SPECIAL STUDY

U. S. GENERAL AVIATION ACCIDENTS INVOLVING FUEL STARVATION 1970 - 1972

ADOPTED APRIL 11, 1974

NATIONAL TRANSPORTATION SAFETY BOARD
Washington, D.C. 20591
REPORT NUMBER: NTSB-AAS-74-1

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. NTSB-AAS-74-1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Special Study - U. S. General Aviation Accidents Involving Fuel Starvation, 1/ 1970-1972		5. Report Date April 11, 1974
		6. Performing Organization Code
7. Author(s)		8. Performing Organization Report No.
9. Performing Organization Name and Address Bureau of Aviation Safety National Transportation Safety Board Washington, D. C. 20591		10. Work Unit No. 1264
		11. Contract or Grant No.
		13. Type of Report and Period Covered Special Study
12. Sponsoring Agency Name and Address NATIONAL TRANSPORTATION SAFETY BOARD Washington, D. C. 20591		14. Sponsoring Agency Code

15. Supplementary Notes 1/ For purposes of this study, fuel starvation is defined as the interruption, reduction, or complete termination of fuel flow to the engine, although ample fuel for normal operation remains aboard the aircraft. This special study contains aviation Safety Recommendations A-74-35 thru A-74-40.

16. Abstract

This report analyzes fuel starvation accidents involving 29 selected makes and models of fixed-wing aircraft, which occurred in all operations of U. S. General Aviation from 1970 through 1972. Of the selected group, 12 aircraft were found to be more, or less, susceptible to fuel starvation than the others. Accidents involving these 12 aircraft were reviewed in detail to define the primary causes of fuel starvation and other associated causal factors. Chronic difficulties and influential factors, found in the accident file review and technical research were discussed with representatives of the Federal Aviation Administration and three manufacturers of general aviation aircraft. From these discussions, remedial measures to reduce the number of fuel starvation accidents were formulated.

17. Key Words Fuel Starvation, All U. S. General Aviation Aircraft, Susceptibility to Starvation Accidents, Chronic Difficulties.		18. Distribution Statement This document is available to the public through the National Technical Information Service, Springfield, Virginia 22151	
19. Security Classification (of this report) UNCLASSIFIED	20. Security Classification (of this page) UNCLASSIFIED	21. No. of Pages 27	22. Price

NTSB Form 1765.2 (11/70)

TABLE OF CONTENTS

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INTRODUCTION

This study was initiated as a result of the findings of a previous National Transportation Safety Board study titled "Accidents Involving Engine Failure/Malfunction U. S. General Aviation 1965-1969," which revealed that 19.3 percent of 4,310 engine failure accidents had been caused by fuel starvation.

For this study, the 3 years from 1970 through 1972 were selected to reflect the most recent information in the Safety Board's automated aircraft-accident data bank. Information thus obtained indicated that 2,741 accidents resulted from engine failure or malfunction during that period. Of this total, fuel starvation was cited as a cause or related factor in 492 accidents. Although the percentage of fuel starvation accidents decreased from 19.3 percent of the engine failure or malfunction accidents for the 1965-1969 period to 17.95 percent for the 1970-1972 period, fuel starvation has remained a significant problem in general aviation safety.

Therefore, the objectives of this study are: (1) To identify the most frequent causes of fuel starvation accidents, (2) to examine the factors involved in those causes, and (3) to propose remedial action to reduce the number of fuel starvation accidents.

During the study, 192 accident reports were examined. In addition, typical fuel system designs and operating procedures for general aviation aircraft were reviewed. Findings of the study were discussed with the Federal Aviation Administration (FAA) and manufacturers of general aviation aircraft before the recommendations were formulated.

BASIS FOR STATISTICAL ANALYSIS

The scope of this study was limited to the most frequently occurring causes so that causal areas and associated factors could be researched thoroughly. Therefore, the study concentrated on airplane makes and models most susceptible to fuel starvation accidents and, for comparison, those least susceptible.

1/ For purposes of this study, fuel starvation is defined as the interruption, reduction, or complete termination of fuel flow to the engine, although ample fuel for normal operation remains aboard the aircraft.

Of the 99 airplane makes and models involved in fuel starvation accidents from 1970 through 1972, 70 makes and models accounted for only 27 percent of the reported accidents. Therefore, to save time, those makes and models which accounted for less than 0.813 percent of the base period fuel starvation accidents were not analyzed further. Accordingly, 29 makes and models were selected for statistical evaluation. 2/

Of the 29 makes and models analyzed, 15 were involved in an average number of fuel starvation accidents in 1970 through 1971, 9 were involved in a higher (H or VH) number of fuel starvation accidents than expected, while 3 were involved in a lower (L or VL) number than expected. Two airplanes could not be analyzed because of insufficient flight-hour data.

Although fuel starvation accident data were available for the 3-year period 1970 through 1972, the airplane population and hours-flown data needed for statistical computations were not available. Therefore, the results of the statistical analysis discussed in the Appendix pertain to only the years 1970 and 1971. However, to assure that significant cause data were not overlooked, the review of individual accident reports included those for 1972 for airplanes identified by the statistical analysis as most susceptible and least susceptible to fuel starvation accidents.

