UNDERSTANDING LOW VISION TELESCOPES

Basic and Advanced

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Applications for Telescopes in Low Vision

Observation tasks from audience

- Theater
- Ballet
- Movies
- Sports
- Classroom, Public speakers
- TV *in communal environments*

General tasks

- Scenery
- Faces
- Cars
- McDonalds Menu
- Computer screens
- Top shelf items

Mobility tasks

- Traffic signals
- Street signs
- Bus numbers, airport signs
- Building directories, wall signs
- Checking traffic

Choices For the Clinician

or the Patient

Optical Factors

- Magnification
- Field size
- Exit pupil size *or entrance pupil for stars*
- Adjustable focus/fixed focus
- Range of focusing (for near and ametropia)
  - Can you include astigmatic Rx ?
  - Image quality
  - Lens Coatings

Practical Considerations

- Cost
- Durability
- Portability *(weight/bulk/holder)*
- Ease of use *(mechanical ergonomics)*
- Cosmesis *(conspicuity and perceived acceptability)*

Design Features

- Binocular/Monocular
- Hand-held /Head mounted
- If head mounted Bi-optic ?
- Tripod/monopod
- Eye-cup, Objective shroud
- Neck, wrist strap, handle

Influenced by frequency of use
(Protracted, Intermittent, Occasional)

Course Outline

Review of basic theory

- Afocal telescopes
- Focal telescopes *for ametropia or close focus*

Apertures and Stops

- Image brightness
- Field of View *and Field of Fixation*

Vergence amplification

- Practical implications
- Checking magnification
- Measuring BVP

Fitting bioptic telescopes

Emerging technologies *zoom, autofocus, video*

How do afocal telescopes work?

Parallel rays in gives parallel rays out

Objective

A converging element (Convex lens, Concave mirror) forms a real inverted image.

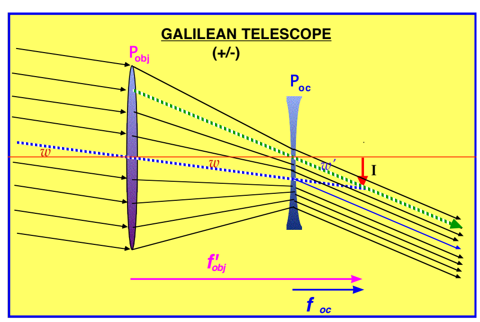
Weak objective- long focal length - larger inverted image

Ocular or Eyepiece

Objective's image must be at primary focal plane of ocular

Stronger ocular - short focal length - large image (infinity)

GALILEAN TELESCOPES



KEPLERIAN TELESCOPES

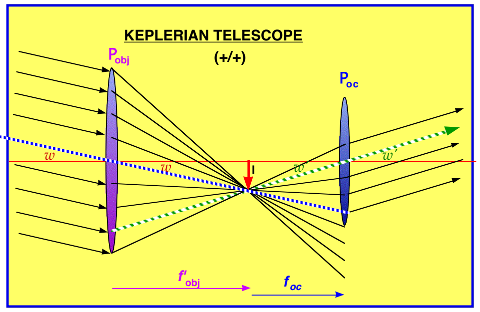
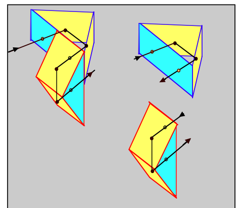
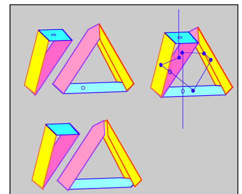


Image Inversion in Keplerian telescopes



Porro Prism System
A pair of right-angled prisms

Total internal reflection
so no mirrored surfaces
45-90-45 45-90-45



Pechan-Schmidt
Roof Prism System
Prism A 112.5-45-22.5
Prism B 45-62.5-62.5
with 45-90-45 roof
Mirrored surface at 45 deg

FOUR BASIC TELESCOPE FORMULAE

The two obvious relationships

$M_{ts} = - P_{oc} / P_{obj}$ Ratio Ocular / Objective

$d = (1 / P_{obj}) + (1 / P_{oc})$ Sum of focal lengths

Two similar formulae (similar to spectacle magnification formula)

