience a lengthy delay and sometimes cancellation. Problems with indicating systems and reverser mechanisms/systems are more numerous."
"A particular indication system problem which has occurred in our fleet is one that causes pilot reports and maintenance delays due to 'false' reverser unlock and ISO valve indications or lights flickering. These problems occurred across one manufacturers fleet of Airline 4 aircraft a total of 28 times during a recent one year study period. This points to the inadequacy of a major portion of the indication system to provide the flight crew with information as to whether an uncommanded reverser deployment is taking place."
"The rate of occurrence of problems are tracked by the number of pilot reports and the number of delays associated with ATA System 78, thrust reverser, and vary from fleet to fleet. For example, the pilot report (PIREP) rate ranges from 1.1 to 3.5 per 1000 flying hours while the delay rate ranges from 0.2 to 1.74 per 1000 landings. These are 12 month rates thru June, 1992."
"The operating cost impact resulting from reverser related delays and cancellations amounts to approximately \$2.7 million for the above mentioned time period."
- Airline 5 "Failure to deploy, unable to stow. 1.5/Khrs [incident occurrence plots provided]
- Airline 6 "Really don't have these kinds of records."
- Airline 7 "T/R system, pilot report rate: 6 per 1000 flt hrs. Typical failure: Actuation problem, i.e. inability to extend or stow."

Figure 28. Airline responses to question 21 (question in bold type).

Airline 8	"Significant level of ancillary component failures." [provided a list of "T/R squawks" from 1991] 727-100: 2 per 10,000 landings 727-200: 1 per 10,000 landings DC-10-10: 7 per 10,000 landings DC-10-30: 8 per 10,000 landings
Airline 9	"Mentioned problems very seldom."
Airline 10	"No problems (yet)."
Airline 11	"There are fault indication, misrigging, etc. 3.2 squawks / 1000 departures on average."
Airline 12	"Primarily inability to stow and inability to deploy. Problems occur between 5 to 10 landings per 1000 depending upon aircraft type. Between 1 and 2 cascade failures per 1000 landings."
Airline 13	"Mainly indication problems."
Airline 14 "	Occurrences of inability to stow after deployment and REV UNLOCK indication in flight."
Airline 15	"Most of the problems are indication malfunctions."
Airline 16	"Inability to stow, light indication problems, hydraulic leaks, hinge pin and bushing wear, translating sleeve ball screw and cable failures, blocker door failures. Say 10 in 1000 landings."
Airline 17	"Won't go into reverse - 40%; Won't stow on the ground - 30%; Indication system - 21%; Blocker doors/links - 9%."
Airline 18	"Cascade failures and inability to stow ok - inadvertent deployment never - 0.6 per 1000 landings."
Airline 19	"Occasional blocker door stay/wear failure."
Airline 20	"DC-10 adjusting cables with a dividend result of 0.005. B-727 microswitch failures with a dividend result of 0.002."
Airline 21	"Actuator light on, 0.3 cases per 1000 landings."
Airline 22	"We used to experience JT9D-7R4 cascade failures in the '83 to '85 years but this problem has been corrected."

Figure 28. Concluded.

22) What is your opinion of removing thrust reversers from commercial transports, assuming a more cost effective and safe alternative is available?

- Airline 1 "In agreement providing cost effective and safety are paramount."
- Airline 2 "If this were true, then it would be attractive. It is unlikely however to prove economic to retrofit such a system - see comments."
- Airline 3 "In such a case there would be no objection for thrust reversers removal, however it should not be excluded to consider such new devices not as alternative but as additional (see comment)."
- Airline 4 "Any alternative would have to be thoroughly demonstrated and proven reliable to even be considered. There would be many obstacles to removing existing thrust reversers from in service commercial transport aircraft, not the least of which would be modification and certification issues and costs."
- Airline 5 [no response]
- Airline 6 "Would not be in favor."
- Airline 7 "Neutral"
- Airline 8 "Within the parameters of equal or greater safety, cost effectiveness, our position would range from interest to unbridled enthusiasm - depending on the magnitude of the parameters."
- Airline 9 "Yes, if safe and cost effective, but new device must produce forces for directional control on slippery runway, also in low speed region where aerodynamic means not functioning."
- Airline 10 "I very much favor the idea."
- Airline 11 "Negative unless the alternative is more reliable."
- Airline 12 "We do not believe that operating pilots would agree to their removal, even though the thrust reverser system is a redundant safety system."
- Airline 13 "It's OK, but the features must be independent of runway friction."
- Airline 14 "Can't comment unless the manufacturer spells out the alternatives in detail."
- Airline 15 "As long as same effectiveness with a new system, Airline 15 is positive about removing T/R."
- Airline 16 "Would agree to remove only if same level of safety is maintained but doubt it can be done."

Figure 29. Airline responses to question 22 (question in bold type).

- Airline 17 "If the proposed new system is as effective as current reversers and less expensive, particularly in fuel consumption, Airline 17 would support it. As you see from our comments on questions 18 and 19, flight crews occasionally need something to help overcome unforeseen events or less than perfect techniques. 'Something to broaden the operating band'."
- Airline 18 "Yes OK."
- Airline 19 "This would be an operational and engineering advantage, compared to current thrust reverser system limitations, problems and effectiveness."
- Airline 20 "Any change with better performance and cost always will be seen in a good way, but always with taking care about the flight safety."
- Airline 21 "Appreciated"
- Airline 22 "Good idea."