The nine airplanes with high or very high ratings were assigned to the subgroup, "high-involvement group." The three airplanes with low or very low ratings were assigned to the "low-involvement group." By so grouping, accidents in 1970-1972 for which fuel starvation was cited as a cause or related factor, could be reviewed conveniently to determine the specific kind of difficulties that caused the fuel starvation.

CAUSES OF FUEL STARVATION ACCIDENTS

From 1970 through 1972, there were 126 fuel starvation accidents in which high-involvement group airplanes were involved. The most frequently cited causes of fuel starvation for this group are: (1) Exhaustion of fuel from the tank in use while ample fuel for continued operation remained on the aircraft, (2) nonadherence to airplane operating limitations imposed by airworthiness directives, (3) mechanical malfunctions which resulted in fuel starvation, (4) incorrect positioning of the fuel selector valve, and (5) contamination of the fuel system (see Table 1).

From 1970 through 1972, there were 66 fuel starvation accidents in which low-involvement group airplanes were involved. The most frequently cited causes for fuel starvation accidents for this group are: (1) Contamination of the fuel system, (2) improper use of powerplant controls, (3) instructional simulation of in-flight power loss, (4) incorrect positioning of the fuel selector valve, and (5) mechanical malfunctions which resulted in fuel starvation (see Table 2).

2/ For details of how these 29 makes and models were evaluated, see Appendix.

CAUSE/FACTOR DATA
FUEL STARVATION ACCIDENTS, 1970-72

High and Very High Involvement Group Airplane

Make/Model	WPFSV	RD	MPFSV	MPFG	CONT	LF	IC	IAD	MEF	IMOD	UNK
Callair A9		2								1	
A9A		1									
A9B		7							2		
Beech 35	2	1							2		
35A	2	2							1		
B35	2	1		1					1		
C35	1	1	1								
D35		1							1		
G35	1	2	1								
H35		3	1						1		
J35		2	1		2						1
K35		1	1								
M35		1									
P35			1								
S35		1									
V-35A			1					1			
V-35B		1									
35-33				1							
35-D33		1									
Conversion E-50			1								
V-35		1									

%*		
6%	WPFSV =	failure/improper use of wobble pump/fuel selector valve unit
41%	RD =	tanks in use exhausted (run dry) in flight, while ample fuel remained aboard
10%	MPFSV =	mispositioned fuel selector valve
2%	MPFG =	fuel gage not reading tank in use
9%	CONT =	contamination; ice, water, foreign matter found in fuel sys/vent lines
4%	LF =	pilot took off with low fuel quantity
2%	IC =	improper use of powerplant control to perform intended function
11%	IAD =	violation of issued Airworthiness Directive
11%	MEF =	mechanical failure
2%	IMOD =	improperly performed modification
2%	UNK =	cause unknown/undetermined

*Indicates percentage of all cause citations for aircraft of this group

Table 1

CAUSE/FACTOR DATA
FUEL STARVATION ACCIDENTS, 1970-72

High and Very High Involvement Group Airplane
(continued)

Make/Model	WPFSV	RD	MPFSV	MPFG	CONT	LF	IC	IAD	MEF	IMOD	UNK
Beech 95						1					
95A55			1								
95B55						1					
95C55								2			
Boeing A-75N1					1				1		
Navion A		1						2			
Bellanca 17-30		3					1	1			
17-30A		2									
Piper PA-12		2			2			1	1	1	
PA-22-		1			1				1		
-135		3		1	1			2	1	1	
-150		1	2		1	2	1	5	1		
-108							1				
-125					1						
-160		1			1						
PA-24-		2									
-180		2			1						
-250		1			1			1	1		
-260		4	1			1					
-400		2	1								

Table 1 (cont'd)

CAUSE/FACTOR DATA
FUEL STARVATION ACCIDENTS, 1970-72

Low and Very Low Involvement Group Airplane

Make/Model	RD	MPFSV	CONT	LF	IC	MEF	IFSE	IAD	IMOD	UNK
Cessna 150	1		3		2	2	4			
150-F			2				3			1
150-G		1	1			1				
150-H			3		4		1			
150-K			1	1	1					
150-L			1		1					
150-J			2		1		1			
Cessna 172	1				1		1			
172-A	1									
172-E			1							
172-F			1			1				
172-G		1								
172-H					1					
172-L		2								
Cessna 182		3	2		1	2				
182-A		1	1		1	1				
182-B								2		
182-E	1									
182-G	1					1				
182-L					1					

%*		
7%	RD =	tanks in use exhausted (run dry) in flight, while ample fuel remained aboard
12%	MPFSV =	mispositioned fuel selector valve
26%	CONT =	contamination; ice, water, foreign matter found in fuel sys/vent lines
1%	LF =	pilot took off with low fuel quantity
22%	IC =	improper use of powerplant control to perform intended function
13%	MEF =	mechanical failure
15%	IFSE =	instructor simulated failed engine; unable to restart engine in time to avoid accident
3%	IAD =	violation of issued Airworthiness Directive
0	IMOD =	improperly performed modification
1%	UNK =	cause unknown/undetermined

*Indicates percentage of all cause citations for airplane of this group

Table 2

Two of the five most frequently cited causes for the high- and low-involvement groups appeared in about the same percentage for each group. These causes were: (1) Mechanical malfunctions, which accounted for 11 percent of the high-involvement group citations and 13 percent of the low-involvement group citations, and (2) incorrect positioning of the fuel selector valve, which accounted for 10 percent of the high-involvement group cause citations and 12 percent of the low-involvement group citations.

