NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

AC/323(SCI-266)TP/986

www.sto.nato.int

**STO AGARDograph 160** **SCI-266**

**Flight Test Instrumentation Series – Volume 23**

# Application of IRIG 106 Digital Data Recorder Standards for Flight Test

(Application aux essais en vol des normes relatives aux enregistreurs de données IRIG 106)

This AGARDograph has been sponsored by the SCI Flight Test Technical Team (FT3) of the Systems Concepts and Integration Panel (SCI) of STO.

Published November 2020

*Distribution and Availability on Back Cover*

NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

AC/323(SCI-266)TP/986

www.sto.nato.int

**STO AGARDograph 160** **SCI-266**

**Flight Test Instrumentation Series – Volume 23**

# Application of IRIG 106 Digital Data Recorder Standards for Flight Test

(Application aux essais en vol des normes relatives aux enregistreurs de données IRIG 106)

This AGARDograph has been sponsored by the SCI Flight Test Technical Team (FT3) of the Systems Concepts and Integration Panel (SCI) of STO.

# The NATO Science and Technology Organization

Science & Technology (S&T) in the NATO context is defined as the selective and rigorous generation and application of state-of-the-art, validated knowledge for defence and security purposes. S&T activities embrace scientific research, technology development, transition, application and field-testing, experimentation and a range of related scientific activities that include systems engineering, operational research and analysis, synthesis, integration and validation of knowledge derived through the scientific method.

In NATO, S&T is addressed using different business models, namely a collaborative business model where NATO provides a forum where NATO Nations and partner Nations elect to use their national resources to define, conduct and promote cooperative research and information exchange, and secondly an in-house delivery business model where S&T activities are conducted in a NATO dedicated executive body, having its own personnel, capabilities and infrastructure.

The mission of the NATO Science & Technology Organization (STO) is to help position the Nations' and NATO's S&T investments as a strategic enabler of the knowledge and technology advantage for the defence and security posture of NATO Nations and partner Nations, by conducting and promoting S&T activities that augment and leverage the capabilities and programmes of the Alliance, of the NATO Nations and the partner Nations, in support of NATO's objectives, and contributing to NATO's ability to enable and influence security and defence related capability development and threat mitigation in NATO Nations and partner Nations, in accordance with NATO policies.

The total spectrum of this collaborative effort is addressed by six Technical Panels who manage a wide range of scientific research activities, a Group specialising in modelling and simulation, plus a Committee dedicated to supporting the information management needs of the organization.

- AVT Applied Vehicle Technology Panel
- HFM Human Factors and Medicine Panel
- IST Information Systems Technology Panel
- NMSG NATO Modelling and Simulation Group
- SAS System Analysis and Studies Panel
- SCI Systems Concepts and Integration Panel
- SET Sensors and Electronics Technology Panel

These Panels and Group are the power-house of the collaborative model and are made up of national representatives as well as recognised world-class scientists, engineers and information specialists. In addition to providing critical technical oversight, they also provide a communication link to military users and other NATO bodies.

The scientific and technological work is carried out by Technical Teams, created under one or more of these eight bodies, for specific research activities which have a defined duration. These research activities can take a variety of forms, including Task Groups, Workshops, Symposia, Specialists' Meetings, Lecture Series and Technical Courses.

The content of this publication has been reproduced directly from material supplied by STO or the authors.

Published November 2020



ISBN 978-92-837-2306-6

# AGARDograph Series 160 & 300

Soon after its founding in 1952, the Advisory Group for Aerospace Research and Development (AGARD) recognized the need for a comprehensive publication on Flight Test Techniques and the associated instrumentation. Under the direction of the Flight Test Panel (later the Flight Vehicle Integration Panel, or FVP) a Flight Test Manual was published in the years 1954 to 1956. This original manual was prepared as four volumes: 1. Performance, 2. Stability and Control, 3. Instrumentation Catalog, and 4. Instrumentation Systems.

As a result of the advances in the field of flight test instrumentation, the Flight Test Instrumentation Group was formed in 1968 to update Volumes 3 and 4 of the Flight Test Manual by publication of the Flight Test Instrumentation Series, AGARDograph 160. In its published volumes AGARDograph 160 has covered recent developments in flight test instrumentation.

In 1978, it was decided that further specialist monographs should be published covering aspects of Volumes 1 and 2 of the original Flight Test Manual, including the flight testing of aircraft systems. In March 1981, the Flight Test Techniques Group (FTTG) was established to carry out this task and to continue the task of producing volumes in the Flight Test Instrumentation Series. The monographs of this new series (with the exception of AG237 which was separately numbered) are being published as individually numbered volumes in AGARDograph 300. In 1993, the Flight Test Techniques Group was transformed into the Flight Test Editorial Committee (FTEC), thereby better reflecting its actual status within AGARD. Fortunately, the work on volumes could continue without being affected by this change.

Since that time, The Flight Test Editorial Committee has had a number of changes of identity which have in recent years been closely associated with a series of Task Group identities bearing the acronym FT3. This period has also seen FT3 migrate from the Air Vehicle Technology Panel to The Systems Concepts and Integration Panel reflecting the changing nature and focus of NATO Flight Testing. This AGARDograph is sponsored by FT3 against their current Task Group, SCI-305 Flight Test Technical Team (FT3).

An Annex at the end of each volume in both the AGARDograph 160 and AGARDograph 300 series lists the volumes that have been published in the Flight Test Instrumentation Series (AG 160) and the Flight Test Techniques Series (AG 300), plus the volumes that were in preparation at that time.

# Application of IRIG 106 Digital Data Recorder Standards for Flight Test

**(STO-AG-160-V23)**

# Executive Summary


During flight tests, data is acquired from different sources and in different formats. Sensor data, aircraft avionics bus data, time, voice and video are essential for analysis of these flight tests. IRIG 106 standards exist for recording and transferring of these data types. However, to enhance interoperability of flight test data between (multi-national) test teams, a standard was needed to encapsulate all these data types. For this purpose, the Telemetry Group of the Range Commanders Council (RCC) first published in 2004 the IRIG 106 Chapter 10 Standard, "Solid-State On-Board Recorder Standard". This standard is evolving up to present.

This AGARDograph gives an introduction to the standard, explains how the standard is positioned among other relevant standards, and describes the equipment and their application in flight tests with some examples. The topics covered include IRIG 106 Chapter 10 compatible recording of (multiple) data streams, synchronization of data, data recorders, data retrieval, processing, and examples of flight test programs. Further development of the standard, originally published for on-board recorders, is described for extending the requirements for ground-based data recorders. The last chapter addresses a number of issues related to the application of the Chapter 10 standard with references to information and possible solutions.

This document shows how data acquisition and data processing in accordance to IRIG 106 Chapter 10 can be applied in NATO flight tests and will thereby contribute to collaboration and cost efficiency.

# Application aux essais en vol des normes relatives aux enregistreurs de données IRIG 106

## (STO-AG-160-V23)

# Synthèse

Pendant les essais en vol, les données acquises proviennent de différentes sources et sont enregistrées sous divers formats. Les données des capteurs, les données des bus d'avionique de l'appareil, l'heure, la voix et la vidéo sont essentielles à l'analyse de ces essais en vol. Il existe des normes pour enregistrer et transférer ces types de données, les normes IRIG 106. Cependant afin de favoriser l'interopérabilité des données d'essais en vol entre les équipes d'essais (multinationales), il était nécessaire qu'une norme englobe tous ces types de données. Dans ce but, le groupe Télémétrie du Range Commanders Council (RCC) a publié en 2004 la première édition du Chapitre 10 de la norme IRIG 106, « Solid-State On-Board Recorder Standard » (norme relative aux enregistreurs embarqués à semi-conducteurs). Cette norme n'a cessé d'évoluer.

La présente AGARDographie est une introduction à la norme. Elle explique la position de la norme parmi les autres normes pertinentes et décrit l'équipement et son application dans les essais en vol, avec quelques exemples. Les sujets couverts sont l'enregistrement compatible de (multiples) flux de données, la synchronisation des données, les enregistreurs de données, la récupération des données, le traitement et les programmes d'essais en vol (exemples), traités dans le chapitre 10 de l'IRIG 106. L'évolution ultérieure de la norme, publiée au départ pour les enregistreurs embarqués, est décrite afin d'élargir les exigences en matière d'enregistreurs de données au sol. Le dernier chapitre traite un certain nombre de questions liées à l'application de la norme du Chapitre 10, en faisant référence à des informations et des solutions possibles.

Le présent document montre comment l'acquisition et le traitement des données conformément au Chapitre 10 de l'IRIG 106 peuvent être appliqués aux essais en vol de l'OTAN et contribuer ainsi à la collaboration et à l'efficacité économique.

# Acknowledgements

The lead author would like to express special thanks to Mr. Balázs Bagó of Zodiac Data Systems for allowing the use of parts of his publication and Mr. Bob Baggerman, Independent IRIG 106 FTI Consultant, for providing editable text of his Chapter 10 Handbook. Furthermore, special thanks to Mr. Rian Striegel from NLR Royal Netherlands Aerospace Centre for his contributions to the text, review of the manuscript and mental support.

The co-author would like to thank Jon Morgan from the Mission Control Systems group at JT4 LLC, and Joy Bland at Analytical Mechanics Associates Inc. for their support of this effort. In addition, the co-author would like to thank Kevin Knudtson at the Dryden Aeronautical Test Range for reviewing the manuscript.

# Preface

The introduction of solid-state recording for flight test around the year 2000 was a great improvement in the operability and reliability of flight test instrumentation. Compared to the legacy instrumentation tape recorders, the equipment became smaller, more robust and less sensitive to environmental conditions. Data processing became faster and the turn-around time to provide data to customers significantly improved.

The introduction of solid-state recorders in-turn started efforts to improve interfaces with data processing, equipment control, and operational procedures. Interoperability of the files created on solid-state recorders and the software used to process these files was difficult without standardization. In 2004, Chapter 10 of the IRIG-106 Telemetry Standards was released to improve standardize these files. Since that time, the Range Commanders Council has continued to update Chapter 10 to improve standardization of recorder interfaces. Solid-state recorder end-users and suppliers worldwide now use the Chapter 10 standard.

At the Royal Netherlands Aerospace Centre NLR, Chapter 10 is the standard used in new flight-test instrumentation installations. Since NLR had no direct influence on the evolution of the standard, it has been difficult to explain to flight-test instrumentation engineers and managers the advantages of Chapter 10 standardization. After several successful applications of Chapter 10 at NLR, the idea arose in 2013 to write an AGARDograph on the Chapter 10 to advocate the use of this technology in the NATO flight test community.

Where at NLR Chapter 10 experience covered on-board recording, NASA Armstrong Flight Research Center also applies the Chapter 10 standard in ground facilities. Ground recorders has been a main area of evolution of the Chapter 10 standard. A significant part of the AGARDograph deals with ground-based recorders.

For engineers and software developers, Chapter 10 provides a level of detail required for implementing solid-state recorders and software. For the casual reader this AGARDograph offers an introduction to the Chapter 10 standard and describes the main areas where it evolved over the years. A primary message of the AGARDograph is to communicate that verification of compliance with Chapter 10 is a shared responsibility of users and vendors. Different approaches for verification and the tools available for this task are given. The AGARDograph provides examples of projects, which illustrate how the standard can enable the more efficient execution of flight test programs. In a concluding chapter, the AGARDograph discusses issues the user may encounter with Chapter 10.

It took long to finalize this AGARDograph, not only due to the limited availability of the authors, but also by the fact that the Chapter 10 standard was still evolving and user experience was building up rapidly. It made the final issue of this AGARDograph even more valuable for both the beginning as more experienced flight test instrumentation engineer to gain knowledge about application of the Chapter 10 standard.

# Biographical Sketches

**JOHAN KLIJN**

Johan Klijn holds a BSc degree in Electrical Engineering from the Institute of Technology of Amsterdam where he graduated in 1981. Since that time, he has worked at the Royal Netherlands Aerospace Centre, presently at the department Flight Test and Certification of the Aerospace Systems Division, recently as Principal Project Engineer. He was involved in the design and installation of flight test instrumentation systems in both military (F-16, several helicopter types like Apache, Chinook, NH-90) and civil (Fokker prototype) aircraft. He was project leader for the design and installation of flight test instrumentation in an F-16 MLU aircraft of the Royal Netherlands Air Force and project leader of the Advanced Flight Test Facilities project, which aims at general modernization of flight test equipment within NLR. At present he has tasks in instrumentation projects with regard to qualification and certification, system safety analysis and configuration management. He presented papers about flight test instrumentation at symposia of the Society of Flight Test Engineers (SFTE) (1991, 2000, 2006 and 2015) and AGARD (1996).

**BRUCE LIPE**

Bruce Lipe has over 30 years of experience as a project manager, and test range engineer specializing in flight-test mission control systems. Bruce is a member of the Range Commander's Council Telemetry Group where he served as Secretary and is currently the Vice Chairmen. He also served as the project manager and systems engineer for many control rooms builds, the Interactive Analysis and Display System (IADS), and the USAFs Mission Control System (MCS) telemetry processor at Edwards Air Force Base. Bruce also served as project manager for the Integrated Network Enhanced Telemetry (iNET) project in the USAF Advanced Range Telemetry Office. Bruce is currently the chief engineer for the NASA Armstrong Flight Research Center's Dryden Aeronautical Test Range (DATR).

# Table of Contents

# List of Figures

# List of Tables

# List of Acronyms and Nomenclature

| | |
|---|---|
| A/D | Analog to Digital |
| ACMI | Air Combat Manoeuvring Instrumentation |
| ACTTS | Air Combat Test and Training System |
| ADC | Analog-to-Digital Converter |
| ADVISE | Apache Data and Video Intelligence System |
| AEHOO | All Encompassing Hierarchical Object Oriented format |
| AFB | Air Force Base |
| AFDX | Avionics Full-Duplex Switched Ethernet |
| AGARD | Advisory Group for Aerospace Research and Development |
| AIDS | Aircraft Integrated Data System |
| AIT | Avionics Interface Technologies |
| ANSI | American National Standards Institute |
| ARINC | Aeronautical Radio, Incorporated |
| ARP | Address Resolution Protocol |
| ASCII | American Standard Code for Information Interchange |
| ASTM | American Society for Testing and Materials |
| ATA | Advanced Technology Attachment |
| ATF | Aeronautical Tracking Facility |
| ATP | Acceptance Test Procedure |
| | |
| BIT | Built-In Test |
| BMP | Bitmap (file format) |
| | |
| CAN | Controller Area Network |
| CCSDS | Consultative Committee for Space Data Systems |
| CDF | Common Data Format |
| CLI | Command Line Interface |
| CMDP | Common Mission Debrief Program |
| COFDM | Coded Orthogonal Frequency Division Multiplexing |
| COTS | Commercial Off-The-Shelf |
| CSA | Canadian Standards Association |
| CSV | Comma Separated Values |
| CTS | Combat Training Range |
| CWC-AE | Curtiss-Wright Controls Avionics & Electronics |
| | |
| D/A | Digital to Analog |
| DAS | Data Acquisition System |
| DATR | Dryden Aeronautical Test Range |
| DAU | Data Acquisition Unit |
| DC | Direct Current |
| DCRSi | Digital Cassette Recorder System incremental |
| DDC | Data Device Corporation |
| DDLS | Digital Data Link System |
| DHC | Defence Helicopter Command |
| DHCP | Dynamic Host Configuration Protocol |
| DoD | Department of Defence |
| DORS | Digital On-board Recording Standard |
| DRS | Digital Recording System |
| DQE | Data Quality Encapsulation |

| | |
|---|---|
| EAG | European Air Group |
| EMI | Electro-Magnetic Interference |
| EOS | Earth Observing System |
| EPAF | European Participating Air Forces |
| EU | Engineering Unit |
| | |
| FC-PLDA | Fibre Channel –Private Loop SCSI Direct Attach |
| FDAS | Flight Data Access System |
| FDM | Frequency Division Modulation |
| FDR | Flight Data Recorder |
| FEC | Forward Error Correction |
| FFT | Fast Fourier Transformation |
| FITS | Flexible Image Transport System |
| FLIDAS | Flight Data Studio |
| FM | Frequency Modulation |
| FTDP | Flight Test Data Processing |
| FTI | Flight Test Instrumentation |
| | |
| GEMS | Ground Equipment Monitoring Server |
| GFTF | Graphics Foundations Task Force |
| GIS | Generic Instrumentation System |
| GPS | Global Positioning System |
| GRS | Ground Recording System |
| | |
| h | Hexadecimal |
| HDF | Hierarchical Data Format |
| HEDAS | Helicopter Data Acquisition System |
| | |
| IADS | Interactive Analysis and Display System |
| ICT | Information and Communication Technology |
| IEEE | Institute of Electrical and Electronics Engineers |
| IENA | Test Installation for New Aircraft (French acronym) |
| IF | Intermediate Frequency |
| iGU | Instrumentation Gateway |
| iNET | integrated Network Enhanced Telemetry |
| iNET-X | iNET eXtended |
| IP | Internet Protocol |
| IRIG | Inter-Range Instrumentation Group |
| iSCSI | Internet Small Computer System Interface |
| ISO | International Organization for Standardization |
| | |
| JBOD | Just a Bunch Of Disks |
| JPEG | Joint Photographic Experts Group |
| | |
| KLV | Key-Length-Value |
| KNAPI | KLu-NLR Application Platform Interface |
| | |
| LAN | Local Area Network |
| LNA | Low Noise Amplifier |
| LSB | Least Significant Bit |
| LUN | Logical Unit Number |
| | |
| MAC | Media Access Control |
| MATLAB | Matrix Laboratory |

| | |
|---|---|
| MCC | Mission Control Center |
| MDR | Modular Data Recorder |
| METS | Metadata Encoding and Transmission Standard |
| MITR | Modular Instrumentation TAP Recorder |
| MJPEG | Motion JPEG |
| MLU | Mid-Life Update |
| MMSC | Micro Miniature Signal Conditioner |
| MoD | Ministry of Defence |
| MONSSTR | Modular Non-volatile Solid State Recorder |
| MP@ML | Main Profile at Main Level |
| MPEG | Moving Picture Experts Group |
| MST | Master location |
| | |
| NADSI | NATO Advanced Data Storage Interface |
| NASA | National Aeronautics and Space Administration |
| NATO | North Atlantic Treaty Organization |
| NCSA | National Center for Supercomputing Applications |
| ND | Neighbour Discovery |
| netCDF | Network Common Data Format |
| NIC | Network Interface Controller |
| NLR | Royal Netherlands Aerospace Centre |
| NM | Nautical Mile |
| NMEA | National Marine Electronics Association |
| NSF | National Science Foundation |
| NSSDC | National Space Science Data Center |
| | |
| ODE | Omega Data Environment |
| OMG | Object Management Group |
| ORB | Operation Request Block |
| OTIS | Open Telemetry Interactive Setup |
| | |
| PAM | Pulse Amplitude Modulation |
| PATA | Parallel Advanced Technology Attachment |
| PC | Personal Computer |
| PCM | Pulse Code Modulation |
| PCU | Programmable Conditioner Unit |
| PDM | Pulse Duration Modulation |
| PMU | Programmable Master Unit |
| PPS | Pulse Per Second |
| PTP | Precision Time Protocol |
| PWM | Pulse Width Modulation |
| | |
| R&R | Recorder and Reproducer |
| RAID | Redundant Array of Independent Disks |
| RCC | Range Commanders Council |
| RDA | Raw Data Archive |
| RDTL | Recorder Data Streaming Transport |
| RF | Radio Frequency |
| RFPA | Radio Frequency Power Amplifier |
| RMM | Removable Memory Module |
| RNLAF | Royal Netherlands Air Force |
| RTC | Real-Time Counter |
| RTCM | Radio Technical Commission for Maritime Services |

| | |
|---|---|
| SATA | Serial Advanced Technology Attachment |
| SBP | Serial Bus Protocol |
| SCA | Ship Controlled Approach |
| SCSI | Small Computer System Interface |
| SDS | Scientific Data Systems |
| SHOL | Ship-Helicopter Operational Limit |
| SSR | Solid State Recorder |
| STANAG | Standardization Agreement |
| S-VHS | Super-Video Home System |
| | |
| TAI | International Atomic Time |
| TCP/IP | Transmission Communication Protocol/Internet Protocol |
| TDM | Time Division Multiplexing |
| TDP | Time Data Packet |
| TDS | Telemetry Data System |
| TG | Telemetry Group |
| TIFF | Tagged Image File Format |
| TM | Telemetry |
| TMATS | Telemetry Attributes Transfer Standard |
| TMoIP | Telemetry Transmission over Internet Protocol |
| TSF | Transport Stream Frames |
| TSPI | Time Space Position Information |
| TTC | Teletronics Technology Corporation |
| | |
| UART | Universal Asynchronous Receiver-Transmitter |
| UCAR | University Corporation for Atmospheric Research |
| UCP | UCAR Community Programs |
| UDP | User Datagram Protocol |
| US | United States |
| USAF | United States Air Force |
| USB | Universal Serial Bus |
| USNO | United States Naval Observatory |
| UT1 | Universal Time (version 1) |
| UTC | Universal Time Coordinated |
| | |
| VMR | Video and Metadata Registration |
| | |
| WAV | Waveform Audio File Format |
| | |
| XML | eXtensible Mark-up Language |
| | |
| YPG | Yuma Proving Ground |

# Author Contact Information

Name: Mr Johan M. Klijn (Lead Author)
Mailing Address: Project Engineer
NLR Royal Netherlands Aerospace Centre – Flight Test & Certification
Anthony Fokkerweg 2
1059 CM Amsterdam
THE NETHERLANDS
Email: johan.klijn@nlr.nl

Name: Mr Bruce A. Lipe (Co-Author)
Mailing Address: Chief Engineer
NASA Armstrong Flight Research Center
Dryden Aeronautical Test Range
Edwards Air Force Base
4800 Lilly Drive Mailstop 3302
Edwards CA 93523
UNITED STATES
Email: bruce.a.lipe@nasa.gov

## PANEL/GROUP MENTOR

Name: Dr Henk W. Jentink
Mailing Address: NLR Royal Netherlands Aerospace Centre – Flight Test & Certification
Anthony Fokkerweg 2
1059 CM Amsterdam
THE NETHERLANDS
Email: henk.jentink@nlr.nl

# Chapter 1 – INTRODUCTION

## 1.1 OBJECTIVE

Digital data acquisition during flight tests covers many different types of data including sampled sensor data, aircraft avionics bus data, voice and video. Data streams are synchronized and nowadays stored on solid-state memory. Standards are in use for the administration of the data that enhance interoperability between equipment manufacturers and (multinational) test teams. One of these standards is the Telemetry Standards, IRIG Standard 106 Chapter 10, “Solid-State On-Board Recorder Standard”, first published in 2004 and evolving up to the present day.

The IRIG 106, Chapter 10 standard is available and is maintained by the Range Commanders Council (RCC). This document explains how data acquisition and data processing in accordance with this standard can be applied in NATO flight testing and will thereby contribute to collaboration and cost efficiency.

## 1.2 HISTORY OF FLIGHT TEST DATA RECORDING

On-board data recording is a general used method used to store and record flight test data. Even when telemetry is used, the same data is often recorded on-board the aircraft. On-board recording stores data that might be lost if the telemetry link should fail [1].

In the earliest days of flight test, paper and a pencil were used to record data from the cockpit instruments by the pilot or observer. Later photographic methods used a camera to film the aircraft instrument panel. This technique led to the use of Photo-Panel Recorders or “Automatic Observers.” Photo-Panel Recorders used a separate flight test instrument panel equipped with warning or indicator lights integrated with a camera system. The aircrew could remotely activate the camera viewing the flight test instrument panel to photographically record data during a test [2].

Direct recording was developed to address an increase in data requirements for continuous-trace recording of time history data. Direct recording used a stylus with electro-sensitive, pressure sensitive, or inked papers. Limited recording speed, the friction of the stylus, and the difficulty synchronizing several measurements led to the abandonment of direct recording [3].

Optical recording used a set of D’Arsonval type galvanometers, one for each channel and grouped side-by-side into a device called an oscillograph. Each galvanometer used a mirror attached to a coil suspended in a magnetic block housing. When current flows through the coil, a magnetic field produced by the current flow reacts with the field of the magnetic block causing the coil to deflect through an angle proportional to the current flowing through the coil. The attached mirror then deflects a beam of light onto a moving strip of photosensitive paper. The trace on the moving paper captures the time history of a data measurement [4].

In 1949, flight test started recording data using analog magnetic tape, since it offered the capability to record very large quantities of data at high rates. A digital computer could easily process the magnetic tape recorded data more efficiently, but data review cannot occur until after the data processing. Initially this was a disadvantage since data recorded on an oscillograph could be reviewed immediately. Direct recording of data utilized the maximum bandwidth capability of the analog magnetic recorder but was limited in accuracy by all the extraneous phenomena causing data dropouts (amplitude instability). Various modulation schemes addressed limitations in the direct recording process. Among these schemes are Frequency Modulation (FM), Pulse Duration Modulation (PDM), and Pulse Code Modulation (PCM) [5].

