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Law Enforcement and Corrections Standards and Testing Program

Development of NIST Standard Bullets and Casings Status Report

NIJ Report 603–00

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Development of NIST Standard Bullets and Casings Status Report

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This report was prepared by the Office of Law Enforcement Standards (OLES) of the National Institute of Standards and Technology (NIST) under the direction of Alim A. Fatah, Program Manager for Chemical Systems and Materials, and Kathleen M. Higgins, Director of OLES.
The work resulting from this report was sponsored by the National Institute of Justice (NIJ), Dr. David G. Boyd, Director, Office of Science and Technology.

FOREWORD

The Office of Law Enforcement Standards (OLES) of the National Institute of Standards and Technology (NIST) furnishes technical support to the National Institute of Justice (NIJ) program to strengthen law enforcement and criminal justice in the United States. OLES's function is to conduct research that will assist law enforcement and criminal justice agencies in the selection and procurement of quality equipment.

OLES is: (1) Subjecting existing equipment to laboratory testing and evaluation, and (2) conducting research leading to the development of several series of documents, including national standards, user guides, and technical reports.

This document covers research conducted by OLES under the sponsorship of the National Institute of Justice. Additional reports as well as other documents are being issued under the OLES program in the areas of protective clothing and equipment, communications systems, emergency equipment, investigative aids, security systems, vehicles, weapons, and analytical techniques and standard reference materials used by the forensic community.

Technical comments and suggestions concerning this report are invited from all interested parties. They may be addressed to the Office of Law Enforcement Standards, National Institute of Standards and Technology, 100 Bureau Drive, Stop 8102, Gaithersburg, MD 20899–8102.

Dr. David G. Boyd, Director
Office of Science and Technology
National Institute of Justice

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FIGURES

COMMONLY USED SYMBOLS AND ABBREVIATIONS

A	ampere	H	henry	nm	nanometer
ac	alternating current	h	hour	No.	number
AM	amplitude modulation	hf	high frequency	o.d.	outside diameter
cd	candela	Hz	hertz	Ω	ohm
cm	centimeter	i.d.	inside diameter	p.	page
CP	chemically pure	in	inch	Pa	pascal
c/s	cycle per second	IR	infrared	pe	probable error
d	day	J	joule	pp.	pages
dB	decibel	L	lambert	ppm	parts per million
dc	direct current	L	liter	qt	quart
°C	degree Celsius	lb	pound	rad	radian
°F	degree Fahrenheit	lbf	pound-force	rf	radio frequency
dia	diameter	lbf·in	pound-force inch	rh	relative humidity
emf	electromotive force	lm	lumen	s	second
eq	equation	ln	logarithm (base e)	SD	standard deviation
F	farad	log	logarithm (base 10)	sec.	section
fc	footcandle	M	molar	SWR	standing wave ratio
fig.	figure	m	meter	uhf	ultrahigh frequency
FM	frequency modulation	min	minute	UV	ultraviolet
ft	foot	mm	millimeter	V	volt
ft/s	foot per second	mph	miles per hour	vhf	very high frequency
g	acceleration	m/s	meter per second	W	watt
g	gram	N	newton	λ	wavelength
gr	grain	N·m	newton meter	wt	weight

area=unit^2 (e.g., ft^2, in^2, etc.); volume=unit^3 (e.g., ft^3, m^3, etc.)

PREFIXES

d	deci (10^{-1})	da	deka (10)
c	centi (10^{-2})	h	hecto (10^2)
m	milli (10^{-3})	k	kilo (10^3)
µ	micro (10^{-6})	M	mega (10^6)
n	nano (10^{-9})	G	giga (10^9)
p	pico (10^{-12})	T	tera (^{1012})

COMMON CONVERSIONS
(See ASTM E380)

0.30480 m =1ft	4.448222 N = 1 lbf
2.54 cm = 1 in	1.355818 J =1 ft·lbf
0.4535924 kg = 1 lb	0.1129848 N m = 1 lbf·in
0.06479891g = 1gr	14.59390 N/m =1 lbf/ft
0.9463529 L = 1 qt	6894.757 Pa = 1 lbf/in^2
3600000 J = 1 kW·hr	1.609344 km/h = 1 mph

