Outline

16.687

- Pilotage (look out the window)
- NDBs monitored via ADF (needle points to radio station)
- VOR (1950s upgrade to NDB)
- GPS and moving map

MIT AEROASTRO

16.687

Section A

PILOTAGE AND DEAD RECKONING

MIT AEROASTRO

Pilotage

16.687

- Navigation using visual landmarks
- VFR charts emphasize objects easy to identify from the air, e.g., highways, towns, big towers
- Ground procedure:
  - Plot planned course (avoid restricted areas, open water)
  - Select checkpoints along the route
  - Measure distance from checkpoint to checkpoint
  - Develop flight plan and navlog
- In-flight procedure
  - Fly planned headings and airspeed
  - At each checkpoint, use left/right deviation for wind correction

Example

16.687

- From: Hanscom Field, Bedford, MA (BED)
- To: Morse State Apt., Bennington, VT (DDH)

Source: Public Domain

Planning Goal: Navlog

16.687

Waypoints Fixes	MEA / (MORA) FREQ	Route	MC	Fuel (gal) LEG REM	Dist (NM) LEG REM	GS (Kts) EST ACT	ETE TTE	ATE ATA	WIND OAT
KBED HANSCOM N42° 28.197' W71° 17.340'		ALT	MH	54	90				
level off	(4900)		298	1	9	123	**00:04**		
		4500	**292**	52	81		00:04		
KFIT FITCHBURG MUN N42° 33.247' W71° 45.538'	(4900)		298	1	13	123	**00:05**		227@17
		4500	**292**	51	69		00:10		
start descent	(6100)		301	5	55	143	**00:23**		
		4500	**297**	46	14		00:33		
KDDH MORSE STATE N42° 53.472' W73° 14.765'	(6100)		301	1	14	143	**00:05**		230@14
		827	**297**	45	0		00:39		
ROUTE TOTALS				**9**	**90**		**00:39**		

Dead Reckoning

16.687

- Navigation solely by means of computations based on time, airspeed, distance and direction
- Use in conjunction with pilotage
- Steps:
  - Plot course on chart, including landmarks
  - Measure true course (TC) at meridian nearest the center of the course
  - Correct for forecast wind to find true heading (TH)
  - Correct for magnetic variation to find MH
  - Estimate ground speed and ETE for each leg (account for time, speed, distance to climb in the POH)

Courses and Headings

16.687

- Course
  - Direction over the ground
- Heading
  - Direction aircraft is pointing
  - Wind can make **heading** different from **course**
- True (course or heading)
  - Referenced to true north pole
- Magnetic (course or heading)
  - Referenced to magnetic north pole

Courses and Headings

16.687

- True Course
  - Direction of line from A to B relative to true north
- True Heading
  - Direction airplane is pointed, given wind corrections, relative to true north
- Magnetic Course
  - Direction of line from A to B relative to magnetic north
- Magnetic Heading
  - Direction airplane is pointed, given wind corrections, relative to magnetic north
- Compass Heading
  - Magnetic Heading corrected for airplane-specific compass errors

Magnetic Variation

16.687

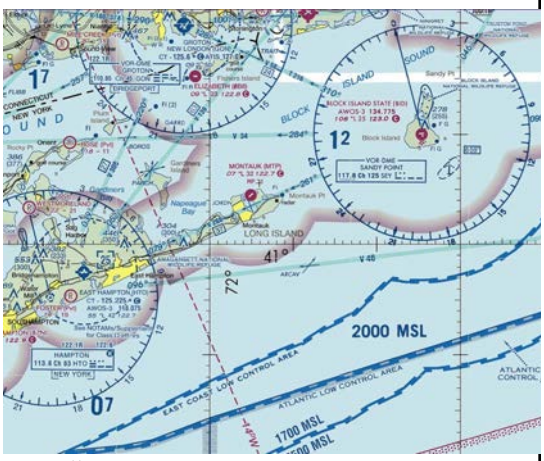
- Isogonic Line: correction factor to convert from True to Magnetic
  - east is least, west is best (subtract east, add west)