A detailed review of the accident reports indicated that the mechanical malfunctions occurring for high- and low-involvement group airplanes generally were component failures, such as a ruptured flow divider diaphragm and fractured fuel pump gear, a sticking needle valve in the carburetor, or a broken powerplant control cable. Patterns of chronic mechanical failure were not found in either group. This review also revealed that most instances of incorrect fuel selector valve positioning resulted because the pilot was confused about the mode of valve operation, valve handle design, or fuel selector tank display. Many pilots positioned fuel selector valve handles to the "off" position or to an empty tank, while under the impression that they had selected a tank which contained fuel. These kinds of difficulties with fuel selector valve operation were common to both the high- and low-involvement group airplanes.

FACTORS INVOLVED IN FUEL STARVATION ACCIDENTS

An explanation of the deviation of both groups from the average cannot be based logically on a comparison of cause citation percentages between the high- and low-involvement groups, because the high-involvement group percentages reflect only the magnitude of the problems which plague that group, and the low-involvement group percentages reflect only the magnitude of problems which plague that group. It is important to realize that, in some cases, the high percentages of cause citations presented for both groups may reflect the fact that only a relatively small number of accident cases were studied, rather than a significant difference in the frequency of occurrence of a specific cause. Similarities and differences in the cause citation percentages between the high- and low-involvement groups indicated trends in the kinds of problems affecting airplanes at both ends of the fuel starvation spectrum. These trends were used to formulate plans for more detailed research of the fuel starvation problem.

Operational Difficulties

One hundred sixty-six (86.6%) of the 192 accident reports reviewed cited operational causes. Exhaustion of fuel from a tank in use, noncompliance with airworthiness directives, fuel system contamination, improper use of engine controls or fuel selector, and deliberate starvation for emergency simulation indicated that most fuel starvation accidents were related to improper fuel management, inadequate preflight preparation, lack of familiarity with the airplane or errors in judgment.

All these causes involve operational procedures and techniques employed by pilots.

Two of the 10 causes cited for high-involvement group airplanes accounted for 52 percent of the fuel starvation accidents. These causes were: Exhaustion of fuel from a tank in use while ample fuel for continued operation remained aboard the aircraft, and noncompliance with operating limitations imposed by airworthiness directives. For the low-involvement group airplanes 3 of 9 cited causes accounted for 63 percent of the fuel starvation accidents. These causes were: Fuel system contamination, improper use of powerplant controls, and instructional simulation of in-flight power loss. To provide a better understanding of the reasons for the difficulties, high- and low-involvement group airplane accidents which involved these causes were examined more closely. The main reasons stated in accident reports for the problems peculiar to each group were:

<u>High Group</u>

- For exhaustion of fuel from a tank in use:

  (1) Allowing fuel to become exhausted was normal procedure recommended in owner manuals of some aircraft; (2) pilots forgot to switch tanks before exhaustion of fuel from the tank in use; (3) engine was not restarted in sufficient time to prevent an accident.

- For lack of compliance with fuel system operational limitations imposed on certain aircraft by airworthiness directive:

  (1) pilots did not fully comprehend the AD requirements;
  (2) they simply ignored them.

<u>Low Group</u>

- For improper use of powerplant controls: The pilot used the mixture control when he intended to apply carburetor heat.

- For fuel system contamination:

  (1) Water was not properly drained from the fuel system,
  (2) foreign objects obstructed fuel tank vent lines.

- For instructional simulation of in-flight power loss: The instructor attempted a power loss simulation, as a test for a student pilot, by turning the selector valve "off," or placing the mixture control in the "idle cutoff" position (three of these simulated emergencies were initiated at less than 1,200 feet above the ground).

Other Related Factors

A comparison of time in airplane type and total time for pilots of high- and low-involvement group airplanes was made to determine if a correlation existed between pilot experience and the statistical disparity of these groups. The ratio of pilot time in make and model to total flying time in all makes and models was comparable for pilots of the five different airplanes. Therefore, a correlation was not obtained.

Only one multiengine general aviation airplane, the Beech 95, was involved in a more-than-average number of fuel starvation accidents during the 1970-1972 period. Four of the five fuel starvation accidents in which this multiengine airplane was involved were attributed directly to a violation of recommended operating limitations imposed by an airworthiness directive. The directive required takeoff on main tanks only and prohibited turning takeoffs or takeoffs immediately following fast taxi turns.

POTENTIAL SOURCES OF OPERATIONAL DIFFICULTIES

Most fuel starvation accidents reviewed involved operational problems which indicated a need to evaluate certain influential factors associated with operational techniques. Accident case research indicated that operational techniques involving such factors as awareness and understanding of proper fuel management could be influenced significantly by information provided in airplane owner manuals and by fuel system components which may induce operational errors.

Lack of Information in Owner Manuals

The airplane owner manual is the primary source of operating information for a specific airplane. Several owner manuals for high- and low-involvement group airplanes were reviewed to determine what information is available to the general aviation pilot with regard to fuel management and draining procedures.

