

CHEMICAL AND PHOTOGRAPHIC EVALUATION OF RIGID EXPLOSIVE TRANSFER LINES*

ELEONORE G. KAYSER

Naval Surface Weapons Center, 10901 New Hampshire Avenue, Silver Springs, MD 20910 (U.S.A.)

(Received January 30, 1985; accepted in revised form May 26, 1985)

Summary

This paper describes the chemical and photographic analyses performed on 112 explosive transfer lines used to initiate aircraft emergency escape systems for a variety of military and NASA aircraft. The purpose was to provide quantitative chemical data on in-service explosive transfer lines as affected by both age and heat treatment. These data are necessary in order to make reliable, responsible, and conservative estimations of in-service cord life extension. The approach was to (a) develop a test methodology, (b) characterize the types of transfer lines in use in this country, (c) analyze these lines following a repeat of the thermal tests conducted in the original qualification, and (d) conduct a degradation investigation on the explosives currently in use. The results of this testing indicate that rigid explosive transfer lines are not adversely affected by age, service, or a repeat of the thermal qualification tests.

Introduction

Extending the service life of explosive transfer lines, used to initiate and sequence aircraft emergency crew escape systems, provides an opportunity for significant savings [1] for a wide variety of military and NASA aircraft (see Table 1). Previous surveillance programs [2] have relied on methods which provided limited information on the functional status of transfer lines having full service, and the projection of further service extension. The purpose of the effort described in this report is to provide quantitative information on explosive transfer lines which will contribute to responsible, conservative, service life determinations.

Rigid explosive transfer lines (Fig. 1), commonly called shielded mild detonating cord (SMDC), are designed to transfer a fully contained explosive stimulus, and are the most extensively applied components in aircraft crew escape systems. These lines utilize small quantities of highly stable explosives (i.e., 2,2',4,4',6,6'-hexanitrostilbene (HNS)[3] and dipicramide (DIPAM) [4]) in a metal sheath (i.e., silver or aluminum). SMDC lines are normally used to interconnect the components of emergency escape functions. More

*Paper presented at the 1985 ADPA Joint Symposium on Compatibility/Processing of Explosives and Ingredients, March 11–13, 1985, Hilton Head, SC, U.S.A.

TABLE 1

Number of lines and rated service life of various aircraft

Aircraft	No. of lines/aircraft	Service life in years	
		initial	current (as of May 84)
AH-1G ^a	13	5	on condition
AH-1S ^a	16	5	on condition
B-1 (capsule)	1200	3	13
B-1B	504	3	15
F-111	258	1.5	15
F-14	156	3	5
F-15 (fighter)	22	6	15
F-15 (trainer)	68	6	15
F-16	27	15	15
F-18 (fighter)	13	5	5
F-18 (trainer)	52	5	5
RSRA	145	5	on condition

^aProjected savings of \$9M with extension to 10 years [1].