FM recording employs a carrier frequency which is frequency modulated by the signal to be recorded. A DC signal of positive polarity would deviate the carrier frequency some percentage in one direction. A DC signal of negative polarity signal would deviate the carrier frequency in the opposite direction. Information recorded is in the frequency domain and amplitude instabilities have little or no effect on the recording. Frequency Division Multiplexing (FDM) maximizes storage on an FM recording. A series of non-overlapping frequency bands are setup across the available bandwidth to record data. Current from a transducer modulates a subcarrier oscillator. Each subcarrier oscillator differs in frequency from other subcarrier oscillators. A mixer combines the signals from the subcarrier oscillators for recording. On the ground, the combined signal passes through band-pass filters and subcarrier discriminators to obtain the data signal [4]. The FM recording process made stringent demands on the tape transport to move tape across the recording heads at a precise and uniform speed. Any speed variations (known as “Tape Flutter”) of tape speed over the recorder head introduced unwanted modulation of the center carrier frequency and resulted in noise on the recording. Tape flutter was the limiting factor in the dynamic range and accuracy of FM recording. FM recording also required more complex electronics including modulators, low-pass filters, and a tape transport engineered to a high standard of precision [5].

Time-Division Multiplexing (TDM) samples measurements in a recurring sequence rather than simultaneously. Pulse Duration Modulation (PDM) represents an analog TDM technique. A commutator samples data from multiple channels in sequence at discrete intervals. The commutator provides frame synchronization and two channels are used for calibration corresponding to full-scale voltage and zero voltage of a channel. To prevent amplitude instability, a device called a “keyer” or keying amplifier converts varying amplitude signals from the commutator to constant amplitude signals of varying pulse width or pulse duration. Each value of an input signal is assigned a pulse duration within the total interval available between samples. PDM recording could record over 1000 channels of information on a 14-track recorder at high accuracy because of the self-calibration feature. The disadvantage of PDM recording was the limited frequency response of each channel compared with FM recording. Like FM recording, PDM recording also required more complex electronics including commutators, keying amplifiers, and filters [5].

In the early 1960s, digital recording on analog tape began to replace earlier methods of recording. The fundamental unit in a digital computer is the “bit”, which may represent either a one or a zero state. The properties of magnetic tape worked well with a two-state system. Digital recording magnetizes the tape as either a positive or a negative state. Previous analog recording methods used a carrier that was a continuously varying wave. A modulated train of pulses comprises the carrier used for digital recording. The many methods of modulating pulses include Pulse Width Modulation (PWM), Pulse Amplitude Modulation (PAM), and Pulse Code Modulation (PCM) [5].

In PDM, the duration or the width of the pulse varies with the amplitude of the modulating signal. PAM uses the amplitude of each pulse to represent the amplitude of the modulating wave at the time of the pulse. PCM is radically different when compared to the other pulse modulation methods. PCM associates (or quantizes) data sample signal magnitude levels to a set of code group values. An Analog-to-Digital Converter (ADC) is an example of a device used to perform quantization. Using PCM, the large-scale aggregation of many measurements into a larger data stream is possible using TDM.

The change from recording pure analog data to recording higher quality PCM data led to a need for high-density digital recorders, which were at the outset engineered around IRIG 106 multi-track tape transports. The Range Commanders Council (RCC), a group of test ranges in the United States, published the Inter-Range Instrumentation Group (IRIG) IRIG 106 telemetry standard. IRIG 106 included:

- Standardization of PCM formats (Chapter 4).
- Standardization of encapsulating MIL-STD-1553 bus communication embedded in a PCM data stream (Chapter 8).
- Using a metadata description language for defining the size, format and coding of physical values in PCM streams and MIL-STD-1553 bus data (Chapter 9).

In the 1980s small hard disk drives for use in Personal Computers (PC) were introduced. The offered hard drives increased in capacity over time from megabytes up to terabytes at present but lacked the ability to withstand extreme shock and vibration. In the 1990s, flash memory based solid-state hard drives offered the ability to withstand extreme temperatures, shock, and vibration. These new solid-state based systems offered an astonishing high performance / price ratio, rendering the large and expensive IRIG multi-track tape recorders obsolete. From 2004 until present there has been a dramatic decrease in costs for solid-state memory devices. According to an overview of McCallum [6] the costs for flash memory dropped from circa 0.2 $/MB in 2004 to around 0.2 $/GB in 2018, thus a reduction of a factor of 1,000.

At the same time the requirements for in-flight data recording increased in terms of number of signals and data rate [7], which made it attractive to use these new devices in the application of Flight Test Instrumentation (FTI).

With all these new digital devices available, the RCC Telemetry Group (TG) established a standard for recording on digital devices: In 2004, the RCC TG IRIG 106 Chapter 10 digital recording standard was introduced and has been enhanced bi-annually. At the introduction of Chapter 10, the RCC TG extended the IRIG 106 Chapter 9 Telemetry Attributes Standard to provide metadata support for Chapter 10. In 2015, the RCC TG extended Chapter 10 capability by adding IRIG 106 Chapter 7 Packet Telemetry Downlink. This standard provides a means to transmit the same packets used in IRIG 106 Chapter 10 down a serial streaming telemetry link. Most recently in 2017, the RCC TG relocated the Chapter 10 recorder data packets into a new IRIG 106 Chapter 11 Recorder Data Packet Format Standard.

## 1.3 ADVANTAGES OF SOLID-STATE DATA RECORDING

The advantages of the use of solid-state recorders instead of (partly) mechanical devices fit into two main categories:

1) **The Device Does Not Contain any Mechanical Moving Parts.** The absence of moving parts makes the FTI recording device are more reliable and require less maintenance. Preventive maintenance is rarely required. The FTI recording device will be less sensitive to shock and vibration. While magnetic tape recorders experienced flutter (which is a rapid change in signal parameters like amplitude, phase, and frequency) or Wow (a slow variant of flutter), solid-state recorders eliminated this cause of error. The absence of moving parts also offers better possibilities for miniaturization and therefore a reduction of weight and volume of the device. Solid-state drives require less electrical power as they do not require motors to operate.

2) **The Device Offers a More Efficient Integration with Data Processing Facilities.** The data stored on an FTI recorder is stored in machine-readable files. FTI data processing facilities can utilize computer software applications to post process the data stored in these files. This has reduced the requirement for specialized hardware but not the requirement for specialized software to process FTI data.

   The retrieval time from the recorder media is shorter and solid-state drives offer random access capability. Random access enables read-while-write capability. Using this read-while-write capability, the recorder can, if required, serve data through a bi-directional telemetry system to the ground [8].

   The initial disadvantage of the application of solid-state recorders was the need to transfer data from the flight-qualified media to magnetic tape in the FTI data center. More recently, high capacity hard-drive based storage systems replaced magnetic tape storage in FTI data centers.

## 1.4 PURPOSE OF STANDARDIZATION

A standard is an agreed upon way of doing something. Standards can cover a range of activities including making a product, managing a process, delivering a service or supplying materials. In FTI, standards define interfaces between FTI components. In the FTI community, standardization is the process of implementing and developing technical standards based on the consensus of different parties that include FTI system integrators, FTI component vendors, and test ranges.

Types of standards include:

- De facto (in practice) standards, achieve a dominant position by public acceptance or market forces. An example of a de facto standard regarding data formats is the Comma Separated Values (CSV) file format.
- De jure (obligatory) standards enforced by legal or contractual rules or endorsed by an official standards organization, such as ISO (International Organization for Standardization) or ANSI (American National Standards Institute). An example of such a de jure standard is the ASCII (American Standard Code for Information Interchange) character set.
- Voluntary standards, which are published and available for people to consider for use. Examples of voluntary standards organizations include ASTM International and CSA Group.

The IRIG 106 Chapter 10 standard, described in this document, is a voluntary standard controlled by the Telemetry Group of the RCC with representation of both users and vendors of recording and data processing equipment.

From a customer perspective:

- In the past, many FTI systems were comprised of components using proprietary interfaces from a single FTI vendor. Open interfaces allow systems integrators to build-up FTI systems comprised of components from many vendors. The systems integrator can build the FTI system with the most capable transducers, data acquisition units, and recorders from different vendors FTI systems integrators can avoid single source solutions with vendor lock-in. In economics, vendor lock-in occurs when a customer is dependent on a vendor for products and services and is unable to switch vendors without substantial cost.
- Standardization also offers interoperability. An FTI recorder for example could be interoperable with a vendors FTI post-test processing software with an exchange of metadata about the recording and little more pre-planning.

From a vendor perspective:

- Standardization lowers the cost of device and application development and increases the speed to market of a new product. This occurs because new applications can reuse hardware and software developed to comply with standards.
- Customer confidence that products like FTI recorders are interoperable with FTI instrumentation systems and data processing software.
- Open interfaces eliminate barriers that prevent a business from entering a market.
- Vendors can reach a larger (international) market while maintaining consistent product quality.

The main disadvantage of standardization is the increased risk for innovation stagnation. Adhering (too much) to standards can block creativity to find new and more efficient techniques. To avoid stagnation the RCC Telemetry Group has continuously introduced new capabilities to Chapter 10 since its introduction in 2004.

## 1.5 REFERENCES

[1] Pool, A. and D. Bosman (Eds.)., Basic Principles of Flight Test Instrumentation Engineering, AGARDograph 160, Vol. 1, March 1994.

[2] Suppe, F., The Changing Nature of Flight and Ground Test Instrumentation and Data: 1940-1969. In: P. Galison P. and A. Roland (Eds.) Atmospheric Flight in the Twentieth Century. Archimedes (New Studies in the History and Philosophy of Science and Technology), Vol. 3. Springer, Dordrecht, 2000.

[3] Richardson, N.R., NACA Technical Note 2265, NACA VGH Recorder, Feb 1, 1951.

[4] Stange, R.A., Flight Test Rotary Wing Manual, AD-A955 359, Naval Air Test Center, Patuxent River, Md. June 1, 1959.

[5] Lowman, C.E. and Angerbauer, G.J., Magnetic Recording Theory for Instrumentation, Ampex Corporation, CA, USA, 1963.

[6] McCallum, J.C., Memory Prices (1957 – 2018), March 23 2020. Available at https://www.jcmit.net/memoryprice.htm.

[7] Mace, W.D., Flight Test Instrumentation, AGARD Lecture Series No. 50, AGARD-LS-50, 1972.

[8] Morgan, J. and Jones, C.H., PCM Backfill: Providing PCM to the Control Room Without Dropouts, 2014, Available at http://repository.arizona.edu/handle/10150/577490.

# Chapter 2 – ESTABLISHMENT OF A STANDARD

## 2.1 AVAILABLE DATA RECORDING STANDARDS

The 'format' of a dataset refers to the way in which the data is structured and made available for humans and machines. There exist many standards for data recording and exchange formats for general and specific applications. Examples of present general standards for scientific data are:

- Common Data Format (CDF) [1]: a license free and open standard design starting in 1985 by the National Space Science Data Center (NSSDC) at the NASA Goddard Space Flight Center. CDF supports scalar and multi-dimensional datasets. The platform independent format contains metadata and is therefore self-describing.
- Network Common Data Format (netCDF) [2]: despite its resemblance in name evolved independently from CDF. It is also a self-describing platform independent data format for multi-dimensional datasets. The Unidata Program developed and currently maintains the NetCDF. Unidata provides data and software tools for use in geoscience education and research. Unidata is part of the University Corporation for Atmospheric Research (UCAR) Community Programs (UCP) funded primarily by the National Science Foundation (NSF). The recent version netCDF-4 includes HDF5 (see below) as underlying data format.
- Hierarchical Data Format (HDF) [3]: The quest for a portable scientific data format, originally named All Encompassing Hierarchical Object Oriented format (AEHOO) began in 1987 by the Graphics Foundations Task Force (GFTF) at the National Center for Supercomputing Applications (NCSA). NSF grants received in 1990 and 1992 were important to the project. Around this time NASA investigated 15 different file formats for use in the Earth Observing System (EOS) project. After a two-year review process, NASA selected HDF (renamed HDF-EOS) as a standard to transfer data between systems. The current version HDF-EOS5 is based on HDF5.

An example of a data format standard for a more specific application is the Flexible Image Transport System (FITS) [4]. FITS is an open standard, defining a digital file format useful for storage, transmission and processing of data: formatted as N-dimensional arrays (for example a 2D image), or tables. FITS is the most commonly used digital file format in astronomy. The FITS standard has special (optional) features for scientific data; for example it includes many provisions for describing photometric and spatial calibration information, together with image origin metadata.

Another field of application is the Geospatial Information System for which many raster or vector file formats exist, often enriched with GIS specific metadata, such as GeoTIFF.

In the field of aviation the ARINC573 [5] and its successor ARINC717 [6] standards should be mentioned, which define the data bus formats for the Flight Data Recorder (FDR). For flight test instrumentation purposes, the IRIG 106 document defines in Chapter 4 similar formats for data to be recorded on magnetic tape recorders.

With the fast developments in the field of the Information and Communication Technology (ICT) it became attractive to use Commercial Off-The-Shelf (COTS) products for flight test instrumentation applications. This makes the associated common protocol standards, such as Transmission Communication Protocol/Internet Protocol (TCP/IP) and User Datagram Protocol (UDP) applicable.

## 2.2 APPLICABILITY OF STANDARDS FOR FLIGHT TEST PURPOSES

The Inter-Range Instrumentation Group (IRIG) was the original standards body of the Range Commanders Council (RCC). Ever since its establishment, domain specific standards bodies in the RCC like the Telemetry Group (TG) have absorbed the IRIG functions. IRIG Standard 106 is a comprehensive telemetry standard for aeronautical applications. First published in 1960, the IRIG 106 telemetry standards contained recording standards focused on magnetic tape recorders. Then in early 2000's the use of digital tape recorders and the rising use of solid-state recorders, the desire for standard recorder interfaces and a storage file format emerged. In addition, the organization of data into packets instead of serialized data streams, required new standards for data recording and processing. The required functionality was not available in the existing IRIG 106 or other existing general standards like those mentioned in Section 2.1.

For the following reasons, data recording and processing for flight test purposes requires a dedicated standard:

- Since it takes time for transition to new techniques, compatibility with the standards from the past, especially the PCM formats defined in IRIG 106 Chapter 4, was necessary.
- Flight test instrumentation poses specific requirements for metadata, such as information about system configuration and calibration. This metadata provides a record of the types of data collected by the instrumentation and the information needed to process the data into a final product for distribution.
- A standard interface for specific input data formats, like avionics data bus protocols such as MIL-STD-1553 and ARINC429, was needed because aircraft under test were also migrating to ICT.
- A standard interface with existing data processing facilities. This standard interface reduces software development and maintenance costs.

## 2.3 CHAPTER 10 STANDARD ESTABLISHMENT

Acquisition and storage of telemetry data in the past used analog magnetic tape recording technology. One of the great successes in this field was the standardization using IRIG 106 compatible multi-track magnetic tape recording systems. The Telemetry Group within the US Range Commanders Council (RCC) Inter-Range Instrumentation Group (IRIG) organization created the IRIG 106 standard [7]. A number of European and US companies manufactured analog magnetic tape recording systems in quantity for 40 years.

Since the 1970s, digital data storage devices have become increasingly available as commercial off-the-shelf products from the commercial audio, video, and computer data storage industry. These new systems offered an astonishing high performance / price ratio, rendering the large and expensive IRIG multi-track analog tape recorders obsolete.

Vendors of airborne equipment started to use the technologies offered by the new digital tape storage systems. They modified and ruggedized devices for use as on-board data recording systems. The diversification of tape recording technologies meant the end of the IRIG 106 instrumentation analog tape media standard; although the RCC has continued to use tape technologies offered by the industry like the commercial Super-Video Home System (S-VHS) and the professional Sony D-1 videocassettes.

Without an existing standard, each digital data recorder manufacturer tried to invent better and more efficient proprietary digital recording systems. The DCRSi, MARS-II, DATaRec-2, DATaRec-3 were just some the digital recording systems in use at the time [8]. This made any direct data exchange between manufacturers' systems completely impossible. Often vendor specific software and additional hardware (reproducers) were required to reproduce data from these recording systems. This situation occurred because the proprietary data formats were generally not open for the users to develop in-house software. Conversion between formats led to loss of quality. The incompatibility of formats locked most projects into a single-source for purchasing recorder systems.

The RCC decided in 1994 to take a different approach. Instead of standardizing the media format, the RCC tried to standardize the format of the data located on the media. Standardizing the digital data format would enable the movement of recorded data across different media. A standardized data format also makes it easier to transfer data over a computer network. In addition, a standard data format facilitates the development of common data processing tools that could process data from digital recorders produced by multiple manufacturers.

The RCC contracted with TRW to develop a new standard in 1998, called IRIG 107-98 [9] based on the well-established telemetry standard developed by the Consultative Committee for Space Data (CCSDS) [10], [11]. The major space agencies of the world founded CCSDS in 1982 to develop communications and data systems standards for spaceflight. In common with aeronautical mobile telemetry systems, spacecraft used a Time-Division Multiplexing (TDM) scheme. Each space mission developed a unique telemetry system because of the lack of established standards in this field. In the early 1980s, the CCSDS developed an international standard for a telemetry that used data packets [12].

This standard used a variable-length data unit called the “source packet”. Various instruments and subsystems on the spacecraft generate source packets. These packets are transmitted to the ground as a stream of continuous fixed-length transfer frames. IRIG 107-98 attempted to use elements of CCSDS as a standard Digital On-board Recording Standard (DORS) and a data packetization standard for telemetry applications.

Standards are only successful if they receive active support from a user community. IRIG 107-98 did not receive active support from the flight test instrumentation community. The IRIG 107-98 was not a success, for the following reasons [12]:

- The standard was ahead of the need for a standard digital data format. The flight test instrumentation community did not have a compelling need to adopt a new standard. Most of the data recorded at the time was still on analog magnetic tape or digital recorder albeit in proprietary format.
- Vendors did not see any financial benefit in changing from proprietary data formats to an open standard data format.
- The standard was not mature enough for a recording system vendor to use without using proprietary technology to fill the missing elements. For example, IRIG 107-98 lacked the detailed packet formats for different data types that IRIG 106 Chapter 10 and later Chapter 11 provide.

However, the need for a standard data format otherwise remained. First, there was an attempt to complete the unfinished IRIG 107 standard with a new packet format (called version 1 packets) in order to correct deficiencies in the standard. The RCC realized in time that this attempt could not work.

Team members from the original IRIG 107-98 development staffed an RCC TG Ad-Hoc committee formed to work on Task Group TG-56 “Solid State Recorder Standard.” One of the first decisions was to end the effort to develop a standard that combined a packetized telemetry data format with a digital data format. Instead, the Ad-Hoc committee decided to focus the group’s efforts on the digital data format.

Given the earlier problems with the first attempt at digital data format standard IRIG 107-98, how does Chapter 10 compare?

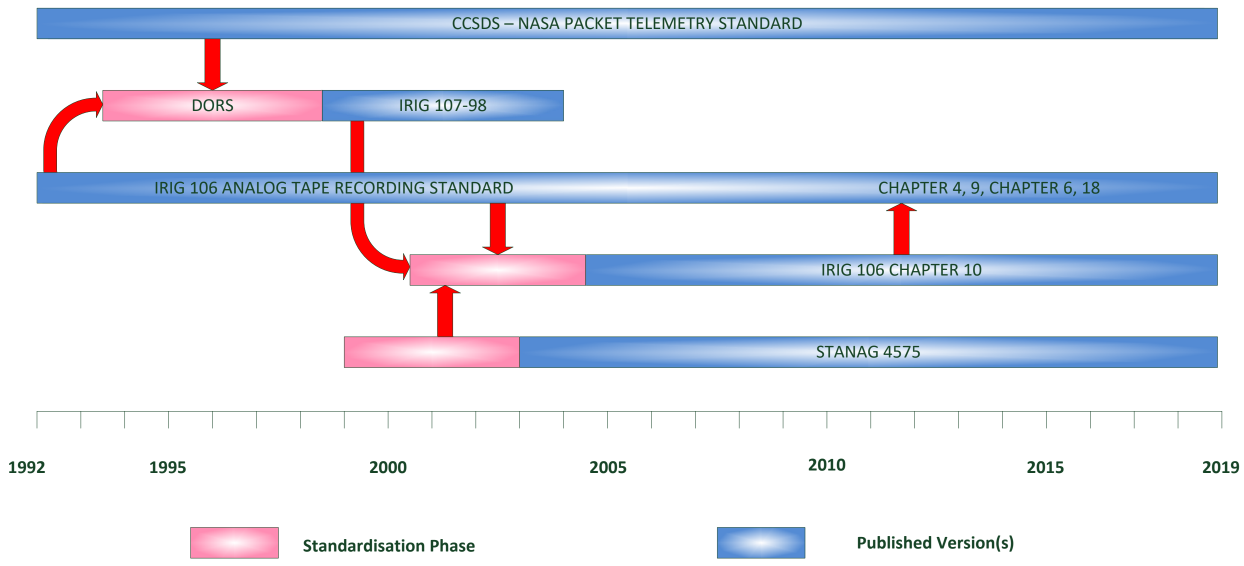



**Figure 2-1: Timeline of the IRIG 107 and IRIG 106 Chapter 10 Development.**

One point made earlier was that standards are only successful if they receive active support from a user community. IRIG 106 Chapter 10 has this active support. Following the release of IRIG 106 Chapter 10 in 2004, by 2006, the standard was in use throughout the world including [8]:

- U.S. B-1 and B-52 bombers;
- U.S. fighter programs including platforms such as the A-10, F-15, F-16, and F-35;
- U.S. helicopter platforms (e.g., Apache Longbow);
- U.S. transport platforms (e.g., C-130);
- Japan Defense Agency F-15 Flight Test;
- Korea Aircraft Industries T-50 Trainer;
- The Royal Netherlands Air Force;
- The Israeli Air Force; and
- Several Boeing Company programs (including the Airborne Laser).

Eventually Chapter 10 recorders replaced videocassette recorders installed in USAF operational aircraft [15]. These new recorders archived data during missions. After the mission, Chapter 10 Operational Debrief Stations could playback video and aircraft data gathered from avionics data buses.

Another problem with IRIG 107-98 was that it was ahead of its time. In 1998, the RCC recognized the need for a digital data format standard but the flight test user community was slow to follow.

Five years later the flight test community was spurred to action by problems with analog and digital recording systems. This included the lack of interoperability between multiple proprietary formats in digital recorders and failures of legacy tape recorders during high-G aircraft maneuver flight tests. Finally, the introduction of solid-state media recorders moved users to look at new technologies for flight test data recording and processing.

Moreover, with IRIG 107-98, vendors did not see any financial benefit in changing from proprietary data formats to an open standard data format. While the user community was the primary forcing function for the implementation of the IRIG 106 Chapter 10 standard, by 2006, multiple vendors developed recorders or data processing software [8].

Chapter 10 established a common interface standard for the implementation of solid-state digital data acquisition and on-board recording systems by the organizations participating in the RCC. It became rapidly clear to vendors that many members of the flight test community were no longer interested in procuring proprietary data recording solutions.

Finally, IRIG 107-98 was not mature enough for a recording system vendor to use without using proprietary technology to fill the missing elements. The Chapter 10 standard released in 2004 and 2005 was mature enough to support flight test operations. In addition, this maturity continues to increase since Chapter 10 has been a “work in progress” with regular standards releases every 2 years with new capabilities. The RCC TG may increase the IRIG 106 release interval to every year to accommodate rapid technological advancements in aeronautical mobile telemetry and recording systems. IRIG 106 release intervals are designated by adding the year of release to the standard number, for example the 2005 release of the standard would be titled IRIG 106-05.

## 2.4 REFERENCES

[1] Space Physics Data Facility, CDF User’s Guide, Space Physics Data Facility NASA / Goddard Space Flight Center, version 3.7.0, February 20, 2018.

[2] Rew, R., Davis, G., Emmerson, S., and Davies, H., The netCDF User’s Guide, 2018. Available at https://www.unidata.ucar.edu/software/netcdf/docs/user_guide.html.

[3] HDF5 Group, HDF5 User’s Guide, HDF5 Release 1.10, The HDF Group, June 2019. Available at https://portal.hdfgroup.org/display/HDF5/HDF5+User%27s+Guide.

[4] Definition of the Flexible Image Transport System (FITS), Version 4.0: IAUFWG, FITS Working Group, Updated on 22 July 2016.

[5] ARINC573, Mark 2 Aircraft Integrated Data System (AIDS Mark 2), ARINC, 1974 Edition, December 2, 1974.

[6] ARINC717, Flight Data Acquisition and Recording System, ARINC, 6 June 2011.

[7] IRIG TG, Telemetry Standards, IRIG Standard 106-96, Telemetry Group, Range Commanders Council, May 1996.

[8] Lockhard, M.T., and Garling, J.A., Chapter 10 Recording Standard Update, International Telemetry Conference, 2006.

[9] IRIG TG, Digital Data Acquisition and On-Board Recording Standard, IRIG Standard 107-98, Telemetry Group, Range Commanders Council, June 1998.