Fuel Management Instructions

A review of the fuel management information for selected airplanes, which is presented in Example 1, indicated that the older manuals contained less fuel management information than more recent manuals contain. Although running one tank dry before switching to another tank was once an accepted practice, most manufacturers no longer recommend it. In fact, the most recently published Beech manuals consider engine failure caused by insufficient fuel an emergency and lists in-flight engine start procedure as an emergency procedure.

The yearly variation in fuel management information presented in the owner manuals showed that some pilots possessed more specific information on which to base operational techniques and judgments. The extent to

BEECH MODEL 35

YEAR	
1962:	"...There is no reason for not running a cell dry before switching. However, if the engine is allowed to stop firing, the throttle should be retarded as the engine picks up."
1965:	"...If desired, fuel can be drawn from either cell until engine operation indicates the cell is empty. The best time to switch cells is immediately after noting a fluctuation in fuel flow. However, if the engine is allowed to stop firing, it is important that the following procedure be observed: ..."
1972:	"...Take-offs and landings should be made using the main cell that is more nearly full. In no case should a takeoff be made if the fuel indicators are in the yellow band, or with less than 13 gallons of fuel in each main tank... If the engine is allowed to stop firing, due to insufficient fuel, refer to the Emergency Procedure Section for the Air Start procedures."

CESSNA MODEL 182

YEAR	
1957:	"...Take-off should be made in the "BOTH ON" position to prevent inadvertent take-off on an empty tank."
1972:	"...IMPORTANT the fuel selector valve should be in the "BOTH" position for take-off, climb, landing, and maneuvers that involve prolonged slips or skids. Operation from from either "Left" or "Right" tanks is reserved for cruising flight."

EXAMPLE 1. FUEL MANAGEMENT PROCEDURES

which pilots operating early model year airplanes are aware of improved procedural information presented in later model owner manuals could not be evaluated.

Fuel Draining Instructions

Fuel system contamination was responsible for 26 percent of low-involement group fuel starvation accidents and 9 percent of high-involvement group fuel starvation accidents. Water in the fuel and foreign object obstruction of fuel tank vents were the primary contamination difficulties which caused an investigation of fuel system draining procedures and preflight checklist procedures in owner manuals of high- and low-involvement group airplanes. Selected passages which show owner manual instructions regarding fuel draining appear in Example 2.

Obviously, some owner manuals for airplanes in both the high- and low-involvement groups were more explicit about fuel system draining procedures than were others. Procedures insufficiently detailed could result in incomplete draining operations; for example, instructing a pilot only to open a quick drain sump in a fuel strainer or selector to purge water or sediment from the system may not alert the operator to the absolute necessity of purging all fuel lines and tank sumps in the proper sequence to assure the elimination of all contaminants. Detailed draining procedures, such as those presented in Federal Aviation Administration Advisory Circular No. 20-43B "Aircraft Fuel Control," which specify the correct sequence and duration of purging procedures would be an asset to pilots who seek and follow the guidance of owner manuals.

Owner manuals for high- and low-involvement group airplanes were also inconsistent with regard to fuel tank vent-check procedures; some manuals included a fuel tank vent check as part of the preflight inspection; others did not.

Federal Aviation Regulations (14 CFR 23.2581(a)) concerning airplane flight manuals require that applicable information regarding operating limitations, operating procedures, performance information and landing information "must be furnished (1) for each airplane of more than 6,000 pounds maximum weight, in an airplane flight manual; and (2) for each airplane of 6,000 pounds or less maximum weight, in an airplane flight manual, or in any combination of approved manual material, markings, and placards." The manufacturer must provide information concerning normal and emergency procedures and other pertinent information necessary for safe operation. Within these broad regulatory guidelines, a manufacturer may present as much fuel system operational information as deemed necessary for safe operation. These options, as allowed by the regulations, have resulted in the variety of information presented in owner manuals as shown by Examples 1 and 2. The amount of detailed information varied not only from year to year, but also among different makes and models in the same year.

BEECH MODEL 35 YEAR		PIPER MODEL PA-24 YEAR		CESSNA MODEL 182 YEAR	
1956:	"...Each cell has a sump drain at its outlet and there is an additional sump drain on the strainer...A small quantity of fuel should be drained from each sump daily, to eliminate moisture and sediment from the fuel system."	1958:	"...The fuel strainer, equipped with a quick drain, is mounted under... the fuselage. The strainer should be drained regularly to check for water or dirt accumulations. The procedure for draining the right and left tanks and lines is to open the gasculator (sic) quick drains for a few seconds with the fuel tank selector on one tank. Then change the fuel selector to the opposite tank and repeat the process, allowing enough fuel to flow out to clear the line as well as the gasculator (sic)."	1957:	"...A two ounce quantity (approximately 3 to 4 seconds of drain knob operation) should be drained from the strainer before the initial flight of the day or after each refueling operation...A fuel tank sump drain plug is located on the underside of each wing...these plugs are used to drain any sediment or water that may collect in the fuel tanks. Under normal operating conditions, it is recommended that the wing tank sumps be drained at each 100 hour inspection period."
1965:	"...Open the three snap-type fuel drains daily to purge any condensed water vapor from the system..."	1967:	"...The general procedure for draining the fuel system is to open the strainer quick drain for a few seconds with the fuel cell selector on one cell, then change fuel selector to the opposite cell and repeat the process...Allow enough fuel to flow to clear lines as well as the strainer."	1972:	"...On first flight of day and after each refueling, pull out strainer drain knob for about four seconds to clear fuel strainer of possible water and sediment. Check strainer drain closed. If water is observed, there is a possibility that the wing tank sumps contain water. Thus, the wing tank sump drain plugs and fuel selector valve drain plug should be removed to check for the presence of water."

