Unclassified

SECRET

NOFORN

Defense Intelligence Reference Document

30 December 1999
NAIC-1361-2253-00

Iraqi L-29 UAV Conversion (U)

SECRET

Unclassified

Unclassified

~~SECRET//NOFORN//MR~~

SUBJECT: Errata to NAIC-1362-2662-01

23 January 2001

TO: Recipients of NAIC-1362-2662-01

1. (U) Reference NAIC-1362-2662-01, "(U) Arms Market Assessment: Air-to-Air Missile Proliferation at a Glance," dated October 2000.

2. ~~(S//NF)~~ [redacted]

Exp B1

3. ~~(S//NF)~~ [redacted]

4. (U) File this errata sheet in the back of the document after the above action has been taken.

~~SECRET//NOFORN//MR~~

Unclassified

Defense Intelligence Reference Document

Iraqi L-29 UAV Conversion (U)

Information Cutoff Date: 1 May 1999

This product is published under the auspices of the Department of Defense Intelligence Production Program (DoDIPP). It is produced by the National Air Intelligence Center as the designated DoDIPP producer for this subject and reflects the Defense Intelligence Production Community position.

Prepared by:

[redacted]
Air-to-Surface Weapons Branch
Aerodynamic Systems Division
Directorate of Technical Assessments
National Air Intelligence Center

Ex 8
B6

This product responds to the US Central Command's production requirement I005-98-0166.

Derived from MNS: 2299124 05 06 270
Declassify on: DCU Determine REQ

NAIC-1361-2253-00

(Reverse Blank)

Ex? B1

Iraqi L-29 UAV Conversion (U)

Summary (S) [redacted]

(S) [redacted]

(S) The Iraqi have used the L-29 (MAYA) aircraft as a jet trainer since 1960. Sixty were purchased from Aero-Vodochody and were the primary jet trainer for the Iraqis Air Force until the mid 80s. They have since been replaced by newer L-39 (Albatross) jet trainers.

(S) [redacted]

(S) [redacted]

(S) [redacted]

Information Cutoff Date: 1 May 1999

Derived from MNS: 2299124 05 06 270
Declassify on: DCI Determine REQ

NAIC-1361-2253-00

[redacted]

(S) [redacted]

Ex 1
B1

Contents

Contents (Continued)

Appendix

Tables

Figures

Contents (Continued)

Iraqi L-29 UAV Conversion (U)

Foreword

(U) This document addresses the Iraqi unmanned aerial vehicle (UAV) conversion of the Aero-Vodochody L-29 DELFIN jet trainer, which was manufactured in Czechoslovakia during the 1960's and early 1970's. This document has been organized to provide a quick snapshot of the Iraqi UAV conversion and development processes and the problems encountered with the project. An evaluation of the capabilities and potential missions that could be applicable to the L-29 UAV is also included. Appendix A provides the estimated flight performance data of the fully converted L-29 aircraft.

(U) Performance/characteristics are listed in English units (where possible), with metric units offered in parentheses.

(U) Information on systems for which NAIC has primary analytical responsibility was provided by the personnel listed below.

Contributors:	[redacted]	TAMP
	[redacted]	TANW
	[redacted]	ONI/NAVY RESERVE
	[redacted]	ONI/NAVY RESERVE
	[redacted]	ONI/NAVY RESERVE
	[redacted]	ONI/NAVY RESERVE
	[redacted]	TANN
	[redacted]	TANN

Ex B6

(U) Contact NAIC/TAAS at (937) 257-6600 (commercial) or 787-6600 (DSN) for comments or questions, and send requests for additional copies of this document to NAIC/DXLA, 4180 Watson Way, Wright-Patterson AFB, OH 45433-5648.

(U) This document has been processed for INTELINK.

Section I
Introduction (U)

EXP B1

1. Project Overview (U)

(S) [redacted].

[redacted]

(S) [redacted].

2. Brief History (U)

(S) The Aero-Vodochody L-29 DELFIN aircraft is a tandem two-seat jet trainer manufactured in Czechoslovakia during the 1960's and early 1970's. (See Figure 1.) Over 4,000 were produced. The L-29 has been used by Eastern Block countries as well as African and Middle East countries. Between 60 and 90 L-29 aircraft were sold to Iraq for pilot training. Most of the aircraft are now derelict. However, some of the aircraft are being used as airfield decoys and as training aids at the Iraqi Air Force Technical College.

(S) [redacted].

(S) [redacted]

Figure 1. (U) DELFIN (MAYA) L-29 Jet Trainer

EXP B1

[redacted]

(S) [redacted]

(S) [redacted]

(S) [redacted]

~~SECRET~~ CA86-93

Figure 2. (U) UAV Al-Bai'aa Project Progression of Nose Art

~~SECRET~~ CA86-94

EXP B1

Figure 3. (U) L-29 Optionally Piloted Test Vehicle

(S) [redacted]

SECRET CA[illegible]-05

Figure 4. (U) L-29 in Storage at Iraqi Air Force Technical College

3. Mission Description (U)

(S) [redacted]