Figure 29. Concluded.

23) In your opinion, which of the following potential alternatives to engine mounted thrust reversers are most worthy of study:

- A Airframe mounted flap/thrust deflector system.**
- B Variable pitch fans.**
- C Reduce airplane landing speeds via improved high lift systems.**
- D Airframe mounted high drag devices (i.e. chutes, overextended flaps/spoilers, speed brakes).**
- E Off airframe drag devices (i.e. arresting hook, nets, pickup devices, other ground based systems).**
- F Concepts which improve brake effectiveness (i.e. friction coefficient).**
- G Runway solutions (i.e. soft extensions, overrun nets).**
- H Other(s)**

Airline 1	C
Airline 2	[no response, but see additional comments]
Airline 3	B, F
Airline 4	B, C, D, F; "Cost and reliability would be high airline concerns."
Airline 5	C, D, F
Airline 6	B, C
Airline 7	D
Airline 8	C, F
Airline 9	B
Airline 10	A, B
Airline 11	B, D
Airline 12	B
Airline 13	D
Airline 14	C, F, I; "More effective/positive steering control on slippery surfaces."
Airline 15	B, D, F
Airline 16	B, C, F: "NO! to item E."
Airline 17	B, C; "A new approach to the problems involved in controlling and stopping aircraft on varied surfaces/conditions."
Airline 18	B, G, H; "Should not be tire related ones."
Airline 19	C, D, F
Airline 20	D
Airline 21	C, F
Airline 22	A, B, D, F

Figure 30. Airline responses to question 23 (question in bold type).

- Airline 2** "Any alternative to a thrust reverser must be equally reliable and safe. It must also provide an independent, positive (i.e. non drag) decelerating force. Off runway devices (nets, etc) appear dangerous for commercial aviation, but may be worthwhile as a further addition. I would suggest that a more fruitful area of study would be to attempt to reduce the weight of the existing reverser (e.g. the use of composite or hollow cascade vanes). Modern reversers are generally a reliable and simple means of providing positive deceleration to the aircraft and I would be reluctant to move away from the basic concept."
- Airline 3** "To provide an incentive to develop more reliable and effective retarding devices, including the present thrust reverser system, some credit should be given in the regulations to calculate the accelerate-stop distances on dry, wet and contaminated runways. This would determine positive effects on ROI."
- Airline 4** "Since it appears likely that this study was initiated as a result of the Air Lauda accident and Boeing findings related to that accident we offer the following comments on evolving design requirements for existing and future aircraft:
- 757 and 767 - add third level of protection (sync shaft lock), inhibit autostow inflight, incorporate additional locking actuator with proximity switch, and modify existing reversers such that aircraft will tolerate deployment in flight.
- A300 - Airline 4 initiated thrust reverser health check, and a design review to see if third lock is required, and will apply 'lessons learned from Boeing experience'.
- Future aircraft - Airline 4 will not accept aircraft (e.g. 777) unless:
- Normal pilot skill retains control with thrust reverser deployed (engine at idle) at cruise speed and altitude.
- Normal pilot skill retains control at max. landing weight with one thrust reverser deployed and engine shut down."
- Airline 5** "I cannot answer your operational questions as well as our pilots. If you want answers as to why pilots want thrust reversers you should canvas the various pilots organizations."
- "Target type T/R's on B737 are very effective, quite reliable and relatively easy to maintain. High bypass ratio cascade type reversers require more maintenance, have a higher snag rate and are much less effective. They are probably not cost effective." [provided plots of "snag rates"]

Figure 31. Additional comments made by the airlines.

- Airline 9** "Directional control on slippery runways with low speed is very important (taxiing, apron area)."
- "Investigate runway accidents/incidents during 70's and 80's where F28 (no thrust reversers) was used in domestic network (to my knowledge)."
- Airline 13** "The requirements for new braking devices are: - Light weight,- Low maintenance costs, - Effective on slippery runways (μ below 0.20)"
- Airline 16** "Relative to the brake effectiveness comment in item 23 -- This is a sore spot!! We have a brake certified on the aircraft and it remains forever. Major improvements require re-certification and high cost -- so are not done. For example, the 727 has had the same lining for 20 years -- the 747, L1011, and DC-9's are the same. We do not see the latest state-of-the-art improvements. The airlines are locked in -- and suffer."

Figure 31. Concluded.

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13. ABSTRACT (Maximum 200 words) Although thrust reversers are used for only a fraction of the airplane operating time, their impact on nacelle design, weight, airplane cruise performance, and overall airplane operating and maintenance expenses is significant. Why then do the airlines want and use thrust reversers? In an effort to understand the airlines need for thrust reversers, a survey of the airline industry was made to determine why and under what situations thrust reversers are currently used or thought to be needed. The survey was intended to help establish the cost/benefits trades for the use of thrust reversers and airline opinion regarding alternative deceleration devices. A compilation and summary of the responses given to the survey questionnaire is presented.				
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