EXAMPLE 2. FUEL DRAINING PROCEDURES

Error-Inducing Elements of the Fuel System

The high-involvement group airplanes experienced difficulty with fuel exhaustion from a tank in use while ample fuel for normal operation remained onboard. Both high- and low-involvement groups experienced accidents which resulted from mispositioning the fuel selector valve. Improper use of engine controls and fuel contamination were troublesome for pilots of low-involvement group airplanes. As a result of these findings, tank switching requirements, fuel system purging features, and powerplant control configuration were researched to find possible error-inducing sources within the fuel system.

Fuel Selector Valves

Virtually all tank switching problems involved the fuel selector valve. Although fuel selector mispositioning was an operational error, the degree to which selector handle design, selector orientation, location, and tank display influenced selector operation was of interest. The extent to which pilot error was induced by fuel selector design was documented in NTSB Report PB175629, "Aircraft Design Induced Pilot Error," dated July 1967. Accident reports from 1970 through 1972 period indicate that selector design still confuses operators and induces tank selection errors.

The influence of tank switching requirements as a factor in fuel starvation accidents was illustrated by the Cessna 150 accident statistics. This airplane is equipped with a two-position (ON or OFF) fuel shutoff valve, instead of a multiposition fuel selector valve so tank selection is not necessary. Although the Cessna 150 had accumulated the largest airplane hour total in 1970 and 1971, and ranked third in airplane population from 1970 through 1972, it was involved in only 38 fuel starvation accidents in 1970 through 1972. Of these, only one was caused by improper positioning of the fuel valve and one by fuel exhaustion.

Accident statistics for airplanes with and without a "BOTH TANKS" position on the fuel selector were compared to further determine the relationship between tank switching and fuel starvation. The "BOTH TANKS" selector position allows fuel from both wing cells to feed the engine simultaneously. The tanks are interconnected at the selector valve and switching is not necessary to manage the fuel supply properly. Fuel tank switching, however, is required to manage fuel properly in those airplanes which do not have the "BOTH TANKS" selector position. Four airplane models were chosen from the low- and high-involvement groups for this comparison. The two airplane models with the "BOTH TANKS" selector position accounted for 24 percent of the total airplane population and 21.2 percent of the total airplane hours in 1971 (see Appendix Table 2). The two airplane models without the "BOTH TANKS" selector position accounted for 11.6 percent of the total 1971 airplane population and 9.3 percent of the total airplane hours that year. Despite the larger population and airplane hour total of the two airplanes with the "BOTH TANKS" selector position, they were involved in only four fuel starvation accidents caused by exhaustion of fuel from a tank in use, from 1970 through 1972. Those airplanes without the "BOTH TANKS" selector position were involved in 30 such accidents. These accident statistics reinforced the emerging relationship between the necessity to switch tanks and fuel starvation attributed to exhaustion of a single tank.

Draining Features

The features used to purge fuel system contaminants were similar for airplanes in both the high- and low-involvement group. In general, the fuel system had tank sump drains, strainer drains, and selector valve drains which were adequate for complete system purging. The disparity in the percentage of starvation accidents attributed to fuel system contamination --26 percent for the low-involvement group and 9 percent for the high-involvement group airplanes --could not be attributed to system design since the purging features of both groups are similar.

Powerplant Controls

The use of an incorrect engine control accounted for 22 percent of all causes cited for low-involvement group fuel starvation accidents from 1970 through 1972. Only 2 percent of the high-involvement group's causes involved incorrect use of engine controls. Inadvertent use of the mixture control, when the pilot thought he was using the carburetor heat control, accounted for most of the causes cited for low-involvement group airplanes. The placement of the engine controls for low-involvement group airplanes has varied through the years. Early models were configured so that carburetor heat, throttle, and mixture controls were juxtaposed horizontally with little variation in knob shape, size, or color between the carburetor heat and mixture controls. Control knob size, shape, and color has been varied in recent models of these airplanes. From 1970 through 1972, the Beech 35 was not involved in a starvation accident caused by improper use of engine controls. The mixture control in the Beech 35 is isolated sufficiently from other powerplant controls so that pilots did not confuse them. Proximity of controls of a similar size and shape, which perform entirely different functions, was considered as a possible source of error inducement in accidents which involved the use of the wrong control. To minimize incorrect control operation, the Federal Aviation Regulations (14 CFR 25.777 through 25.781) specify standards of powerplant control location, knob shape, and mode of actuation for transport category airplanes; however, except for throttle actuation regulations, similar powerplant control specifications do not exist for normal, utility, and acrobatic category airplanes which comprise the largest segment of the general aviation fleet.

Manufacturers' Viewpoint Regarding Error Inducement

Three major general aviation airplane manufacturers, who deal with multifaceted fuel system design problems, were invited to discuss the elements of the fuel system which are regarded as potential sources of operational problems. The difficulties associated with tank selection requirements, fuel exhaustion from a tank in use, fuel contamination, and adequacy of owner manual procedures were discussed.