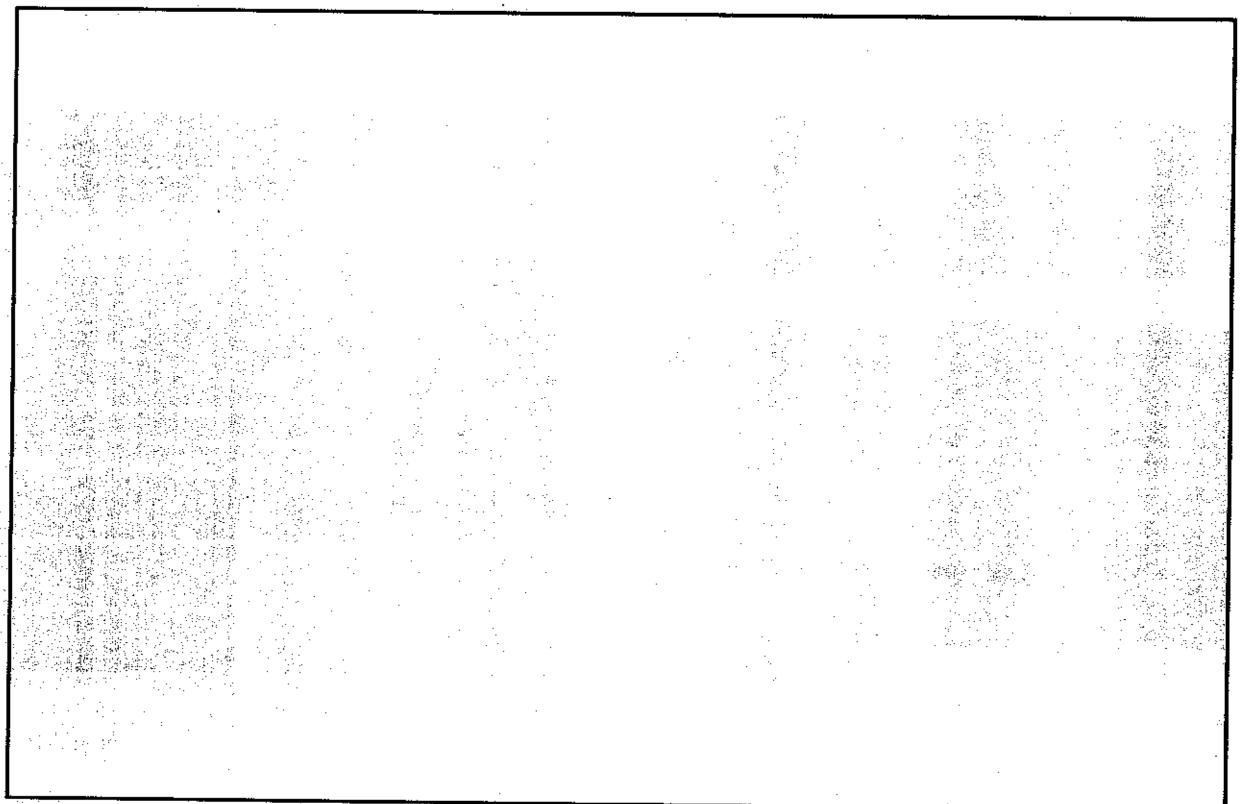

Figure 5. (U) Flight Stabilizer Package (C611)

(S) [redacted]

(S) [redacted]

(S) [redacted]

Figure 6. (U) Nose-Mounted Color Video Camera on POV

[redacted]

[redacted]

EXP B1

(S) [redacted]

4. Production and Deployment (U)

(S) [redacted]

[redacted]

5. Exports (U)

(U) No exports of this vehicle have been identified, and none are expected.

6. Future Developments (U)

(S) [redacted]

(S) [redacted]

(S) [redacted]

(S) [redacted]

Section II
L-29 Unmanned Aerial Vehicle (U)

1. General Description (U)

(U) The production L-29 (DELFIN) entered service in 1965 as a primary jet trainer. (See Figure 7.) It provides a tandem double-seat alignment, mid-winged, self-supporting, all-metal monoplane, equipped with a single M 701 C 250 jet engine. The airplane is specifically designed as an economical jet trainer suitable for initial jet pilot training and can be used for transition training before passing to more advanced jet aircraft. According to the producer, the aircraft is not limited to concrete runways, but can be operated from improved surfaces composed of sand or grass. The performance and flying characteristics of this aircraft, as well as the available avionics equipment, provide an economical aircraft that can meet the training requirements for basic and special pilot training. Additionally, the aircraft can provide dual instrument flight training.

~~(S)~~ The L-29 DELFIN is made mostly of light alloys. Located in the front section of the aircraft fuselage is the crew cabin. The cabin provides tandem seating for two crew members. The cabin is sealed hermetically with a transparent canopy. The L-29 is equipped with full dual controls that use purely mechanical flight control linkage. The suite of avionics equipment is typical for jet training aircraft. The crew cabin is air conditioned and pressurized. The crew seats are ejectable. [redacted]

(S) [redacted]

[redacted]

(S) [redacted]

(S) [redacted]

Basic and advanced training can be performed with a single aircraft

Dimensions	
Wing Span	10.29 m/34 ft.
Wing area	19.8 m^2/213.13 sq.ft.
Wing aspect ratio	5.36
Wing taper	0.52 m/1.65 ft.
Overall length	10.81 m/35 ft.
Height on the ground	3.13 m/10 ft.
Weights	
Weight of empty aircraft	2,280 kg/5,027 lbs.
Normal all-up weight	3,280 kg/7,243 lbs.
Maximum all-up weight	3,540 kg/7,596 lbs.
Wing loading	166-179 kg/m^2 34-37 lbs/sq.ft.
Engine weight	340 kg/750 lbs.
Engine thrust	860 kgf/1,895 lbs. st. t.
Thrust loading	3.815-4.124 kg/kgt 3.815-4.124 lbs/lbs. st. t.
Usable fuel in main tanks	962 l/211 gal. (imperial)
Usable fuel in auxiliary tanks	300 l/ 66 gal (imperial).

All this can be achieved with the L-29 DELFIN turbojet training aircraft

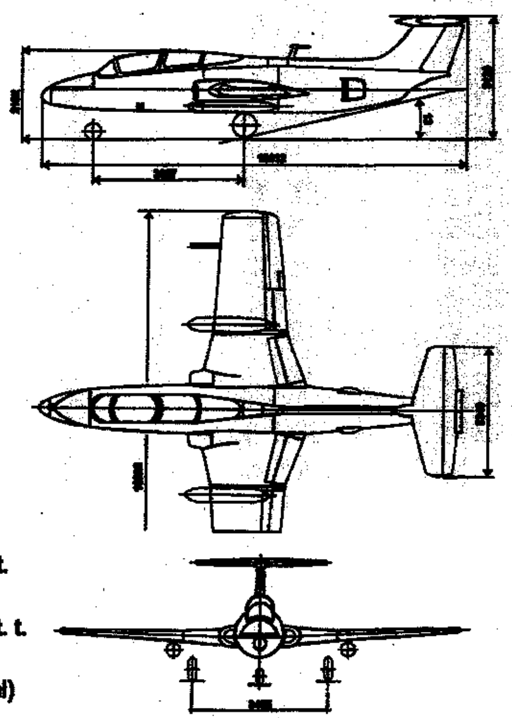

Figure 7. (U) L-29 Silhouette

Exp B1

Figure 8. (U) L-29 Pilot-Optional Vehicle (POV)

ExP B1

Figure 9. (U) Location of Actuators Necessary for Remote Flight Control Functions

EXP B1

Figure 10. (U) Front and Rear Cockpit Modifications

Figure 11. (U) Ground Control Station and Camera Locations

2. Aerial Vehicle L-29 (U)

(U) The L-29 is equipped with a retractable three-wheel landing gear and uses differential brakes for steering. Aerodynamic controls consist of a traditional elevator, rudder, and ailerons, with three position fowler flaps used for takeoff and landing. The aircraft also has rear-fuselage mounted speed brakes, one on either side. A novel feature of the tailplane is that its incidence angle is automatically adjusted to compensate for deployment of the flaps.

2.a. External Configuration/Stores (U)

(U) Two pylons under the wings can be fitted with either two 150-liter drop tanks, two 100-kg bombs, or two rocket pods.