[10] CCSDS Secretariat, Communications and Data Systems Division (Code-TS), National Aeronautics and Space Administration, Telemetry: Concept and Rationale, Green Book, CCSDS 100.0-G-1, Washington, USA, December 1987.

[11] CCSDS Secretariat, Communications and Data Systems Division (Code-TS), National Aeronautics and Space Administration, Packet Telemetry, Blue Book, CCSDS 102.0-B-4, Washington, USA, November 1995.

[12] Bago, B., Data Formats: IRIG-107, DATaRec-3, IRIG-106 Chapter10, International Conference on Health and Usage Monitoring Systems, 2005.

[13] Telemetry Standards, IRIG Standard 106-04, Telemetry Group, Range Commanders Council, May 2004.

[14] NATO, NATO Advanced Data Storage Interface (NADSI), STANAG 4575, December 2014.

[15] Keller, J., Air Force Chooses Solid-State Data Recorders from Calculex for F-15 Jet Fighters and Bombers, Military & Aerospace Electronics Magazine, 10 June 2015.

# Chapter 3 – INTRODUCTION TO THE CHAPTER 10 STANDARD

## 3.1 GENERAL

The IRIG 106 is composed of chapters, each devoted to a different element of the telemetry system or process. IRIG 106 first included Chapter 10, the Solid-State On-Board Recorder Standard in 2004. Chapter 10 defines the interfaces and operational requirements for digital data recording devices. Chapter 10 also references elements of Chapter 4 (Pulse Code Modulation Standards), Chapter 6 (Digital Cassette Helical Scan Recorder/Reproducer, Multiplexer/Demultiplexer, Tape Cassette, and Recorder Control and Command Mnemonics Standards), Chapter 9 (Telemetry Attributes Transfer Standard), and later Chapter 11 (Recorder Data Packet Format Standard).

Chapter 10 is comprehensive in its scope. The purpose of this chapter is to provide a summary of the basic elements of the standard.

## 3.2 FILE STRUCTURE

In Section 10.5 of the Chapter 10 standard the interface file structure is defined as a subset and adaptation from STANAG 4575 [1], Section 3, File Structure Definition. This file structure was selected to facilitate host computing platform independence and commonality. An independent file structure ensures backward and forward compatibility for the life of the Chapter 10 standard.

This file structure definition does not define how data is physically stored on the recorder media but does provide a standardized method for access of the stored data at the data download interface. A manufacturer can physically organize data in any way appropriate to the media, including multiple directories, as long as the file structure as seen at the data download interface is in accordance with Chapter 10 Section 10.5.

The following elements of the file structure are defined:

- Data organization, describing the hierarchy of directories and data files;
- Directory definitions; and
- Data definitions.

Figure 3-1 depicts the general directory structure.

## 3.3 DATA FORMAT DEFINITION

Chapter 10 defines how one or more data streams from flight-test instrumentation are multiplexed, time-tagged, and stored in a data recording. The standard's central focus is a recording format defined in Section 10.6. This recording format is designed to operate on a recorder that uses random access digital media, i.e., solid-state memory. In addition to defining the overall file structure, Chapter 10 initially delineated specific data format and packet definitions for data monitored from MIL-STD-1553 buses, ARINC429 buses, PCM (only one format), Analog, computer-generated data, images (only one format), discretes, UARTs, IRIG time, video (MPEG2). Chapter 10 added more packet definitions over time to support new data formats.

### 3.3.1 Overall Data Packet Format

The partitioning of IRIG 106 Chapter 10 data occurs on a packet basis, with all of the data within an individual packet associated with a specific channel (e.g., "4") and data type (e.g., "MIL-STD-1553"). Figure 3-2 illustrates the general format of an IRIG 106 Chapter 10 packet. Each packet begins with a defined packet header which identifies channel number and data type; an 8-bit sequence number, which gets incremented for each packet for the respective channel; packet length information; an indication of the channel's relative time to the first data bit of the packet; and a checksum. The Packet Header is followed by an optional packet secondary header, a packet body, and an optional packet trailer.

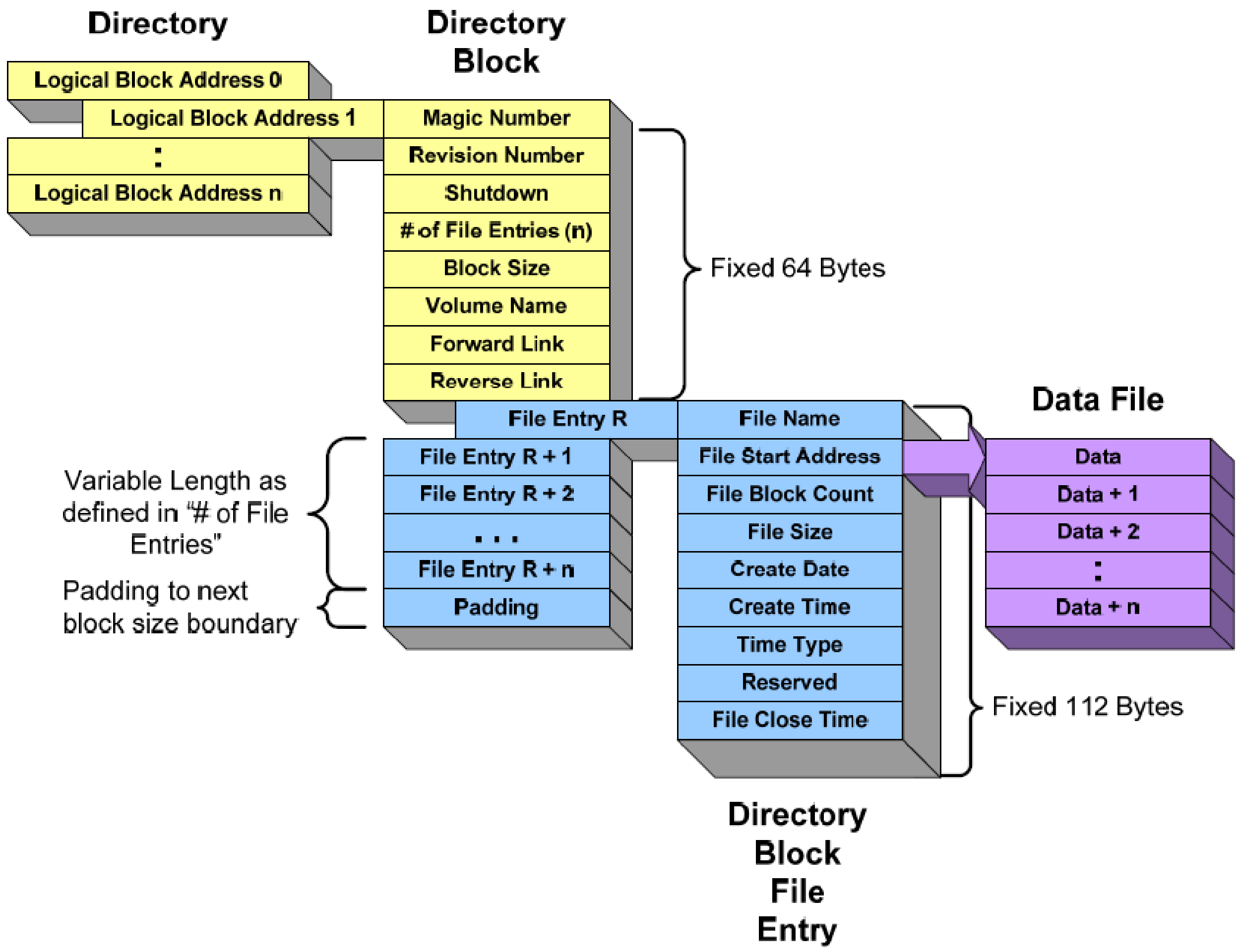



**Figure 3-1: Directory Structure.**

The first packet of any IRIG 106 Chapter 10 data recording is the "Computer-Generated Data Packet, Format 1 Setup Record". This packet describes the hardware, software, and data channel configuration used to produce the other data packets in the file. The size of this packet is limited to 134,217,728 bytes.

There are two limitations on all other packets following the Setup Record:

1) They are limited to a maximum size of 524,288 bytes. This total size includes the Packet Header, Packet Body, Packet Trailer, and optional Packet Secondary Header if enabled.

2) A single packet cannot contain more than 100ms of data.

For channel recordings that exceed either or both of these constraints, the channel data must be stored in multiple packets using the packet sequence counter.

| | |
|---|---|
| PACKET SYNC PATTERN | Packet Header |
| CHANNEL ID | |
| PACKET LENGTH | |
| DATA LENGTH | |
| HEADER VERSION | |
| SEQUENCE NUMBER | |
| PACKET FLAGS | |
| DATA TYPE | |
| RELATIVE TIME COUNTER | |
| HEADER CHECKSUM | |
| TIME | Packet Secondary Header (Optional) |
| RESERVED | |
| SECONDARY HEADER CHECKSUM | |
| CHANNEL SPECIFIC DATA | Packet Body |
| INTRA-PACKET TIME STAMP 1 | |
| INTRA-PACKET DATA HEADER 1 | |
| DATA 1 | |
| : | |
| INTRA-PACKET TIME STAMP n | |
| INTRA-PACKET DATA HEADER n | |
| DATA n | |
| DATA CHECKSUM | Packet Trailer |

**Figure 3-2: General Packet Format.**

The following paragraphs provide descriptions of the various fields within the general packet data structure.

The Packet Sync Pattern marks the start of a packet. It is a 16-bit pattern containing a fixed value of 'EB25'h. The Channel_ID provides an identifier for the specific data channels being monitored and recorded, with all channels in a system required to have unique Channel_ID values, and the value '0000'h being reserved. For example, for an 8-channel MIL-STD-1553 data recorder, the respective channels of Channel_ID could have values '0001'h through '0008'h.

The Data Length and Packet Length fields are four bytes each and indicate the number of bytes in a packet. For a given packet, the Data Length indicates the number of bytes in all of the Channel Specific Data, Intra-Packet Time Stamp, and Intra-Packet Data Header fields that are contained in the overall packet. The value of the Packet Length field equals the value of the Data Length field plus the number of bytes in the Packet Header, optional Secondary Packet Headers (if used), and Packet Trailer (if used). Assuming that the Secondary Packet Header and Packet Trailer (Filler and/or Data Checksum) fields are not used; the value of the Packet Length field will equal the value of the Data Length field plus 24.

The Header Version field is a one-byte indication of the applicable release of the IRIG 106 Chapter 10 standard. The single byte Sequence Number represents the packet sequence number. Its value increments by one for each packet processed by the respective channel and rolls over from 'FF'h to '00'h following every 256 packets processed for the respective channel.

The one-byte Packet Flags field provides information regarding the format of the data packet. The bits in this field relate to the use of the optional Packet Secondary Header, formatting of the time stamp, indications of data overflow error; along with an indication about the data checksum field; that is, whether or not it is used, and if so, its width, which may be 8, 16, or 32 bits.

The value of the single byte Data Type field indicates the type of format of data contained within the packet. The IRIG 106-04 version of Chapter 10 only defined 12 different types of data. See Table 3-1.

**Table 3-1: The IRIG 106-04 Version of Chapter 10 Defines 12 Different Types of Data.**

| Packet Header Value | Data Type Name | Data Type Description |
|---|---|---|
| 0x00 | Computer-Generated Data, Format 0 | User-Defined |
| 0x01 | Computer-Generated Data, Format 1 | Setup Record |
| 0x09 | PCM Data, Format 1 | Chapter 4, 7, or 8 |
| 0x11 | Time Data, Format 1 | RCC/Global Positioning System (GPS)/ Relative Time Counter (RTC) |
| 0x19 | MIL-STD-1553 Data, Format 1 | MIL-STD-1553B Data |
| 0x21 | Analog Data, Format 1 | Analog Data |
| 0x29 | Discrete Data, Format 1 | Discrete Data |
| 0x30 | Message Data, Format 0 | Generic Message Data |
| 0x38 | ARINC-429 Data, Format 0 | ARINC-429 Data |
| 0x40 | Video Data, Format 0 | MPEG-2/H.264 Video |
| 0x48 | Image Data, Format 0 | Image Data |
| 0x50 | UART Data, Format 0 | UART Data |

Chapter 10 reserved additional packet header values for future data types.

The Relative Time Counter field provides a 48-bit (6-byte) representation of the Relative Time Counter. This value represents the output of a free-running counter clocked to a 10 MHz oscillator. The Relative Time Counter is common to all channels. The method for time stamping is specific to each individual data type. The two-byte Header Checksum provides an integrity check of the overall packet header by providing the 16-bit arithmetic sum of all 16-bit words in the header, excluding the Header Checksum Word.

The Packet Secondary Header is an optional 12-byte field. If used, this header may include a 48-bit time stamp value for the packet, along with a two-byte Secondary Header Checksum for the time value.

One or more instances of the Packet Body follow the Packet Header or the Packet Secondary Header (if it is used). The size and duration of each Packet Body are constrained by the 524,588-byte and 100ms limitations mentioned above.

Chapter 10 defines a unique packet body format for each individual data type. The first field within the packet body is the Channel Specific Data. There is only one Channel Specific Data field for each data packet. An optional Intra-Packet Time Stamp follows the Channel Specific Data. The contents of the Channel Specific Data are Data Type specific. The Intra-Packet Time Stamp provides either 48-bit Relative Time or 64-bit absolute time, as indicated by the Packet Flag Bits. An optional Intra-Packet Data Header follows the Intra-Packet Time Stamp. The Intra-Packet Data Header contains additional information pertaining to the data that follows. One or more variable-sized representations of monitored channel data follow the Channel Specific Data field, the optional Intra-Packet Time Stamp, and the optional Intra-Packet Data Header.

The optional Packet Trailer follows the last Packet Body of the Packet. If used, the Packet Trailer may contain the Filler Field, a Data Checksum, or both the Filler Field and the Data Checksum.

The Filler Field includes bits to keep all packets aligned on 32-bit (4-byte) boundaries and to optionally keep all packets for a particular data channel the same length.

As a result, there will be some applications where the Filler Field is not required. If used, the value for all Filler bytes must be either ‘00’h or ‘FF’h.

If the Packet Flag Bits 1-0 bits are set for a Data Checksum, then the Data Checksum field contains a 32-bit, 16-bit, or 8-bit value (depending on the Packet Flag Bits value.) The 1 byte in the 8-bit Data Checksum Field represents a sum of the bytes in the packet. The 2 bytes in the 16-bit Data Checksum Field represents a sum of the words in the packet. The 4 bytes in the 32-bit Data Checksum Field represents a sum of the double words in the packet. These sums do not include the Packet Header, the Packet Secondary Header (if enabled), and the Data Checksum Word.

### 3.3.2 Time Stamping

IRIG 106 Chapter 10 provides two different options for the time stamping packets and individual messages. These two formats are a 48-bit relative time or a 64-bit absolute time. Both methods use a common time base to time stamp all data stored by the data recorder, regardless of the data type. Using the absolute time method makes it possible to correlate the times of data events for data stored across *all* data recorders at a specific location, or across multiple locations.

For each packet stored, flag bits in the respective packet header indicate the selection of the time stamping format used. Both formats assume use of a local 10 MHz clock, thereby providing a time resolution of 100 ns/LSB.

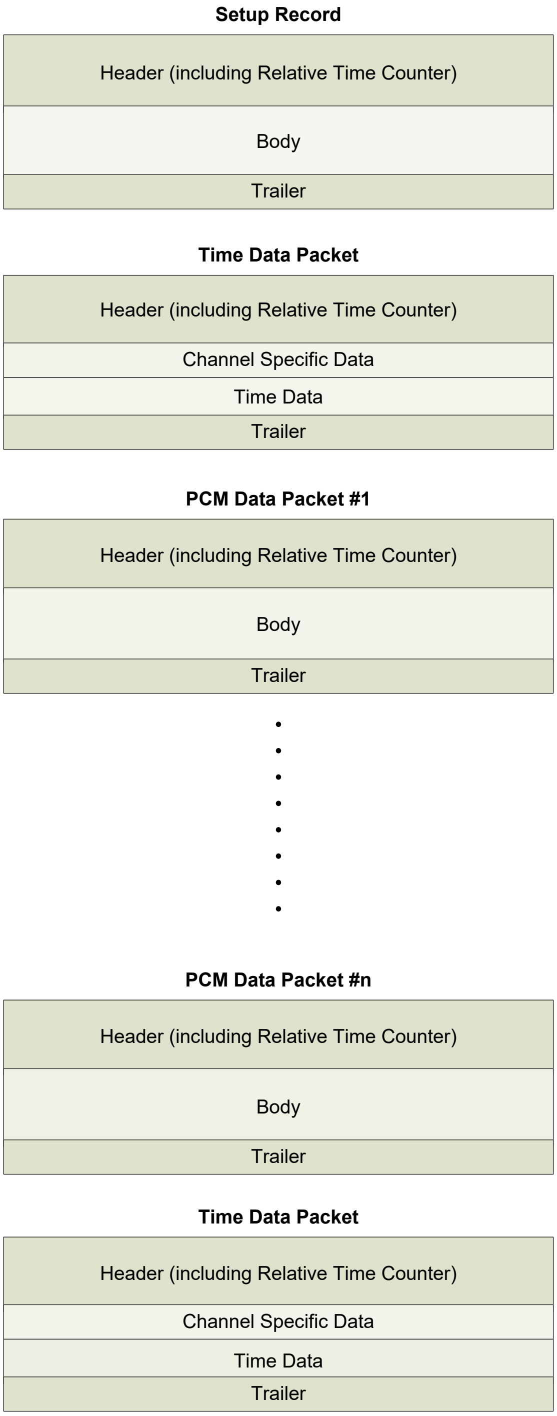
The absolute time format is a hypothetical time that runs at the same rate for all the observers in the universe. Alternatively, the rate of time for each observer can be scaled to the “absolute time” by multiplying the rate by a constant of 1. In the case of US DoD test ranges and facilities, and other government agencies such as NASA, the reference for time is Universal Time Coordinated (UTC) referenced to the United States Naval Observatory (USNO) Master Clock.

The IRIG Standard 200 defines the 64-bit absolute time stamping method for Time Distribution [2]. An analog pulse stream sends out an update every second and clock pulses are output once per millisecond. This implies, assuming a worst case tolerance of ±0.01% (100 PPM) for a receiver’s oscillator (which is the tolerance for MIL-STD-1553B transmission rate) for an absolute time user, a worst case error of ±100 ns, or precisely one “tick” of a 10 MHz clock.

The output of a free-running 48-bit 10 MHz binary counter determines the relative time. This relative time is distributed to all channels within the same data recorder, thereby providing a local common time base for all stored data, regardless of the data type. When relative rather than absolute time is used, the standard requires that it be accurate to within ±100µs of absolute time, with a recommended accuracy of 1µs.

For MIL-STD-1553 messages, the 48-bit time value corresponds to a specific bit indicated in the MIL-STD-1553 Channel Specific Data. This time may correspond to the time of either the start or end of the first word, or the end of the last word of the 1553 message.

Time reconstruction of PCM data and MIL-STD-1553 data is given in the figures below, PCM time reconstruction in Figure 3-3 and MIL-STD-1553 in Figure 3-4.




Every chapter 10 file starts with a Setup Record. As all other packet types it consist of a Header, Body and Trailer. An optional Secondary Header is omitted in these examples. All headers contain a Relative Time Counter (RTC) containing the value of a free running 10 MHz binary counter of 48 bits.

The first packet after the Setup Record is always a Time Data Packet (TDP). The TDP is repeated at least every second.
The TDP body contains the time from either an external source (IRIG-B) or the internal Real-Time Clock of the recorder indicated in the Channel Specific Data information, Time Format (FMT) and Time Source (SRC). For the PCM-type S3DR-F and -C recorders internal time is used.

The PCM Data Packet body contains in case of Throughput Mode (indicated in the header) the **not** synchronized and **not** aligned bit stream of the PCM data. The Relative Time Counter value corresponds to the first data bit in the packet, which can be any bit in the major frame.

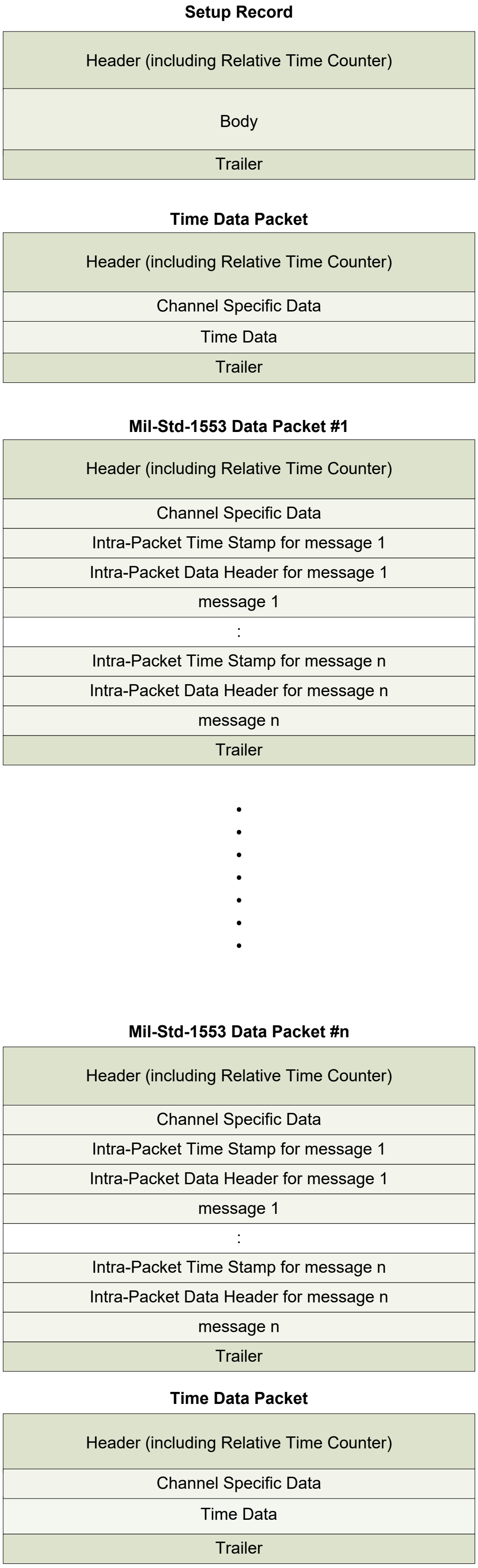
The time of an arbitrary PCM Data Packet (at first data bit in packet) can be calculated by:

$t_n = t_{tdp} + (RTC_n - RTC_{tdp}) * 0.1\ \mu s$

where:
$t_n$ : time first data bit in $n^{th}$ Data Packet
$t_{tdp}$ : time in previous TDP
$RTC_{tdp}$ : RTC in previous TDP
$RTC_n$ : RTC in PCM Data Packet

For the time of any other bit in the packet knowledge of the PCM bit rate is necessary, either from the Setup Record or by interpolation between two data packets.

**Figure 3-3: PCM Time Reconstruction.**




Every chapter 10 file starts with a Setup Record. As all other packet types it consist of a Header, Body and Trailer. An optional Secondary Header is omitted in these examples. All headers contain a Relative Time Counter (RTC) containing the value of a free running 10 MHz binary counter of 48 bits.

The first packet after the Setup Record is always a Time Data Packet (TDP). The TDP is repeated at least every second.
The TDP body contains the time from either an external source (IRIG-B) or the internal Real-Time Clock of the recorder indicated in the Channel Specific Data information, Time Format (FMT) and Time Source (SRC). For the MIL-STD-1553-type S3DR-F recorders external IRIG-B time is used. The time is captured at the on-time reference marker as defined in the IRIG-200 document.

The MIL-STD-1553 Data Packet body contains the captured messages, each preceded by an Intra-Packet Time Stamp and Intra-Packet Data Header.
The Intra-Packet Time Stamp contains either the value of the 48-bit Relative Time Counter or the Absolute Time in a format indicated by bits 2 and 3 of the packet flags in the header.

The reference of the Intra-Packet Time Stamp is indicated in the Channel Specific Data of the packet with the Time Tag Bits (TTB):
00 = Last bit of the last word of the message
01 = First bit of the first word of the message
10 = Last bit of the first word (command word) of the message

The Relative Time Counter value in the header corresponds to the first data bit in the packet.

The time of an arbitrary message in a MIL-STD-1553 Data Packet in case of using the RTC in the the Intra-Packet Time Stamp can be calculated by:

$$t_{mes\ n} = t_{tdp} + (RTC_{mes\ n} - RTC_{tdp}) * 0.1\ \mu s$$

where:
$t_n$ : time message n
$t_{tdp}$ : time in previous TDP
$RTC_{tdp}$ : RTC in previous TDP
$RTC_{mes\ n}$ : RTC in the Intra-Packet Time Stamp of message n

**Figure 3-4: MIL-STD-1553 Time Reconstruction.**

## 3.4 CONTROL AND STATUS

Chapter 10 compliant recorder mandatory control interfaces include discrete control, status lines and/or serial communication ports (both RS-232 and RS422 full duplex serial communications). In addition to these mandatory interfaces, Fibre Channel, IEEE-1394B or Ethernet can control a recorder. Optionally an Ethernet interface and the Telnet Protocol can control a recorder.

