1). Minimization with respect to β yields

$$k_{y_{cr}} = \frac{4}{3}\,\frac{C(2A)^{3/2}}{[(B^2 + 4AC) - B]^{3/2}} - \frac{B(2A)^{1/2}}{[(B + 4AC) - B]^{1/2}} \tag{11}$$

where

$$A = [1 + 12Z_t^2\acute{e}_y^2\lambda_{yy_r}\lambda_{yy_p}/(1 - \nu^2)\pi^4\lambda_{yy}]$$

$$B = 12Z_t^2\nu\acute{e}_y\lambda_{yy_r}(\lambda_{xx_p} + \lambda_{yy_p})/(1 - \nu^2)\pi^4\lambda_{yy}$$

$$C = 36Z_t^2(1 - \nu^2\lambda_{xx_p}\lambda_{xx_p}/\lambda_{yy})/(1 - \nu^2)\pi^4$$

Note that B could be either positive or negative depending on the outside or inside positioning of the rings. Furthermore, if $\bar{e}_y = 0$ then $B = 0$, $A = 1$, and Eq. (11) reduces to

$$k_{y_{cr}} = 1.04Z_t^{1/2}[(1 - \nu^2\lambda_{xx_p}\lambda_{yy_p}/\lambda_{yy})/(1 - \nu^2)]^{1/4} \tag{12}$$

Finally, when the assumption of isotropy is made, Eq. (10) reduces to the well-known expression

$$-k_{y_{cr}} = 1.04Z \tag{13}$$

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Aircraft Systems Studies under Long-Term World Environmental Storage

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Introduction

WITH the introduction of intercontinental ballistic missiles for field use, the importance of long-term storage effects on these missiles and their operating systems has become quite significant. It is necessary, of course, that these weapons be stored in their concrete operational silos on a ready-to-go basis for periods of five or more years.

The military personnel and technical staffs using these vehicles have raised the question of what effects this long-term storage has on missile flight control systems, their components and parts. Of particular concern was the effect on hydraulic fluids, "O" rings, and servovalve subassemblies. To help answer some of these questions and aid the preparation of military storage specifications, the Society of Automotive Engineers Long-Term Storage Panel was organized in 1959 with the author as chairman.

The problem at the outset of any long-term storage study, obviously, is acquisition of study material. Controlled experiments can be set up, but even under accelerated conditions, these take time.

As part of the investigations of this panel, hydraulic systems and hydraulic components from certain World War II types of aircraft were evaluated, with the data then being extrapolated for present-day systems. Many components were removed from aircraft at Davis-Monthan Air Base in Arizona for study, where they had been stored in the open desert, by the Air Force, for 5-to-10 yr periods of time. It was no surprise that the hydraulic equipment, instrumentation, and various other items of equipment proved to be in excellent condition. At this point, luck entered the picture.

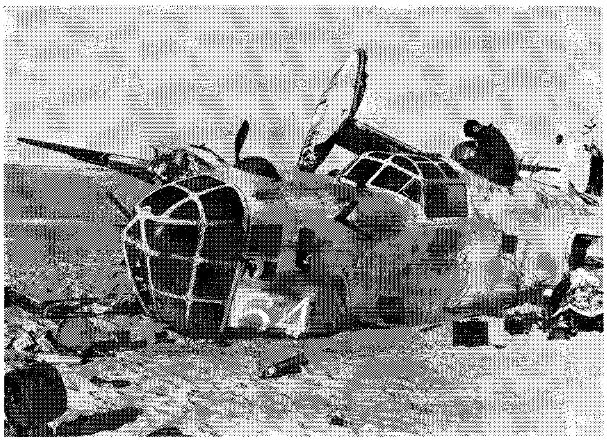

Fig. 1 "Lady Be Good" aircraft—African desert.

Desert Environmental Investigations

In 1960, a study was made of 16 peices of equipment removed from the B-24 aircraft "Lady Be Good" (Fig. 1) that had lain in the North African desert for 17 years. The environment was generally warm and dry—excellent for the equipment, as our investigations subsequently proved. The Vickers engine-driven pump and turret retraction motor met the requirements of new units, following this 17-yr storage period.

"Lady Be Good" had spent her last 17 years in a solar oven, baking at air temperatures of 120°F in the summer. Equipment inside the plane probably had been heated to more than 200°F. As far as her hydraulic system was concerned, this intense heat had seemingly provided a near-perfect environment, with one exception; the Buna-N diaphragm of the accumulator had slightly stiffened and had caused the unit to lose its gaseous charge.

Arctic Environmental Investigations

When the Air Force rediscovered the B-17 aircraft "My Gal Sal" in the middle of the Greenland icecap (Fig. 2) in October 1964, it was believed that this would be an excellent situation

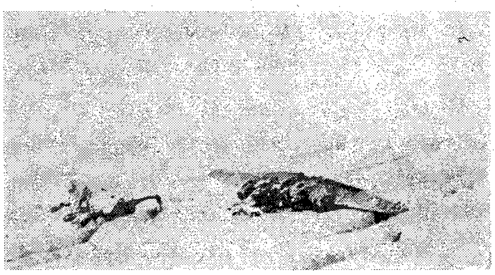

Fig. 2 "My Gal Sal" on Greenland icecap.