2.b. Internal Configuration (U)

(S) [redacted]

(S) [redacted]

[redacted]

[redacted]

2.c. Materials and Construction (U)

(S) [redacted]

(S) [redacted]

Figure 12. (U) L-29 Damaged Nose Section

(S) [redacted]

(S) [redacted]

EX P B1

~~SECRET~~

CA00-104/F-284815

Figure 13. (U) L-29 Rear Fuselage Section Showing the Secondary Fuel Tank

~~SECRET~~

CA00-105/F-284985

Figure 14. (U) Video Cameras Mounted in Front Cockpit

ExP B1

~~(S)~~ [redacted]

Figure 15. (U) C611 Auto Pilot (Flight Stabilizer) Installed in Rear Cockpit of POV

~~(S)~~ [redacted]

Figure 16. (U) Servo Actuators Installed in Cockpit

(b)(1)

(S) [redacted]

SECRET

CA80-100F-294628

Figure 17. (U) Camera Mounted in Rear Cockpit of POV

(S) [redacted]

(S) [redacted]

EXPB1

~~SECRET~~

CA99-169

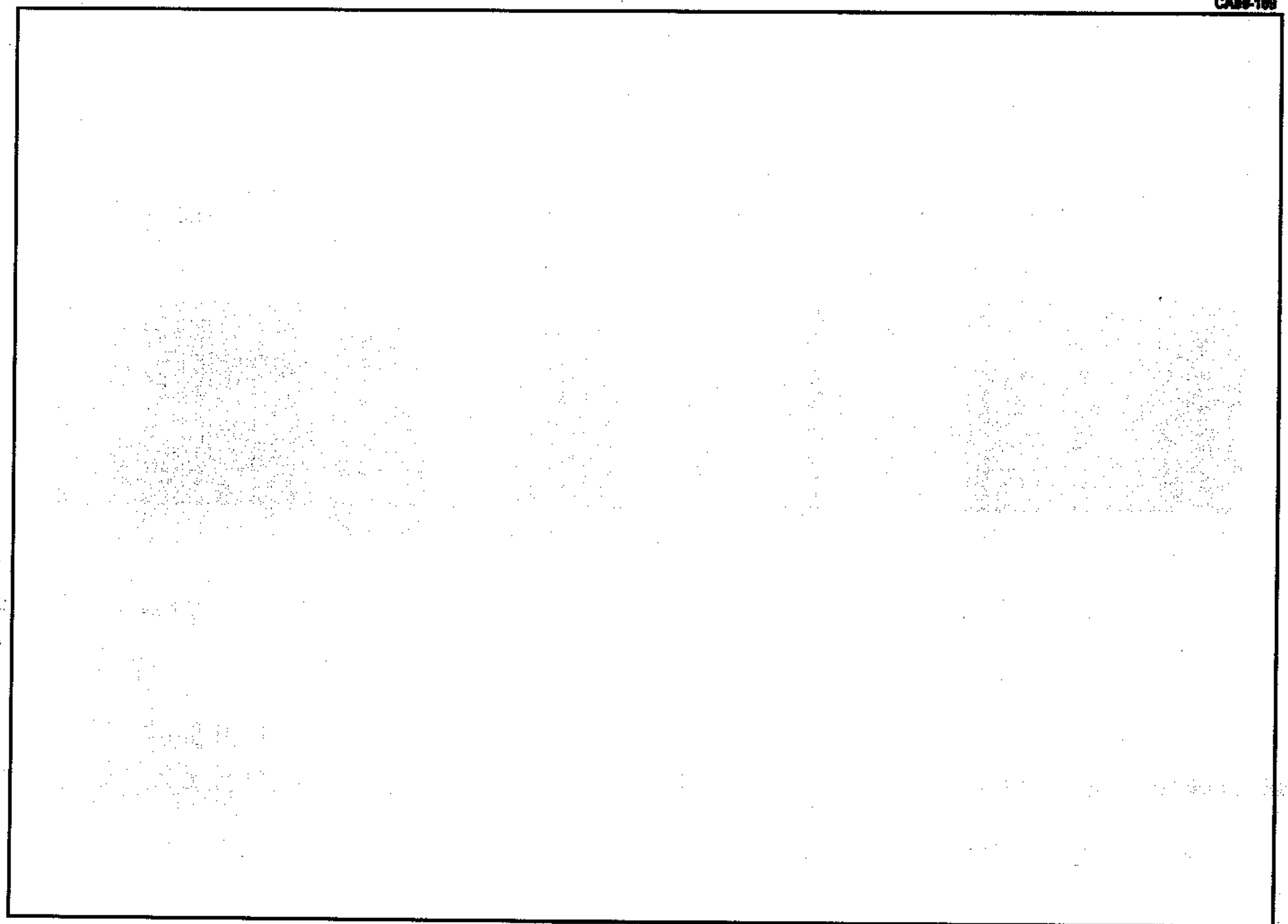

Figure 18. (U) Nose Camera in POV

ExP B1

Figure 19. (U) Data Link Receiver Mounted on Seat Rail

(S) [redacted]

(S) [redacted]

SECRET

CA09-111

Figure 20. (U) Data Link Antenna Mounted on Canopy

(S) [redacted]

Figure 21. (U) Battery Located in Nose Section

2.d. Visibility and Vulnerability (U)

2.d.(1) General (U)

~~(S)~~ [redacted]

2.d.(1)(a) Naked Eye (U)

~~(S)~~ [redacted]

[redacted]

2.d.(1)(b) Radar and IR cross Section (U)

~~(S)~~ [redacted]

2.d.(1)(c) System Vulnerability (U)

~~(S)~~ [redacted]

Figure 22. (U) Blackened-Out Canopy and Data Link Receiver Antenna

[redacted]

3. Control and Mission Stations (U)

(S) [redacted]

3.a. Shelter and Prime Mover (U)

(S) [redacted]

Figure 23. (U) ALAMAK Ground Control Station and Portable Ground Power Unit

[redacted]

~~(S)~~ [redacted]

[redacted]

3.b. Portable Receiving Station (U)

~~(S)~~ [redacted]

EXP B1

Figure 24. (U) L-29 RID GCS Station

Figure 25. (U) Portable Ground Control Station

3.c. Tracking and Navigation System (U)

(S) [redacted]

[redacted]

[redacted]

(S) [redacted]

3.d. Launch and Retrieval (U)

(S) [redacted]

(S) [redacted]

(S) [redacted]

4. Support Equipment (U)

(S) [redacted]

EXPB1

Section III
UAV Subsystem Description (U)

1. Aerial Vehicle (U)

1.a. General (U)

(U) Iraq has produced a ground-controlled unmanned aerial vehicle (UAV) based on the L-29 (DELFIN) jet trainer. This UAV uses components from various avionics systems; i.e., C611 cruise missile; the Target Technology, Limited (TTL), Banshee target system; and the Mirach 100 target system. Iraq has been successful in launching and flying two of the converted L-29 aircraft using this combined technology. The various subsystems are discussed in the following subsections.