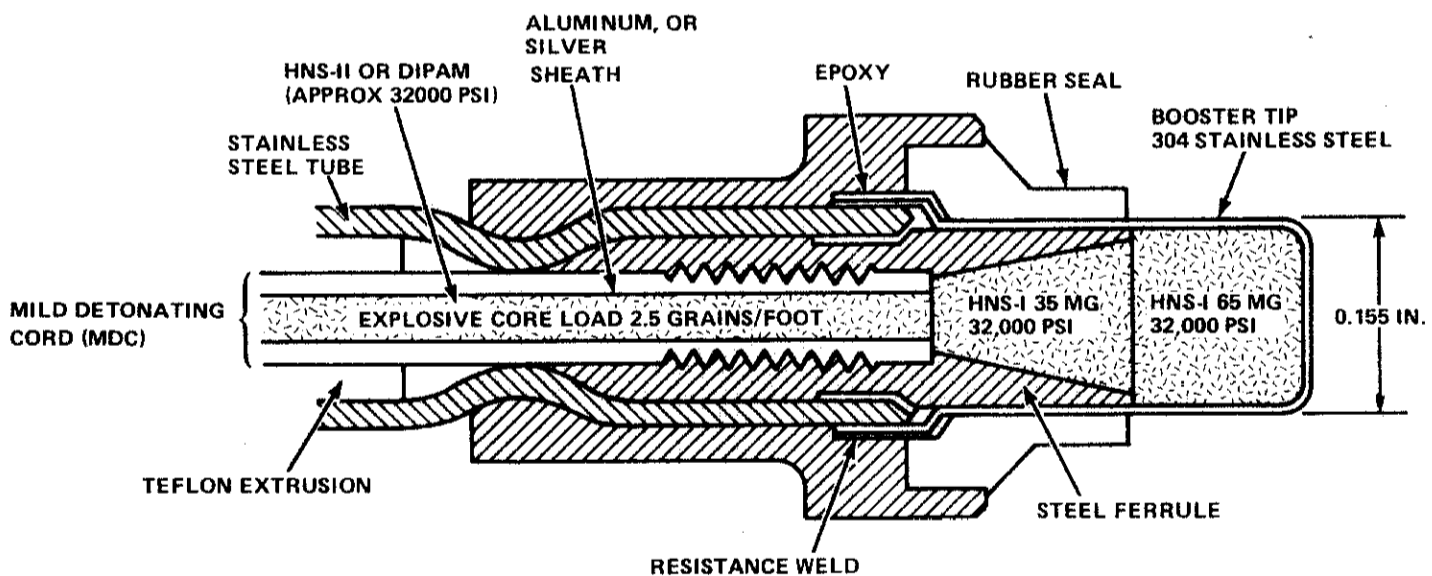


Fig. 1. Cross section of rigid explosive transfer line (1 grain = 65 mg).

than one million cords have been manufactured for various aircraft, spacecraft, and missiles, which include the army AH-1, The NASA/Army Rotor Systems Research Aircraft (RSRA), the NASA Space Shuttle [5], the Air Force F-111 [6], F-15, F-16, and B-1, and the Navy TA-7, S-3A, F-14, and F-18. To date, this program has evaluated transfer lines from the following aircraft: the Army AH-1G, and AH-1S, the Air Force F-111, F-15, and B-1, and the Navy F-14. Each of the lines used in these aircraft is different from the others in terms of materials and manufacturing processes and represents all of the rigid transfer line types in use in this country (see Table 2).

TABLE 2

Types of SMDC lines currently in use

SMDC lines	Aircraft/spacecraft/missile
HNS-II (silver sheathed)	AH-1 EA-6 F-14 F-16 F-18 RSRA S-3A Harpoon missile Delta launch vehicle
HNS-II (aluminum sheathed)	B-1 Trident missile
DIPAM (silver sheathed)	F-111 F-15

The establishment of a rated service life for these lines has been approached on a conservative basis, due to the life-critical function that they perform. A relatively short service life, from three to five years for most aircraft systems, was originally established. Until recently, little interchange of service life technology has occurred among the various aircraft surveillance programs. The chemical and photographic techniques described in this report are part of a joint Army, Air Force, NASA, explosive transfer line service life extension program [7].

More than 800 rigid explosive transfer lines [7] have been evaluated. Lines were removed after full service from the Army AH-1G and AH-1S, the Air Force F-111, B-1, and F-15 and the Navy F-14 aircraft. Seven year-old B-1 lines with no service were also evaluated. These lines represent the three explosive cord types (1) silver-sheathed HNS-II, (2) aluminum-sheathed HNS-II, and (3) silver-sheathed DIPAM currently in use. The three manufacturing methods used to fabricate these cords are: (1) swage-hammering of fully annealed tubes, (2) swage-hammering of work-hardened tubes using three 425°F/one-hour annealing cycles, and (3) pultrusion.

The overall objectives of this program were:

1. to develop a chemical and functional test methodology, and establish standards for comparison to all subsequent samples;
2. to determine chemical and functional reproducibility among line types, manufacturing methods, and batches;
3. to determine effects of age and service on the oldest available lines;
4. to evaluate lines with rated service which have undergone a repeat thermal qualification test;

5. to conduct thermal degradation studies to determine the limits at which line functionality can be maintained; and

6. to establish degradation limits and mechanisms for the energetic materials HNS and DIPAM.

The chemical [5, 7, 8] and photographic [7] analyses (color macrophotographs and scanning electron microphotographs (SEMs)) were developed and carried out at the Naval Surface Weapons Center-White Oak, while the functional tests (velocity and energy measurements) as well as the nondestructive tests (helium leak detection and X-ray photography) were developed and performed at the NASA Langley Research Center. The results of all these tests can be found in Ref. [7].

Experimental

Technical approach

The technical approach included the five following test objectives:

1. Establish chemical standards against which all subsequent test groups would be compared. The most recently manufactured lines with the least service were used to establish this baseline. New lines with no history of service would have provided the best reference standards. However, only new AH-1S aircraft lines were available.

2. Determine the effects of age (shelf life) without service. The only components available for this study were the spares for the B-1 aircraft system qualification with a storage life of 7 to 8 years.

3. Evaluate the effects of rated, installed service time (service life) on lines from each aircraft. The oldest age-with-service group was used for this evaluation with the exception of the AH-1G where the service life demonstration was omitted. Thermal qualification tests including 72-hour exposure at -110°F to $+200^{\circ}\text{F}$ for the Army AH-1G and AH-1S as well as the thermal parameters detailed in Fig. 2 were repeated on full service lines to provide a credible basis for possible service life extension.