Tank Selection Requirements

The manufacturers agreed that a balanced single-tank fuel system (where interconnected cells act as a single tank to supply fuel to the engine through a shutoff valve instead of through a fuel selector valve) would simplify fuel management procedures. A balanced gravity-feed system is used in some high-wing airplanes of the low-involvement group. However, experiments by one manufacturer of low-wing airplanes indicated that fuel feeding problems would be encountered if the balanced system without a sump tank (a small tank in which fuel from the main wing cells accumulates before passing through the fuel shutoff valve) were adapted to existing low-wing airplanes.

The concept of a balanced fuel system with a sump tank appealed to the manufacturers. However, two manufacturers stated that the wing position and forward fuselage structure of low-wing airplanes do not leave a safe location for the installation of such a system in current models. Nevertheless, the benefits to be derived from the balanced, single-tank system with a sump tank warranted development work on such a system for future low-wing airplanes by at least one major manufacturer.

Exhaustion of a Tank

Manufacturers were greatly concerned about the apparent lack of attention to fuel supply which is apparent from the number of accidents resulting from the exhaustion of a tank while ample fuel remained onboard the aircraft. While one obvious solution to the problem appears to be better education about fuel management, two manufacturers indicated that a low-fuel warning device could be used to alert a pilot of impending fuel starvation. One manufacturer believed that after further development work, a more accurate capacitance-type fuel gaging system could replace the float-type gaging system and thereby provide operators with more reliable fuel quantity information. Manufacturers agreed that such devices would aid the pilot as long as such improvements did not produce a sense of complacency regarding fuel system management.

Contamination

Manufacturers showed much interest in fuel contamination problems. They agreed that strict adherence to fuel system draining procedures was the most effective method of minimizing these problems. Some skepticism was expressed about the effectiveness of publishing more explicit draining procedures in owner manuals. Some manufacturers believed that pilot awareness of the importance of fuel system purging would not be increased significantly by simply presenting detailed draining procedures. One manufacturer indicated that increased accessibility and ease of operation of fuel system drains would encourage more thorough fuel system draining by airplane operators and, thereby, minimize the possibility of fuel starvation caused by contamination. The same manufacturer discussed the feasibility of a fuel system water detection device which has been developed and successfully tested. With further development and testing, the device could substantially reduce contamination problems which result from water in the fuel.

The fuel system's vents are most frequently obstructed by ice, insect nests, and vegetation. Manufacturers are aware of the problems caused by tank vent obstruction and believe that the best method of avoiding these problems is a thorough preflight vent inspection. Manufacturers have attempted to alleviate vent contamination through system design improvements. Multiple tank vents have been designed to provide alternate venting sources in case one source becomes obstructed. A NASA-designed nonicing vent has been adapted to some recent aircraft.

Pilot Awareness

While manufacturers expressed the general opinion that fuel system design improvements and operational procedure improvements could diminish fuel starvation problems, they stressed the importance of pilot awareness with regard to proper fuel system maintenance and operation, and the fundamental sources of fuel starvation.

Recognition of the Problem

The General Aviation Manufacturers Association has two projects underway which could lead to the elimination of several factors which contribute to fuel starvation. One is a study by the Technical Policy Committee of the feasibility of fuel system design standardization in general aviation airplanes; the second is the development of specifications for the content and format of owner manuals.

FINDINGS

General aviation airplanes involved in a higher number of fuel starvation accidents than expected statistically, from 1970-1971 were: Callair A-9, Beech 35, Beech 95, Piper PA-12, Piper PA-22, Piper PA-24, Navion A, Bellanca 17-30, and Boeing A-75. From 1970 through 1972, the most frequently cited causes of fuel starvation accidents for these airplanes were:

(1) Exhaustion of fuel from a tank in use while ample fuel for normal operation remained aboard.

(2) Nonadherence to aircraft operating limitations imposed by airworthiness directive.

(3) Mechanical malfunctions.

(4) Incorrect positioning of fuel selector valve.

(5) Fuel system contamination.

General aviation airplanes involved in a lower number of fuel starvation accidents than expected statistically, from 1970-1971, were: Cessna 150, Cessna 172, and Cessna 182. From 1970 through 1972, the most frequnely cited causes of fuel starvation accidents for these airplanes were:

(1) Fuel system contamination.

(2) Incorrect use of powerplant controls.

(3) In-flight power loss simulation during instructions.

(4) Incorrect positioning of fuel selector valve.

(5) Mechanical malfunctions.

Mechanical difficulties or malfunctions, which were cited as causes of high- or low-involvement group starvation accidents, were isolated. Chronic mechanical problems were not evident.

Procedures for fuel management and fuel system purging, which are contained in owner manuals of selected high- and low-involvement group airplanes, often lacked detail.

Airplanes with fuel systems which require minimal tank switching to manage fuel properly were involved in far fewer starvation accidents than aircraft with more complex tank selection requirements.

The improper use of an engine control appeared to be directly related to the absence of adequate control differentiation.

CONCLUSIONS

The message which evolves from the causes of fuel starvation accidents is very clear -- thorough preflight fuel system inspection and draining, complete familiarity with powerplant control configuration and operation, and attentiveness to fuel supply are all absolutely essential to safe airplane operation.