Temperature: $T()_C = (T()_F - 32) \times 5/9$
Temperature: $T()_F = (T()_C \times 9/5) + 32$

Development of NIST Standard Bullets and Casings Status Report

J.F. Song and T.V. Vorburger, National Institute of Standards and Technology, Precision Engineering Division, Manufacturing Engineering Laboratory (MEL), Gaithersburg, MD 20899.

In April 1998, two prototype standard bullets were developed at the National Institute of Standards and Technology (NIST). In October 1999, prototype standard casings were also developed at NIST. The standard bullets and casings are intended for use in Federal, State, local, and international crime laboratories as reference standards. The implementation of standard bullets and casings will help verify that the computerized optical-imaging equipment used in those laboratories is operating properly. These standard bullets and casings are being developed to enable nationwide and worldwide ballistics measurement traceability and unification. Test results at NIST indicate that the prototype standard bullets have essentially identical signature marks and minimal geometrical nonuniformity. Additional testing performed at the Bureau of Alcohol, Tobacco and Firearms (ATF) National Laboratory Center and at Forensic Technology Inc. (FTI, Canada) has also shown that these prototype bullets have unique properties, specifically repeatable and reproducible signature marks. The digitized bullet signature is stored in a computer and can be used for reproducing the same bullet signature anytime. This project report addresses the prototype design, manufacturing technique, testing results, potential enforcement impact and continued development of the standard bullet.

The Authors gratefully acknowledge R. Clary, M. McGlauflin, E. Whitenton, C. Evans, and T.B. Renegar of NIST for their contributions in the manufacturing and measurement of the NIST prototype standard bullets; and to M. Ols of the ATF and R. Belanger and M. McLean of the FTI for their measurements with the IBIS system and many enlightening discussions. We are also grateful to Prof. R. Baldur, University of Waterloo of Ontario, Canada, and Dr. A. Fatah of the Office of Law Enforcement Standards (OLES) for key consultations.

1. PROJECT OVERVIEW

The National Institute of Standards and Technology (NIST) standard bullets and casings are being developed as reference standards for crime laboratories. The standard bullets and casings will help verify that the computerized optical-imaging equipment in those laboratories is operating properly; i.e., for ballistics measurement quality control. They will also provide a foundation for establishment of nationwide ballistics measurement traceability and unification.

As with fingerprints, each firearm has unique mechanical characteristics that leave unique signatures on the bullets and casings fired by it. By analyzing these ballistics signatures, examiners can connect a firearm to criminal acts. In the early 1990's, the Federal Bureau of Investigation (FBI) established the DRUGFIRE[1] program, and the Bureau of Alcohol, Tobacco and Firearms (ATF) established the CEASEFIRE[2] program. Both agencies established these programs to develop a national integrated ballistics information network [1,2].[3] Both systems are based on optical image capture, image analyses and electronic database techniques. In the DRUGFIRE program, the image capture system itself is also called DRUGFIRE. In the CEASEFIRE program, the image capture system is the Integrated Ballistics Identification System (IBIS[4]). Unfortunately, these systems are incompatible. The measurements are made with different instrumentation under different testing conditions. The respective data files have different digital formats. In 1997, the ATF and the FBI signed a concept paper to establish the National Integrated Ballistics Information Network (NIBIN) [1,2]. The foundation of NIBIN consists of establishment of ballistics measurement traceability, unification of ballistics measurements, and information sharing between these two types of systems.

In December 1995, an ATF Firearms Examiner wrote to the Director of the Office of Law Enforcement Standards at NIST. In the letter, the Firearms Examiner outlined the concept of mass-producing "quality assurance standard bullets and casings." The proposed standard bullets and casings would bear reproducible and recognizable patterns of striae, which could be entered at different IBIS locations and produce signatures that would be essentially identical.