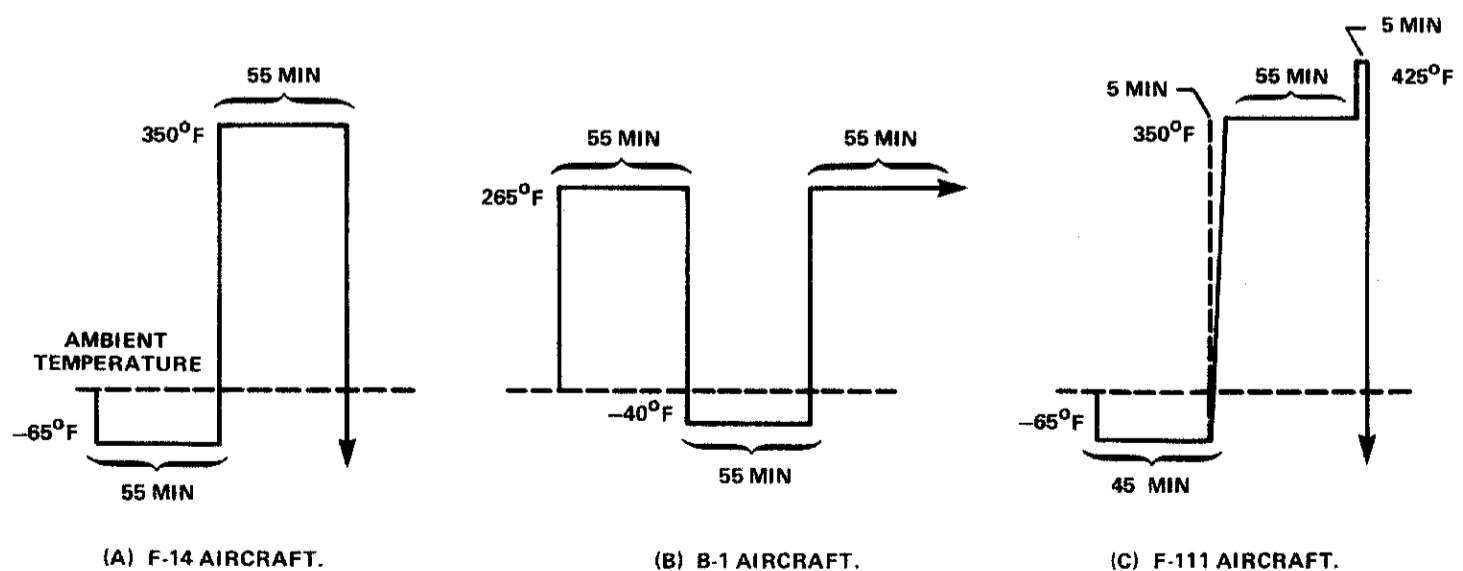


Fig. 2. Temperature/time cycles (100 each) required for thermal qualification of rigid explosive transfer lines.

TABLE 3

Explosive transfer lines tested

Aircraft	Explosive core	MDC sheath	Manufacturing process (MDC)	Manufacturer	Initial service (years)	No. of aircraft	Pyro change-out time (manhours)
AH-1G	HNS-II	silver	swage/hammer, with annealing	Teledyne McCormick-Selph (TMc/S)	5	13	60
AH-1S	HNS-II	silver	pultrusion	Space Ordnance Systems (SOS)	5	16	60
F-14	HNS-II	silver	swage/hammer, no annealing	Explosive Technology (ET)	3	156	500
B-1 (capsule)	HNS-II	aluminum	swage/hammer, with annealing	Teledyne McCormick-Selph (TMc/S)	3	1200	40000
F-111	DIPAM	silver	swage/hammer, with annealing	Teledyne McCormick-Selph (TMc/s)	1.5	258	
F-15	DIPAM	silver	swage/hammer, no annealing	Explosive Technology (ET)	6	22-68	

4. Define the chemical and physical changes which occur as the transfer lines degrade.

5. Determine to what extent material degradation can cause functional failure. Since no functional failure due to ambient storage and/or service was observed, degradation was induced by exposure to elevated temperatures. Lines subjected to 50-hour exposures at 375°F, 400°F, 425°F, and 450°F were chemically and photographically analyzed. To investigate even broader degradation limits, lines from the F-111 aircraft were exposed to temperatures up to 600°F. Each line was inventoried in terms of aircraft, service, manufacturer, manufacturing lot, manufacturing process, manufacturing date, part number, and serial number.

Lines tested

Data describing the investigated rigid explosive transfer lines can be found in Table 3.