IRIG 106 Chapter 6 defines the recorder commands used over serial interfaces. As of the IRIG 106-17, (2017) release of Chapter 10, almost all content regarding recorder control and status moved to Chapter 6. Not all commands may be applicable for every make and model of recorder. Table 3-2 lists a mandatory subset of recorder commands.

**Table 3-2: Mandatory Serial Commands According IRIG 106-17.**

| | | |
|---|---|---|
| .CRITICAL | [*n* [*mask*]] | Specify and view masks that determine which of the .HEALTH status bits are critical warnings. |
| .FILES | [drive ID] | Displays information about each recorded file. |
| .HEALTH | [*feature* [drive ID]] | Display detailed status of the recorder system. |
| .HELP | | Displays table of dot commands supported by the R/R. |
| .IRIG106 | | Returns supported version number of IRIG 106 Recorder Command and Control Mnemonics. |
| .IRIG 106 | | Synonym for .IRIG106. |
| .RECORD | [*filename*] [stream-ID] [drive ID] | Starts a recording at the current end of data of [stream ID] to [drive ID]. |
| .SETUP | [n] | Displays or selects 1 of 16 (0…15) pre-programmed data recording formats. |
| .STATUS | | Displays the current system status. |
| .STOP | [*mode*] [stream-ID] [drive ID] | Stops the current recording, playback, or both. |
| .TIME | [*start-time*] | Displays or sets the internal system time. |
| .TMATS | {mode} [*n* \| ALL] | Write, Read, Save, Delete, Version, Checksum, or Get TMATS file. |

The discrete control and status lines have priority over commands received over serial communications.

Chapter 10 recorders require control lines for Record, Built-In Test (BIT), Erase, Declassify and Enable (of the Erase or Declassify command). Required indicator lines include the states of Record, Fault, BIT, Erase and Declassify. Figure 3-5 depicts the control and status lines.

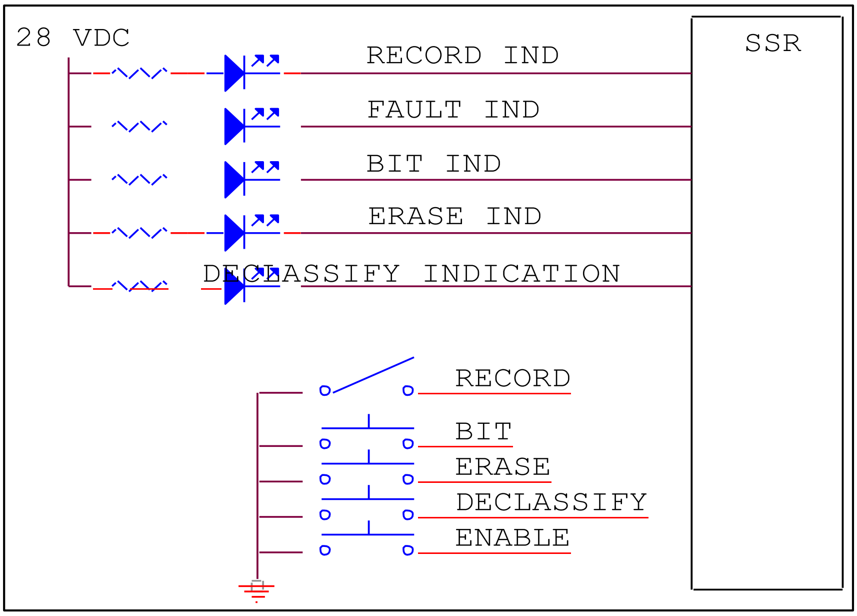



**Figure 3-5: Mandatory Command and Status Lines.**

## 3.5 REFERENCES

[1] NATO, NATO Advanced Data Storage Interface (NADSI), STANAG 4575, December 2, 2014.

[2] IRIG Serial Time Code Standards, IRIG Standard 200-04, September 2004.

# Chapter 4 – DEVELOPMENT OF THE CHAPTER 10 STANDARD

## 4.1 GENERAL DEVELOPMENT

### 4.1.1 History of the Chapter 10 Standard Development

Prior to the initiation of the Chapter 10 standard development, FTI recording systems used unique and proprietary data structures. These data structures required unique software to post-process recorded data. This was a problem because development and testing of software is time consuming and costly.

At the same time during the 1990s, flight-test organizations began to use the first digital tape recorders. These factors led the Range Commanders Council (RCC) and others in the U.S. Air Force instrumentation community to demand common file formats and interfaces for digital data recorders [1], [2].

At that time, the Range Commanders Council (RCC) Telemetry Group (TG) formed an ad hoc committee to develop a computer compatible, digital data acquisition standard. TG Ad-Hoc committees are formed for a single purpose and then disbanded after an agreed upon period [3]. The objective of this TG Ad-Hoc Committee was to replace existing proprietary data structures in use with an interoperable digital data recorder standard. This change would enable processing of recorded data at any test range equipped with the software compliant with the digital data acquisition standard [4].

The new standard development was a cooperative effort between the Government members of the TG Ad-Hoc Committee and commercial vendors. The TG Ad-Hoc Committee representatives brought years of operational expertise using recording systems on various test ranges. Commercial vendors provided recording system subject matter expertise during the standards development. Commercial vendors also assisted the standards development effort by working with the Government to avoid developing a standard that was expensive and difficult to implement in a recorder

### 4.1.2 Chapter 10's Early Requirements

The RCC TG Ad-Hoc committee determined that a future computer compatible, digital data recording standard should include the following requirements [4]:

- Data download and interface;
- One or more multiplexed data streams;
- One or more single data streams;
- Read-after-write and read-while-write options;
- Data format definitions;
- Recorder control; and
- Solid-state media declassification.

The new standard needed to support the multiplexing of both synchronous and asynchronous digital inputs from sources like PCM, ARINC 429 data buses, MIL-STD-1553 data buses, serial buses, analog data, IRIG time video streams, and discrete data.

In addition, the new standard through common interfaces would facilitate a common set of data processing software.

Finally, the new standard should not specify hardware architecture; instead, the FTI integrator determines what recording hardware is required for an application [4].

These requirements evolved into the Chapter 10 Standard.

The original ad hoc committee transformed into the RCC TG Recorder and Reproducer (R&R) Committee. Today the TG R&R Committee is responsible for addressing issues involving airborne and ground telemetry recording systems, telemetry recording standards, and the test methods for these systems [3]. Since 2004, the TG R&R committee has continually evolved Chapter 10 to include new capabilities.

### 4.1.3 The Evolution of Chapter 10's Functional Layout

The Chapter 10 standard's functional layout began with four interface areas. These interface areas included:

- The Data Download and Electrical Interface area, which describes interfaces with a recorder (Section 10.4 of the standard).
- The Interface File Structure area defines the data access structure (Section 10.5 of the standard).
- The Data Format interface area defines data types and data packetization requirements (Section 10.6 of the standard).
- Finally, the Recorder Control and Status interface area defined recorder command and control mnemonics (section 10.7 of the standard) [4].

Updates to the functional layout began in the IRIG 106-05 release of Chapter 10, which included the Host Platform Interface to Recorder Removable Media (RMM) interface area (Section 10.9 of the standard). This new interface area defined the interface between removable media and the host recorder as IEEE 1394B. Chapter 10 adopted this protocol to facilitate a common interface between removable media and the recorder [5].

The IRIG 106-07 release of Chapter 10 added two new interface areas. One interface area added described Ground Recording and Remote Data Access interfaces (Section 10.10 of the standard). This section of the standard specifies the basic requirements of Ground Recorders [6].

The second interface area introduced in the IRIG 106-07 version of Chapter 10 addressed Data Inoperability (Section 10.11 of the standard). Section 10.11 of Chapter 10 introduced and defined the terms "Original Recording Files", "Modified Recording Files", and "Data Transfer File." Section 10.11 of Chapter 10 also introduced file extensions *.tf10 or *.t10 for Chapter 10 files [6].

The current functional layout of Chapter 10 (as of the IRIG 106-19 release in 2019) is shown in Figure 4-1.

### 4.1.4 The Evolution of Chapter 10's Data Interfaces

The initial release of Chapter 10 in 2004 used a Fibre Channel download port [4]. A Chapter 10 recorder uses either a copper or optical fiber interface with fiber channel framing and signaling. The command interface used Fibre Channel – Private Loop SCSI Direct Attach (FC-PLDA). FCPLDA specified a subset of the control protocol defined for the Small Computer System Interface (SCSI-3) interface [4].

The IRIG 106-05 Chapter 10 release included a second method to download data from the recorder the IEEE-1394B interface (Section 10.4 of the standard). The Host Platform Interface to Recorder Removable Media used the same IEEE-1394B interface (Section 10.9 of the standard) [5]. IEEE-1394B packets encapsulate Serial Bus Protocol (SBP-2) packets that transported commands and data. RMMs use SCSI commands in SBP-2 Operation Request Blocks (ORB) [5].

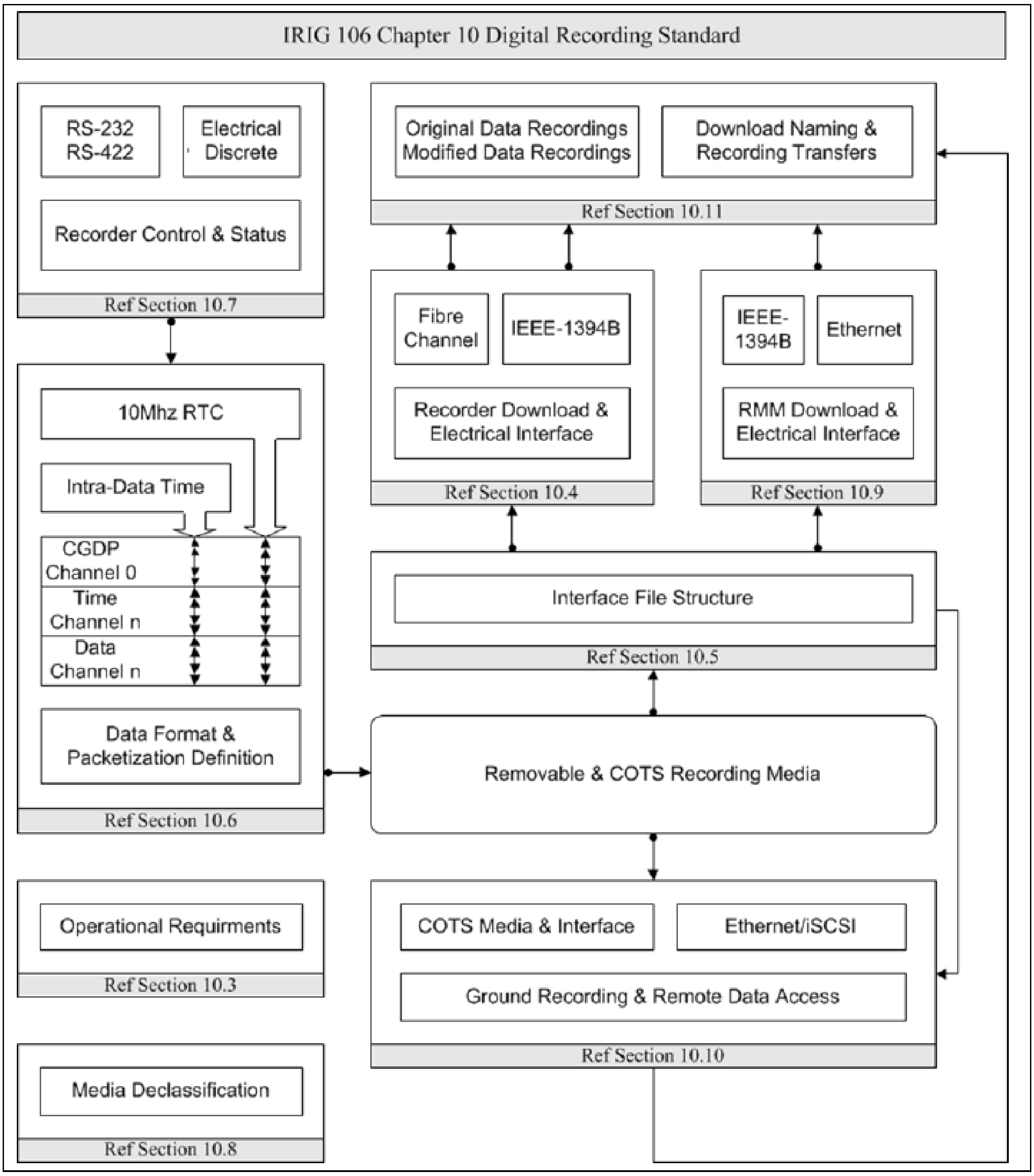



**Figure 4-1: Functional Layout of the Chapter 10 Document.**

Section 10.9 of Chapter 10 provided a means for recorder time synchronization. An RMM could synchronize the time of the installed recorder with an external time source [5]. The RMMs that used the IEEE-1394B interface contained a real-time clock device backed up by a battery. The formatting of time and date used on the RMM comes from IRIG 106 Chapter 6 [5].

The IRIG 106-07 release of Chapter 10 added RS-422 full duplex serial communications for Recorder Control (Section 10.7 of the standard). Chapter 10 also added the interface support for ground recorders (Section 10.10 of the standard). At this time, Chapter 10 added Ethernet for remote data access, remote command and control, and data streaming for both on-board and ground recorders [6].

The Ethernet recorder interface used the iSCSI protocol. This provided common SCSI protocols across Fibre Channel, IEEE-1394B (SPB-2) and Ethernet (iSCSI) recorder download interfaces.

IRIG 106-07 also introduced the use of Common Off-The-Shelf (COTS) media to Chapter 10. Chapter 10 recorders not equipped with on-board media or an RMM can use COTS media. The COTS media needs to support the SCSI command set. COTS media could be any readily available hard-drives, tape-drives, or Redundant Array of Independent Disks (RAID) arrays. The COTS media electrical interface could be readily available interface like Universal Serial Bus (USB), IEEE-1394, SCSI, Ethernet or Serial-ATA (SATA) [6].

In the IRIG 106-13 Chapter 10 release, section 10.9 of the standard is expanded to include the Ethernet interface to download data from an RMM [7].

### 4.1.5 Evolution of Chapter 10's Internal File Structure Definition

One of the principle goals for the Chapter 10 standard was to combine or multiplex different types of data from multiple sources in a single recording. To do this Chapter 10 needed a file structure. The Chapter 10 development adopted an independent file structure that would be forward and backward compatible for the life of the standard [4]. For this reason, the internal file structure of Chapter 10 has remained the same since the introduction of the standard.

The Chapter 10 team adopted a file structure from STANAG 4575 (Section 3 File Structures Definition). The STANAG-4575 File Structures Definition supports large files and has low overhead. The STANAG 4575 file structure does not define how data is physically stored on the media. As long as the STANAG 4575 file structure is visible at the interface, the recording system integrator can define the physical organization of data on the recorder [8].

The "Data Recording" is the high-level data organization structure used in Chapter 10. Multiple data recordings can reside on the same media [4]. A Data Hierarchy containing Directories, Directory Blocks (containing Directory Block File Entries), and Data Files are contained within each Data Recording [8].

A STANAG-4575 formatted disk includes two sections. The first section contains a series of directory blocks that describe the files written on the disk. The second section contains the actual file data. Each block is typically one sector on the underlying media. Each directory block contains a header that consists of the following items [8]:

- Magic Number (forty-two): The identifier for a directory block.
- Revision Number: Revision number of the standard version.
- Shutdown Bit: If the volume was not property dismounted this bit is set.
- Number of File Entries in the Block.
- Volume Name Characters.
- Forward Block: Block address of the directory block pointing to this block.
- Reverse Block: Block address of the directory block pointing to this block.
- Directory Block File Entries: One entry for each file.

A file entry describes a file on the disk and includes:

- File Name.
- FileStartAdd: Address of the first block of data associated with the file.

- FileBlKCnt: Count of consecutive address blocks reserved for this file.
- FileSize: The number of bytes contained in the file.
- File Create Date: Numeric data for when the file was created.
- File Create Time: Numeric data for when the file was created.
- Time Type: A numeric code that qualifies the time and date values (UTC, System Time).
- File Close Time: Numeric data for when the file was closed.

Files written in STANAG-4575 are in sequential order. To read a file, Chapter 10 data processing software only needs to know the file starting block number and the actual size of the file in bytes [8].

### 4.1.6 Evolution of Chapter 10's Data Format Interfaces

Data is stored in Chapter 10 using packets.

Metadata for the recorded data is stored in a setup record (which must be the first data packet) of the Data Recording. The setup record describes the hardware, software, and data channel configuration used for the other data packets in a file.

The setup record uses the IRIG 106 Chapter 9 TMATS standard to define metadata [4]. TMATS XML was included in IRIG 106-09 [9]. The TMATS entry describes the recorder setup configuration including all of the data channels in the file. This makes it possible for each Chapter 10 file's channel configuration to be self-describing. Additional out-of-band TMATS files or avionics bus metadata is required to describe data parameter processing. The data processing software only needs to understand the Chapter 10 data and the Chapter 9 setup packet.

After the Setup Record the next required item is a time data packet using time from a 10 MHz real-time clock in the recorder. The time data packet is the first dynamic data packet at the start of each recording.

Each packet only has data from one source (channel). The recorder must commit a packet to the recording for most data types in less than 100 milliseconds, exceptions are computer-generated packets which must commit data to the recorder in 1000 milliseconds [5].

Chapter 10 stores data for many different types of data channels. Pulse Code Modulation (PCM) data packets transport PCM streams. MIL-STD-1553 data packets contain multiple messages from MIL-STD-1553 data buses. ARINC-429 Data Packets contain multiple words from one or more ARINC-429 buses. Parallel data packets provided Chapter 10 backward compatibility with the Ampex DCRsi digital tape recorder interface. Analog packets contain data for multiple analog data sources. Image packets contain one or more video images. Video packets stored data from video streams. Discrete packets capture event states for multiple bits of data. The UART data packet contains data from one or more separate asynchronous serial communication interface channels (RS-232, RS-422, RS-485, etc.) [4].

The initial Chapter 10 video packet defined in 2004 supported MPEG-2 Main Profile @ Main Level (MP@ML) and Transport Stream Frames (TSF) per ISO/IEC 13818-1:2000 (see Table 10-6). These two MPEG algorithm features combined to produce an encoded video stream encapsulated using IRIG-106 Chapter 4 PCM and then placed in the video packet [4].

In the IRIG 106-05 release of Chapter 10, another video packet format was added to support ISO 13818-1 MPEG-2 Bit Streams [5].

The IRIG 106-07 release eliminated the use of PCM and encapsulated a MPEG-2/H.264 encoded video stream in the video packet [6]. These packets support MPEG-2 stream embedded time, KLV video metadata, and AVC/H.264 audio insertion into the video transport stream.

The IRIG 106-09 release of Chapter 10 added support for MPEG4 video encoding as defined by ISO 14496 MPEG-4 Part 10 [9].

A third Motion JPEG (MJPEG) video packet definition entered the standard in the IRIG 106-15 release of Chapter 10 [10].

In the IRIG 106-05 release of Chapter 10, a IEEE-1394 data packet was added to support FireWire data as described by IEEE 1394-1995, IEEE 1394a and IEEE 1394b [5].

In the IRIG 106-07 release of Chapter 10, marked the addition of a new computer-generated data packet that contained a recording index. This index supports accessing data inside a Chapter 10 file. The IRIG 106-07 version of Chapter 10 also added data packets to support the F-16 MIL-STD-1553 weapons multiplex bus [6].

The version of Chapter 10 in IRIG 106-11 added support for Time Space Position Information (TSPI) / Combat Training Range (CTS) data packets. The three TSPI/CTS data packet types added included:

- A Chapter 10 packet that supports Global Positioning System (GPS) data as defined by the National Marine Electronics Association (NMEA) and Radio Technical Commission for Maritime Services (RTCM) standards.
- A Chapter 10 packet that supports data from Air Combat Manoeuvring Instrumentation (ACMI) defined by the European Air Group (EAG).
- And finally a Chapter 10 packet that supports data from the Air Combat Test and Training System (ACTTS) [11].

IRIG 106-13 Chapter 10 added support for the Controller Area Networks (CAN) bus. Data from one or more Controller Area Networks (CAN) bus interfaces are placed in a CAN bus Chapter 10 data packet. IRIG 106-13 also included support for the ARINC-664 bus. Any User Datagram Protocol (UDP) packets from Ethernet and/or ARINC-664 networks can be placed into a Chapter 10 Ethernet data packet. Finally, the IRIG 106-13 Chapter 10 released added support for new image data packets. Images from cameras are saved as Chapter 10 data packets [7].

In the version of Chapter 10 implemented in IRIG 106-17, section 10.6 of Chapter 10 was moved to IRIG 106 Chapter 11 [12].

Chapter 11 was created to maintain and document the packet configurations used in Chapter 10 recorders more efficiently. The IRIG 106-17 version of Chapter 11 added support for data from a Fibre Channel bus [13].

Data Type Names and Descriptions in Chapter 11 are shown in Table 4-1.

**Table 4-1: Data Type Names and Descriptions in Chapter 11.**

| Packet Header Value | Data Type Name | Data Type Description |
|---|---|---|
| 0x00 | Computer-Generated Data, Format 0 | User-Defined |
| 0x01 | Computer-Generated Data, Format 1 | Setup Record |
| 0x02 | Computer-Generated Data, Format 2 | Recording Events |
| 0x03 | Computer-Generated Data, Format 3 | Recording Index |
| 0x04 | Computer-Generated Data, Format 4 | Streaming Configuration Records |
| 0x05 – 0x07 | Computer-Generated Data, Format 5-Format 7 | Reserved for future use |
| 0x08 | PCM Data, Format 0 | Reserved for future use |
| 0x09 | PCM Data, Format 1 | Chapter 4, 7, or 8 |
| 0x0A | PCM Data, Format 2 | DQE PCM |
| 0x0B – 0x0F | PCM Data, Format 3 – Format 7 | Reserved for future use |
| 0x10 | Time Data, Format 0 | Reserved for future use |
| 0x11 | Time Data, Format 1 | RCC / Global Positioning System (GPS) / Relative Time Counter (RTC) |
| 0x12 | Time Data, Format 2 | Network Time |
| 0x13-0x17 | Time Data, Format 2-Format 7 | Reserved for future use |
| 0x18 | MIL-STD-1553 Data, Format 0 | Reserved for future use |
| 0x19 | MIL-STD-1553 Data, Format 1 | MIL-STD-1553B Data |
| 0x1A | MIL-STD-1553 Data, Format 2 | 16PP194 Bus |
| 0x1B-0x1F | MIL-STD-1553 Data, Format 3-Format 7 | Reserved for future use |
| 0x20 | Analog Data, Format 0 | Reserved for future use |
| 0x21 | Analog Data, Format 1 | Analog Data |
| 0x22-0x27 | Analog Data, Format 2-Format 7 | Reserved for future use |
| 0x28 | Discrete Data, Format 0 | Reserved for future use |
| 0x29 | Discrete Data, Format 1 | Discrete Data |
| 0x2A-0x2F | Discrete Data, Format 2-Format 7 | Reserved for future use |
| 0x30 | Message Data, Format 0 | Generic Message Data |
| 0x31-0x37 | Message Data, Format 1-Format 7 | Reserved for future use |
| 0x38 | ARINC-429 Data, Format 0 | ARINC-429 Data |
| 0x39- 0x3F | ARINC-429 Data, Format 1-Format 7 | Reserved for future use |
| 0x40 | Video Data, Format 0 | MPEG-2/H.264 Video |

| Packet Header Value | Data Type Name | Data Type Description |
|---|---|---|
| 0x41 | Video Data, Format 1 | ISO 13818-1 MPEG-2 |
| 0x42 | Video Data, Format 2 | ISO 14496-10 MPEG-4 Part 10 AVC/ITU H.264 |
| 0x43 | Video Data, Format 3 | MJPEG |
| 0x44 | Video Data, Format 4 | MJPEG-2000 |
| 0x45-0x47 | Video Data, Format 3-Format 7 | Reserved for future use |
| 0x48 | Image Data, Format 0 | Image Data |
| 0x49 | Image Data, Format 1 | Still Imagery |
| 0x4A- | Image Data, Format 2 | Dynamic Imagery |
| 0x4B-0x4F | Image Data, Format 3-Format 7 | Reserved for future use |
| 0x50 | UART Data, Format 0 | UART Data |
| 0x51-0x57 | UART Data, Format 1-Format 7 | Reserved for future use |
| 0x58 | IEEE 1394 Data, Format 0 | IEEE 1394 Transaction |
| 0x59 | IEEE 1394 Data, Format 1 | IEEE 1394 Physical Layer |
| 0x5A-0x5F | IEEE 1394 Data, Format 2-Format 7 | Reserved for future use |
| 0x60 | Parallel Data, Format 0 | Parallel Data |
| 0x61-0x67 | Parallel Data, Format 1-Format 7 | Reserved for future use |
| 0x68 | Ethernet Data, Format 0 | Ethernet Data |
| 0x69 | Ethernet Data, Format 1 | Ethernet UDP Payload |
| 0x6A-0x6F | Ethernet Data, Format 2-Format 7 | Reserved for future use |
| 0x70 | TSPI/CTS Data, Format 0 | GPS NMEA-RTCM |
| 0x71 | TSPI/CTS Data, Format 1 | EAG ACMI |
| 0x72 | TSPI/CTS Data, Format 2 | ACTTS |
| 0x73-0x77 | TSPI/CTS Data, Format 3-Format 7 | Reserved for future use |
| 0x78 | Controller Area Network Bus | CAN Bus |
| 0x79 | Fibre Channel Data, Format 0 | Fibre Channel Data |
| 0x7A | Fibre Channel Data, Format 1 | Fibre Channel Data |
| 0x7B-0x80 | Fibre Channel Data, Formats 2-7 | Reserved for future use |

### 4.1.7 Evolution of Chapter 10's Command and Control Interfaces

Initially either discrete control/status lines and/or serial communication ports could control Chapter 10 recorders. The serial interface supported both RS-232 and RS-422 full duplex serial communications. In addition to the five contacts for discrete control, five lines convey recorder status information. Grounding a control line activates a function.