Whereas nearly 87 percent of the fuel starvation accidents in this study were attributed to operational problems, these problems are not independent of the factors which influenced or caused them. Therefore, remedial action must be directed at the primary factors which influence fuel system operation. These factors are as follows:

Design-Associated Factors

- Owner manuals which often lack detailed information on fuel management and fuel system purging operations.
- Fuel systems which require tank switching in order to manage the fuel supply properly.
- Fuel selector valves with handle design, mode of operation, or tank display which may be conducive to mispositioning.
- Placement of engine controls and similarity of appearance which may be conducive to improper use.

Pilot-Associated Factors

- Instructional techniques for emergency simulation by deliberate fuel starvation at low altitude.
- Lack of knowledge or concern for good fuel management procedures and techniques, including the need for thorough preflight fuel system inspection and purging.

RECOMMENDATIONS

The National Transportation Safety Board believes that the number of U. S. General Aviation fuel starvation accidents can be substantially reduced by constructively changing the above conditions. Accordingly, the Safety Board recommends that the Federal Aviation Administration:

1. Issue an Advisory Circular, which augments the information presented in Federal Aviation Administration Advisory Circular No. 20-43B "Aircraft Fuel Control," (a) to alert general aviation pilots of the primary difficulties causing fuel starvation; and (b) to warn certificated flight instructors of the danger associated with simulation of emergency engine failure by positioning the fuel selector valve to "off" or the mixture control to "idle cutoff." (Recommendation A-74-35)

2. Amend 14 CFR 23.1581 so that an approved Airplane Flight Manual is required for all airplanes regardless of weight,

thereby assuring greater consistency and attention to detail than is currently available in most owner manuals for airplanes which weigh less than 6,000 pounds. (Recommendation A-74-36)

3. Promote awareness of fuel starvation problems among those individuals who are beginning careers as student pilots by:

   a. Requiring a written test as part of student pilot flight requirements in 14 CFR 61.63, similar to that required for private pilots in 14 CFR 61.87.

   b. Structuring written tests so that an applicant's knowledge of fuel system operating principles and factors which cause fuel starvation can be determined. (Recommendation A-74-37)

4. Amend 14 CFR 23.777 through 23.781 to include specifications for standardizing powerplant control location, visual and tactile appearance, and mode of actuation, similar to the specifications for transport category airplanes appearing in 14 CFR 25.777 through 25.781. (Recommendation A-74-38)

5. Amend 14 CFR 23 to include specifications for standardizing fuel selector valve handle designs, displays, and modes of operation. (Recommendation A-74-39)

In addition, the Safety Board recommends that the General Aviation Manufacturers Association (GAMA) establish industry-wide recommended design practices for fuel systems of future general aviation airplanes, and where practicable apply these same practices to existing models through system modifications. Application of these practices to all existing airplanes may be impossible for reasons of cost or physical constraints; however, the following practices could be applied to the design of future airplanes at a minimum cost: (Recommendation A-74-40)

a. Specifications for a low fuel warning device which operates independently of the fuel gage system.

b. Specifications for a water contamination warning system.

c. Specifications for more accurate type of fuel quantity gaging system.

d. Specifications for multiple fuel tank vents and nonicing tank vents to minimize the possibility of vent obstruction.

e. Simplification of the fuel system through the use of the balanced, single-tank design concept.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

/s/ JOHN H. REED
Chairman

/s/ FRANCIS H. McADAMS
Member

/s/ LOUIS M. THAYER
Member

/s/ ISABEL A. BURGESS
Member

William R. Haley, Member, was absent and did not participate in the adoption of this report

April 11, 1974

APPENDIX

METHOD OF STATISTICAL ANALYSIS

The selected 29 airplane makes and models were evaluated by the single degree of freedom chi-square analysis. The chi-square analysis produced a numerical rating for each of the 29 makes and models. This quantitative rating was used to determine a qualitative rating which describes airplane involvement in base period fuel starvation accidents as being higher or lower than expected. Numerical ratings were determined in the following manner:

$$X^2 = \frac{(F_o - F_e)^2}{F_e}$$

where: X^2 = the numerical rating of a make and model

F_o = the actual number of fuel starvation accidents for a particular make and model in 1970 and 1971

F_e = the expected number of fuel starvation accidents for that particular make and model in 1970 and 1971

To calculate the expected number of fuel starvation accidents (F_e), it was assumed that for a given period the ratio of the number of fuel starvation accidents for a particular make and model airplane to its hours flown was directly proportional to the ratio of the total number of fuel starvation accidents for all 29 selected airplane makes and models to the total airplane hours for these makes and models.

$$\frac{F_e \text{ for airplane Y (1970-1971)}}{\text{Hours for airplane Y (1970-1971)}} = \frac{\text{All fuel starvation accidents for selected group airplanes (1970-1971)}}{\text{Hours for all selected group airplanes (1970-1971)}}$$

The number of fuel starvation accidents for a given make and model airplane (F_o) was obtained from the accident data bank. Based on a known value of F_o obtained from the accident data and a computed value of F_e, the numerical rating (X^2) of airplane makes and models comprising the selected group was calculated.

Airplane hour and population data used in statistical computations are presented in Appendix Tables 1 and 2. Results of the statistical analysis and assignment of qualitative ratings appear in Appendix Table 3.