To fulfill this request, the NIST Precision Engineering Division (PED) began in 1997 a new project—NIST Standard Bullets and Casings. Four designs and manufacturing techniques were proposed for producing the standard bullet prototypes. After comparing these designs and manufacturing plans, the numerical control (NC) diamond turning process was selected for manufacturing the prototype NIST standard bullets. The NC diamond turning process had been previously used at NIST [3,4] and elsewhere [5] for producing prototype roughness standards.

On April 15, 1998, five master bullets and casings were fired into a water tank and recovered at the ATF National Laboratory Center in Rockville, MD. One digitized bullet signature was used

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[1]Certain commercial equipment, instruments, or materials are identified in this paper to specify adequately the experimental procedure. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

[2]Ibid.

[3]Numbers in brackets refer to Suggested Readings in section 6.

[4]See footnote 1.

for producing two bullet prototypes by means of the NC diamond turning process of the Precision Manufacturing and Research Facility (PMRF) at NIST. Test results at NIST, ATF and Forensic Technology Inc. (FTI, Canada) confirmed that these two prototype bullets have unique properties, specifically their identical, repeatable and reproducible signature marks. The digitized bullet signature is stored in a computer and can be used anytime for reproducing standard bullets with the same bullet signature by means of the NC diamond turning technique. These unique properties make the prototype standard bullets potentially powerful tools for measurement quality control and nationwide measurement unification in ballistics measurements. In October 1999, several of the prototype casings were also delivered.

Fiscal year (FY) 1998 and FY 1999 accomplishments are reported in the following sections. Topics include discussions of the design, manufacturing procedure and test results of the prototype NIST standard bullets, and the status of the prototype NIST standard casings. We also discussed our working plan for FY 2000 and beyond.

2. WORK ACCOMPLISHED

2.1 Design of the Prototype NIST Standard Bullets

2.1.1 Technical Requirements

Based on discussions with ATF and FBI bullet examiners, and the instrument manufacturers for both the IBIS and DRUGFIRE systems, basic requirements for the NIST standard bullets were defined:

- **Size, shape, color and material:** The size, shape, color and material of the NIST standard bullets should be as close as possible to conventional bullets. A hard coating can be used on the bullet surface for protection from rust and long life. However, this coating should not change the geometry of the bullet signatures.
- **Bullet signature:** Bullet signature patterns on the standard bullets must come from conventional bullets. However, these bullet signatures must be identical in different axial sections of the same standard bullet. Furthermore, identical bullet signatures must also be found in a group of standard bullets. Geometric nonuniformity, including pits and damage on the surfaces of the standard bullets, should be minimized.
- **Repeatability and reproducibility:** Bullet signatures on the standard bullets should show high repeatability and reproducibility. Repeatability here means that the bullet signatures are highly repeatable at different axial sections on the same standard bullets. Reproducibility means that the bullet signatures on different standard bullets are essentially identical. For these reasons it is highly desirable to use information technology for production of the NIST standard bullets. That means the standardized bullet signatures are stored in a computer and can be produced and reproduced essentially anytime anywhere.

2.1.2 Technical Design

The prototype NIST standard bullet was designed as shown in figure 1. The bullet signature AB was measured from one of five master bullets fired at the ATF National Laboratory Center in Rockville, MD, in April 1998. The digitized bullet signature was stored in a computer and reproduced on a NC diamond turning machine generating six lands numbered from 1 to 6, as shown in figure 1. The purpose of making two prototype bullets with six lands, all having the same bullet signature, is to test the repeatability and reproducibility of the manufacturing technique. In the future production of NIST standard bullets, all six lands will have different signatures.

For the prototype bullet shown in figure 1, the signature was machined on a radius of approximately 4.5 mm for lands 1, 2, 5, and 6, and was machined flat for lands 3 and 4. In addition, the bullet signatures on lands 3, 4, 5, and 6 were machined in the clockwise direction, while the bullet signatures on lands 1 and 2 were machined in the counter-clockwise direction (fig. 1). The purpose of designing the bullet signatures of the prototype standard bullets in this way was to test the repeatability and reproducibility of the NC manufacturing process and to test the capability of different bullet-measuring instruments for measuring and quantifying the same bullet signature pattern but with different directions.