(S) [redacted]

1.b. Command and Control (U)

(S) [redacted]

(S) [redacted]

[redacted]

(S) [redacted]

Figure 26. (U) Block Diagram of the ALAMAK Ground Control Station

~~(S)~~ [redacted]

[redacted]

~~(S)~~ [redacted]

~~(S)~~ [redacted]

Figure 27. (U) Cameras Located in the Cockpit

[redacted]

~~(S)~~ [redacted]

[redacted]

1.b.(1) Modes of Operation (U)

~~(S)~~ [redacted]

[redacted]

[redacted]

1.b.(2) *Modes of Navigation (U)*

[redacted]

[redacted]

(U) Currently, there have not been any operations conducted by the UAV that did not include a chase plane. This is normal given the current stage of the project. Even if other navigation options were active, they would still include a chase plane.

1.c. Propulsion (U)

(U) Propulsion is provided by one Walter (Motorlet) M701 turbojet engine. (See Table 1 and Figure 28.) The compressor is a single-stage centrifugal type. The combustor is cannier and consists of seven externally mounted cans interconnected by flame tubes with igniter plugs installed in cans two and seven. A single-stage axial-flow turbine powers the compressor. The control is hydromechanical and an electric starter is used.

Table 1.
M701 Characteristics and Performance (U)

Type	Turbojet
Length	6.78 ft
Diameter	2.95 ft
Weight	740.7 lb
Airflow	37.3 lb/sec
SLS, ISA, uninstalled performance rating	
Maximum thrust*	1,962 lb
Maximum continuous thrust	1,760 lb
Maximum SFC	1.14 lb/hr/lb
Maximum continuous SFC	1.14 lb/hr/lb

*A 6-minute time limit.

UNCLASSIFIED

(U) The engine is installed in the aft fuselage and is fed air via a bifurcated duct. The two D-shaped pitot inlets are located in the wing roots and come together inside the fuselage just forward of the engine. A fixed-geometry nozzle exhausts just under the tail.

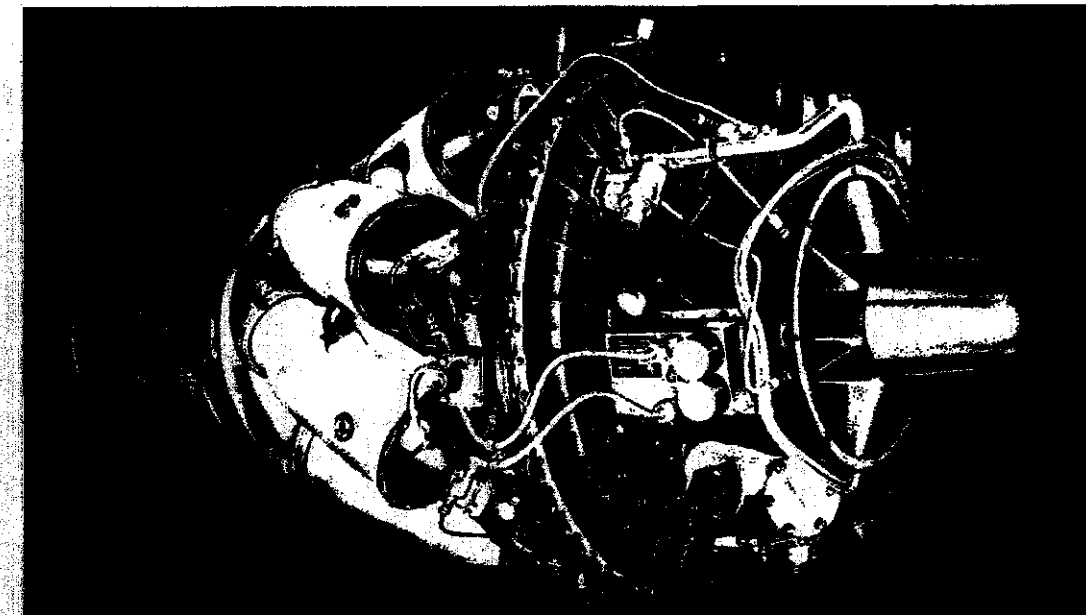

Figure 28. (U) Jet Engine for the L-29

1.d. Power Supply (U)

(U) The aircraft primary DC power is 27 V. The engine alternators provide 115-V AC, 400-Hz three-phase power which is converted to 27-V DC to maintain battery charge. The availability of wet cell aircraft batteries appears to be a supply problem in country. One of the converted L-29 UAVs had a dry cell mounted in the forward nose section of the aircraft and skin modifications were made to accommodate the extra battery height; a bubble of aluminum is located over the battery. Dry cell batteries are not normally rechargeable, so NAIC does not know how the charge from the aircraft DC bus system is managed.

1.e. Payloads (U)

1.e.(1) Aerial Vehicle (U)

(U) The following descriptions, unless otherwise noted, apply to all L-29 UAVs and the DELFIN jet trainer from which it was modified. The L-29 (DELFIN) is a subsonic, single-engine, turbojet powered, twin place, trainer and light attack aircraft. It was built in Czechoslovakia by Omnipol.

1.e.(1)(a) External Configuration (U)

(U) The L-29 aircraft is a self-supporting, all-metal monoplane construction and is fitted with a tapered, mid wing. The tail section is T-shaped with the trapezoidal swept back vertical fin supporting a trapezoidal swept back horizontal tailplane and elevator. The cockpits are enclosed with two canopies consisting of transparent plastic secured within a metal frame. Under normal operation the canopies are manually operated. Pneumatic actuators are provided to jettison the canopies in case of emergency. The L-29 (DELFIN) is fitted with retractable tricycle landing gear and a hydraulic dampened tail skid that permits operation from concrete runways as well as from semi-prepared fields. The aircraft is fitted with a single M-701 turbojet engine with centrifugal compressor and no afterburner. The trainer/light attack aircraft is equipped with two wing hard points, one per wing. Each hard point is fitted with a BDZ-53 type bomb shackle that is flush mounted with the external surface of the under wing. Each wing has plumbing for transfer of fuel from external fuel tanks to the rear internal fuel tank. Each hard point can support the carriage of a single, 150-liter external fuel tank. Each tank has a built-in mounting adapter that contains the necessary connectors and fuel fittings. Gravity type iron or cluster bombs are carried without the use of a wing adapter. However, when carrying rocket pods and packs, a wing adapter must be used. The DELFIN is reported, by its builder, to be limited to the carriage of stores weighing 120 kg (~260 lb) or less. Each bomb shackle can be loaded with either a single 57/4M rocket pod, a 100-kg bomb, or a 150-liter (117-kg) external fuel tank. As the BDZ-53 is designed to carry payloads up to 300 kg, NAIC can only conclude that the store limit of about 120 kg is based on the structure of the hard points.