Source: Public Domain

Local Magnetic Variation

16.687

- True north != magnetic north
- VORs in magnetic
- Isogonic lines
- “east is least; west is best”: true + W variation = mag



Source: Public Domain

Magnetic Deviation

16.687

- Magnetic and electrical fields inside the cockpit disturb compass
- Compass Correction Card
  - Magnetic heading -> Compass heading
  - Specific to each airframe (not just aircraft type)
  - Must be updated periodically

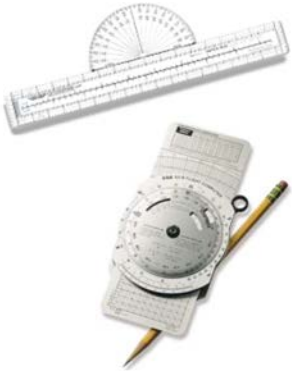
For	N	30	60	E	120	150
Steer	0	27	56	85	116	148
For	S	210	240	W	300	330
Steer	181	214	244	274	303	332

Worthless if heated windshield is turned on!

Plotter and E6B Introduction

16.687

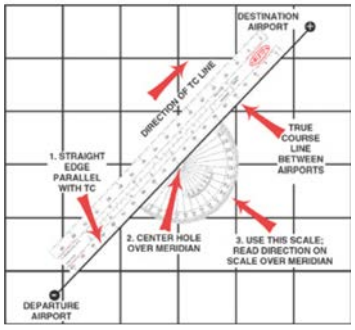
- Plotter
  - Flight planning tool to measure distances and courses
    - Sectional: 1 inch -> 6.86nm / 7.89sm
    - TAC: 1 inch -> 3.43nm / 3.95sm
    - World Aeronautical Chart (WAC): 1 inch -> 13.7nm / 16sm
- E6B
  - Evolved to make common calculations easier (slide rule)
  - Two sides: computer side and wind side
  - Waterproof and no batteries required



Using the Plotter

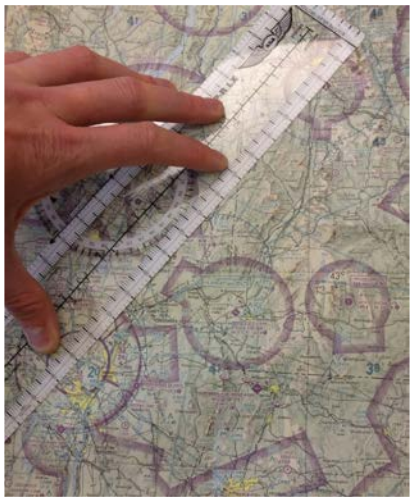
16.687

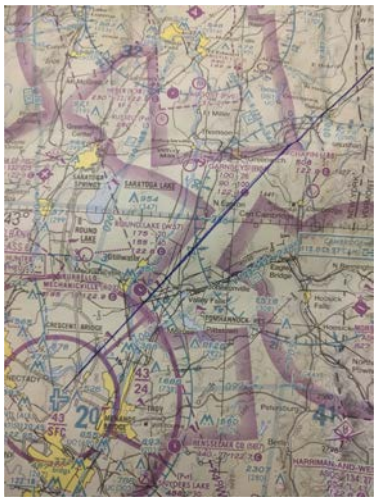
- Used to determine true course between two waypoints
- Different distance scales
- Key points:
  - Use correct distance scale for chart type in use
  - Use Meridians (North-South Lines) for course calculations



Using the Plotter

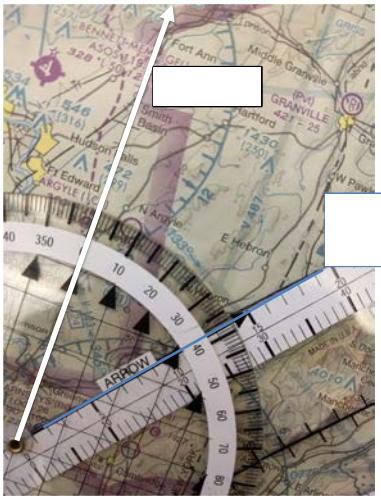
16.687





Using the Plotter

16.687



Using the E6B: Computer Side

16.687

- Calculator is a simple way to calculate ratios between values
- Sliding inner ring normally represents TIME
- Outer ring normally represents VALUE of interest
  - Fuel per unit time
  - Distance per unit time