Testing sequence

The chemical and photographic analyses were carried out in the following order:

1. Color macrophotographs.
2. Scanning electron microscopy (SEM).
3. HPLC analyses.

Explosive materials

The explosives used in the investigated rigid transfer lines include HNS [9–11] (Navy Spec. WS-5003 [12]) and DIPAM (Navy Spec. WS-4660 [13]). HNS-I, the initial product derived in the synthesis is used in the booster tips due to its sensitivity to low initiation inputs (pressure impulse and fragment impacts), while HNS-II (recrystallized HNS-I) is employed in the transfer lines because of its more desirable flow properties. High purity standards of HNS, DIPAM, and HNBiB (major impurity in HNS synthesis) were prepared to provide a reference calibration for the materials removed from the five aircraft types.

Booster tip sampling

The booster tip (Fig. 3) was dissected with a tube cutter at the ferrule charge-to-booster charge plane. The cup was cut and broken open to minimize any physical disturbance of the pressed explosive. For the HPLC analyses, HNS was removed from the cup and the material was mechanically blended. The samples were weighed on a Mettler microbalance (standard deviation 1.0 μg) and then dissolved in dimethylsulfoxide (DMSO). Two to three HPLC analyses were determined on each booster tip. Additional analyses were obtained whenever changes were observed. The HNS-I booster tip analyses were reproducible to within ± 3 percent.

Transfer line sampling

The explosive cord (Fig. 3) was cut with a tubing cutter approximately 4 cm from each end, and at the midpoint if the cord length was greater than 26 cm (10 inches). For the HPLC analyses, a 1 to 2 mm cross section was cut from the cord. DMSO was added to the Ag or Al sheathed transfer line samples. This solution was placed in an ultrasonic bath at room temperature for approximately 30 minutes to completely dissolve the explosive. The quantity of explosive was determined by the tare in weighing the original and empty cord length. Two or more transfer lines were tested with a minimum of 3 HPLC analyses on each sample. Additional lines and samples were tested whenever changes were observed.

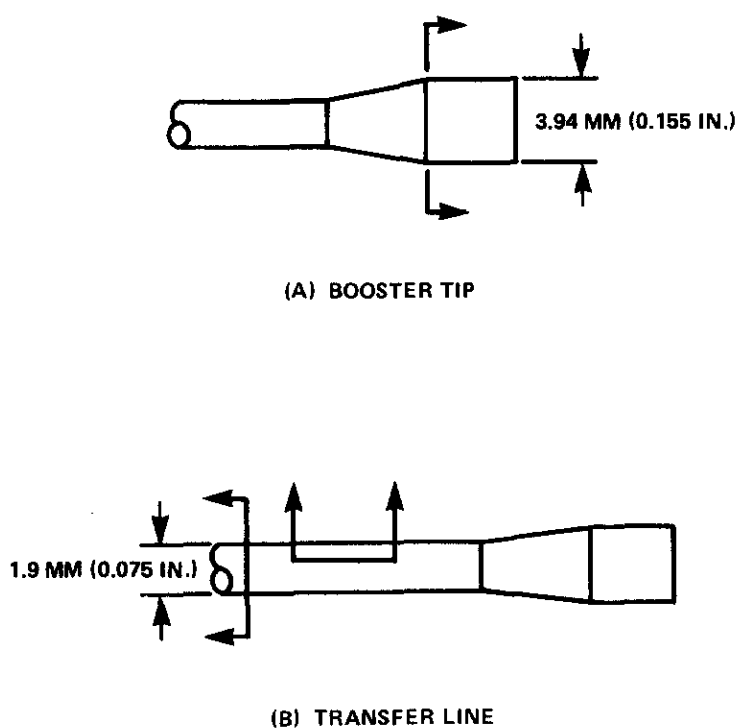


Fig. 3. Dissection sites used for photographic and chemical analyses.

HPLC conditions

A high performance liquid chromatograph (Waters Associates Model ALC 202) equipped with a 254 nm wavelength detector, a solvent delivery system (Model 6000), and a U6K high pressure loop injector was used with a Model RCM-100 module containing a reverse-phase C-18 Radial-Pak cartridge. Sample solutions were eluted isocratically at ambient temperature. Column flow was 2.0 ml/min, with the mobile phase consisting of HPLC grade methanol and distilled water, 50:50 (v/v). The solvent mixtures were not degassed prior to HPLC analysis and sample injections of 2 to 20 microliters were used. A typical time plot of the materials [8] used in this study can be found in Fig. 4.