1.e.(2) General (U)

(S) [redacted]

1.e.(2)(a) Rocket Pods (U)

(S) [redacted]

(U) The R 57/4M is a 4-shot rocket pod intended for the carriage and launching of S-5M folding fin aircraft rockets (FFAR). The S-5M is a 57-mm unguided FFAR fitted with a blast fragmentation warhead. The pod is cylindrical in shape and is composed of a steel and aluminum body, a rear cover, an attachment lug, and multipin electrical plug connectors to link up with pigtail connectors in the wing. Although an external 7.62-mm gun pod (one per each wing, attached on the bomb shackle) is referenced in a builder's brochure, there is no indication on the weapons control panel that a provision has been made for gun operations.

(U) A 4-shot 55-mm FFAR rocket packet is also reported in the builder's brochure. The packet is composed of four individual box-shaped containers constructed of riveted aluminum sections. The boxes are joined as pairs, two each attached side by side. The pack is formed by mounting one pair of boxes above the other with a small separation between the two units. Firing cables are installed, running within the area formed by the separation. The cables run back to firing units installed at the end of each box. A reinforcement unit is added to the top of the upper pair of boxes to serve as a surface for the mounting lug. The packet is mounted to the bomb shackle using the mounting lug.

1.e.(2)(b) ASP-3NM/U Gun Sight (U)

(S) [redacted]

2. Mission Planning and Control Station (U)

(S) [redacted]

2.a. General (U)

~~(S)~~ [redacted]

2.b. Stations (U)

~~(S)~~ [redacted]

2.b.(1) Navigation Station (U)

~~(S)~~ [redacted]

[redacted]

2.b.(2) Piloting Station (U)

(U) This station is used to remotely control the L-29 during flight operations. This station is now able to control takeoff and landing of the aircraft without having to leave the consoles. All the necessary inputs to maintain control of the aircraft are conducted at this station.

2.b.(3) Payload Station (U)

(U) This work station is no longer required in the normal operation of the L-29 UAV. The payload functions that were initially directed from this station are not part of the flight control station requirements. This station may still function in some other capacity such as the video link from the air vehicles, but it is no longer an integral part of the flight control station. Depending on future payloads that eventually may be installed on the L-29, other optical tasking may be assigned to this station.

2.b.(4) Camera Monitoring Station

~~(S)~~ [redacted]

Section IV
Performance (U)

1. Aero Analysis (U)

(U) Figure 29 and Figure 30 provide some indication of the capabilities of the production version of the L-29. The information is for a new L-29 with a fresh engine, and the data are optimized for the aircraft. The Iraqi L-29 unmanned aerial vehicles (UAVs) have been out of production for an extended period and have been refurbished for this project. The engines are old, and their performance will be downgraded from a factory fresh engine.

(U) The data in the illustrations will also be altered by the modifications needed to operate the L-29 aircraft remotely. Appendix A provides the weight, aerodynamics, and propulsion data used in computing mission capability and fight characteristics that may reflect the L-29 in its converted state. The information is based, in most part, on the L-29 in the trainer configuration and is an assessment only.