The discrete control lines include [4]:

- Record Command. This discrete control commands the recorder to start recording.
- Erase Command. This discrete control commands the recorder to erase its data.
- Declassify Command. This discrete control causes the recorder to start the declassify procedure.
- Command Enable. Used in combination with the Erase and Declassify Commands.
- Bit Command. This control commands the recorder to start a Built-In Test (BIT) procedure.

The recorder status information below is typically activating lamps on a control panel [4]:

- Record Status. This status signal that the recorder is on or off.
- BIT Status. This status indicates the BIT procedure is running.
- Fault Status. This status indicates recorder fault.
- Erase Status. This status indicates an erase procedure is in process.
- Declassify Status. This status indicates a declassify procedure is in process.

The serial commands used are a subset of the Recorder Command and Control Mnemonics defined in IRIG Standard 106, Chapter 6 Section 18 [14]. The SSR commands are simple ASCII command strings delimited by spaces [4].

In the version of Chapter 10 released in IRIG 106-07, the Fibre Channel, IEEE-1394B, or Ethernet download ports could control the recorder. These interfaces need to support communications using SCSI (Fibre Channel), SCSI over SBP-2 (IEEE-1394B), and SCSI over iSCSI (Ethernet). Recorder login and IRIG-106 Chapter 6 Command and Control Mnemonics use the SCSI ORB structures [6].

The IRIG 106-09, version of Chapter 10 allowed the use of the TELNET protocol over the ground recorder Ethernet interface. TELNET used IRIG106 Chapter 6 Command and Control Mnemonics over a TCP/IP connection [9].

## 4.2 GROUND BASED RECORDERS

### 4.2.1 The Introduction of Chapter 10 Ground Recorders

Ground recorders were introduced in the IRIG 106-07 release of Chapter 10 (Section 10.10 of the standard) [6]. Over time many of the capabilities initially introduced in Chapter 10 ground recorders are now included in on-board recorders as well. Ground recorders have served a useful purpose in providing a way to try out technologies with a Chapter 10 recorder before introduction to the more costly to build and environmentally qualified on-board recorders.

### 4.2.2 Ground Recorder Functionality

The main functional requirements of Chapter 10 ground recorders include [15]:

- The Ground Recorder Interface.
- The Ground Recorder Data Format.
- The Ground Recorder Media.
- The Ground Recorder Command and Control (if the recorder is controlled remotely).

In Chapter 10, a ground recorder records IRIG-106 Chapter 10 data and may optionally reproduce the recorded data [15].

Typically, a test range or mission control facility would use a Chapter 10 ground recorder to record one or more real-time telemetry signals from a test. The optional playback capability means the recorder can reproduce the signals of a channel as recorded in the Chapter 10 file. For example, the ground recorder could reproduce a PCM signal from recorded PCM packets or alternatively a 1553 bus signal, Ethernet traffic, or other channels and data available in the Chapter 10 file.

The primary functionality of the ground recorder for an end-user could also be to exclusively playback data. Chapter 10 ground recorders configured as post-flight debrief stations are a common use case. The ground recorder configuration reads a Chapter 10 file and then displays data and video for a post-flight debrief. This provides a method for flight participants to review recorded flight events post-mission.

A ground recorder can reproduce telemetry signal(s) for another computer system. This computer system would in-turn process data for displays or produce files for other engineering software tools. This capability could support real-time data display in a mission, control room training, or data review post-mission.

A variation of playback capability is to stream data received or recorded by the ground recorder to another computer system using a network instead of reproducing the telemetry signal. The IRIG 106-07 release of Chapter 10 introduced Recorder Data Streaming Transport (RDTL) for ground recorders [6]. The introduction of Recorder Data Streaming Transport marked the introduction by the RCC of methods to stream telemetry data over networks [15]. This capability let a Chapter 10 ground recorder use a UDP stream to broadcast packets from the recorder to another computer system. When streaming data from a ground recorder, Stream Commit Time is contained in the packet header using time from a 10 MHz real-time clock just like an on-board recorder. Like the on-board Chapter 10 recorder, this Stream Commit time must occur at a rate less than 1000 ms [15].

A variation of this approach is to use the Chapter 10 ground recorder as telemetry front-end to translate signals into packets. The ground recorder receives the incoming telemetry or avionics bus signals and then the recorder packetizes this data and streams it over the network to another computer for additional processing. The source of the telemetry could be a telemetry ground station or an aircraft using an umbilical cable.

Another ground recorder function is to provide access to recorded data. A ground recorder will typically provide methods to download Chapter 10 files to another media like a removable hard drive. Another option is to access the recorder’s file system remotely through a network. A remote computer can use this functionality to copy files to the ground recorder for playback or retrieve recorded data files from the recorder.

### 4.2.3 Ground Recorder Interface

Ground recorders introduced the Ethernet interface to Chapter 10 recorders. A Chapter 10 ground recorder requires Ethernet for remote command and control. Chapter 10 also allows other interfaces for remote command and control, remote data access, and data streaming [15].

### 4.2.4 Ground Recorder Data Format

Like on-board Chapter 10 recorders, ground recorders format data using IRIG 106 Chapter 11. Channel recording on Chapter 10 ground recorders use the same packet structure defined in IRIG 106 Chapter 11 and shown in Figure 4-2 below [15].

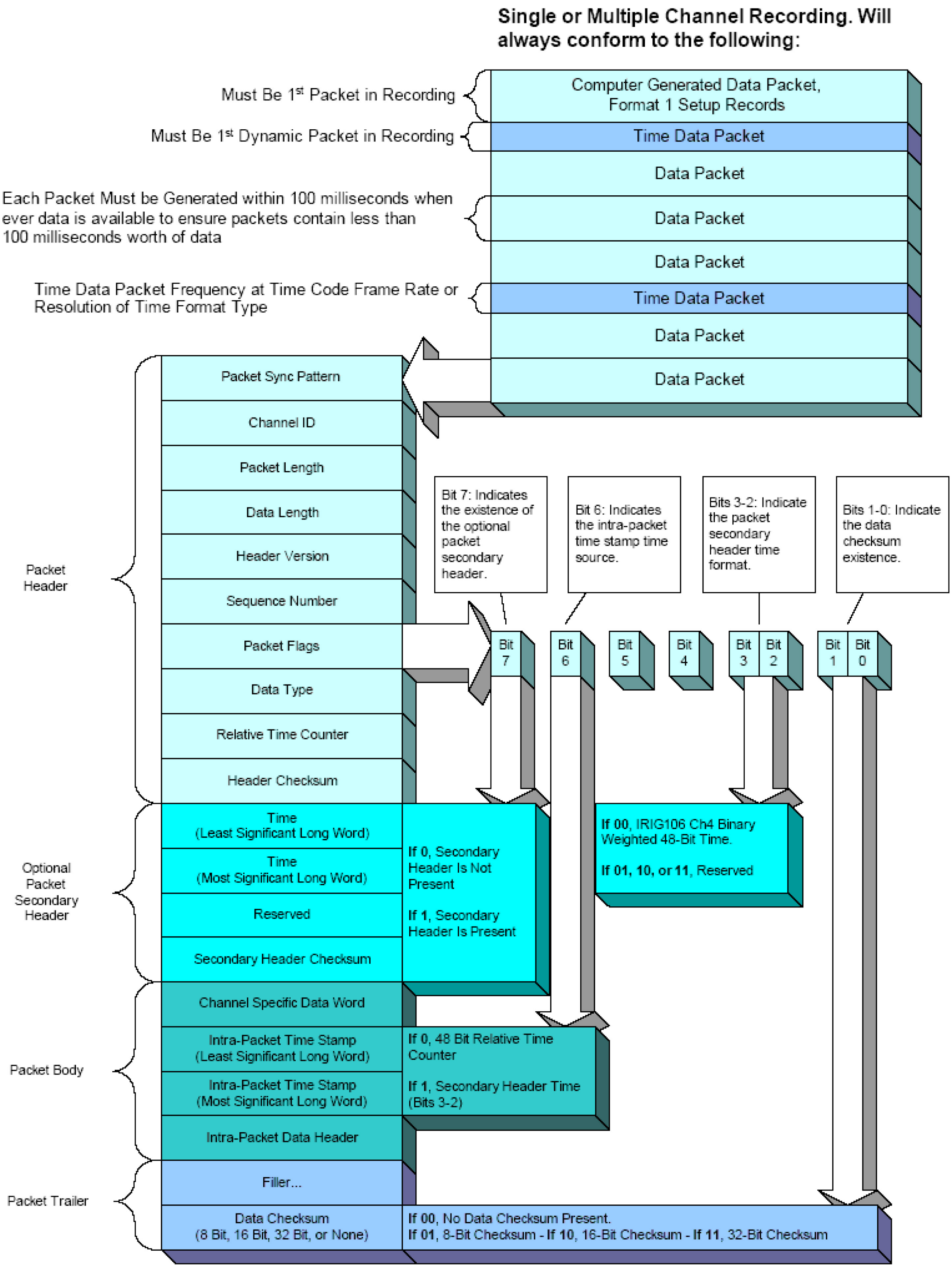



**Figure 4-2: Chapter 10 Packet Structure.**

### 4.2.5 Ground Recorder Media

Ground recorders use COTS media. COTS media in the Chapter 10 standard could be any hard disk, solid-state drive, tape drive, Redundant Array of Inexpensive Disks (RAID), or Just a Bunch Of Disks (JBOD) available for sale. Like the media itself, the interfaces for COTS media could be any interface available for sale like Parallel ATA (PATA), Serial ATA (SATA), IEEE 1394, USB, SCSI, or Ethernet [15].

The Chapter 10 standard requires that any COTS media must be accessible via remote access using the network interface. Chapter 10 also requires that all COTS media used with the recorder must support recording and playback.

### 4.2.6 Ground Recorder Command and Control

A ground recorder defined under Chapter 10 has many different command and control options. Chapter 10 ground recorders must have an Ethernet interface. This Ethernet interface supports iSCSI for data access and TELNET for command and control. TELNET uses the IRIG-106 Chapter 6 Command and Control Mnemonics which in-turn use the SCSI ORB data structures for command and control [5].

IEEE 1394, Fibre Channel, or a serial port interface can also optionally support command and control in Chapter 10 ground recorders. A Fibre Channel interface needs to support SCSI commands. An IEEE-1394B interface needs to support SCSI over SBP-2 commands. A serial port would use a Command Line Interface (CLI) to control and monitor operation of the Chapter 10 ground recorder. The commands for recorder command and control using a CLI reside in section 6.2 of IRIG 106 Chapter 6 [14].

### 4.2.7 Ground Recorder Logical Channel Mapping

A Ground Recorder configured for playback must support Logical Channel Mapping. Logical Channel Mapping lets a user assign Chapter 10 channels to hardware in the ground recorder. This is a preferable alternative to moving input/output interface cards around in the recorder to support a specific recording or playback configuration [15].

## 4.3 DATA INTEROPERABILITY

Interoperability is the ability to join-up and merge data without losing meaning. In practice, data is interoperable when it can be used and re-used in different computer applications.

A goal of the IRIG 106 Chapter 10 development was to enable interoperability between digital flight recorders. Standards-based interoperability gives users the ability to record data using one manufacturer's recorder and then use a different manufacturer's recorder to reproduce data from that recording. Signal reproduction interoperability within a project is achievable.

Range-to-Range Chapter 10 interoperability has been challenging at the hardware level since it is cost prohibitive for every test range's ground recorder to reproduce signals from every possible channel type. One NASA research aircraft has more than 100 channels in its Chapter 10 recording. To overcome this problem, test ranges and ground processing facilities are migrating to Chapter 10 processing workflows that do not reproduce the signals from Chapter 10 files and instead use computer applications to process the packets in these files directly [16].

To ensure interoperability in the exchange of data, either the original files from the recorder media, or modified files, the Chapter 10 standard defines a set of requirements with regard to file structure and naming.

In addition, the standard suggests a means to transfer data between recorders or recorder media data between organizations.

Files contained within a recorder, or byte-for-byte copies on any media or platform are "Original Recording" files. The *original recording attribute* in the setup record, being the first packet in each data file, will contain a "Y" for these files.

"Modified Recording" files will have the *original recording attribute* in the setup record set to "N".

Modifications can be:

- Filtered or sanitized data;
- A subset of channels;
- A superset of channels;
- A subset of time;
- A subset of both channels and time;
- A superset of channels and subset of time;
- Sequence numbering;
- Packet length; and
- Checksum changes in the appropriate packet data header fields.

The file extension of an original recording or modified recording file shall be *.ch10 or *.c10.

File naming will contain a file number and if possible, a creation date, creation time and closing time.

## 4.4 REFERENCES


[1] Berard, A.J., Chalfant, T., Lloyd, J., Small, M., Buckley, M., Bagó, B., and Lockard, M., Who Moved My Tape Recorders Flavored Cheese, International Telemetry Conference Proceedings, 2002.

[2] Glass, M., IEEE Xplore Digital Library, IRIG 106 Chapter 10 standardizes MIL-STD-1553B data recording, Presented at Conference on 21-25 Oct. 2007, 04 December 2007.

[3] Range Commanders Council (RCC) Telemetry Group (TG) Operations Guide Version 5, March 2019.

[4] Telemetry Standards, IRIG Standard 106-04, Part 1, Chapter 10, Solid State On-Board Recorder Standard.

[5] Document 106-05, Part 1: Telemetry Standards, Chapter 10, Digital On-Board Recorder Standard, July 2005.

[6] RCC Document 107-07, Telemetry Standard, Chapter 10, Digital Recording Standard, September 2007.

[7] Telemetry Standards, IRIG Standard 106-13 (Part 1), Chapter 10, June 2013.

[8] Kupferschmidt, B., Accessing Chapter 10 Recorder Media from Windows PCs, International Telemetry Conference, 2010.

[9] RCC Document 107-09, Telemetry Standard, Chapter 10, Digital Recording Standard, April 2009.

[10] Telemetry Standards, IRIG 106-15 (Part 1), Chapter 10, July 2015.

[11] Telemetry Standards, IRIG Standard 106-11 (Part 1), Chapter 10, June 2011.

[12] Telemetry Standards, IRIG 106-17 Chapter 10, July 2017.

[13] Telemetry Standards, IRIG Standard 106-19 Chapter 11, July 2019.

[14] Telemetry Standards, RCC Standard 106-19 Chapter 6, July 2019.

[15] Telemetry Standards, IRIG Standard 106-19 Chapter 10, July 2019.

[16] Telemetry Transmission over Internet Protocol (TMoIP) Standard, October 2010.

# Chapter 5 – VERIFYING COMPLIANCE WITH THE CHAPTER 10 STANDARD

The preface of IRIG 106 (including Chapter 10) states the ultimate purpose of that document is "to ensure efficient spectrum utilization, interference-free operation, interoperability between ranges, and compatibility of range user equipment with the ranges" [1]. In addition, as previously stated in Chapter 4, a major design for the IRIG 106 Chapter 10 development was to replace existing proprietary data structures in use with an interoperable digital data recorder standard. The Chapter 10 standard made file interoperability between test articles, test ranges, and data processing organizations a reality. How can a flight test organization determine if a device or application is compliant with Chapter 10? This chapter will try to answer that question by providing verification approaches for Chapter 10 applications or equipment and a list of known vendors providing Chapter 10 compliant products.

## 5.1 VERIFYING COMPLIANCE WITH CHAPTER 10

To achieve basic interoperability, both on-board and ground recorders need to be 100 percent compliant with Section 10.3 of Chapter 10. The vendor can also optionally implement a number of features described in Chapter 10. These optional features must be in accordance with the standard. The RCC TG does not have a formal program to verify device or application compliance with the Chapter 10 standard. Occasionally the RCC TG does sponsor events where vendors can test file interoperability between devices and applications, but these events are voluntary. Therefore, Chapter 10 defines the requirements, but the RCC TG leaves the task of actually verifying compliance up to the organizations using Chapter 10. As a result, verifying compliance with the IRIG 106 Chapter 10 standard is a task left to the vendor producing products and the end-user that procures products.

### 5.1.1 Chapter 10 Compliance Testing Using RCC Document 118 (Vol. 5)

Both vendors and end-users can use information provided by the TG in RCC document 118-16, Test Methods for Telemetry Systems and Subsystems Volume 5, subtitled Test Methods for Digital Recorder/Reproducer Systems and Recorder Memory Modules. This document provides procedures used to measure the compliance of the device with Chapter 10 but also to measure the performance of recorders and RMMs [2].

The RCC 118 document distinguishes between acceptance testing and operational testing. Acceptance testing in the RCC 118 context refers to the methods and analysis used to determine the compliance of a device with the Chapter 10 standard. Acceptance testing will be primarily an activity for a Chapter 10 vendor who has to prove compliance to the standard. Operational testing will be a responsibility of the user or system designer who has to demonstrate suitability for the specific use of the equipment. Operational testing consists of a subset of acceptance testing with some additional steps and/or methods to verify operational suitability [2].

The test methods in RCC 118 use commercially available test equipment and validation software to generate data channels described in Chapter 11; exceptions are Message and Image channels [2].

The Metadata Encoding and Transmission Standard (METS) family of test equipment and software from Scientific Data Systems (SDS) can generate other data channels needed to test Chapter 10 recorders. The METS system generates known inputs with known timing to the recorder system as a reference for the resulting recorded data. The METS validator software performs the comparison between the input and the data output from the test [3].

The METS generates test data, providing IRIG Time Code, Universal Asynchronous Receiver/Transmitter (UART) serial data (RS-232/RS-422) channels, and IRIG 106 Chapter 4 PCM channels. The METS also provides MIL-STD-1553 channels, Ethernet channels, and CAN Bus data channels. The METS also generates ARINC-429 output channels, video channels, and discrete data channel [3].

All channels which transmit data words (i.e., the PCM, 1553, Chapter 8, UART, Ethernet, and ARINC-429 channels) have a microsecond resolution "time of transmission" embedded in the channel. For video channels, the METS test equipment inserts a millisecond resolution timestamp into the video image. The METS contains an internal GPS receiver and an IRIG time code input. This allows all timing information to be synched with UTC to one microsecond resolution [3].

The METS test equipment connects to the recorder using an appropriate wiring harness and generates data channels for every data type it is equipped to produce. The recorder receives and archives this generated data. The METS validation software then compares the generated data with the recorded data [2].

A baseline configuration consisting of time, MIL-STD-1553, video, ARINC-429, and PCM (packed, unpacked, and throughput modes) will be used to verify these five packet types plus the computer-generated packets. Ethernet, UART, discrete, and analog packet types are individually tested [2].

For MIL-STD-1553 and PCM testing, there will be tests with the METS configured to produce data with no errors, and additional tests with errors. For MIL-STD-1553, testing includes single and multi-message settings at bus loading of 30, 40, and 50 percent along with no response and protocol errors. For PCM data, the configuration includes various data rates from 100 kbps up to 5 Mbps [2].

A signal generator generates analog test data for the Chapter 10 recorder. The EMC Chapter 10 Packet View application can save the data from the analog packets generated by the recorder. Appendix C of RCC 118 provides a Python program to parse this Hex data and convert it into a format compatible with the Matrix Laboratory (MATLAB®) software from Mathworks, Inc. Matlab can then perform a Fast Fourier Transform (FFT) function to verify the frequency of the recorded data [2].

Chapter 10 requires that every recorder have an RS-232/422 port to accept commands and provide status. Optionally, a recorder can accept commands and provide status using a Fibre Channel, an IEEE 1394B interface, or an Ethernet connection. RCC 118 provides test steps to verify that the recorder meets the requirements of Section 10.7 [2].

### 5.1.2 Chapter 10 Operational Testing

End-users perform the operational testing of Chapter 10 recorders. An end-user verifies that the Chapter 10 product functionality satisfies the requirements for the intended application. An Acceptance Test Procedure (ATP) should be used to validate that the end-user's operational requirements are satisfied by a Chapter 10 product.

The ATP should test the Chapter 10 product with any organizational workflows. For a Chapter 10 recorder example workflows include configuring the TMATS file for use with the recorder, commanding and controlling the recorder, downloading data from the recorder for processing.

A TMATS file configures most Chapter 10 products. A vendor-supplied application often helps the end-user configure the TMATS file based on user inputs. The complete user specific workflow for generating TMATS files with this application needs to be included in the ATP [4].

An ATP should validate the Chapter 10 product's interfaces, both software and hardware. For a ground recorder these interfaces could include those from the device to a range's signal distribution system used to send and receive telemetry and time. Alternatively, all software interfaces to the Chapter 10 product should be in the ATP, an example is a data processing application that displays data streamed from a Chapter 10 product [4].

### 5.1.3 Chapter 10 Operational Testing at NLR

The flight test department of the Royal Netherlands Aerospace Centre NLR is responsible for the processing of flight test data from military and civil flight test projects. The data processing facility at NLR uses Chapter 10 compliant equipment and software. The main concern is the integrity of the data delivered to the customer.

NLR uses a combination of data generators, such as MIL-STD-1553 and ARINC429 data simulators and supporting software to implement a subset of the RCC-118 test procedures. NLR uses a software workflow comprising simple spreadsheet based solutions and third party validation tools as described in the next section for the required data analyses. This software workflow compares the simulated input and the output from the data processing facility (see Figure 5-1).

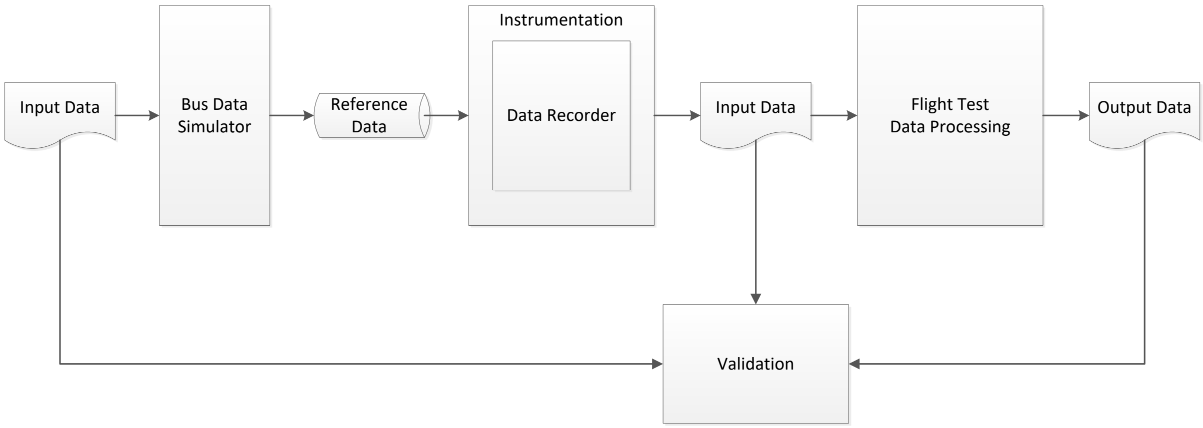



**Figure 5-1: Data Validation Process.**

## 5.2 VENDOR IMPLEMENTATION

### 5.2.1 Vendor Overview

Many vendors provide hardware and software that utilize the IRIG-106 Chapter 10 standard. This list is not complete and does not endorse any one product, but provides some examples of recording equipment, data processing software and test tools that use Chapter 10.

**AIM** is a leading designer and manufacturer of high performance test and simulation modules, embedded interfaces, data bus analyzers, and network analyzers [5]:

- PBA.pro™ is AIM's software suite for Test and Analysis, used in conjunction with AIM's family of avionics test and simulation modules.
- PBA.pro™ acts as a standalone data bus analyzer, a visualizer tool for a systems test bench, or an avionics integration facility. The PBA.pro™ software can import IRIG 106 Chapter 10 file with captured avionics bus data.

**Amergint Technologies** designs and manufactures RF equipment and processing systems used to process telemetry and command data streams for satellite control centers, satellite ground testing, and launch sites [6]:

- The softFEP Chapter 10 ground recorder is capable of recording and playing back PCM and IRIG B time either as the actual signals or through Chapter 10 UDP output. This recorder integrates inside the Ground Equipment Monitoring Server (GEMS) environment standardized through the Object Management Group (OMG).