Color macrophotography

Color photographs (15–25 \times magnification) were taken of cross sections of the booster tips. In order to expose the core, a 2-inch section was opened

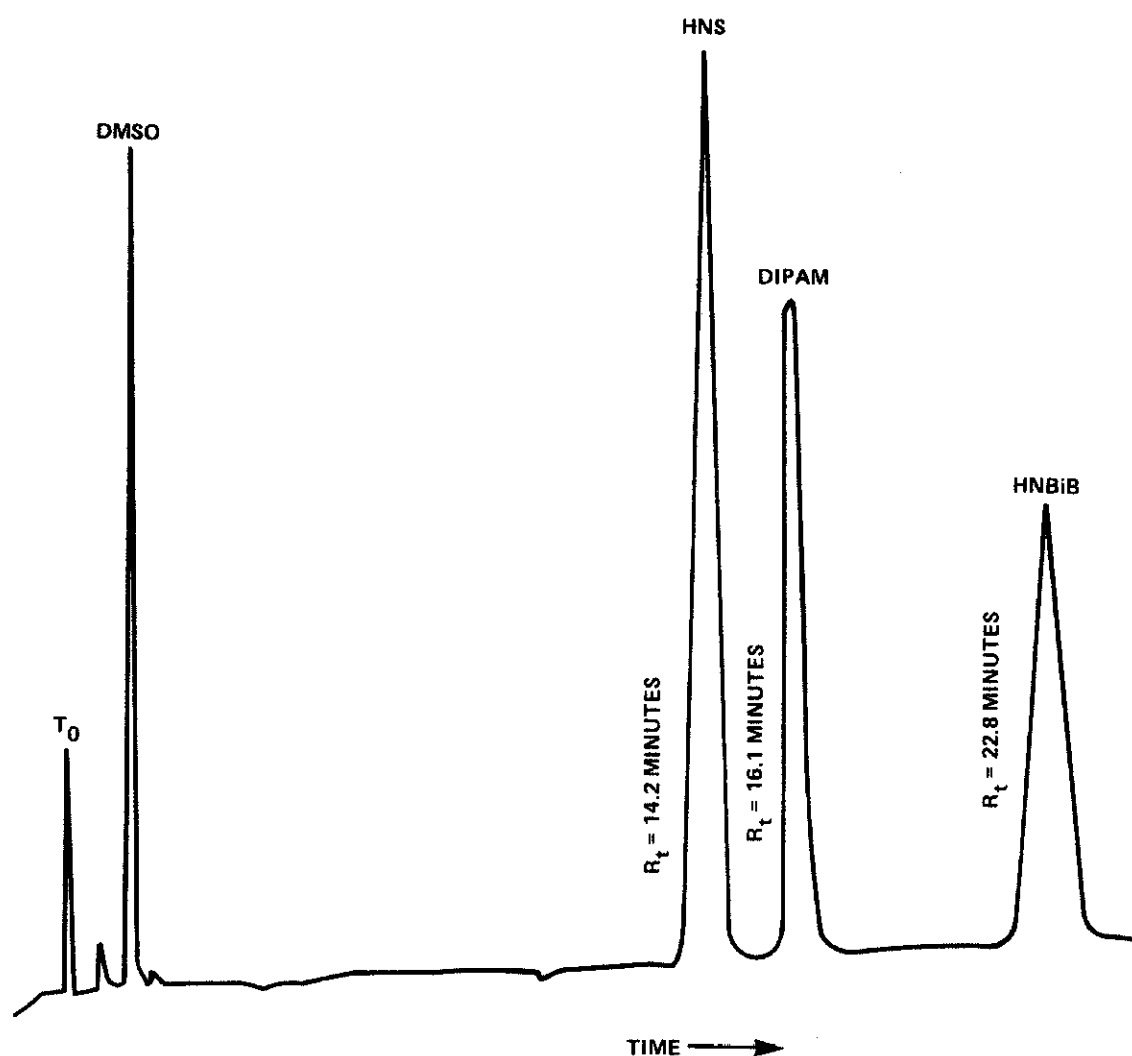


Fig. 4. HPLC chromatogram of HNS, HNBiB and DIPAM. Isocratic elution; detector wavelength: 254 nm; mobile phase: methanol:water (50:50, by volume); flow rate: 2.0 ml/min; scale: 0.05 absorbance units full scale; sample size: $5\mu\text{l}$; chart speed: 0.5 cm/min; sample solvent: DMSO; R_t : retention time at max. peak height, min; T_0 : test start.

longitudinally with a Nicholson flat file. The photographs were obtained with a Polaroid camera and a Wild Microscope lens (M-75, type 352873), made in Herrbrugg, Switzerland — Kodak Vericolor II, type L (4X5) film was used for documentation.

Scanning electron microscopy (SEM)

The SEM photographs were obtained with an AMRAY, Model 1000A, scanning electron microscope (5000 \times magnification). The SEM data were processed on a cathode ray tube (7 inch diagonal, 2500 line resolution) and photographed with a Polaroid camera. Sample preparation included vacuum sputter-coating with gold.