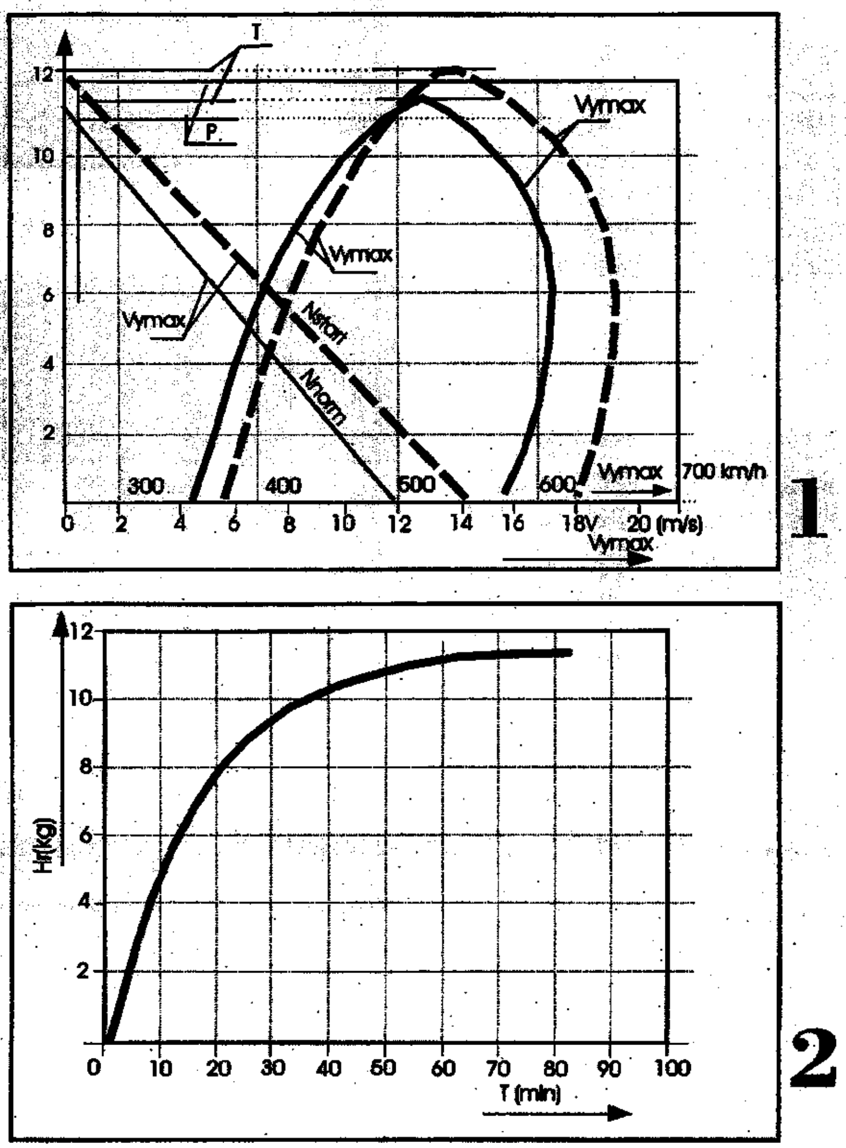

Figure 29. (U) L-29 Performance Data

3 4

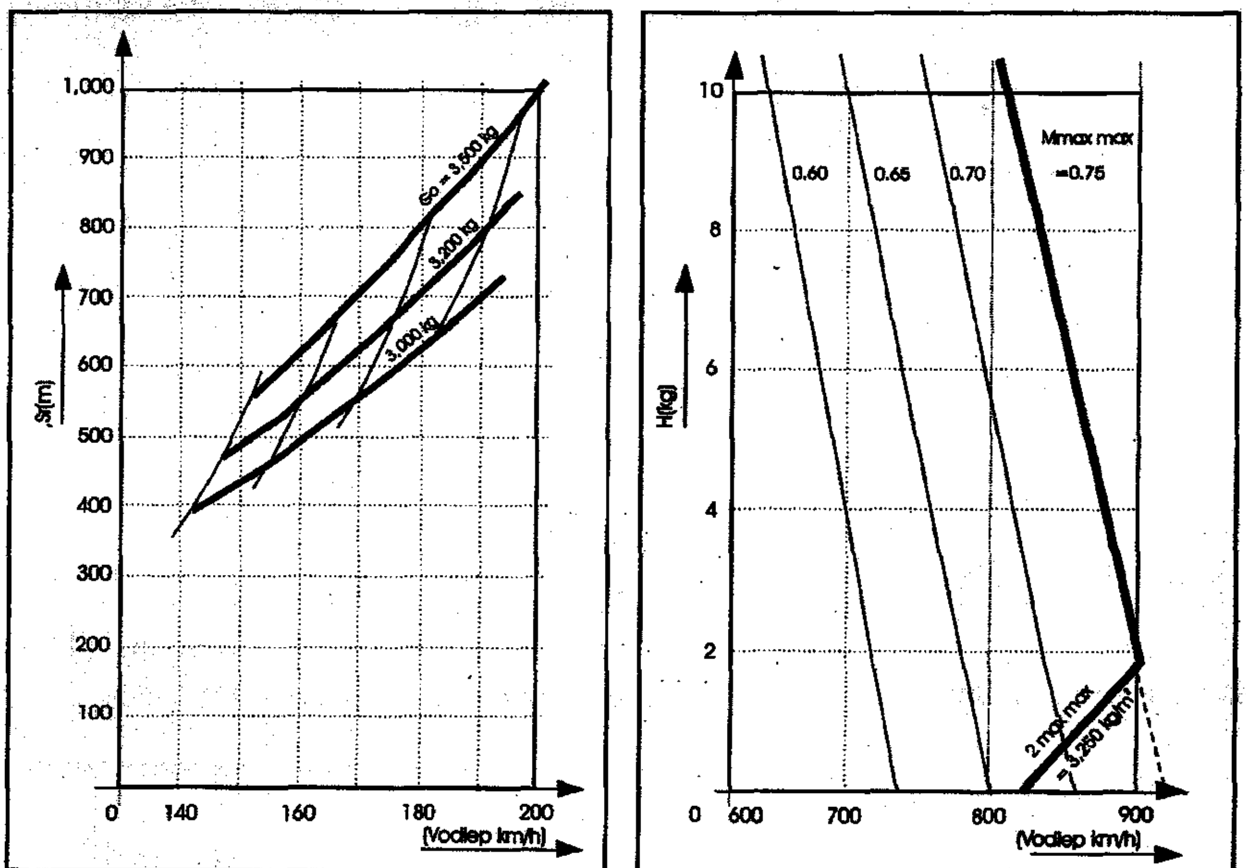

Figure 30. (U) Additional L-29 Performance Data

EX P B1

Section V
Future Developments (U)

~~(S)~~ [redacted]

[redacted]

[redacted]

Ex B1

Appendix A
Aero Performance (U)

Introduction (U) ~~(S)~~ [redacted]

UNCLASSIFIED CA00-122

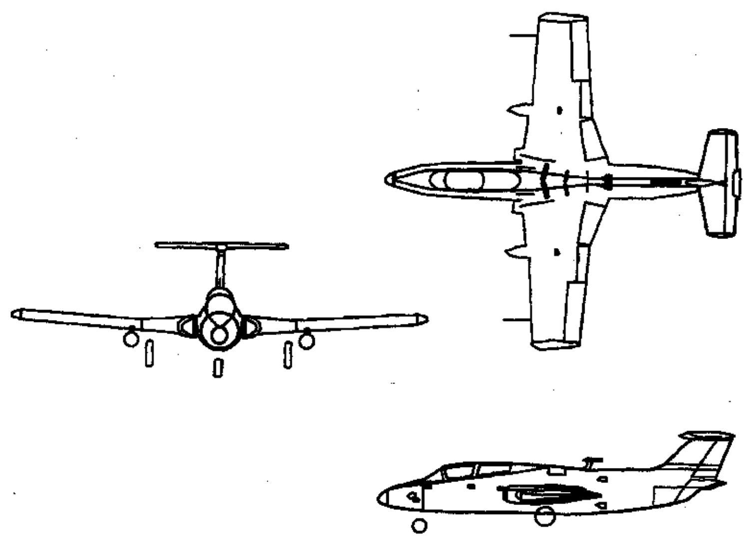

Figure 31. (U) L-29 UAV

~~(S)~~ [redacted] Called "MAYA" in NATO reporting and "Daulphin" by the manufacturer, the L-29 is a very old, low capability platform [redacted]. The L-29 UAV is powered by a single M-701 turbojet engine with centrifugal compressor and no afterburner. [redacted]

Exp B1

(U) This assessment of the L-29 UAV is based largely on a 1981 assessment of the L-29 MAYA. Recent intelligence received on the original L-29 has shown that analysis still to be valid.

Physical Characteristics (U)

Dimensions (U)

(U) The dimensions for L-29 UAV are shown in Table 2. These values were taken from the NAIC/DXH drawing 67E-1028.

Table 2.
L-29 UAV Dimensions (U)

SECRET

Fuel Layout (U)

(S) [redacted]

Figure 32. (U) Fuel Loading Diagram

Weapons Loading (U)

(S) [redacted]

Figure 33. (U) Weapons Loading Diagram

Weight and Structures (U) (S) [redacted]

Table 3.
UAV Related Equipment (U)

EXP B1

Table 3.
UAV Related Equipment (U)

SECRET

(U) [redacted]

Table 4.
UAV Weights Changes (U)

SECRET

(S) [redacted]

- (S) [redacted]
- (S) [redacted]
- (S) [redacted]

(S) [redacted]

(S) [redacted]

(S) [redacted]

- (S) [redacted]
- (S) [redacted]
- (S) [redacted]
- (S) [redacted]

(U) The operation empty weight for the aircraft is presented in Table 5. The performance weights are presented in Table 6.

Table 5.
Operational Weight Empty (U)

SECRET

ExP B1

Table 5.
Operational Weight Empty (U)

SECRET

Table 6.
Performance Weight Statement (U)

Aerodynamics (U) (S) [redacted]

(U) Note: To find the total CD for a desired CL and Mach number, subtract the proper value of CD, as indicated in the upper left corner of the drag polar chart, from the CD' value read from the chart.