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Table 1 Summary of conditions and equipment

	Environment and location					
	Desert/Africa		Arctic/Greenland		Jungle/Panama	
Aircraft	B-24		B-17		C-54	
Location	Libyan desert		Icecap		Mtn. rain forest	
Temp. extremes, °F	+26–120 (Comp. temp. to +200)		−80–+38		+71–+88	
Av humidity—%	10–36		55–70		90–100	
Av yrly. rain	Less than $\frac{1}{4}$ in.		No rain; heavy snow		148 in.	
Max. wind velocity, mph	50		In excess of 180		70	
Component examined	Unit oper.	Visual insp.	Unit oper.	Visual insp.	Unit oper.	Visual insp.
Engine-driven pump	Like new	Exc.	Like new	Exc.	Funct.	Fair
Hydraulic cylinder	Good	Exc.	Like new	Exc.	Good	Good
Accumulator	No orig. air chg.	Good	Like new—had 1942 air chg.	Exc.	Not retrieved	

for studying the other extreme of environmental storage, coldness and wetness. As a result, a program was initiated by the author for removing various pieces of hydraulic equipment and other materials from this aircraft for examination.

This plane had crashed on the icecap in 1942 on its way to England. The equipment then lay on the icecap for 23 years,

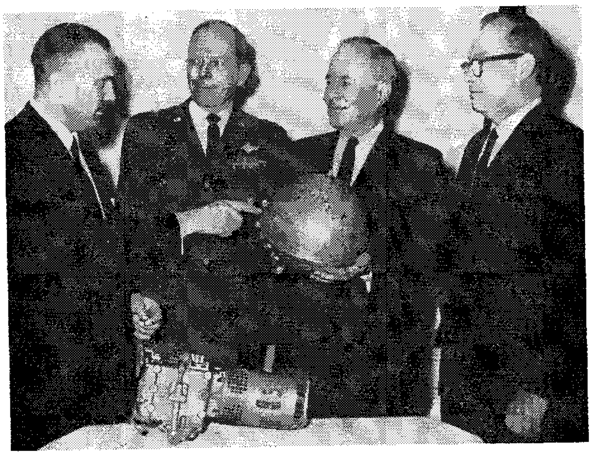

Fig. 3 Presentation of "My Gal Sal" equipment to the Smithsonian Institute.

completely undisturbed in the frigid arctic environment, with temperatures ranging from −80°F in the winter to an occasional +38°F in the summer. In the winter, winds of 180 mph swept across the icecap, creating an extremely hostile environment.

Fig. 4 C-54 wreckage on cloud enshrouded jungle mountain.

Figure 3 shows the hydraulic turret transmission and hydraulic accumulator that were removed from this aircraft and have been given to the Smithsonian Institute for permanent exhibit. The hydraulic accumulator was found to contain its normal 325-psi air charge that was made in 1942. The turret transmission, upon test, met the requirements of a new unit following these 23 years of storage in the Arctic. Disassembly of the turret transmission found it to be in excellent condition, with all parts bright and shiny. The seals were soft and pliable and there was zero external leakage.

The navigator's sextant box was found full of a green fungus or mold. This was later determined to be a tropical fungus that originated from the former aircraft base at McDill Air Force Base in Florida. Air Force biological scientists are now trying to determine how this germ could grow and mature to completely fill up the sextant case under arctic environments.

Jungle Environmental Investigations

Since the results of both the desert and arctic equipment investigations showed the equipment to be in excellent condition, the only major environment remaining in the world which had not been evaluated was that of the extremely humid, fungus-growing, tropical jungle.

The author then made an expedition into the jungles of Panama in the latter part of 1966, to visit two wrecked World War II aircraft, one of which is shown in Fig. 4. Similar hydraulic and electrical system components were removed from these aircraft as from the desert and arctic equipment retrievals.

The equipment removed from 6 to 24 years storage in a jungle environment showed heavy deterioration on assemblies that were not sealed, such as electrical motors, radio panel, and thin gage sections. The fungus growth on much of this equipment was heavy and damaging. On the sealed components, such as hydraulic pumps, deterioration was only partial with some of the units still operable. The "O" rings were in good condition and still functional in most cases.

A summary of the more pertinent desert, arctic, and jungle environments, together with a summary of three of the major components removed, are shown in Table 1.

As a result of these environmental studies, it is believed that the present military specifications for shelf life of hydraulic "O" rings can be changed from its present 24- to 36-month period to five years', and perhaps with further information, even to seven years' duration. In designing equipment for the more severe environments around the world, it appears that if the equipment can be sealed or semisealed, its chances of surviving long-term storage will be excellent.