FUEL STARVATION ACCIDENTS BY AIRPLANE TYPE 1970

Make/Model (*denotes twin engines)		Number of Active Airplanes	Number of Hours Flown	Number of Fuel Starvation Accidents
Callair	A-9	248	30,666	5
Beech	18*	1,130	201,106	4
	35	6,168	654,775	17
	95*	518	65,932	4
	23,24	1,480	184,091	3
Cessna	150	10,583	2,128,355	11
	172	11,232	1,383,154	4
	182	7,591	848,676	5
	310*	2,102	297,920	2
	337	783	116,400	0
	177	1,124	147,043	3
Amer. Aviation	AA-1	308	37,946	0
	AA-1A	N/A	N/A	-
Mooney	M-20	4,037	438,157	3
Piper	PA-12	1,095	62,094	1
	18	2,357	215,055	3
	22	4,956	273,933	13
	23*	3,125	498,450	2
	24	3,273	372,412	6
	25	1,592	260,134	1
	28	11,029	1,815,297	16
	32	1,346	222,958	1
	J-3	2,345	104,134	3
Stinson	108	N/A	N/A	2
Taylorcraft	BC12-D	948	35,961	2
Navion	A	152	10,975	2
Grumman	G-164	493	110,356	2
Bellanca	17-30	255	25,432	3
Boeing	A-75	61	7,032	1
Totals		80,826	10,548,444	119

N/A = Not Available

Appendix Table 1

FUEL STARVATION ACCIDENTS BY AIRPLANE TYPE 1971

Make/Model (*denotes twin engines)		Number of Active Airplanes	Number of Hours Flown	Number of Fuel Starvation Accidents
Callair	A-9	227	41,059	5
Beech	18*	1,060	218,948	0
	35	6,019	747,341	16
	95*	496	70,731	2
	23,24	1,449	203,196	2
Cessna	150	10,465	2,575,034	18
	172	11,306	1,706,321	6
	182	7,533	960,258	4
	310*	2,112	345,996	2
	337*	802	133,367	3
	177	1,212	183,996	2
Amer. Aviation	AA-1	331	50,207	1
	AA-1A	176	31,465	2
Mooney	M-20	3,958	515,298	3
Piper	PA-12	1,056	71,623	5
	18	2,210	248,374	3
	22	4,907	339,536	10
	23*	3,027	548,406	7
	24	3,241	416,609	9
	25	1,572	316,991	3
	28	11,218	2,168,335	15
	32	1,322	265,369	1
	J-3	2,266	119,847	1
Stinson	108	N/A	N/A	2
Taylorcraft	BC12-D	946	43,646	0
Navion	A	138	9,082	1
Grumman	G-164	533	164,867	0
Bellanca	17-30	331	44,851	2
Boeing	A-75	70	9,180	0
Totals		79,983	12,549,933	125

N/A = Not Available

Appendix Table 2

STATISTICAL DATA
FUEL STARVATION ACCIDENTS, 1970-71
BY AIRPLANE TYPE

Make/Model (*denotes twin engines)		Number of Accidents Reported	Number of Accidents Expected	X^2		Qualitative Rating 1/
Callair	A-9	10	0.75	114.08	(1)	VH
Beech	18*	4	4.41	.03		A
	35	33	14.72	22.70		VH
	95*	6	1.43	14.60	(1)	VH
	23,24	5	4.07	0.21		A
Cessna	150	29	49.39	8.41		L
	172	10	32.44	15.52		VL
	182	9	18.99	5.25		L
	310*	4	6.76	1.12		A
	337*	3	2.62	0.05		A
	177	5	3.48	0.66		A
Amer. Aviation	AA-1	1	0.93	0.005		A
	AA-1A	-	-	-		-
Mooney	M-20	6	10.01	1.60		A
Piper	PA-12	6	1.40	15.11	(1)	VH
	18	6	4.87	0.26		A
	22	23	6.44	42.58		VH
	23*	9	10.99	0.36		A
	24	15	8.28	5.45		H
	25	4	6.06	0.69		A
	28	31	41.83	2.57		A
	32	2	5.13	1.91		A
	J-3	4	2.35	1.15		A
Stinson	108	-	-	-		-
Taylorcraft	BC12-D	2	0.84	1.60		A
Navion	A	3	0.21	37.04	(1)	VH
Grumman	G-164	2	2.89	0.27		A
Bellanca	17-30	5	0.74	24.52	(1)	VH
Boeing	A-75	1	0.17	4.05	(1)	H

(1) NOTE: For these airplanes, the large chi-square (X^2) values may only reflect the small values of F_e (number of accidents expected) rather than a significant departure of F_o (number of accidents observed) from F_e, as indicated by qualitative ratings. In the absence of definite criteria for determining the significance of these qualitative ratings for airplanes with small values of F_e, it was decided that these airplanes should be retained in the high involvement group as an additional source of information for accident case review.

1/ Qualitative ratings assigned as follows:

Appendix Table 3

for: $3.84 < X^2 \leq 10.8$ a rating of low (L) is assigned when $(F_o - F_e)$ is negative.

for: $3.84 < X^2 \leq 10.8$ a rating of high (H) is assigned when $(F_o - F_e)$ is positive.

for: $X^2 > 10.8$ a rating of very low (VL) is assigned when $(F_o - F_e)$ is negative.

for: $X^2 > 10.8$ a rating of very high (VH) is assigned when $(F_o - F_e)$ is positive.

for: $X^2 \leq 3.84$ a rating of average (A) is assigned.