Source: Public Domain

Using the E6B: Computer Side

16.687

Source: Public Domain

Using the E6B: Wind Side

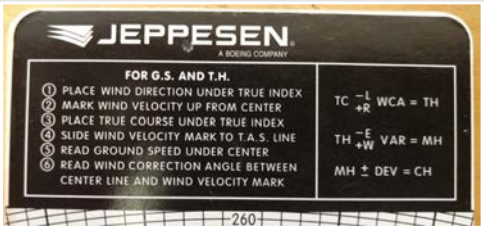
16.687

- Used to find impact of wind
  - Wind correction angles
  - Groundspeed
- Given partial information, useful for determining other missing information
  1. True airspeed
  2. Groundspeed
  3. Wind correction angle
  4. Wind speed
  5. Wind direction

Source: Public Domain

Using the E6B: Wind Side

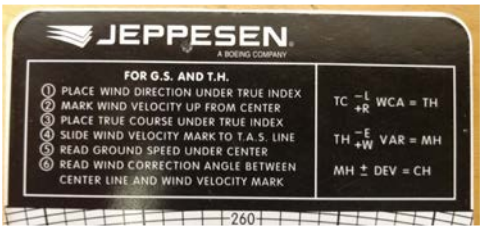
16.687



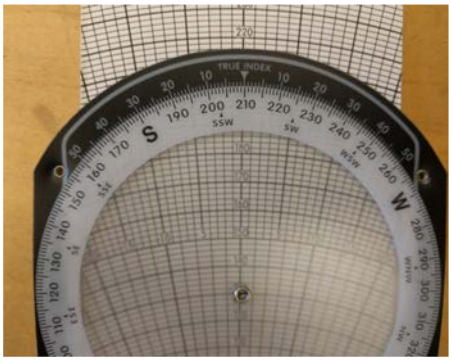
Wind Direction: 210°
Wind Speed: 20 knots
True Course: 180°
True Airspeed: 147 knots

Using the E6B: Wind Side

16.687



Wind Direction: 210°
Wind Speed: 20 knots
True Course: 180°
True Airspeed: 147 knots



Using the E6B: Wind Side

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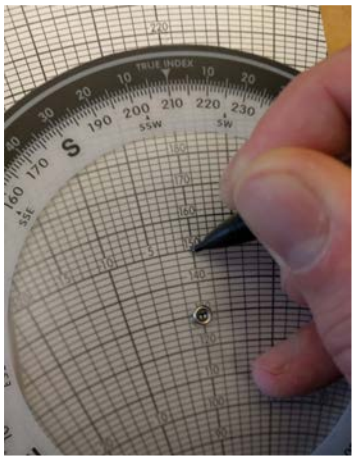
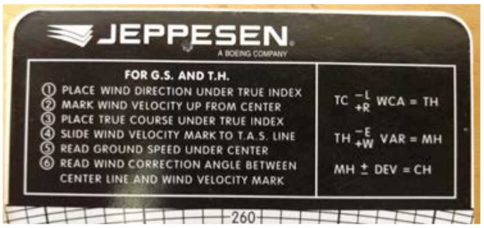
JEPPESEN
A BOEING COMPANY
FOR G.S. AND T.H.
1 PLACE WIND DIRECTION UNDER TRUE INDEX
2 MARK WIND VELOCITY UP FROM CENTER
3 PLACE TRUE COURSE UNDER TRUE INDEX
4 SLIDE WIND VELOCITY MARK TO T.A.S. LINE
5 READ GROUND SPEED UNDER CENTER
6 READ WIND CORRECTION ANGLE BETWEEN CENTER LINE AND WIND VELOCITY MARK
TC −L +R WCA = TH
TH −E +W VAR = MH
MH ± DEV = CH
260