Figure 34. (U) Maximum Lift Coefficient

Figure 35. (U) Zero Lift Drag Coefficients

Figure 36. (U) Lift Drag Coefficient

EXP B1

Figure 37. (U) Maximum Lift/Drag

Exp B1

Figure 38. (U) Drag Polar

EXP B1

Figure 39. (U) CL Alpha versus Mach

ExP B1

Table 7.
Drag Data (U)

SECRET

Propulsion (U) (U) This subsection contains the installed propulsion data for the M-701 engine that powers the L-29 UAV. The data consist of installed thrust and fuel flow values for two power settings. Thrust data are presented in pounds thrust per engine. Fuel flow data are presented in pounds per hour per engine. (See Figure 40 through Figure 43.)

(S) The L-29 UAV is powered by a single M-701 single-stage centrifugal turbojet engine. The powerplant is rated at 1,900 lb (8.45 KN) sea level static thrust. Since the L-29 UAV is a single-engine aircraft, data on the following plots represent aircraft total values.

ExPB1

Figure 40. (U) Installed Thrust per Engine, Maximum Power

EXP B1

Figure 41. (U) Installed Fuel Flow per Engine, Maximum Power

EXP B1

Figure 42. (U) Installed Thrust per Engine, Maximum Continuous Power

Figure 43. (U) Installed Fuel Flow per Engine, Maximum Continuous Power

Performance (U) (S) [redacted] ons:

- (S) [redacted]
- (S) [redacted]
- (S) [redacted]

EXP B1

~~(S)~~ [redacted]

~~(S)~~ [redacted]:

~~(S)~~ [redacted]

~~(S)~~ [redacted].

~~(S)~~ [redacted]

~~(S)~~ [redacted]

~~(S)~~ [redacted]

~~(S)~~ [redacted]

~~(S)~~ [redacted]

~~(S)~~ [redacted]

~~(S)~~ [redacted]

~~(S)~~ [redacted]

~~(S)~~ [redacted]

~~(S)~~ [redacted]

~~(S)~~ [redacted]

~~(S)~~ [redacted]

EXP B1

(S) [redacted]

Table 8.
Mission Performance (U)

~~SECRET~~

EXP B1

Figure 44. (U) Velocity

Figure 45. (U) Maximum Rate of Climb

EXP B1

Figure 46. (U) Climb Distance, Fuel, and Time

Figure 47. (U) Takeoff Speed

EXP B1

Figure 48. (U) Takeoff Distance

Figure 49. (U) Turn Radius

EXP B1

Figure 50. (U) Turn Rate

Figure 51. (U) Load Factor

Figure 52. (U) Speed Altitude Envelope

Exp B1

[redacted]

CA00-144

Figure 53. (U) Range-Altitude Tradeoff

Metric Conversion Table

(U) Parameters and measurements in this document are reported in metric units, to bring Department of Defense intelligence reporting into consonance with internationally accepted standards for measurement. For the benefit of users who require parametric values expressed in customary units, the accompanying table lists each metric unit applicable to this document, along with its corresponding value in customary units.

(U) The metric system used is the International System of Units (SI), along with certain non-SI metric units approved by the International Committee on Weights and Measures (ICWM) for use with the SI system. Certain non-metric, international customary units such as nautical mile, degree of arc, and the customary units of time also have been approved by ICWM for continued use with the SI system and will continue to be employed where appropriate. US customary units also will continue to be employed for items that are defined or named in terms of customary units, such as 1-megaton warhead, .38-caliber pistol, and two-by-four. An asterisk (*) beside a customary unit indicates that the customary unit will continue to be used for the indicated parameter.

(U) Use of the International System of Units requires that a distinction be made between force and mass, which customarily have been expressed in pound-force and pound-mass, respectively. Because one lbf/lbm (i.e., one "*g*") converts to 9.80665 newtons/kilogram (owing to the fact that standard free fall is 9.80665 meters per second squared, and one N/kg is equivalent to one m/s^2), parameters that involve force-to-mass ratios, such as thrust/weight and specific impulse, are approximately an order-of-magnitude greater in SI units than in customary units. Thus:

1 lbf/lbm (or 1 "*g*") = 9.80665 N/kg (thrust/weight), and

1 lbf-sec/lbm (or 1 "second") = 9.80665 N•s/kg (specific impulse).

Quantity	Metric Unit	Symbol	Multiply By	To Get
		Speed, Velocity, Acceleration		
Speed (air, sea)	kilometer/hour	km/hr	0.539 956 8	*knot
Speed (highway)	kilometer/hour	km/hr	0.621 371 2	mph
Rate of climb	meter/second	m/s	196.850 4	ft/min
Velocity	meter/second	m/s	3.280 840	ft/sec
Velocity	meter/second	m/s	1.943 844	*knot
Acceleration	meter/second squared	m/s^2	3.280 840	ft/sec^2
Acceleration	meter/second squared	m/s^2	0.101 971 6	*"*g*"
		Distance, Altitude, Dimension, Length		
Range, distance	kilometer	km	0.539 956 8	*NM
Distance (highway)	kilometer	km	0.621 371 2	mile (statute)
Altitude, dimension	meter	m	3.280 840	foot
Dimension	meter	m	1.093 613	yard
Dimension, wavelength	centimeter	cm	0.393 700 8	inch