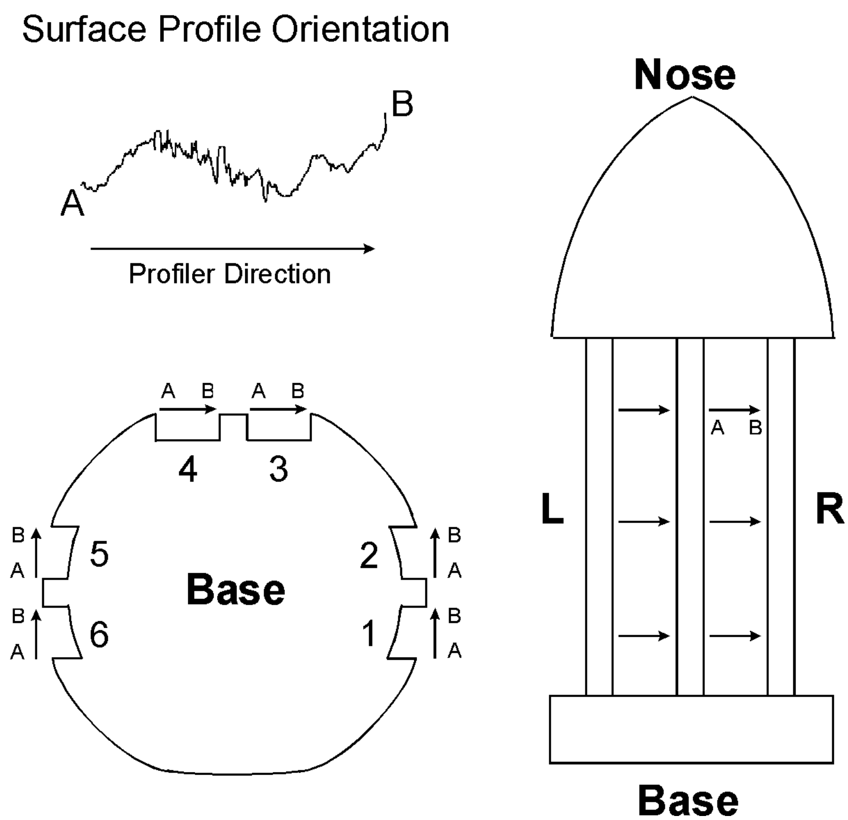

Figure 1. Design for the NIST prototype standard bullets

2.2 Manufacturing

The five master bullets and casings were generated using a standardized shooting procedure at the ATF National Laboratory Center. Master bullet No. 1 is shown in figure 2, on the left. The mechanical signature of figure 1 was measured on land No. 1 using a stylus instrument at NIST. On April 23, 1998, two prototype NIST standard bullets were made at the PMRF at NIST using a NC diamond turning machine. The prototype standard bullets, numbered No. 1 and 2, are also shown in figure 2, in the middle and on the right. A separate detailed manufacturing process report was published as NIJ Report 0601-00 [4].

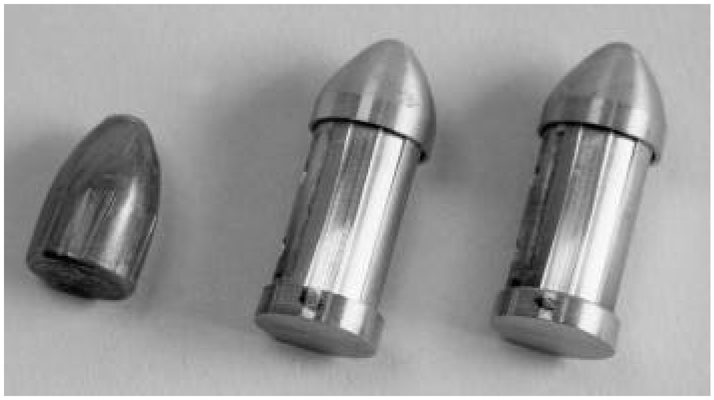

Figure 2. ATF master bullet No.1 obtained by a standardized shooting procedure (left) and NIST prototype standard bullets No.1 and 2 made by NC diamond turning process (middle and right)