Results and discussion

To date, a total of 112 transfer lines have been analyzed chemically and photographically. This evaluation revealed physical and chemical changes in both HNS and DIPAM at elevated temperatures ($>375^\circ\text{F}/50$ h). Material uniformity was shown to exist among (a) various line manufacturers, (b)

several manufacturing methods, (c) line types, and (d) material batches. None of the five aircraft line types exhibited any significant change due to (a) shelf life ranging from 1 to 10 years, (b) service life of 3 to 7 years, (c) rated service with a repeat thermal qualification, or (d) thermal exposure up to and including a 375°F/50 h heat cycle which is well beyond the temperature requirements (Fig. 2) for the above mentioned aircraft [1].

Material degradation was only noted at high thermal inputs. As expected, the HNBiB (m.p. 424°F) degraded more rapidly than the HNS (m.p. 602°F). The weight percent of HNBiB found in the HNS-I of the AH-1G, AH-1S, F-111, and F-14 lines was approximately 2 percent, and 6 percent for the B-1, while the percentage of HNBiB in the HNS-II ranged from zero to 2.1 percent. DIPAM exhibited no degradation up to and including the 450°F/50 h heat cycle. The effects of thermal inputs on DIPAM up to and including 500°F can be seen in Table 4.

TABLE 4

Effect of heat on chemical composition

Aircraft	As received	Repeat thermal qualification	Average chemical results, % explosive by weight				
			375°F/50 h	400°F/50 h	425°F/50 h	450°F/50 h	500°F/50 h
<i>Transfer lines</i>							
AH-1S	98.6/0.1	97.8/0.0	99.8/0.0	87.9/0.1			
AH-1G	96.5/0.6	94.8/1.0	98.4/0.2	77.0/0.2	23.2/0.0		
F-14	100/0.0	97.7/0.9	99.1/0.9	94.6/0.0	68.2/0.2		
B-1	97.5/0.0	94.3/1.6	100/0.0	93.5/0.0	88.4/0.0		
F-111	98.4	98.6		99.4	98.3	100	5.4
F-15	96.5						
<i>Booster tips</i>							
AH-1S	96.2/3.2	97.0/3.4	96.3/1.8	91.2/2.9			
AH-1G	96.2/3.3	94.8/2.4	95.2/2.7	91.5/2.2	90.7/1.1		
F-14	98.6/0.8	93.5/2.9	93.4/3.3	91.0/1.6	90.2/2.2		
B-1	93.4/5.5	89.0/6.0	94.4/4.8	88.9/5.1	86.7/3.3		
F-111	97.5/2.5	97.7/1.8		91.0/2.3	79.1/1.4	74.8/0.9	22.0/0.0
F-15	98.4/0.7						

HNS-II degradation in the aluminum sheathing was less than that observed in the silver sheathing. This could be due to the lower HNS-II loading density of the aluminum cords. The velocity data [7] obtained from the Ag and Al cords corroborates these results. HNS degradation observed at the high temperatures was also accelerated by the presence of HNBiB.

As heat-induced degradation occurred in the explosive materials, both color and physical texture changed. The booster tip explosive was found to darken progressively from the outer circumference. Removal and analysis of the darkened material revealed considerably more degradation at the explosive/stainless steel interface than could be found in the center material.

Color macrophotographs and scanning electron micrographs provided qualitative corroboration for the chemical analyses by high performance