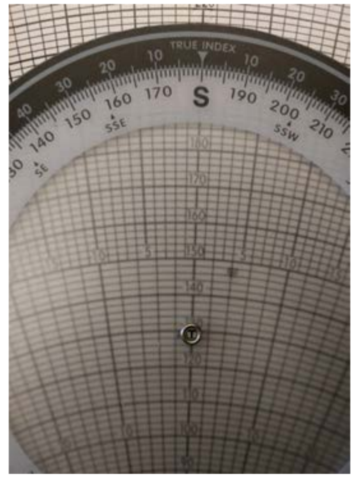
Wind Direction: 210°
Wind Speed: 20 knots
True Course: 180°
True Airspeed: 147 knots



Using the E6B: Wind Side

16.687





Wind Direction: 210°
Wind Speed: 20 knots
True Course: 180°
True Airspeed: 147 knots

Groundspeed: 129 knots
Wind Correction Angle: 4°

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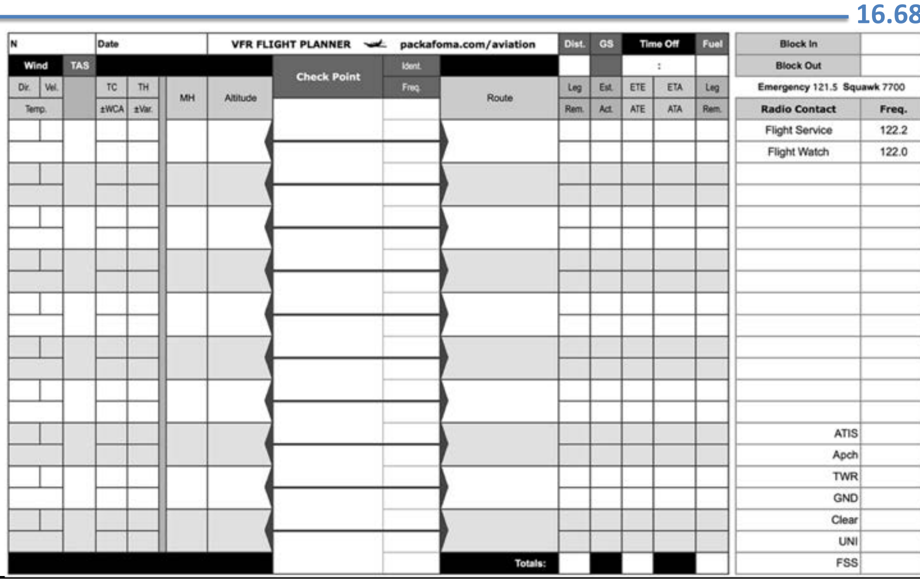
Navigation Log Form

16.687



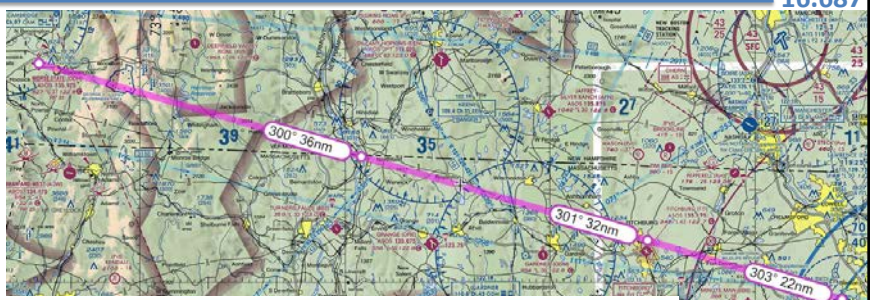
Filled-out

16.687

Waypoints Fixes	MEA / (MORA) FREQ	Route ALT	MC MH	Fuel (gal) LEG REM 54	Dist (NM) LEG REM 90	GS (Kts) EST ACT	ETE TTE	ATE ATA	WIND OAT
KBED HANSCOM N42° 28.197' W71° 17.340'									
level off	(4900)		298	1	9	123	**00:04**		
		4500	**292**	52	81		00:04		
KFIT FITCHBURG MUN N42° 33.247' W71° 45.538'	(4900)		298	1	13	123	**00:05**		227@17
		4500	**292**	51	69		00:10		
start descent	(6100)		301	5	55	143	**00:23**		
		4500	**297**	46	14		00:33		
KDDH MORSE STATE N42° 53.472' W73° 14.765'	(6100)		301	1	14	143	**00:05**		230@14
		827	**297**	45	0		00:39		
			ROUTE TOTALS	**9**	**90**		**00:39**		