2.3 Testing and Results

2.3.1 Geometrical Measurement Results

Figure 3 shows profiling signature comparisons between the master bullet and one of the prototype standard bullets. These profiling signatures were measured using a stylus instrument at NIST. In the vertical direction, the digital resolution is 10 nm, and the expanded measurement uncertainty is about 1 % (k = 2). In the horizontal direction, the digital resolution is 0.25 μm, and the expanded measurement uncertainty is about 1 % (k = 2). Figure 3a shows the profiling signature from land 1 of master bullet No. 1. This profiling signature was used to produce the standard bullets. Figure 3b shows a profiling signature from land 3 of the standard bullet No. 2. Figure 3 illustrates that the profiling signature on the standard bullet has high fidelity with respect to the master bullet.

The profiling signatures of the standard bullet No. 2 were also tested in different lands and different axial sections. For example, figures 4a and 4b show profiling signatures of land 4 and 3, respectively, both measured at the top section. Figure 4c shows a profiling signature from the bottom section of land 3. From figure 4, the profiling signature tests indicate that the NC diamond turning process can produce the bullet signature with precision and repeatability on the same standard bullet.

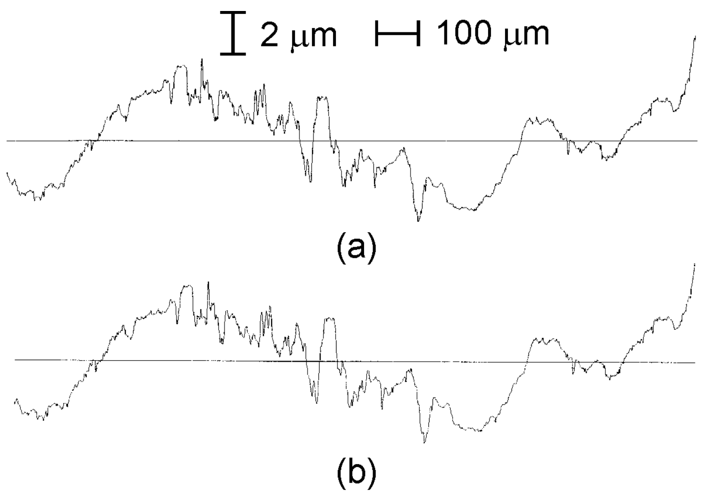

Figure 3. Bullet signature comparison between the master bullet No. 1, land 1 (fig. 3a) and the standard bullet No. 2, land 3 (fig. 3b)

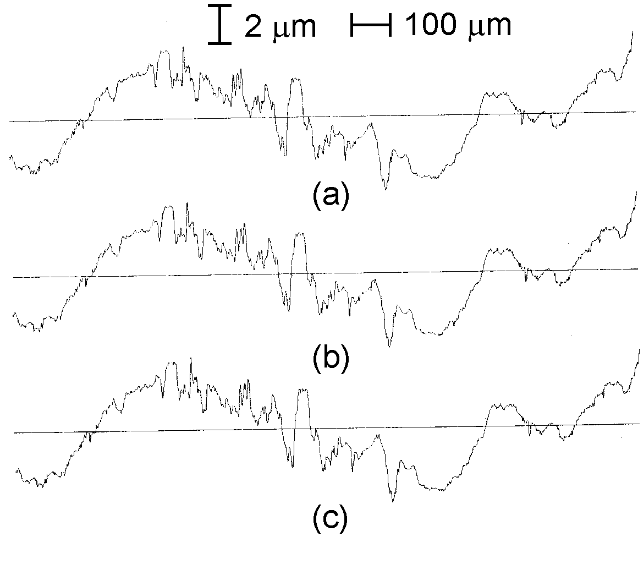

Figure 4. Bullet signature comparison on the same standard bullet No. 2, between land 4 and land 3, both in the top section (fig. 4a and 4b), and land 3, bottom section (fig. 4c)

Figure 5 shows a profiling signature comparison between the standard bullets No. 1 and No. 2, both measured at the No. 4 land, central section. It can be seen that the standard bullets can be manufactured with high reproducibility.