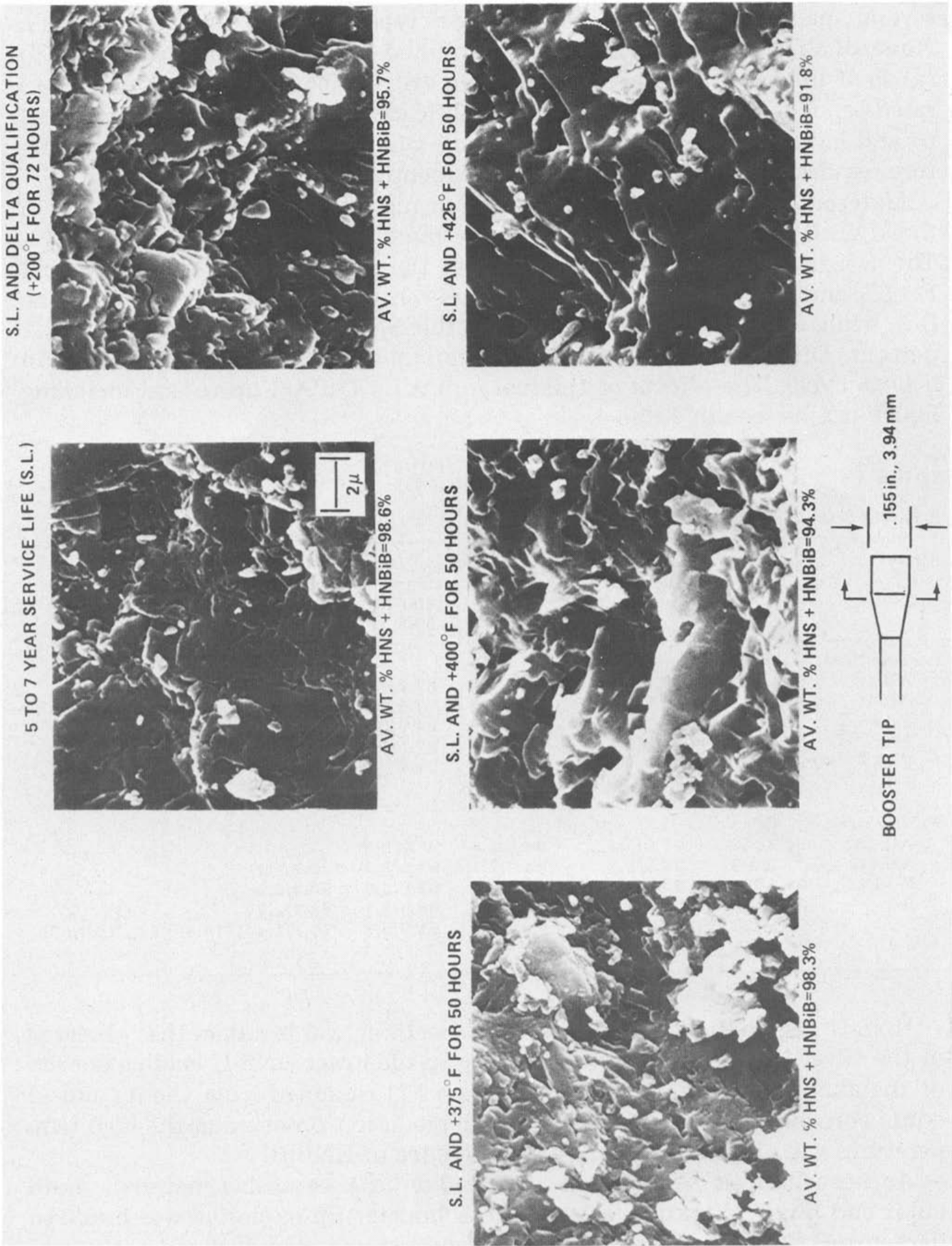


Fig. 5. Scanning electron micrographs of AH-1G booster tip explosive; all lines are 9 years old.