**AMPEX** manufactures instrumentation and recording systems for flight test, mission data acquisition, and space data acquisition [7]:

- The MiniR family of recorders archive to Chapter 10.
- The AMux Ethernet Data Acquisition Units receive and time stamp data received from multiple network interfaces. Then this data is transferred using Chapter 10 UDP format to another recording system.
- AMPEX also provides equipment to interface RMMs to recorder download stations.

**Avionics Interface Technologies (AIT)** provides High Speed Avionics Network Interface Controllers (NIC), Switching Systems, and Flight Test Network Solutions for Fibre Channel and Ethernet [8]:

- The eDAQ-1553-FQ is a small, rugged MIL-STD-1553 and Serial Data Acquisition Unit (DAU) that is capable of streaming captured Avionics Bus data over Ethernet (UDP/IP) in IRIG 106 Chapter 10 format to remote data loggers, data recorders, and telemetry gateway systems.
- The F-SIM-1553-CH10-STREAM MIL-STD-1553 IRIG 106 Chapter 10 Streaming Application streams data captured from one or multiple MIL-STD-1553 Bus Interfaces over Ethernet (UDP/IP) in IRIG 106 Chapter 10 format.
- F-SIM-1553-AVOE IRIG 106 Chapter 10 SDK for MIL-STD-1553 Applications Supports Capture, Recording, and Analysis of MIL-STD-1553 Chapter 10 Ethernet Data Stream.

**CALCULEX** is another well-known supplier of airborne digital recording systems and multiplexers used for flight test and mission data acquisition [9]:

- The RIPR recorder in five configuration groups is optimized for different customer applications. The RIPR family records video, audio, PCM, and avionics bus data (MIL-STD-1553, ARINC 429, sFDP, Ethernet, Fibre Channel) to Chapter 10 format. The RIPR can generate IRIG 106 Chapter 7 telemetry that transports Chapter 11 packets using PCM.

**Curtis Wright Defence Solutions** produces aerospace instrumentation systems used for flight test [10]:

- The Axon data acquisition system supports many cards supporting analog instrumentation and avionics bus data. The Axon system can broadcast a Chapter 10 UDP stream to another system on the FTI network.
- The NGWY network data selector can receive data from an aircraft instrumentation network and then generate a Chapter 7 PCM stream containing Chapter 11 packets.
- The TTC MSSR is a Chapter 10 recorder that functions either standalone or in combination with the MCDAU and MEDAU encoders. The MSSR is compatible with the MCDAU and MEDAU I/O modules supporting PCM, avionics buses, Ethernet, and video.
- The TTC series of Common Airborne Instrumentation Bus Chapter 10 recorders support up to six data acquisition cards that provide various data interfaces. These interfaces include Fibre Channel, IEEE-1394, PCM, MIL-STD-1553, and Ethernet, among others.

- The nREC recorder is an Ethernet recorder that records network packets in Chapter 10 format with IEEE1588 time. The nREC can also output an IRIG 106 Chapter 7 PCM stream containing Chapter 11 packets for telemetry.
- Curtis Wright also provides rackmount download stations used to transfer data from TTC Chapter 10 recorders.

**Data Bus Tools** produces software to process Chapter 10 files [11]:

- FLIDAS reads IRIG 106 Chapter 10 files and provides the capability to process data at the raw, protocol, and measurement level. FLIDAS can subscribe to Chapter 10 UDP streams to display data. FLIDAS can also convert Chapter 10 files to XML files.

**Data Device Corporation (DDC)** designs and manufactures high-reliability Connectivity, Power and Control solutions [12]:

- DDC produces interface cards compatible with ruggedized and lab computer systems. These interface cards monitor MIL-STD-1553, ARINC 429, and CAN bus avionics. Data obtained is stored in Chapter 10 format.

**Dell EMC Corporation** develops systems used for telemetry processing, aircraft instrumentation setup and display, data storage, and Chapter 10 data processing. Dell EMC provides ground and airborne solutions such as ILIAD, Odyssey, WebQLS, and Video Debrief Stations. Dell EMC provides utilities like the Chapter 10 Packet Viewer to view Chapter 10/11 packets and the Chapter 10 Validator to validate Chapter 10 streams.

**DEWESoft, LLC** designs and develops data acquisition systems and software. Dewesoft's X data acquisition, recording and analysis software can decode and visualize data from any Chapter 10 recorder [13].

**Diversified Technical Services** manufactures the SLICE6 AIR data acquisition units. These small form factor units, record data to Chapter 10 files from analog transducers while also streaming data in Chapter 10 UDP format [14].

**GDP Space Systems** designs and manufactures ground-based Telemetry and Communications/Data Transport products for the aerospace industry [15]:

- The Model 3500 Ethernet Data Recorder records streaming Chapter 10 UDP data.
- The Model 4426, 4460 and RDM207 telemetry receivers can publish PCM data to Chapter 10 UDP streams.
- The Model 4000 Compact Telemetry System can publish/subscribe to a Chapter 10 UDP.
- The Model 2350 TM gateway provides the capability to transfer PCM telemetry over a ground network using Chapter 10 UDP. This unit can also convert Chapter 7 PCM telemetry to Chapter 10 UDP (PCM packets).
- The Acroamatics Data File Utility imports and exports Chapter 10 files while also providing the capability to export measurements and to perform data processing.
- The Model 2628AP PCM Simulation System can playback PCM data from Chapter 10 files.

**JDA Systems** develops flight test support equipment including the VuSoft telemetry software application:

- VuSoft provides simultaneous recovery, recording, display and distribution of real-time telemetry and other formatted data streams in a modular, network centric environment. VuSoft supports Chapter 10 file processing and Chapter 7 telemetry [16].

**Kratos RT Logic** develops capabilities for communication with satellites, spacecraft, missiles, and airborne platforms [17]):

- The T500RX Recorder family of ground recorders are Chapter 10 compatible. These recorders can archive analog baseband signals, 70MHz IF signals and digital PCM. The T500RX family also supports video, IP data, and time code signals.

**NetAcquire Corporation** manufactures test range instrumentation, aircraft instrumentation, and systems for satellite operations [18]):

- The NetAcquire Data Recorder records up to 256 channels of PCM, MIL-STD-1553, and ARINC 429 data to a Chapter 10 file.
- The NetAcquire ARINC 429 network gateway receives data from up to 256 buses and then publishes this data to a network. The ARINC 429 gateway can archive data to Chapter 10 files.
- The NetAcquire Server Software processes both Chapter 7 data and Chapter 10 UDP data in real-time.
- NetAcquire Recording Data Export Tool is software that extracts data from Chapter 10 files. This tool exports raw Chapter 10 packet data, it processes PCM data, and avionics bus packets (MIL-STD-1553 data and ARINC 429 data).
- The NetAcquire Telemetry over IP product can produce and process Chapter 10 UDP packets with PCM.
- Data Flow Engine decodes Chapter 10 UDP traffic received by the NetAcquire products

**Safran Aerosystems** produces airborne instrumentation, telemetry, and space communication products [19], [20], [21]:

- Modular Data Recorder (MDR) is a family of Chapter 10 recorders. These recorders can publish data to Chapter 10 UDP and produce Chapter 4 and 7 PCM. MDR recorder modules can support analog data, video, PCM, and avionics bus data (MIL-STD-1553, Ethernet, ARINC-429, Serial, CAN bus).
- GMDR ground recorder can receive, and record PCM telemetry and in-turn publish data to a Chapter 10 UDP stream. The GMDR can also reproduce avionics bus data, PCM, voice and network signals from Chapter 10 files.
- Safran provides software that can remotely control recorders, process Chapter 10 video and publish/subscribe to a Chapter 10 UDP stream.

**Scientific Data Systems LLC** is the supplier of the METS data simulator and Chapter 10 data validation software. METS is a family of products providing powerful single system simulation capabilities for multiple Chapter 10 data [22].

**Smartronix Telemetry and Data Systems** produces Chapter 10 recording systems and processing system products [23]):

- IMUX G2 Chapter 10 Recorder/Reproducer.
- Omega Data Environment (ODE) provides a tool to post-process large data sets. ODE’s data processing engines process PCM, MIL-STD-1553, ARINC 429, and other data packets from Chapter 10.
- The OMEGA NExT real-time data processing software of Smartronix provides EU conversion, data distribution, real-time display, and Chapter 10 compliant data recording.
- Series 5000 Real-Time Systems are real-time data processing systems.
- X-5000 Network Appliance is used to process real-time data and outputs Chapter 10 UDP streams.

**Spiral Technology** produces the Open Telemetry Interactive Setup (OTIS™) product. OTIS is a set of software tools and utilities specifically designed to support the Telemetry Attributes Transfer Standard (TMATS) Chapter 9 of the IRIG 106 Telemetry Standards [24].

**Symvionics** produces the Interactive Analysis and Display System (IADS) software suite used to display telemetry in a flight test control room. IADS RT Station receives and processes data from Chapter 10 UDP streams including PCM, A429, MIL-STD-1553, Analog, UART, and Video Chapter 11 packets [25].

**Telspan Data** manufactures hardware and software systems supporting Chapter 10 including recorders, ground systems, and software [26]):

- The Modular Instrumentation TAP Recorder (MITR) to record network data, time code data and PCM. The MITR also records MIL-STD-1553, IEEE-1394B and Fibre Channel avionics bus data. This recorder utilizes Chapter 10.
- The Integrate Ethernet Switch family and the instrumentation Gateway (iGU) can act as a gateway to generate Chapter 7 PCM. The iGU can also publish data to Chapter 10 UDP or produce data in Chapter 7 format.
- The Ground Recording System (GRS) is a Chapter 10 ground recorder. This system can record/reproduce PCM, Ethernet, analog, and video channels. The GRS can also publish data as Chapter 10 UDP.
- The Telemetry Data System (TDS) combines a telemetry processor with Chapter 10 ground recorder capability. The TDS can also publish and subscribe Chapter 10 UDP data.
- The NetView Data Fusion and Display software can replay, process and publish/subscribe Chapter 10 RMM data to displays. The NetView software can also export archived data as Chapter 10 files.

**Wideband Systems** designs and manufactures Chapter 10 ground recorder products for test ranges and operational applications [27]. The Digital Recording System (DRS) family of recorders can archive analog baseband signals, 70MHz IF signals, and digital PCM. The DRS family also supports video, network, serial, analog, and MIL-STD-1553 data recording.

## 5.3 REFERENCES

[1] Telemetry Standards, IRIG 106-19 Preface, July 2019.

[2] RCC Telemetry Group, Test Methods for Telemetry Systems and Subsystems, Volume V, Test Methods for Digital Recorder/Reproducer Systems and Recorder Memory Modules, IRIG Document 118-16, RCC Telemetry Group, September 2016.

[3] Scientific Data Systems website, Available at http://sdsnm.com/, October 10, 2019.

[4] Lamphear, E., Berard, A.J., and Klein, L.D., Acceptance Testing Procedure (ATP) Compliance Testing of IRIG-106 Chapter 10 Recorders, October 2005.

[5] AIM website, Available at https://www.aim-online.com/, October 10, 2019.

[6] Amergint Technologies website, Available at https://www.amergint.com/, October 16, 2019.

[7] AMPEX website, Available https://www.ampex.com/, October 9, 2019.

[8] Avionics Interface Technologies website, Available at https://aviftech.com/, October 10, 2019.

[9] Calculex website, Available at https://www.calculex.com/home1, October 16, 2019.

[10] Curtis-Wright Defence Solutions website, Available at https://www.curtisswrightds.com, October 16, 2019.

[11] Data Bus Tools website, Available at https://www.databustools.de/, October 16, 2019.

[12] DDC Connectivity Power Control website, Available at https://www.ddc-web.com/en, October 16, 2019.

[13] Dewesoft website, Available at https://dewesoft.com/applications/aerospace/pcm-telemetry, November 19, 2019.

[14] Diversified Technical Services website, Available at https://www.dtsweb.com/slice6-air/, November 19, 2019.

[15] GDP Space Systems website, Available at https://gdpspace.com/products/, October 16, 2019.

[16] JDA Systems website, Available at http://www.jda-tele.com/, November 19, 2019.

[17] Kratos RT Logic website, Available at http://www.rtlogic.com/, October 16, 2019.

[18] NetAcquire website, Available at https://netacquire.com/, October 16, 2019.

[19] Safran Aerosystems website, Available at https://www.safran-aerosystems.com/control-systems/data-systems-1, October 16, 2019.

[20] Zodiac Data Systems MDR/GMDR Support website, Available at https://support.zdsus.com/products_mdr.phtml, October 16, 2019.

[21] Zodiac Data Systems – HEIM Airborne and Ground Data Acquisition, Presentation, 2015.

[22] Scientific Data Systems LLC website, Available at http://sdsnm.com/, November 19, 2019.

[23] Smartronix website, Available at https://www.smartronix.com/, November 19, 2019.

[24] Spiral Technology website, Available at https://www.spiraltechinc.com/, November 19, 2019.

[25] Symvionics IADS website, Available https://iads.symvionics.com/, November 19, 2019.

[26] Telspan Data website, Available at https://telspandata.com/, October 16, 2019.

[27] Wideband Systems website, Available at https://www.wideband-sys.com/, October 16, 2019.

# Chapter 6 – APPLICATION

## 6.1 FLIGHT RECORDERS

In the last two decades, analog magnetic tape recorders used for Flight Test Instrumentation (FTI) have largely been replaced by solid-state digital recording technologies. In parallel to this change in recording technology, telemetry networks have started to replace serial streaming telemetry in FTI systems. These developments have resulted in a new generation FTI system in which the new standards defined in IRIG 106, such as the Chapter 10 data recorder standard, play a dominant role.

At the Royal Netherlands Aerospace Centre NLR many applications of Ethernet-based data acquisition and Chapter 10 based recording components have been used in major flight test projects. Two example projects include:

- An FTI system used to support helicopter-ship qualification trials for the Defence Helicopter Command (DHC). This FTI system uses a data link that utilizes the IRIG 106 Chapter 10 standard. Data from the helicopter FTI system passes through this data link to the ship in real-time.
- An upgrade to the FTI used in the RNLAF F-16BM “Orange Jumper” test aircraft. This FTI system uses a Data Acquisition System (DAS) that utilizes an Ethernet network. Flight test data from the DAS are archived to an IRIG 106 Chapter 10 recorder.

### 6.1.1 Generic Instrumentation System

For several decades NLR has been involved in the execution of Ship-Helicopter Operational Limit (SHOL) qualification trials [1]. NLR used the Helicopter Data Acquisition System (HEDAS) for the Westland Lynx SH-14D. This helicopter served the Royal Netherlands Navy for 36 years. The arrival in the year 2010 of a new navy helicopter, the NH Industries NH90 NFH, and the development of several new navy vessels has triggered the development of a new FTI system.

The close cooperation between the Royal Netherlands Air Force (RNLAF) and the Royal Netherlands Navy required the new FTI to be more generic. This new helicopter DAS needed to be capable of operating in all defence helicopters presently in service. NLR developed the Generic Instrumentation System for the Defence Helicopter Command (GIS-DHC). Certification of this FTI system was required in all defence helicopter types. During the SHOL trials the helicopter and ship data were combined and presented in real-time. These combined data are used to monitor the safety and progress of the trial, i.e., approve or discard test points flown. With the HEDAS the helicopter data was sent to the ship by means of a legacy telemetry downlink, where the test team monitored and directed the flight trials. For the GIS-DHC it was required to have the capability to direct the flight test trials from either the helicopter or the navy vessel, thus requiring a bi-directional data link.

A serial streaming telemetry system based implementation would require two individual datalinks: one for the uplink to the helicopter and one for the downlink to the ship. For the GIS-DHC development, a bi-directional wireless Ethernet network replaced the serial streaming telemetry system used in the HEDAS.

The GIS-DHC, transferred data using the IRIG 106 Chapter 10 User Datagram Protocol (UDP) packet format over the wireless network. The VuSoft software application was already available from JDA Systems that could concurrently process the two streams of data on the bi-directional datalink.

The Directives for Operating Helicopters on board of Navy Units define telemetry coverage requirements for a typical Ship Controlled Approach (SCA) shown in Figure 6-1. Telemetry coverage for arriving helicopters is required 2.0 NM astern of the naval vessel. Telemetry coverage of departing helicopters is required until the aircraft clears the naval vessel. The estimated data rate needed for the trial is less than 1 Mb/s.

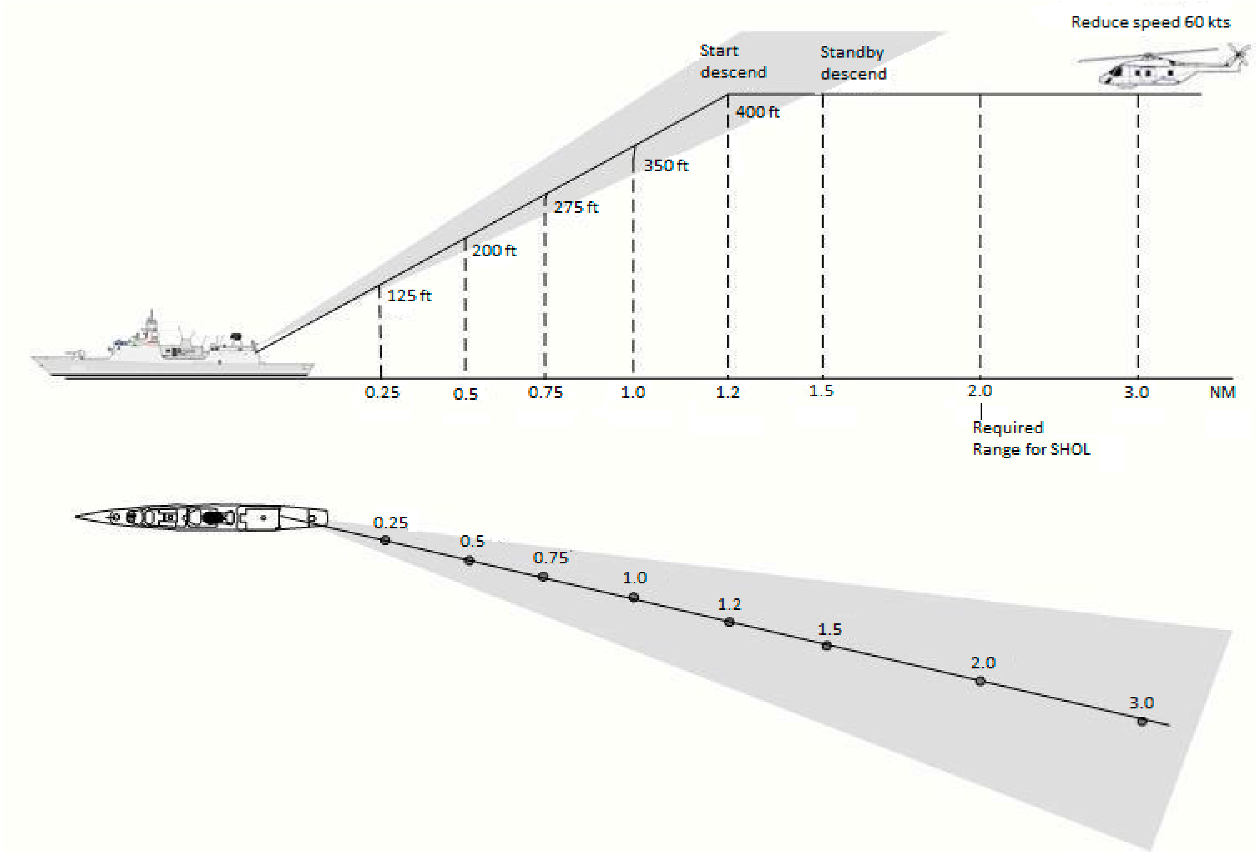



**Figure 6-1: Typical Ship Controlled Approach.**

Figure 6-2 provides a functional block diagram of the GIS-DHC. The GIS-DHC uses wireless datalink system from NSM Surveillance. This datalink utilizes Coded Orthogonal Frequency Division Multiplexing (COFDM) RF transceivers to transfer data between the ship and the helicopter. Transceivers can operate in either the 4400 – 4625 MHz low-frequency NATO band or the 4775 – 5000 MHz high-frequency NATO band. A gap of at least 150 MHz between receive and transmit frequencies maintains proper RF isolation. RF Modulation and Forward Error Correction (FEC) are configurable and operate independently in each direction, allowing for asymmetrical links if desired.

Both the helicopter and the ship are equipped with a Digital Data Link System (DDLS) consisting of two Antenna Assemblies and an Electronics Unit. The Antenna Assemblies use Omni-directional antennas for the previously mentioned frequency ranges and are equipped with diplexers and Low Noise Amplifiers (LNA) for the receive channels. The two antennas ensure that there will be link coverage by means of space diversity combining. The Transceiver, a DC/DC power supply, and a 5 Watt Radio Frequency Power Amplifier (RFPA) are located in the Electronics Unit. A power splitter feeds the two transmit outputs.

The datalink acts like a wireless bridge. A bridge connects two separate networks as if they were one network. As a bridge, the DDLS passes network traffic between the helicopter and ship networks. The DDLS is transparent to IP protocols and passes Dynamic Host Configuration Protocol (DHCP) requests, routing protocols and data packets. Table 6-1 shows the results of link tests performed by NSM. These tests showed that the NSM system had the required range to support the SHOL trials. NLR and DHC jointly conducted a flight trial at sea to verify the predicted link performance. This test was successful and demonstrated that IRIG 106 Chapter 10 stream packets could operate over the DDLS.

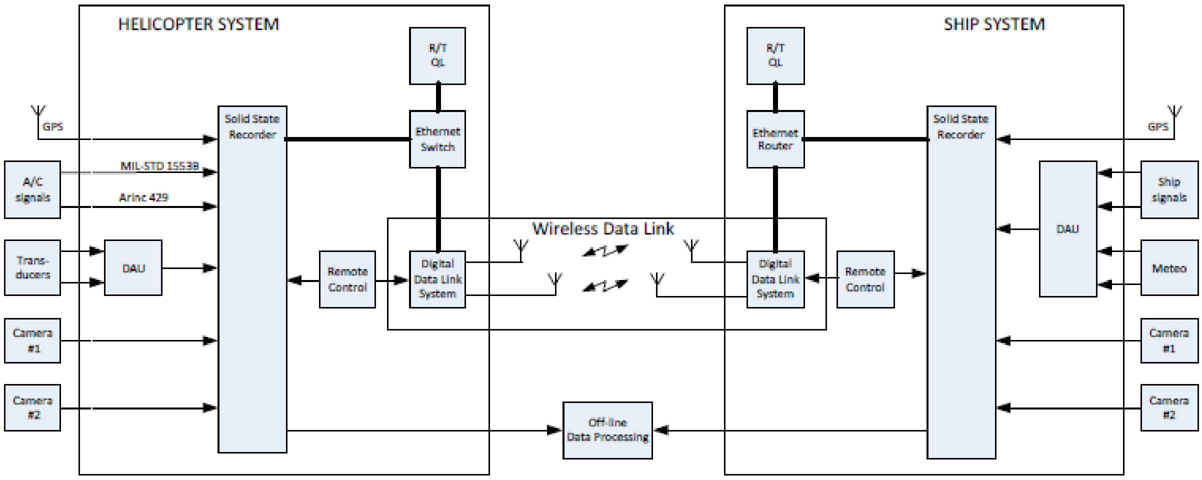



**Figure 6-2: Block Diagram of the Generic Instrumentation System.**

**Table 6-1: Digital Data Link Test Results.**

| Mode | Modulation/FEC | Data Capacity | Distance | Margin |
|---|---|---|---|---|
| 8 | 64 QAM, FEC 2/3 | 5.0 Mbps | 1.3 NM | 5 dB |
| 7 | 64 QAM, FEC 1/2 | 4.2 Mbps | 2.7 NM | 3 dB |
| 6 | 16 QAM, FEC 2/3 | 3.4 Mbps | 2.7 NM | 5 dB |
| 5 | 16 QAM, FEC 1/2 | 2.6 Mbps | 2.7 NM | 7 dB |

### 6.1.2 Instrumentation for F-16BM "Orange Jumper"

Since 1999 the FTI in the F-16BM "Orange Jumper" J-066, as presented in Refs. [2], [3], [4], has been used successfully during the flight tests for the RNLAF. The prolonged lifespan of the F-16 MLU aircraft by the Dutch Ministry of Defence required a technology refresh of the installed legacy FTI system to allow flight tests up to the estimated end-of-life of the aircraft in the year 2023. Since the original data acquisition equipment had become obsolete, a completely new system was required.

Replacing the legacy FTI system was the only option possible. The legacy FTI was obsolete and the original manufacturer Aydin Vector was no longer in business. The Aydin Vector system used a master-slave configuration. A Programmable Master Unit (PMU) at the Master Location (MST) used a proprietary command-response bus to connect with each remote data acquisition unit on the system. Remote data acquisition units used in the legacy FTI including the Aydin Vector Programmable Conditioner Unit (PCU) and the Aydin Vector Micro Miniature Signal Conditioner (MMSC) for use in space-constrained locations. The systems used to configure and process data from the legacy FTI needed technology refreshes as well. Figure 6-3 shows a high level system block diagram of the FTI in F-16BM J-066. Blocks colored in blue indicate the locations of replaced components.