Figure 6 shows a profiling signature comparison between land 1 and land 2 of the standard bullet No. 2. The same bullet signature was machined in the counter-clockwise direction at land 1 and land 2 (see fig. 1).

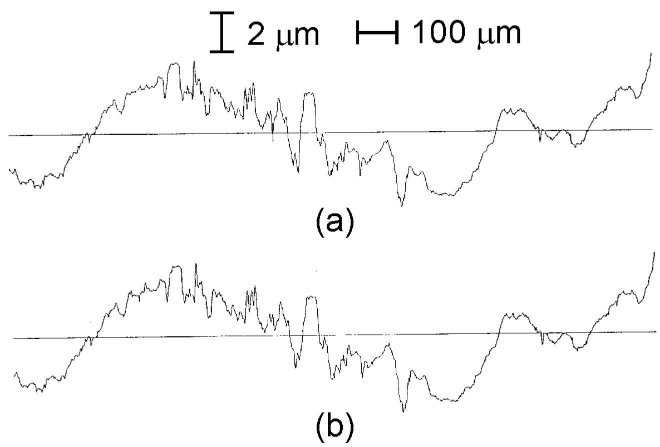

Figure 5. Bullet signature comparison between the standard bullet No. 1 and No. 2, both on the central section of land 4

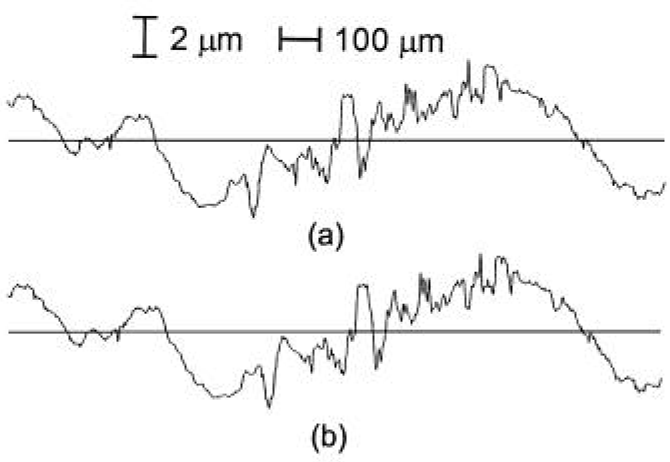

Figure 6. Bullet signature comparison between land 1 and land 2 of the standard bullet No. 2. The same bullet signature was machined in the counter-clockwise direction at land 1 and 2

2.3.2 IBIS Testing Results

The two prototype NIST standard bullets were tested with the IBIS system at FTI in Canada. First, the measurement repeatability of the IBIS was tested by repeatedly measuring land 6 on standard bullet No. 2 and matching these images with each other. The 36 measurement results showed uniformly high IBIS scores with a variation range of 384–472. The score is a proprietary estimator of the degree of matching between pairs of optical images. The score may be calculated between a single pair of land images or between two sets of images containing, say, six lands each. Figure 7 shows two matching images from these tests. The image that yields the maximum IBIS score of 472 is shown in figure 7a; that yielding the minimum IBIS score of 384 is shown in figure 7b.