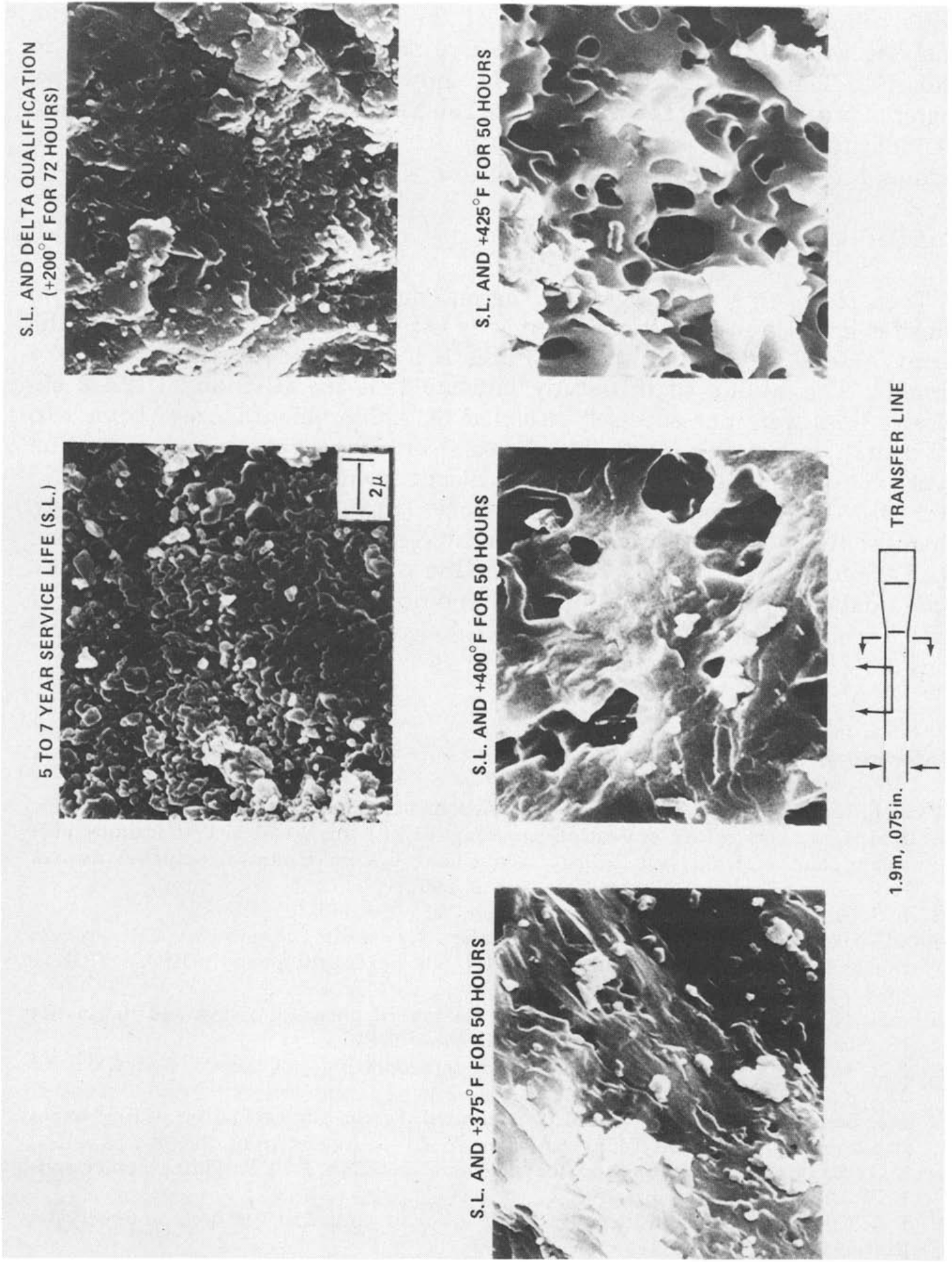


Fig. 6. Scanning electron micrographs of AH-1G transfer line explosive; all lines are 9 years old.

liquid chromatography. The results of these chemical and photographic analyses were also corroborated by actual functional tests as described in Ref. [7]. The color macrophotographs show a darkening of the explosive material with increased thermal inputs. The SEM photographs (Figures 5 and 6) indicate a gradual roughening of the particles, as degradation increased, leading finally to a perforated "swiss cheese"-like texture.

Conclusions

The effects of service, age, and thermal degradation were determined on transfer lines (used to initiate emergency escape systems) removed from the Army AH-1G and AH-1S, the Air Force B-1 and F-111, and the Navy F-14 aircraft. The results of this study indicate that the HNS and DIPAM explosive lines were not adversely affected by age (ambient storage from 1 to 10 years), service life (from 3 to 7 years) or a repeat thermal qualification cycle. These findings suggest that significant savings in the cost of (a) HNS and DIPAM rigid explosive transfer lines, (b) manhours needed for pyro change-out time, and (c) aircraft down-time can be realized for military and NASA aircraft by extending the service life of rigid explosive transfer lines. These data, when added to functional and nondestructive test results can be used to make responsible, conservative judgments concerning cord life extension.

References

- 1 J.M. Boen and J.L. Bement, *Astronaut. Aeronaut.*, 21 (4) (1983) 76.
- 2 B.M. Carr, Service life evaluation program (SLEP) for F-14A aircraft canopy jettisoning and ejection seat ballistic sequencing system explosive actuated devices, Indian Head Technical Report 755, August 1982.
- 3 K.G. Shipp and L.A. Kaplan, *J. Org. Chem.*, 31 (1966) 857.
- 4 J.C. Dacons, H.G. Adolph and M.J. Kamlet, Heat resistant explosives, XIII. Preparation and properties of 3,3'-diamino-2,2',4,4',6,6'-hexanitrobiphenyl, DIPAM, NOLTR 62-82, May 1962.
- 5 E.E. Kilmer, Hexanitrostilbene (HNS): Review of chemical assays and detonation cord performance, II, NSWC TR 80-13, October 1980.
- 6 E.E. Kilmer, Overviews of HNS production/properties/applications, NSWC TR 79-181, July 1979.
- 7 L.J. Bement, E.G. Kayser and M.L. Schimmel, Service-life evaluation of rigid explosive transfer lines, NASA Technical Paper No. 2143, August 1983.
- 8 E.G. Kayser, Analysis method for explosive materials — I. Polynitro compounds, NSWC TR 81-123, March 3, 1982.
- 9 E.E. Kilmer, Hexanitrostilbene (HNS): Review of industrial syntheses and recrystallizations, NSWC TR 79-497, March 1980.
- 10 E.G. Kayser, Analysis of 2,2',4,4',6,6'-hexanitrostilbene (HNS) by high performance liquid chromatography, NSWC/WOL TR 77-154, March 14, 1978.
- 11 E.G. Kayser, An investigation of the shipp hexanitrostilbene (HNS) process, NSWC TR 80-111, August 25, 1980.
- 12 Surface Weapons Center, U.S. Navy, Material specification for HNS explosive, WS 5003 J, February 18, 1981.
- 13 Surface Weapons Center, U.S. Navy, Purchase description DIPAM explosive, WS 4660 C, May 22, 1968.