After an evaluation of available data acquisition systems from different vendors, NLR selected the KAM-500 system from Curtiss-Wright Controls Avionics and Electronics (CWC-AE) to implement an Ethernet-based DAS.

To lower upgrade costs, the new system reused existing wiring from the legacy FTI. In cooperation with CWC-AE, a feasibility test demonstrated that Ethernet could operate over the existing wiring. Additional tests verified that the Ethernet implemented on existing wiring met EMI requirements (Figure 6-4).

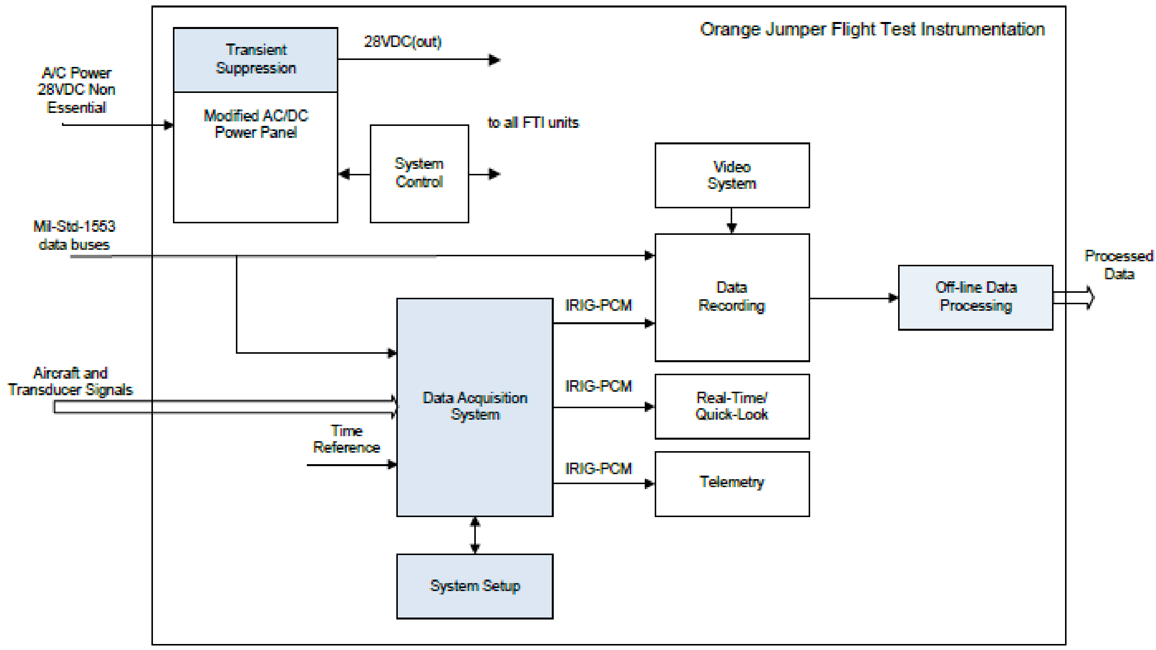



**Figure 6-3: High Level Diagram of the “Orange Jumper” FTI.**

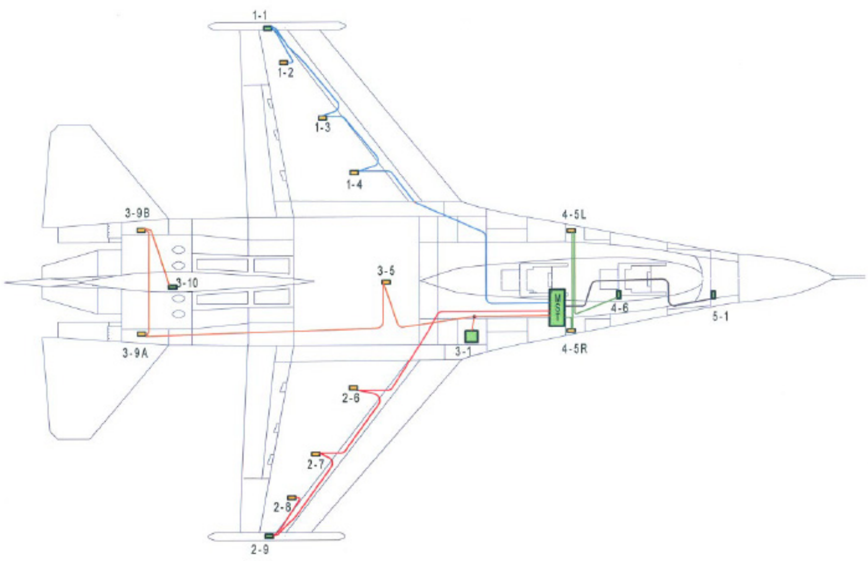



**Figure 6-4: Installation Overview of the Data Acquisition Equipment.**

One KAM-500 chassis (Master Switch Unit) aggregates data received over the Ethernet network from remote data acquisition units. A second KAM-500 chassis acts as a bridge between the DAS network and the telemetry system. This chassis monitors the network and selects data for insertion into IRIG 106 Chapter 4 PCM serial streaming telemetry. Figure 6-5 shows this bridging process between the two KAM-500 chassis.

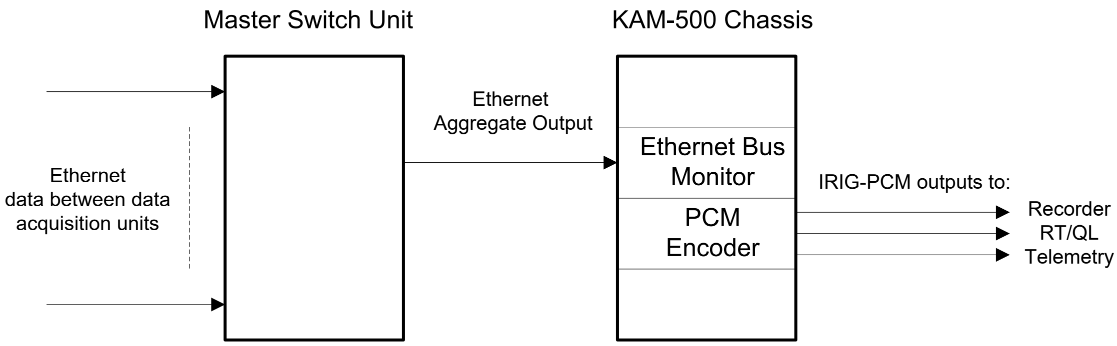



**Figure 6-5: Ethernet-Based KAM-500 FTI System with Ethernet to IRIG-PCM Bridge.**

The KAM-500 system currently supports both the iNET-X and the IENA protocols. The iNET-X protocol is an extension by CWC-AE of early work by the U.S. Department of Defense Integrated Networked Enhanced Telemetry (iNET) project. Since the F-16BM J-066's DAS upgrade, the RCC TG standardized the iNET Telemetry Network System (TmNS) data messages in IRIG 106 Chapter 24. IENA is a proprietary protocol used by Airbus. NLR selected the iNET-X protocol in favor of the proprietary IENA protocol. Time synchronization between DAS components throughout the aircraft is realized with the Precision Time Protocol (PTP) IEEE 1588-2002 v1.0 [5].

The renewed Ethernet-based FTI system allows the RNLAF to perform flight tests with the "Orange Jumper" until the projected end-of-life of the F-16 MLU aircraft. Future improvements of the "Orange Jumper" FTI system will include an extension to a complete Ethernet FTI system concept, providing Chapter 10 data recording, real-time quick-look and telemetry facilities with direct Ethernet interfaces. This will eliminate the need of an Ethernet to IRIG-PCM Bridge, which will reduce the costs for system maintenance and configuration.

The application of the IRIG 106 Chapter 10 recording standard enables exchange of F-16 flight test data between NATO partners such as the European Participating Air Forces (EPAF) and U.S. flight test ranges and therefore contributes to further collaboration.

## 6.2 GROUND BASED RECORDERS

IRIG 106 Chapter 10 ground based recorders support a wide array of end-user applications. These applications include telemetry recording, ground transfer of FTI data, and data playback systems.

### 6.2.1 Chapter 10 Telemetry Recording Systems

Until the introduction of Chapter 10, test ranges used analog and digital tape recorders for telemetry recording. After the introduction of Chapter 10, test ranges rapidly replaced tape based recording systems with hard-drive based recording systems. Ground telemetry recording systems fall into two categories: pre-detection or post-detection systems.

In a pre-detection system, the recorded telemetry signal is down-converted from its received frequency to the Intermediate Frequency (IF) carrier (typically 70 MHz in aeronautical mobile telemetry) with modulation. With a pre-detection recording capability, the recorded telemetry signal can be reconstructed, up-converted and re-inserted into a telemetry receiver for processing [6]. This lets the test range adjust the telemetry receiver systems to obtain the best signal-to-noise ratio after the mission. The RCC is currently developing an enhancement to Chapter 10 to store data from pre-detect recording systems.

A post-detection recording system receives the demodulated telemetry signal from the telemetry receiver.

In addition to recording multiple telemetry sources and a time source "Range Time", ground recorders might also record mission audio, serial data from instrumentation radars, video from range camera systems, and network data. The network data are typically UDP-packets recorded from a situational awareness display system.

Telemetry ground recorders are equipped with recording systems using large capacity hard-drives often setup in a Redundant Array of Independent Disks (RAID) or mirrored drive configurations. In some applications, the recorder is located in one place, but boots from, and records to a remote file system at a different location. Chapter 10 ground recording systems are working remotely over a network.

NASA Armstrong records received research test vehicle serial PCM telemetry data at the Dryden Aeronautical Test Range (DATR) Aeronautical Tracking Facility (ATF), shown in Figure 6-6 onto a non-Chapter 10 compliant hard-drive based Wideband System DRS 3300 recorder.

In addition, received mission telemetry data at NASA Armstrong Mission Control Center area, shown in Figure 6-7, is recorded on a compliant Chapter 10 Wideband Systems DRS 8500X Chapter 10 recorder with included received mission ATF radar serial RS-232, optional ATF mission video, and mission audio data.

**Figure 6-6: DATR Aeronautical Tracking Facility.**


**Figure 6-7: NASA Armstrong Mission Control Center.**

### 6.2.2 Chapter 10 Data Playback Stations

Another specialized ground recorder system is to use a Chapter 10 recorder to process and display recorded data. This system could support mission debriefing systems, or it could function as a download station. A download station supports the download/transfer of Chapter 10 recordings from on-board recorder Removable Memory Modules (RMM).

An example of a mission debriefing system is the United States Air Force (USAF) Common Mission Debrief Program (CMDP) developed to support primary aircrew debriefings after missions at Edwards Air Force Base (AFB), California, Eglin AFB, Florida, and Nellis AFB, Nevada. CMDP performs the simultaneous playback of up to four video streams from any of four different aircraft equipped with Chapter 10 recorders. CMDP displays aircraft data along with a 3-dimensional display driven by position information [7]. The U.S. Army's Yuma Proving Ground (YPG) in Arizona uses the same CMDP system as the Air Force. CMDP displays Chapter 10 data recorded on YPG helicopters during tests [8].

Other ground playback stations function as data download stations. These units accept on-board recorder media RMMs. The end-user can access, copy, delete, and declassify data on the installed RMMs. Data are typically transferred to a temporary location on a storage server. The system administrators then transfer the newly downloaded file to a project file area for post-test processing.

### 6.2.3 Chapter 10 Telemetry Processing

In 2017, the RCC TG released the Packet Telemetry Downlink Standard IRIG 106 Chapter 7. Chapter 7 provides a method to encapsulate IRIG 106 Chapter 11 in a serial streaming telemetry stream. This provides the means to telemetry Chapter 11 packets from a Chapter 10 recorder through a serial streaming telemetry transmitter.

Several manufacturers have used Chapter 10 ground recorders to receive Chapter 7 PCM from a telemetry receiver. The Chapter 10 ground recorder then either reproduce the signals contained in the telemetered Chapter 7 Packets or transfers the Chapter 11 packets using the Chapter 10 UDP streaming protocol to another computer [9].

## 6.3 DATA PROCESSING AND ARCHIVING

### 6.3.1 Chapter 10 Telemetry Data Processing and Archiving at NLR

At the NLR, each project developed a data processing and data management solution for measurement data. Because each project used a custom system, it was difficult to reuse one project's processing system for another project. At the same time, requirements for data quality, traceability, availability and security are increasing constantly. The amount of data generated by modern FTI systems drive the amount of data a project must store. Therefore, a unified NLR system was needed to store, manage and distribute measurement data. This modern measurement and data processing system needed to be compatible with the needs of the FTI system and the end users. NLR also required the storage of both intermediate and final results in the process of data analysis with this system.

Commissioned by the Dutch Ministry of Defence NLR developed and operates a Flight Test Data Processing (FTDP) facility to process FTI data. Figure 6-8 depicts the main capabilities of this facility:

- On-line storage of raw flight test data, not only the measurement data itself but also companying configuration files and other administrative data (e.g., test cards, observer logs);
- Processing of raw FTI data into Engineering Units based on the stored configuration files;
- Publishing of data in the Omega Data Environment (ODE), offering the end-user advanced data mining facilities; and
- Export of selected results for presentation or further processing.

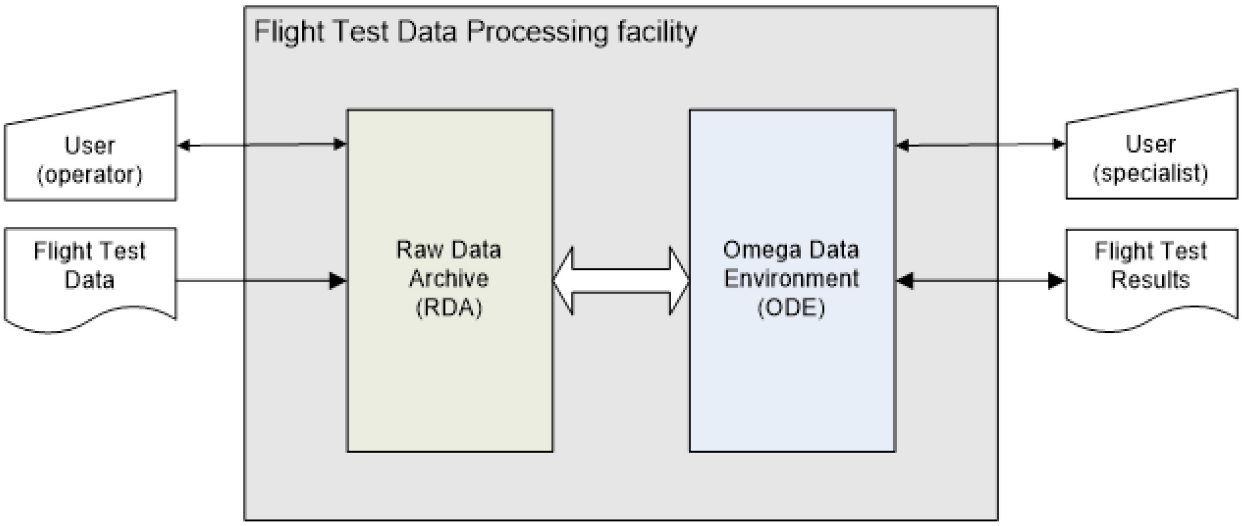



**Figure 6-8: Flight Test Data Processing Facility.**

The FTDP contains a data storage system called the Raw Data Archive (RDA) developed by NLR. Operators have access to the Smartronix Omega Data Environment (ODE) application. ODE can process data contained in the RDA. Flight test data is stored in the system under the operator's control. FTDP Operators add standardized metadata (e.g., flight numbers, dates, aircraft type and tail number) to the data from RDA and then publish these data in the ODE. ODE automatically generates parameter based statistical information (e.g., minimum, maximum and mean values) over defined time intervals.

Once published data is available on ODE, the end-user (aircraft system specialist), will search for data using filters and/or advanced search criteria, ranging from simple expressions to complex C++ algorithms.

The end-user can use ODE to interactively process and present data of interest. This processed data can be stored in the ODE for reuse or exported for reports in predefined formats.

At present, the FTDP processes IRIG 106 Chapter 10 solid-state recording data format. This format has the advantages described in the previous section, i.e., a standardized format including the metadata. This allows a large dataset to be processed and analyzed efficiently. However, the FTDP is also capable of processing other (proprietary) data formats. ODE provides the capability to develop input components capable of processing these formats. ODE can export data to MATLAB, Comma Separated Value (CSV) and Microsoft Excel files. ODE provides the means for an end-user to develop other output components that could generate more specialized analysis files formats.

The FTDP uses a client server architecture. Two servers are used. One server functions as the RDA. A second server hosts ODE. Other computers have network connections with these servers and run ODE desktop client software. Secure remote access from the internet is available using ODE's role based authorization system.

FTDP provides data processing support to the F-16 Flight Test Group and the DHC of the RNLAF. FTDP also supports other NLR research aircraft.

In addition to the FTDP, several task specific applications and utilities used for mission debriefing and data retrieval. The AH-64 Apache helicopter uses the Apache Data and Video Intelligence System (ADVISE) for mission debriefing. An on-board recording system gathers Audio, Video and MIL-STD-1553 avionics bus data during an AH-64 flight. On the ground, this recorded data is processed and saved with metadata in NATO STANAG 4609 compatible files. STANAG 4609 is a common standard for motion imagery. These files support both mission debriefing of operational AH-64 flights and are an essential input to the Dutch Ministry of Defence intelligence chain.

A server-based application called "KLu-NLR Application Platform Interface" (KNAPI) distributes IRIG 106 Chapter 10 recorded and processed data to authorized Dutch Ministry of Defence users. This application offers a standardized means of interacting with IRIG 106 Chapter 10 data.

Data retrieval tools include ODE output components developed for customer specific data formats and data conversion tools. Data conversion tools reformat recorded Chapter 10 data to other post-processing formats. Examples include tools used to extract audio or video and avionics bus processing applications.

Smartronix OmegaNext systems are also used with ODE to process Chapter 10 data.

### 6.3.2 Chapter 10 Telemetry Data Processing and Archiving at NASA Armstrong

At NASA Armstrong, aircraft flight test projects generate large amounts of data. A single flight can generate many gigabytes worth of data. This includes telemetry data sent to a Mission Control Center (MCC) and/or recorded on-board a research aircraft. A single research project can involve a few flights or involve hundreds of flights. Many research projects can occur in parallel at NASA Armstrong and this requires the management of terabytes of data. The use of Chapter 10 recorders at NASA Armstrong starts with the ground recorders used by the Dryden Aeronautical Test Range in the NASA Armstrong MCC during a research flight.

As discussed in Section 6.2, the DATR Aeronautical Tracking Facility receives IRIG 106 Chapter 4 telemetry and instrumentation radar data. A ground network transfers this data to the NASA Armstrong MCC (shown in Figure 6-7) for recording, processing and presentation.

During a research mission, a ground recorder archives telemetry data to a Chapter 10 file. After a research flight, three methods currently exist at NASA Armstrong to process either ground or on-board Chapter 10 files.

Like NLR, NASA Armstrong uses the ODE software application for Chapter 10 processing [10]. Starting in 2003, ODE progressed through prototype, pilot, and limited production use at NASA Armstrong [11]. In the future, the OMEGA NExT data processing software will support ODE in processing Chapter 10 files for post-test analysis [12].

In the DATR, an IRIG 106 telemetry processor can process PCM data reproduced by a Chapter 10 recorder. Alternatively, a computer application in the DATR can process PCM data within the Chapter 10 file [13]. A second computer application reformats the data produced by the first application into a file format compatible with the Flight Data Access System (FDAS). The FDAS is a legacy system that NASA Armstrong uses to store and distribute time history data. Researchers then retrieve data from either ODE or FDAS for data analysis [11]. Mission support, project based archival, and storage systems at NASA Armstrong support ODE and FDAS [13].

## 6.4 REFERENCES

[1] Carico, D., Fang, R., Finch, R.S., Geyer, W.P., Jr., Krijns, H.W., and Long, K., Helicopter/Ship Qualification Testing, RTO/NATO, TR RTO-AG-300-V22, 2003.

[2] Klijn, J.M., Koks, P., and Kobus, G.J., New Flight Test Instrumentation for the RNLAF F-16 MLU Aircraft, NLR-TP-2000-362, presented at the symposium of the Society of Flight Test Engineers, Turin, Italy, 2000.

[3] Koks, P., Kobus, G.J., Cost effective flight testing and certification in a small but ambitious Air Force, presented at the symposium of the Society of Flight Test Engineers, Vergiate, Italy, 2010.

[4] Klijn, J.M., van Rijn, F., Striegel, A.J., Oterdoom, Y.P.H., Development of Ethernet-based Flight Test Instrumentation, NLR-TP-2015-262, presented at the symposium of the Society of Flight Test Engineers, Seville, Spain, 2015.

[5] IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems, IEEE1588-2002, 8 November 2002.

[6] Chambers, H.L. Pre-detection Recording in the Megacycle Range, Consolidated Electronics Company, Bell and Howell Ltd, California, 1964.

[7] Ferrill, P., Reference Design for a Squadron Level Data Archive System, Avionics Test and Analysis Corporation, International Telemetry Conference Proceedings, 2006.

[8] Swain, J., Use of IRIG 106 Chapter 10 at the U.S. Army Yuma Proving Ground, Michael Diehl, and Tab Wilcox, International Telemetry Conference Proceedings, 2012.

[9] Bago, B., IRIG-106 Chapter 7 Telemetry Downlink, Zodiac Data Systems, European Test and Telemetry Conference, June 2015.

[10] McMorrow, S., Sherrard, R., and Gibbs, Y., Mission Information and Test Systems Summary of Accomplishments, 2012-2013, Armstrong Flight Research Center, Edwards, California, December 2015.

[11] Avionics and Instrumentation Technologies, Next-Generation Post-Flight Processing and Analysis with Data Mining Toolset. October 26, 2015. Available from https://www.nasa.gov/feature/avionics-and-instrumentation-technologies#nextgen.

[12] NASA, Research, Technology, and Engineering Accomplishments, Neil A. Armstrong Flight Research Center, 2014. Available from https://www.nasa.gov/sites/default/files/files/Armstrong_RTE_2014.pdf.

[13] Knudtson, K., Dealing with Processing Chapter 10 Files from Multiple Vendors, May 2011.

# Chapter 7 – SPECIAL TOPICS

This chapter identifies a number of issues related to the application of the Chapter 10 standard with references to information and possible solutions.

## 7.1 PROGRAMMING HANDBOOK

To support the developers of the software needed to process Chapter 10 files, the Telemetry Group provides the IRIG 106 Chapter 10 Programmers Handbook designated RCC 123 [1]. The stated purpose of this handbook is to assist software developers with developing software for use with IRIG 106 Chapter 10 recorders. The handbook also covers aspects of IRIG 106 Chapters 6 and 9. Algorithms and data structures, written in American National Standards Institute (ANSI) C, address topics such as Recorder Setup, Configuration and Data Retrieval. The Chapter 10 Programmers Handbook also covers Recorder Control, Chapter 10 File Organization, and Data Packet Organization. Appendixes in the handbook include source code for various Chapter 10 operations.

The www.irig106.org website, maintained by Mr. Bob Baggerman, links to source code files referenced in the IRIG 106 Chapter 10 Programmers Handbook [2].

## 7.2 TIMING ISSUES

Since true Chapter 10 recorders include timing information with the recorded data, there may be issues concerning time. Examples of timing issues include:

- Operating systems may report different file times for the recorded files with respect to the time found internally in the file.
- Differences may exist between the recorder time, found in the recording structures and the platform time in the recorded data.
- The global time standard is Coordinated Universal Time or UTC. UTC is the time standard used across the world. National time standards around the world use UTC time with the appropriate offset for their time zone. Two components, International Atomic Time (TAI), and Universal Time (UT1) determine UTC [3].

  The world does not rotate smoothly. TAI is a time scale that combines the output of 400 atomic clocks worldwide to measure this rotation irregularity. A slow drift occurs between TAI and Earth Rotation Time UT1. Adjustments to UTC with "Leap Seconds" keep TAI within a second of earth rotation time [4].

  The Global Positioning System (GPS) system uses GPS Time. GPS Time is the atomic time scale implemented by the atomic clocks in the GPS ground control stations and the GPS satellites themselves.

  GPS Time is a "uniformly" counting time scale that began on 1/6/1980. January 6, 1980 is a Sunday. GPS Time counts in weeks and seconds of a week from this instant. The word "uniformly" indicates that there are no leap seconds in the GPS Time system [4].

  The GPS Time System is now ahead of UTC by 18 seconds. Instead of reprogramming each satellite's internal clock with every leap second added, the number of leap seconds is included in the GPS message. GPS receivers apply the leap second offset to provide an accurate UTC time to be determined [4].