The second comparison was made between different lands of the standard bullet. The comparison results showed that, when the IBIS optical signatures have the same pattern, there is a very high IBIS score. For example, figure 8a shows a comparison between lands 3 and 4 on the No. 2 standard bullet. The IBIS score is 452. These high IBIS scores are also found in the 36 measurement repeatability tests mentioned above, with the maximum and the minimum scores shown in figure 7. Figure 8b shows a comparison between lands 1 and 6 on the No. 2 standard bullet. There is a low IBIS score of 54 because the same bullet signature was manufactured in opposite directions (see fig. 1 and fig. 6).

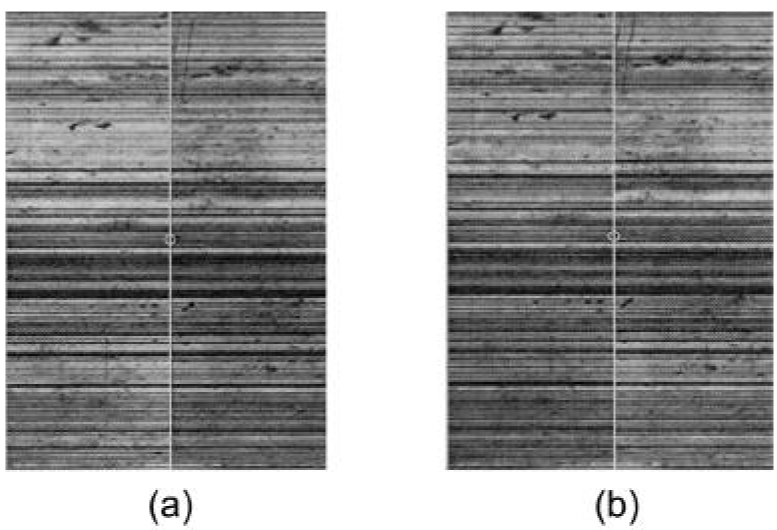

Figure 7. Measurement repeatability tests of standard bullet No. 2, land 6 using the IBIS system at FTI, Canada. The maximum IBIS score is 472 (fig. 7a), the minimum IBIS score is 384 (fig. 7b)

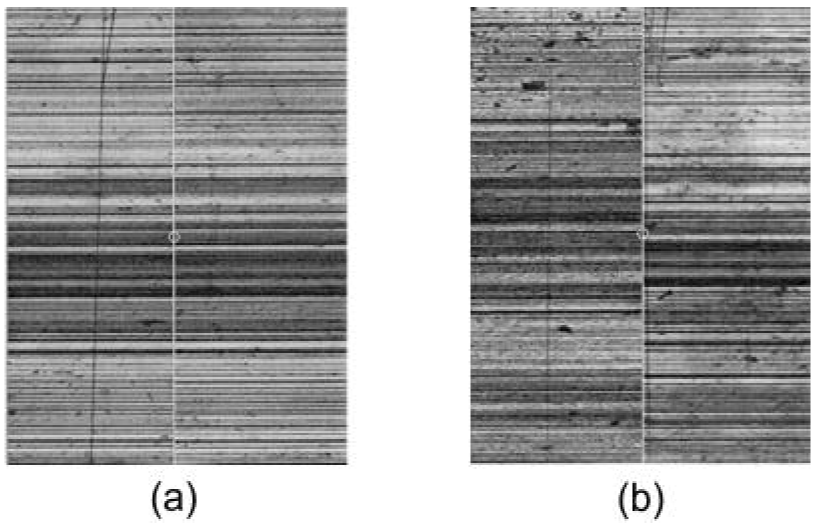

Figure 8. Measurement comparison between lands 3 and 4 of standard bullet No. 2. Where bullet signatures have the same pattern, there is a high IBIS score of 452 (fig. 8a). Figure 8b shows a comparison between lands 1 and 6, where the same bullet signature was manufactured in different directions, yielding a low IBIS score of 54

2.4 Prototype NIST Standard Casings

On April 5, 1998, five master casings QA1 – QA5 were also received with the five master bullets obtained from the standardized shooting procedure at the ATF National Laboratory Center in Rockville, MD. The electroforming technique is being used to fabricate the NIST prototype standard casings. Two companies, GAR Electroforming Division in the United States and Rubert Ltd., in the United Kingdom, were contracted for this work. The master casings were first measured at ATF and FTI using their IBIS system. The digitized casing images were stored so they can be compared with those to be taken from the replica casings.