SkyVector.com: free and easy

16.687



Source: Public Domain

Waypoint	Route / Altitude	wDir wSpd / Temp (dev)	TAS	Track WCA	TH Var	MH	GS	Dist	ETE ETO	ATE ATO	Fuel EFR	Fuel AFR
KBED												
	-Ð-	326° 14	89	287°	293°	309°	77	6.0	4.8		0.0	
TOC	↗	-5°C (-19°)		+6°	+16°				4.8		55.7	
	-Ð-	272° 15	140	287°	285°	301°	126	16.0	7.6		1.6	
UserFix	4500	-2°C (-7°)		-2°	+16°				12		54.1	
	-Ð-	303° 18	140	286°	289°	303°	122	32.2	16		3.5	
UserFix	4500	-4°C (-9°)		+2°	+14°				28		50.6	
	-Ð-	325° 27	140	286°	293°	307°	118	29.9	15		3.3	
TOD	4500	-8°C (-13°)		+7°	+14°				44		47.3	
	-Ð-	325° 30	155	286°	293°	307°	131	6.2	2.8		0.0	
KDDH	↘	-14°C (-20°)		+7°	+14°				47		47.3	

Pilotage Summary

16.687

- Use winds aloft forecast to create a plan
- Correct heading based on passing over/ left/right of previously selected landmarks
- Fun skill, relationship to safety is unclear (Student pilot versus Commercial pilot)
- Still worth doing, but generate the navlog electronically!
- Knowledge Test: Built-in electronic E6B; plotter useful.

16.687

Section B

ADF NAVIGATION

This won't be on the test…

16.687

… still fun to learn about.

Non-directional beacons (NDBs) set up in the 1930s.

Pilot originally had to turn dial to hunt for station direction.

The Automatic Direction Finder (ADF) was a huge innovation.

At right: from *Flying* 1952.

Automatic Direction Finder

16.687

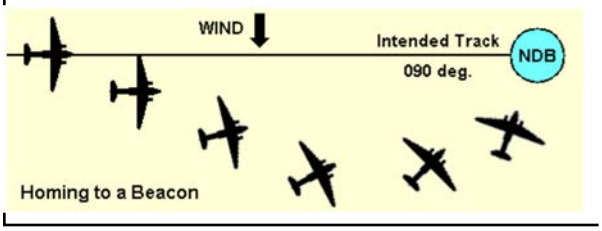
- Automatic Direction Finder (ADF) – Unit in the aircraft
- Non Directional Beacon (NDB) – Ground Station
- Indicator – Compass rose with needle, needle points to the station

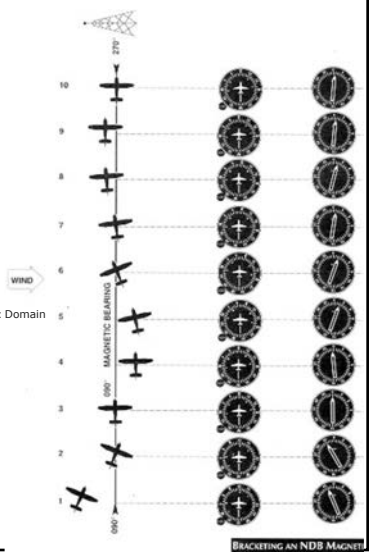
Source: Public Domain

How to use the ADF

16.687

- Homing – Keep the needle pointed forward, airplane tracks curved path in wind
- Tracking – Needle offset due to wind, airplane tracks straight path over ground