UNCLASSIFIED

Quantity	Metric Unit	Symbol	Multiply By	To Get
Dimension	millimeter	mm	0.039 370 08	inch
Gun bore (US, nominal)	millimeter	mm	0.039 370 08	*caliber
Thickness, wavelength	micrometer	µm	0.039 370 08	mil
Wavelength	nanometer	nm	10	*angstrom
		Area, Volume		
Floorspace, wing area, RCS	square meter	m^2	10.763 91	ft^2
Area (small)	square centimeter	cm^2	0.155 000 3	in^2
Territory	square kilometer	km^2	0.291 553 3	$*NM^2$
Land tract	hectare (ha = 10,000 m^2)	ha	2.471 054	acre
Nuclear cross section	10^{-28} meter	10^{-28} m	1	*barn
Volume	cubic meter	m^3	35.314 66	ft^3
Volume	cubic decimeter	dm^3	0.035 314 66	ft^3
Volume (small)	cubic centimeter	cm^3	0.061 023 74	in^3
Volume (oil production)	cubic meter	m^3	6.289 811	*barrel
Fuel capacity	liter (liter = dm^3)	liter	0.264 172 0	gallon
		Mass (Weight)		
Payload, gross weight	kilogram	kg	2.204 623	pound-mass
Mass (small)	gram	g	0.035 273 96	ounce
Mass (bulk)	metric ton (tonne = 10^3 kg)	tonne	1.102 311	ton
		Force, Thrust, Impulse		
Thrust, force	newton (N = kg • m/s^2)	N	0.224 808 9	pound-force
Thrust, force	kilonewton	kN	224.808 9	pound-force
Thrust, force	kilonewton	kN	101.971 6	kilogram-force
Force	micronewton	µN	0.1	dyne
Total impulse	newton-second	N • s	0.224 808 9	lbf-second
Specific impulse	newton-second/kilogram	N • s/kg	0.101 971 6	"second"
Thrust-to-weight	newton/kilogram	N/kg	0.101 971 6	lbf/lbm, *"g"
		Specific Fuel Consumption		
SFC (thrust engine)	milligram/newton-second	mg/(N • s)	0.035 303 94	lbm/lbf • hr
SFC (shaft)	kilogram/kilowatt-hour	kg/(kW • hr)	0.68 277 40	lbm/HP • hr
SFC (shaft)	microgram/watt-second	µg/(W • s)	0.005 918 35	lbm/HP • hr
		Power		
Shaft power, etc.	kilowatt	kW	1.341 022	HP *(550 ft • lbf/s)*
Power	kilowatt	kW	56.869 02	BTU*(IT)*/min
Power	watt	W	3.412 141 3	BTU*(IT)*/hr
		Heat, Energy, Work, Torque		
Heat	joule (J = N • m = W • s)	J	0.238 845 9	calorie*(IT)*
Heat	kilojoule	kJ	0.947 817 0	BTU*(IT)*
Energy	megajoule	MJ	0.277 777 8	*kW • h
Energy	picojoule	pJ	6.241 457	*MeV
Nuclear yield	petajoule	PJ	0.238 095 2	*megaton
Work	microjoule	µJ	10	erg
Work	joule	J	0.737 562 1	ft-lbf
Torque	newton-meter	N • m	0.737 562 1	lbf-ft

UNCLASSIFIED

Quantity	Metric Unit	Symbol	Multiply By	To Get
		Temperature		
Temperature (interval)	kelvin	K	1	°C
Temperature (interval)	kelvin	K	1.8	°F or °R
Temp. (thermodynamic)	kelvin	K	(t_K 1.0)-273.15 =	t_C (in °C)
Temp. (thermodynamic)	kelvin	K	t_K 1.8 =	t_R (in °R)
Temp. (practical)	degree Celsius	°C	(t_C 1.8) + 32 =	t_F (in °F)
		Heat and Energy Values		
Heat flux density	watt/meter^2	W/m^2	0.316 965 3	BTU(*IT*)/ft^2·h
Thermal conductivity	watt/meter-kelvin	W/(m•K)	6.933 471	BTU(*IT*)•in/h•ft^2•°F
Thermal conductance	watt/meter^2-kelvin	W/(m^2•K)	0.176 110 2	BTU(*IT*)/h•ft^2•°F
Thermal resistance	kelvin-meter^2/watt	K•m^2/W	5.678 263	°F•h•ft^2/BTU(*IT*)
Specific heat capacity	kilojoule/kilogram-kelvin	kJ/(kg•K)	0.238 845 9	BTU(*IT*)/lbm•°F
Heat per area	megajoule/meter^2	MJ/m^2	88.055 07	BTU(*IT*)/ft^2
Fuel heating value	megajoule/kilogram	MJ/kg	429.922 6	BTU(*IT*)/lbm
		Pressure, Stress, Strength		
Dynamic pressure	kilopascal (Pa = N/m^2)	kPa	20.885 43	psf
Pressure (gage)	kilopascal (Pa = N/m^2)	kPa (gage)	0.145 037 7	psig
Pressure (absolute)	kilopascal (Pa = N/m^2)	kPa (abs)	0.145 037 7	psia
Overpressure, etc.	megapascal (Pa = N/m^2)	MPa	145.037 7	psi
Tensile, strength	megapascal (Pa = N/m^2)	MPa	0.145 037 7	ksi
Atmospheric pressure	megapascal (Pa = N/m^2)	MPa	9.869 233	*atm (standard)
Atmospheric pressure	megapascal (Pa = N/m^2)	MPa	10	*bar
Atmospheric pressure	kilopascal (Pa = N/m^2)	kPa	10	*millibar
Atmospheric pressure	kilopascal (Pa = N/m^2)	kPa	7.500 638	torr (or mmHg)
		Mass/Area, Mass/Volume		
Wing loading, "beta"	kilogram/meter^2	kg/m^2	0.204 816 1	lbm/ft^2
Density	kilogram/meter^3	km/m^3	0.062 427 97	lbm/ft^3
Fuel density	kilogram/liter	kg/liter	8.345 406	lbm/gal
		Flow, Viscosity		
Air flow, mass flow	kilogram/second	kg/s	2.204 623	lbm/sec
Mass flow	kilogram/second	kg/s	132.277 4	lbm/min
Mass flow	kilogram/second	kg/s	7936.641	lbm/hr
Fuel flow (by volume)	liter/second	liter/s	15.850 32	gal/min
Kinematic viscosity	millimeter^2/second	mm^2/s	1	centistoke
Dynamic viscosity	pascal-second	Pa•s	10	poise
		Angle, Angular Rate		
Plane angle (arc)	radian	rad	57.295 79	*degree (arc)
Plane angle (arc)	milliradian	mrad	3.437 747	*minute (arc)
Plane angle (arc)	microradian	µrad	0.206 264 8	*second (arc)
Rotation, revolution (rate)	radian/second (time)	rad/s	9.549 297	*rpm (rev/min)
Precession (rate)	microradian/second (time)	µrad/s	0.206 264 8	*deg/hr
		Electricity and Magnetism		
Magnetic field strength	ampere/meter	A/m	0.012 566 37	oersted
Quantity of electricity	kilocoulomb (C = A•s)	kC	0.277 777 8	*amp-hr
Magnetic flux	microweber (Wb = V•s)	µWb	100	maxwell
Magnetic flux density	millitesla (T = Wb/m^2)	mT	10	gauss
Electrical conductance	siemens (S = A/V)	S	1	mho
Frequency	hertz	Hz	1	cps

UNCLASSIFIED

Quantity	Metric Unit	Symbol	Multiply By	To Get
		Radiation and Illumination		
Radioactivity	bequerel	Bq	1	*disinteg/sec
Radioactivity	terabequerel	TBq	27.027 03	*curie
X- and gamma-radiation	kilocoulomb/kilogram	kC/kg	3.876 330	*roentgen
Absorbed dose (radiation)	gray (Gy = J/kg)	Gy	100	rad
Solar radiation	megajoule/meter^2	MJ/m^2	23.900 57	langley
Luminance	candela/meter^2	cd/m^2	0.291 863 5	footlambert
Illuminance	lux (lx = lumen/m^2)	lx	0.092 903 04	footcandle

NOTE:
(IT) signifies International Table

UNCLASSIFIED