On July 27 and August 2, 1999, the master casings, QA1 and QA2 were sent to GAR and Rubert, respectively, for manufacture of the replica casings. The set from Rubert was completed in October 1999. Delivery from GAR is expected soon. Following delivery of the replica casings, NIST will test these standard casings by comparing their IBIS images with those of the master casings stored at ATF and FTI.

3. PLANNED ACCOMPLISHMENTS FOR YEAR 2000

3.1 Second Version of NIST Standard Bullet Prototypes

Based on the testing results, as well as discussions with bullet examiners and instrument manufacturers, we are improving the design for the second version of NIST standard bullet prototypes, which are planned to be delivered in 2000. The major improvements for the second version of standard bullets are:

- Reduce the length from 25 mm to (15 – 18) mm.
- Make all six bullet signatures different on the six lands.
- Make all six bullet signatures on the bullet radius, no flat bullet signatures.
- Make all six bullet signatures on the same center of the curvature.
- Increase the cutting diameter to improve the straightness of the bullet signatures.
- Increase the minimum spacing between the bullet signatures and make all the spacings equal.
- Make the prototypes of standard bullets the same shape as the master bullets.
- Possibly provide nose cones or pieces to fit different instruments.

3.2 NIST Standard Casing Prototypes

Ten prototype casings are to be delivered to NIST. The first seven were delivered in October 1999. The prototype standard casings will be tested by using the IBIS systems at ATF and FTI.

4. PLANS FOR FUTURE WORK

Plans for future development include the following:

- Develop 10 second-version NIST standard bullets in 2000, distribute them for testing at both ATF and FBI laboratories, collect comments for the production of NIST Standard Reference Materials (SRM) 2081 Standard Bullets.
- Develop 10 NIST prototype standard casings in 1999 and finish evaluation testing in 2000, distribute them for testing at ATF and FBI laboratories, collect comments for the production of NIST SRM standard casings.
- Produce NIST SRM standard bullets and casings.
- Develop parameters and algorithms for 2D and 3D bullet signature comparisons.

5. SUMMARY

The standard bullets and casings development process has achieved the following results:

- The NC diamond turning process can produce standard bullets and meet essentially all technical requirements.
- Geometric measurements show highly uniform and reproducible profiling signatures.
- IBIS tests also show repeatable matching scores consistent with the profiling signatures.
- NIST standard bullets can be used as a powerful tool for the quality control and unification of ballistics measurements.

6. SUGGESTED READINGS

[1] Office of Firearms, Explosives and Arson, ATF: *ATF's NIBIN Program*, 98 AFTE (Association of Firearm and Tool Mark Examiners), July 12–17, 1998, Tampa, FL.

[2] Casey, W. (Deputy Superintendent, BPD), J. Wooten (Assistant Director, ATF), and R. Murch (Deputy Assistant Director, FBI), National Integrated Ballistics Information Network, 98 AFTE, July 12–17, 1998, Tampa, FL.

[3] Song, J., C. Evans, M. McGlauflin, E. Whitenton, T. Vorburger, and Y. Yuan, "NIST Virtual/Physical Random Profile Roughness Calibration Standards," *Proc. SPIE*, Vol. 3426, 1998, p. 213.

[4] NIJ Report 601–00, *NIST Random Profile Roughness Specimens and Standard Bullets*, U.S. Department of Justice, National Institute of Justice, July 2000, NCJ 183256.

[5] Kruger, R. and M. Krystek, "Diamond-Turned Surface-Roughness Standards for the Calibration of Interference Microscopes," *Proc. 7th Int. Conf. on Metrology and Properties of Engineering Surfaces*, edited by B.G. Rosen and R.J. Crafoord (Chalmers University of Technology, Göteborg, Sweden, 1997).