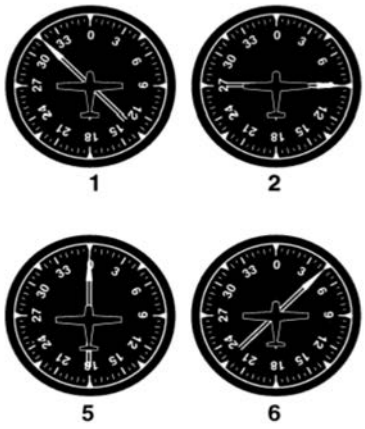


Source: Public Domain

Finding Magnetic Bearing

16.687

- Relative Bearing
  - Number read on face of the ADF
- Magnetic Heading
  - Number read from face of directional gyroscope
- Magnetic Bearing
  - Magnetic heading TO the station



Source: Public Domain

Magnetic Heading + Relative Bearing = Magnetic Bearing

Movable Card ADF

16.687

- Turn card to match heading of aircraft
- Read magnetic bearing under needle

Figure 30. *ADF (movable card).*

Source: Public Domain

16.687

Section C

VOR NAVIGATION

VHF Omni-Directional Range (VOR)

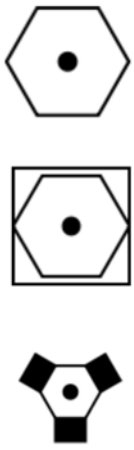
16.687

- 1950s improvement to NDBs
- With no reference to a magnetic compass, receiver can determine the magnetic radial from station
- 360 radials (one for each degree)
- Can track "TO" or "FROM" station on a specific radial
- Can determine lat-long position by intersecting radials from two VORs

Three types of VORs

16.687

- VOR
  - Only transmits azimuth information
- VOR-DME
  - Distance Measuring Equipment (DME)
  - Azimuth plus distance from VOR information
- VORTAC
  - Military: Tactical Air Navigation (TACAN)
  - Azimuth plus distance navigation
  - Private Pilot Standpoint: Same Function as VOR/DME

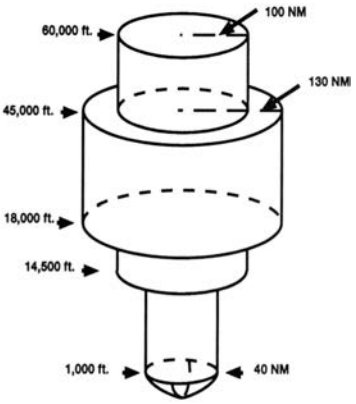


Source: Public Domain

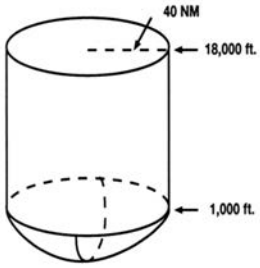
VOR Service Volumes

16.687

High-Altitude

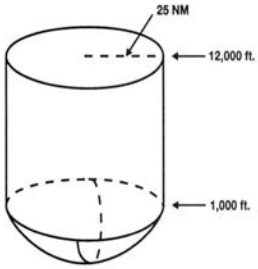


Low-Altitude



NOTE: All elevations shown are with respect to the station's site elevation (AGL). Coverage is not available in a cone of airspace directly above the facility.

Terminal



Source: Public Domain

Parts of the VOR

16.687

- Transmitter
- Receiver
- Indicator
  - OBS – Omni Bearing Selector
  - CDI – Course Deviation Indicator
  - TO/FROM Flag

Source: Public Domain

VOT: test on the ground

16.687

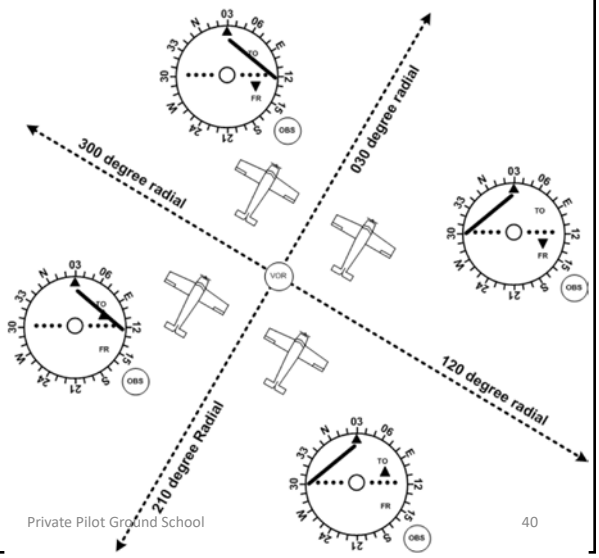
- At Hanscom: tune 110.0
- **"Cessna 182"**: indication should be "180 TO"
- VOR Test Facility (VOT) frequencies buried in the Chart Supplement