Leap seconds can affect Chapter 10 data and these result in "Time Jumps" in the recorder's time. This occurs because the recorder may start up not knowing the amount of leap seconds required. Then after receiving the actual amount of leap seconds from the GPS message, the UTC time is adjusted to incorporate the leap seconds. This adjustment results in a time jump, which can cause problems during post-test processing of Chapter 10 files.

- Another time problem can occur when the time of the test article uses an entirely different time base. Time is often contained in the data gathered from the test article. Data analysts can reconstruct events during the test using this test article time contained in the data stream. The FTI system and the Chapter 10 recorder might have another time source received from an outside source. Differences can exist between the test article time in the data and the time used by the FTI. Since modern time bases are very accurate, the difference is generally constant over the test duration. This makes corrections from Chapter 10 time to aircraft time relatively easy.

## 7.3 TMATS ISSUES

IRIG 106 Chapter 9 defines the Telemetry Attributes Transfer Standard (TMATS). Telemetry attributes are those metadata required by the data processing system to acquire, process, and display the data received from the test article. In the context of Chapter 10, the TMATS Recorder-Reproducer Group (R) documents the recorder configuration, recording events, and the data types and is included in the Chapter 10 file.

The Telemetry Group provides RCC Document 124-19 the Telemetry Attributes Transfer Standard TMATS Handbook [5] to supplement IRIG 106 Chapter 9. The TMATS Handbook provides practical guidance for properly generating and using TMATS files. The handbook also provides examples of the more commonly used TMATS features. Since there may be multiple ways of using TMATS keywords, the examples illustrate best practices. The overall purpose of the handbook is to improve the use of TMATS as a standard by presenting clear guidelines and thereby reducing the misinterpretations that may exist.

Recorder manufacturers usually add only or expect the relevant TMATS setup for the recorder TMATS header of the Chapter 10 file. This is understandable since they have no advanced knowledge of an organization's data acquisition details in advance. Some manufacturers have methods to import full TMATS setup, to include parameter setups. A TMATS editor is a tool used to add additional information merged with metadata written by the Chapter 10 recorder to obtain a complete TMATS description. An FTI system vendor or flight-test organization uses an integrated software suite for recorder and data acquisition system setup.

Due to the development of data acquisition systems and recording systems capabilities, the TMATS specification has also had an extensive evolution over the years. This resulted in a significant increase in the number of TMATS attributes. If a data processing facility is not current with the current version of TMATS, compatibility issues can result between the Chapter 10 recorder and the data processing facility/software.

## 7.4 FIRMWARE DEPENDENCIES

Due to rapid evolution of the IRIG 106 Chapter 9 and Chapter 10 standards, recorder firmware is constantly changing. At the same time, the post-processing software used with Chapter 10 files must keep up with the changes to Chapter 9 and Chapter 10. Software needs to support processing data recorded using earlier versions of the standards in addition to remaining current. The Chapter 10 packet header contains information the data processing system can use to determine what version of Chapter 10 created a file.

Changes in the Chapter 10 recorder firmware may result in differences in the generated Chapter 10 data files. These differences may have an impact on the post-processing software. After firmware changes to the recorder, regression testing is needed to verify the data recording and data processing systems.

## 7.5 REFERENCES


[1] IRIG 106, Chapter 10 Programming Handbook, RCC Telemetry Group, Document 123-09, March 2009.

[2] IRIG 106 website, 23 July 2019. Available at http://www.irig106.org.

[3] UTC – The World's Time Standard. Available at https://www.timeanddate.com/time/aboututc.html. Retrieved November 2019.

[4] Time Systems and Dates – GPS Time. Available at https://www.oc.nps.edu/oc2902w/gps/timsys.html. Retrieved November 2019.

[5] Telemetry Attributes Transfer Standard (TMATS) Handbook, RCC Telemetry Group, Document 124-15, July 2015.

# Annex A – AGARD, RTO AND STO FLIGHT TEST INSTRUMENTATIONAND FLIGHT TEST TECHNIQUES SERIES

## 1. Volumes in the AGARD, RTO and STO Flight Test Instrumentation Series, AGARDograph 160

| Volume Number | Title | Publication Date |
|---|---|---|
| 1. | Basic Principles of Flight Test Instrumentation Engineering (Issue 2) | |
| | Issue 1: Edited by A. Pool and D. Bosman | 1974 |
| | Issue 2: Edited by R. Borek and A. Pool | 1994 |
| 2. | In-Flight Temperature Measurements<br>by F. Trenkle and M. Reinhardt | 1973 |
| 3. | The Measurements of Fuel Flow<br>by J.T. France | 1972 |
| 4. | The Measurements of Engine Rotation Speed<br>by M. Vedrunes | 1973 |
| 5. | Magnetic Recording of Flight Test Data<br>by G.E. Bennett | 1974 |
| 6. | Open and Closed Loop Accelerometers<br>by I. McLaren | 1974 |
| 7. | Strain Gauge Measurements on Aircraft<br>by E. Kottkamp, H. Wilhelm and D. Kohl | 1976 |
| 8. | Linear and Angular Position Measurement of Aircraft Components<br>by J.C. van der Linden and H.A. Mensink | 1977 |
| 9. | Aeroelastic Flight Test Techniques and Instrumentation<br>by J.W.G. van Nunen and G. Piazzoli | 1979 |
| 10. | Helicopter Flight Test Instrumentation<br>by K.R. Ferrell | 1980 |
| 11. | Pressure and Flow Measurement<br>by W. Wuest | 1980 |
| 12. | Aircraft Flight Test Data Processing – A Review of the State of the Art<br>by L.J. Smith and N.O. Matthews | 1980 |
| 13. | Practical Aspects of Instrumentation System Installation<br>by R.W. Borek | 1981 |
| 14. | The Analysis of Random Data<br>by D.A. Williams | 1981 |
| 15. | Gyroscopic Instruments and Their Application to Flight Testing<br>by B. Stieler and H. Winter | 1982 |
| 16. | Trajectory Measurements for Take-off and Landing Test and Other Short-Range Applications<br>by P. de Benque D’Agut, H. Riebeek and A. Pool | 1985 |

| Volume Number | Title | Publication Date |
|---|---|---|
| 17. | Analogue Signal Conditioning for Flight Test Instrumentation<br>by D.W. Veatch and R.K. Bogue | 1986 |
| 18. | Microprocessor Applications in Airborne Flight Test Instrumentation<br>by M.J. Prickett | 1987 |
| 19. | Digital Signal Conditioning for Flight Test<br>by G.A. Bever | 1991 |
| 20. | Optical Air Flow Measurements in Flight<br>by R.K. Bogue and H.W. Jentink | 2003 |
| 21. | Differential Global Positioning System (DGPS) for Flight Testing<br>by R. Sabatini and G.B. Palmerini | 2008 |
| 22. | Application of Fiber Optic Instrumentation<br>by L. Richards, A.R. Parker Jr., W.L. Ko, A. Piazza and P. Chan | 2012 |
| 23. | Application of IRIG 106 Digital Data Recorder Standards for Flight Test<br>by J.M. Klijn and B.A. Lipe | 2020 |

## 2. Volumes in the AGARD, RTO and STO Flight Test Techniques Series, AGARDograph 300

| Volume Number | Title | Publication Date |
|---|---|---|
| AG237 | Guide to In-Flight Thrust Measurement of Turbojets and Fan Engines by the MIDAP Study Group (UK) | 1979 |

The remaining volumes are published as a sequence of Volume Numbers of AGARDograph 300.

| Volume Number | Title | Publication Date |
|---|---|---|
| 1. | Calibration of Air-Data Systems and Flow Direction Sensors<br>by J.A. Lawford and K.R. Nippress | 1988 |
| 2. | Identification of Dynamic Systems<br>by R.E. Maine and K.W. Iliff | 1988 |
| 3. | Identification of Dynamic Systems – Applications to Aircraft | |
| | Part 1: The Output Error Approach<br>by R.E. Maine and K.W. Iliff | 1986 |
| | Part 2: Nonlinear Analysis and Manoeuvre Design<br>by J.A. Mulder, J.K. Sridhar and J.H. Breeman | 1994 |
| 4. | Determination of Antenna Patterns and Radar Reflection Characteristics of Aircraft<br>by H. Bothe and D. McDonald | 1986 |
| 5. | Store Separation Flight Testing<br>by R.J. Arnold and C.S. Epstein | 1986 |
| 6. | Developmental Airdrop Testing Techniques and Devices<br>by H.J. Hunter | 1987 |
| 7. | Air-to-Air Radar Flight Testing<br>by R.E. Scott | 1992 |
| 8. | Flight Testing under Extreme Environmental Conditions<br>by C.L. Henrickson | 1988 |
| 9. | Aircraft Exterior Noise Measurement and Analysis Techniques<br>by H. Heller | 1991 |
| 10. | Weapon Delivery Analysis and Ballistic Flight Testing<br>by R.J. Arnold and J.B. Knight | 1992 |
| 11. | The Testing of Fixed Wing Tanker & Receiver Aircraft to Establish Their Air-to-Air Refuelling Capabilities<br>by J. Bradley and K. Emerson | 1992 |
| 12. | The Principles of Flight Test Assessment of Flight-Safety-Critical Systems in Helicopters<br>by J.D.L. Gregory | 1994 |
| 13. | Reliability and Maintainability Flight Test Techniques<br>by J.M. Howell | 1994 |
| 14. | Introduction to Flight Test Engineering | |
| | Issue 1: Edited by F. Stoliker | 1995 |
| | Issue 2: Edited by F. Stoliker and G. Bever | 2005 |

| Volume Number | Title | Publication Date |
|---|---|---|
| 15. | Introduction to Avionics Flight Test<br>by J.M. Clifton | 1996 |
| 16. | Introduction to Airborne Early Warning Radar Flight Test<br>by J.M. Clifton and F.W. Lee | 1999 |
| 17. | Electronic Warfare Test and Evaluation‡<br>by H. Banks and R. McQuillan | 2000 |
| 18. | Flight Testing of Radio Navigation Systems<br>by H. Bothe and H.J. Hotop | 2000 |
| 19. | Simulation in Support of Flight Testing<br>by D. Hines | 2000 |
| 20. | Logistics Test and Evaluation in Flight Testing<br>by M. Bourcier | 2001 |
| 21. | Flying Qualities Flight Testing of Digital Flight Control Systems<br>by F. Webster and T.D. Smith | 2001 |
| 22. | Helicopter/Ship Qualification Testing<br>by D. Carico, R. Fang, R.S. Finch, W.P. Geyer Jr., Cdr. (Ret.) H.W. Krijns and K. Long | 2002 |
| 23. | Flight Test Measurement Techniques for Laminar Flow<br>by D. Fisher, K.H. Horstmann and H. Riedel | 2003 |
| 24. | Precision Airdrop<br>by M.R. Wuest and R.J. Benney | 2005 |
| 25. | Flight Testing of Night Vision Systems in Rotorcraft<br>by G. Craig, T. Macuda, S. Jennings, G. Ramphal and A. Stewart | 2007† |
| 26. | Airborne Laser Systems Testing and Analysis<br>by R. Sabatini and M.A. Richardson | 2010 |
| 27. | Unique Aspects of Flight Testing Unmanned Aircraft Systems<br>by A.E. Pontzer, M.D. Lower and J.R. Miller | 2010 |
| 28. | Electronic Warfare Test and Evaluation<br>by M. Welch and M. Pywell | 2012 |
| 29. | Aircraft/Stores Compatibility, Integration and Separation Testing<br>by O. Nadar | 2014 |
| 30. | High Altitude Rotary Wing Flight Testing – Considerations in Planning Rotary Wing Performance Testing for High Altitude Operations<br>by J. O'Connor, J. McCue, J. Holder and B. Carrothers | 2018 |
| 31. | Reduced Friction Runway Surface Flight Testing – Wet Runway Taxi Test Procedures at Edwards AFB<br>by T.E. Lundberg | 2018 |

‡ Superseded by Volume 28.

† Volume 25 has been published as RTO AGARDograph AG-SCI-089.

| Volume Number | Title | Publication Date |
|---|---|---|
| 32. | Flight Test Safety and Risk Management<br>by D. Morley, J. Newsome, D. Moore, P. Comeau, B.A. Neal, P.C. Stoliker, A. Karwal, C. Buck, Ö. Kirli, C.B. Rice, F.P. Henderson, J.R. Stevenson, and J.A. Mortensen | 2020 |

NATO OTAN

S&T organization

# REPORT DOCUMENTATION PAGE

| 1. Recipient's Reference | 2. Originator's References | 3. Further Reference | 4. Security Classification of Document |
|---|---|---|---|
| | STO-AG-160-V23<br>AC/323(SCI-266)TP/986 | ISBN<br>978-92-837-2306-6 | PUBLIC RELEASE |

**5. Originator**

Science and Technology Organization
North Atlantic Treaty Organization
BP 25, F-92201 Neuilly-sur-Seine Cedex, France

**6. Title**

Application of IRIG 106 Digital Data Recorder Standards for Flight Test

**7. Presented at/Sponsored by**

This AGARDograph has been sponsored by the SCI Flight Test Technical Team (FT3) of the Systems Concepts and Integration Panel (SCI) of STO.

| 8. Author(s)/Editor(s) | 9. Date |
|---|---|
| Multiple | November 2020 |

| 10. Author's/Editor's Address | 11. Pages |
|---|---|
| Multiple | 90 |

**12. Distribution Statement**

There are no restrictions on the distribution of this document. Information about the availability of this and other STO unclassified publications is given on the back cover.

**13. Keywords/Descriptors**

Flight test data processing; Flight test instrumentation; IRIG-106 chapter 10; Solid-state recording; Standardization.

**14. Abstract**

Digital data acquisition during flight tests covers many different types of data including sampled sensor data, aircraft avionics bus data, voice and video. Data streams are synchronized and nowadays stored on solid-state memory. Standards are in use for the administration of the data that enhance interoperability between equipment manufacturers and (multinational) test teams. One of these standards is the Telemetry Standards, IRIG Standard 106 Chapter 10, "Solid-State On-Board Recorder Standard".

This AGARDograph gives an introduction to the original Chapter 10 standard issued in 2004 and its development until present. Special attention is given to the use of the standard for ground based recording and data processing. Verification of compliance to the standard is a shared responsibility of users and vendors of Chapter 10 compliant equipment. Different approaches for verification and the tools available for this task are given. Examples of projects are described, which illustrate how the standard can be used not only as just a recorder specification but can contribute to a more efficient execution of flight test programs. In a concluding chapter some pitfalls the user may encounter are discussed.

NORTH ATLANTIC TREATY ORGANIZATION

NATO OTAN

BP 25

F-92201 NEUILLY-SUR-SEINE CEDEX • FRANCE

Télécopie 0(1)55.61.22.99 • E-mail mailbox@cso.nato.int

SCIENCE AND TECHNOLOGY ORGANIZATION

## DIFFUSION DES PUBLICATIONS
## STO NON CLASSIFIEES

Les publications de l'AGARD, de la RTO et de la STO peuvent parfois être obtenues auprès des centres nationaux de distribution indiqués ci-dessous. Si vous souhaitez recevoir toutes les publications de la STO, ou simplement celles qui concernent certains Panels, vous pouvez demander d'être inclus soit à titre personnel, soit au nom de votre organisation, sur la liste d'envoi.

Les publications de la STO, de la RTO et de l'AGARD sont également en vente auprès des agences de vente indiquées ci-dessous.

Les demandes de documents STO, RTO ou AGARD doivent comporter la dénomination « STO », « RTO » ou « AGARD » selon le cas, suivi du numéro de série. Des informations analogues, telles que le titre est la date de publication sont souhaitables.

Si vous souhaitez recevoir une notification électronique de la disponibilité des rapports de la STO au fur et à mesure de leur publication, vous pouvez consulter notre site Web (http://www.sto.nato.int/) et vous abonner à ce service.

### CENTRES DE DIFFUSION NATIONAUX

**ALLEMAGNE**
Streitkräfteamt / Abteilung III
Fachinformationszentrum der Bundeswehr (FIZBw)
Gorch-Fock-Straße 7, D-53229 Bonn

**BELGIQUE**
Royal High Institute for Defence – KHID/IRSD/RHID
Management of Scientific & Technological Research for Defence, National STO Coordinator
Royal Military Academy – Campus Renaissance
Renaissancelaan 30, 1000 Bruxelles

**BULGARIE**
Ministry of Defence
Defence Institute "Prof. Tsvetan Lazarov"
"Tsvetan Lazarov" bul no.2
1592 Sofia

**CANADA**
DGSIST 2
Recherche et développement pour la défense Canada
60 Moodie Drive (7N-1-F20)
Ottawa, Ontario K1A 0K2

**DANEMARK**
Danish Acquisition and Logistics Organization (DALO)
Lautrupbjerg 1-5
2750 Ballerup

**ESPAGNE**
Área de Cooperación Internacional en I+D
SDGPLATIN (DGAM)
C/ Arturo Soria 289
28033 Madrid

**ESTONIE**
Estonian National Defence College
Centre for Applied Research
Riia str 12
Tartu 51013

**ETATS-UNIS**
Defense Technical Information Center
8725 John J. Kingman Road
Fort Belvoir, VA 22060-6218

**FRANCE**
O.N.E.R.A. (ISP)
29, Avenue de la Division Leclerc
BP 72
92322 Châtillon Cedex

**GRECE (Correspondant)**
Defence Industry & Research General Directorate, Research Directorate
Fakinos Base Camp, S.T.G. 1020
Holargos, Athens

**HONGRIE**
Hungarian Ministry of Defence
Development and Logistics Agency
P.O.B. 25
H-1885 Budapest

**ITALIE**
Ten Col Renato NARO
Capo servizio Gestione della Conoscenza
F. Baracca Military Airport "Comparto A"
Via di Centocelle, 301
00175, Rome

**LUXEMBOURG**
*Voir* Belgique

**NORVEGE**
Norwegian Defence Research Establishment
Attn: Biblioteket
P.O. Box 25
NO-2007 Kjeller

**PAYS-BAS**
Royal Netherlands Military Academy Library
P.O. Box 90.002
4800 PA Breda

**POLOGNE**
Centralna Biblioteka Wojskowa
ul. Ostrobramska 109
04-041 Warszawa

**PORTUGAL**
Estado Maior da Força Aérea
SDFA – Centro de Documentação
Alfragide
P-2720 Amadora

**REPUBLIQUE TCHEQUE**
Vojenský technický ústav s.p.
CZ Distribution Information Centre
Mladoboleslavská 944
PO Box 18
197 06 Praha 9

**ROUMANIE**
Romanian National Distribution Centre
Armaments Department
9-11, Drumul Taberei Street
Sector 6
061353 Bucharest

**ROYAUME-UNI**
Dstl Records Centre
Rm G02, ISAT F, Building 5
Dstl Porton Down
Salisbury SP4 0JQ

**SLOVAQUIE**
Akadémia ozbrojených síl gen. M.R. Štefánika, Distribučné a informačné stredisko STO
Demänová 393
031 01 Liptovský Mikuláš 1

**SLOVENIE**
Ministry of Defence
Central Registry for EU & NATO
Vojkova 55
1000 Ljubljana

**TURQUIE**
Milli Savunma Bakanlığı (MSB)
ARGE ve Teknoloji Dairesi Başkanlığı
06650 Bakanliklar – Ankara

### AGENCES DE VENTE

**The British Library Document Supply Centre**
Boston Spa, Wetherby
West Yorkshire LS23 7BQ
ROYAUME-UNI

**Canada Institute for Scientific and Technical Information (CISTI)**
National Research Council Acquisitions
Montreal Road, Building M-55
Ottawa, Ontario K1A 0S2
CANADA

Les demandes de documents STO, RTO ou AGARD doivent comporter la dénomination « STO », « RTO » ou « AGARD » selon le cas, suivie du numéro de série (par exemple AGARD-AG-315). Des informations analogues, telles que le titre et la date de publication sont souhaitables. Des références bibliographiques complètes ainsi que des résumés des publications STO, RTO et AGARD figurent dans le « NTIS Publications Database » (http://www.ntis.gov).

NORTH ATLANTIC TREATY ORGANIZATION

SCIENCE AND TECHNOLOGY ORGANIZATION

BP 25
F-92201 NEUILLY-SUR-SEINE CEDEX • FRANCE
Télécopie 0(1)55.61.22.99 • E-mail mailbox@cso.nato.int

# DISTRIBUTION OF UNCLASSIFIED STO PUBLICATIONS

AGARD, RTO & STO publications are sometimes available from the National Distribution Centres listed below. If you wish to receive all STO reports, or just those relating to one or more specific STO Panels, they may be willing to include you (or your Organisation) in their distribution.

STO, RTO and AGARD reports may also be purchased from the Sales Agencies listed below.

Requests for STO, RTO or AGARD documents should include the word 'STO', 'RTO' or 'AGARD', as appropriate, followed by the serial number. Collateral information such as title and publication date is desirable.

If you wish to receive electronic notification of STO reports as they are published, please visit our website (http://www.sto.nato.int/) from where you can register for this service.

## NATIONAL DISTRIBUTION CENTRES

**BELGIUM**
Royal High Institute for Defence – KHID/IRSD/RHID
Management of Scientific & Technological Research for Defence, National STO Coordinator
Royal Military Academy – Campus Renaissance
Renaissancelaan 30
1000 Brussels

**BULGARIA**
Ministry of Defence
Defence Institute "Prof. Tsvetan Lazarov"
"Tsvetan Lazarov" bul no.2
1592 Sofia

**CANADA**
DSTKIM 2
Defence Research and Development Canada
60 Moodie Drive (7N-1-F20)
Ottawa, Ontario K1A 0K2

**CZECH REPUBLIC**
Vojenský technický ústav s.p.
CZ Distribution Information Centre
Mladoboleslavská 944
PO Box 18
197 06 Praha 9

**DENMARK**
Danish Acquisition and Logistics Organization (DALO)
Lautrupbjerg 1-5
2750 Ballerup

**ESTONIA**
Estonian National Defence College
Centre for Applied Research
Riia str 12
Tartu 51013

**FRANCE**
O.N.E.R.A. (ISP)
29, Avenue de la Division Leclerc – BP 72
92322 Châtillon Cedex

**GERMANY**
Streitkräfteamt / Abteilung III
Fachinformationszentrum der Bundeswehr (FIZBw)
Gorch-Fock-Straße 7
D-53229 Bonn

**GREECE (Point of Contact)**
Defence Industry & Research General Directorate, Research Directorate
Fakinos Base Camp, S.T.G. 1020
Holargos, Athens

**HUNGARY**
Hungarian Ministry of Defence
Development and Logistics Agency
P.O.B. 25
H-1885 Budapest

**ITALY**
Ten Col Renato NARO
Capo servizio Gestione della Conoscenza
F. Baracca Military Airport "Comparto A"
Via di Centocelle, 301
00175, Rome

**LUXEMBOURG**
*See* Belgium

**NETHERLANDS**
Royal Netherlands Military Academy Library
P.O. Box 90.002
4800 PA Breda

**NORWAY**
Norwegian Defence Research Establishment, Attn: Biblioteket
P.O. Box 25
NO-2007 Kjeller

**POLAND**
Centralna Biblioteka Wojskowa
ul. Ostrobramska 109
04-041 Warszawa

**PORTUGAL**
Estado Maior da Força Aérea
SDFA – Centro de Documentação
Alfragide
P-2720 Amadora

**ROMANIA**
Romanian National Distribution Centre
Armaments Department
9-11, Drumul Taberei Street
Sector 6
061353 Bucharest

**SLOVAKIA**
Akadémia ozbrojených síl gen M.R. Štefánika, Distribučné a informačné stredisko STO
Demänová 393
031 01 Liptovský Mikuláš 1

**SLOVENIA**
Ministry of Defence
Central Registry for EU & NATO
Vojkova 55
1000 Ljubljana

**SPAIN**
Área de Cooperación Internacional en I+D
SDGPLATIN (DGAM)
C/ Arturo Soria 289
28033 Madrid

**TURKEY**
Milli Savunma Bakanlığı (MSB)
ARGE ve Teknoloji Dairesi Başkanlığı
06650 Bakanliklar – Ankara

**UNITED KINGDOM**
Dstl Records Centre
Rm G02, ISAT F, Building 5
Dstl Porton Down, Salisbury SP4 0JQ

**UNITED STATES**
Defense Technical Information Center
8725 John J. Kingman Road
Fort Belvoir, VA 22060-6218

## SALES AGENCIES

**The British Library Document Supply Centre**
Boston Spa, Wetherby
West Yorkshire LS23 7BQ
UNITED KINGDOM

**Canada Institute for Scientific and Technical Information (CISTI)**
National Research Council Acquisitions
Montreal Road, Building M-55
Ottawa, Ontario K1A 0S2
CANADA

Requests for STO, RTO or AGARD documents should include the word 'STO', 'RTO' or 'AGARD', as appropriate, followed by the serial number (for example AGARD-AG-315). Collateral information such as title and publication date is desirable. Full bibliographical references and abstracts of STO, RTO and AGARD publications are given in "NTIS Publications Database" (http://www.ntis.gov).

ISBN 978-92-837-2306-6