Using VORs

16.687

NOTE:
Easiest method to determine VOR deflection is to imagine the airplane is pointed in same direction as OBS

OBS reading is NOT sensitive to actual aircraft heading



Source: Public Domain

2. (Refer to Figure 20, area 3; and Figure 28.) The VOR is tuned to Elizabeth City VOR, and the aircraft is positioned over Shawboro. Which VOR indication is correct?

- A. 2.
- B. 8.
- C. 9.

Source: Public Domain

2. (Refer to Figure 20, area 3; and Figure 28.) The VOR is tuned to Elizabeth City VOR, and the aircraft is positioned over Shawboro. Which VOR indication is correct?

- A. 2.
- B. 8.
- C. 9.

Source: Public Domain

VOR simulators

16.687

- LuizMonteiro.com (Flash)
- List of apps: AOPA

16.687

Section D

GPS NAVIGATION

Global Positioning System (GPS)

16.687

- 1973 U.S. military idea: Navstar ("Navigation System Using Timing and Ranging")
- Broadcast time and position from multiple stations
- Each "time of flight" gives a position somewhere on a sphere
- Intersect 4 spheres to get an x,y,z location

Global Positioning System (GPS)

16.687

- Constellation of 32 satellites (2016); 31 in use
- Minimum of 5 observable from any point on earth
- 5 or more used for IFR operations

GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination

WAAS/SBAS

16.687

- Wide Area Augmentation System (WAAS): FAA-established ground stations that gather correction information
- Generic name: satellite-based augmentation system (SBAS)

From Wikipedia: WAAS uses a network of ground-based reference stations, in North America and Hawaii, to measure small variations in the GPS satellites' signals in the western hemisphere. Measurements from the reference stations are routed to master stations, which queue the received Deviation Correction (DC) and send the correction messages to geostationary WAAS satellites in a timely manner (every 5 seconds or better). Those satellites broadcast the correction messages back to Earth, where WAAS-enabled GPS receivers use the corrections while computing their positions to improve accuracy.

A Garmin GTN 750

16.687

Combination of
- GPS
- NAV radio (VOR/ILS)
- COM radio

Garmin G1000 moving map

16.687

Avidyne PFD moving map

16.687

Brandon Abel

91.161 - DC Area

16.687

- When operating VFR within 60 NM of Washington, DC (DCA VOR), must have taken special awareness training
- Must have course certificate to show, but not onboard

After the navigation mistake…

16.687

- 91.25 - Aviation Safety Reporting Program
- Reports submitted to the Aviation Safety Reporting Program will not be used in enforcement against a pilot
  - Exception: reports containing info about accidents or criminal offenses
  - Program intended to encourage reporting of situations hazardous to aviation safety
    - Subject to some important limitations, the FAA will actually waive fines or penalties for people who voluntarily report unintentional violations of the Federal Aviation Regulations through the program
- Run by NASA: http://asrs.arc.nasa.gov

Summary

16.687

- Pilotage
- NDBs monitored via ADF
- VOR
- GPS and moving map

Captain Sully: “"If I'm ever unable to access [GPS] or use the compass…, I could just keep Venus in the left front corner of the windshield and we would reach California.“

Summary

16.687

- Pilotage
- NDBs monitored via ADF
- VOR
- GPS and moving map

Captain Sully: “"If I'm ever unable to access [GPS] or use the compass…, I could just keep Venus in the left front corner of the windshield and we would reach California.“

Alternative: call ATC with “Request vectors SFO.”

16.687 Private Pilot Ground School
IAP 2019