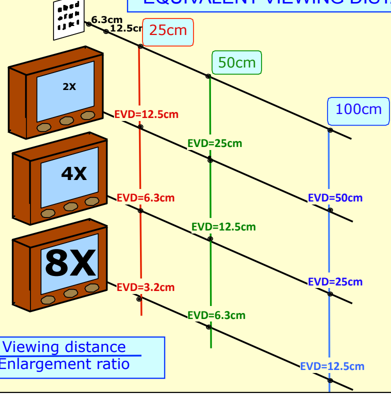
$M_{ts} = 1 / (1 - dP_{obj})$

$M_{ts} = 1 - d P_{oc}$

Comparing Galilean and Keplerian

	GALILEAN	KEPLERIAN
Optical path length	Short	Long
Image	Erect (M=+ve)	Inverted (M= -ve)
Prisms	No	Yes *Makes it terrestrial*
Ocular	Single lens	2 or more lenses
Optical surfaces	4	10 or more
Exit pupil	*inside*	*outside*
Field of view	*smaller*	*larger*
Field limits	*tapered*	*sharp outline*
Image quality	*poorer*	*better*

EQUIVALENT VIEWING DISTANCE



$$EVD = \frac{\text{Viewing distance}}{\text{Enlargement ratio}}$$

AFOCAL TELESCOPES

AFOCAL if Parallel rays in
give Parallel Rays out

Afocal telescopes
have some mathematically sweet properties

Usually telescopes not quite afocal
Objects not at infinity
Patients often do not want or demand *image at infinity*

Adapting Afocal Telescopes
for Ametropia

Assume object at infinity
What can you change?

(a) OCULAR — *Place ocular against spec Rx*
OR *Change ocular to include spec Rx*

(b) LENGTH — *Change length, changes exit vergence*

(c) OBJECTIVE — *Low Powered Lens Cap OR power change at objective changes exit vergence RARELY USED*

(a) POWER CHANGE AT OCULAR
Simple and intuitive

Hold afocal telescope against own spectacle lens
OR
Change ocular lens by adding spectacle Rx

Magnification gain = magnification of original telescope

Total magnification = (Spectacle mag) (Telescope mag)

No differences for Galilean/Keplerian

EVD = viewing distance / M_{ts}

(b) CHANGE LENGTH

Changing length, changes exiting vergence

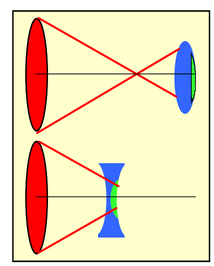
Increasing length adds plus (HYPEROPE)
Also increase length to focus for near (adding plus)

Decreasing length adds minus (MYOPE)

FOR HYPEROPE Increase length
Re-assign PLUS power from ocular to provide Rx.

Keplerian telescope
Borrow plus from ocular
Weaker ocular, longer TS
Reduced magnification

Galilean telescope
Borrow plus from ocular
Stronger ocular, longer TS
Increased magnification

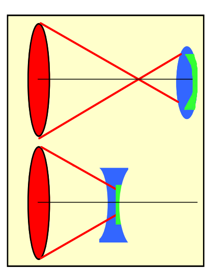


Be able to calculate TS length and M_{ts}

FOR MYOPE Decrease length
Re-assign MINUS power from ocular to provide Rx.

Keplerian telescope
Borrow minus from ocular
Stronger ocular, shorter TS
Increased magnification

Galilean telescope
Borrow minus from ocular
Weaker ocular, shorter TS
Reduced magnification



Be able to calculate TS length and M_{ts}

TELESCOPES FOR NEAR VISION

1 Afocal TS with a cap

EVD = u/M_{ts} = f_{cap}/M_{ts}

2. Adjust TS length of afocal telescope

EVD = $(u/M_{ts}) - f_{oc}$ EVD ≈ u/M_{ts}
Where f_{oc} = focal length of ocular *(usually 1-2 cm)*

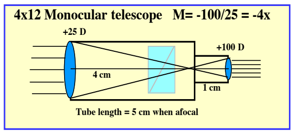
3. Afocal telescope over a high add
Rarely used
EVD = $M_{ts} \cdot f_{add}$

Working distance = $M^2 f_{add} - dM_{ts}$

System gives low magnification
Long EVD and much longer WD

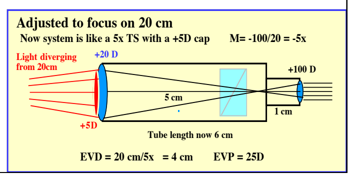
Increasing length
a 4x12 TS focused for 20 cm

Increase length to "add plus" for near vision focus.



Effectively borrow +5D from objective

System behaves like an afocal telescope with a cap on the objective



Labeling Telescopes

Two numbers

Magnification x Objective diameter mm

Manufacturers never state negative magnification for Keplerian TS's

4x12

is a 4x TS, with objective 12 mm in diameter

10x50

is a 10x TS with objective 50 mm in diameter

EXIT PUPILS

Small images of Objective lens
- Located quite close to eyepiece lens
  - Keplerian telescopes (Exit pupil outside TS)
  - Galilean telescopes (Exit pupil outside TS)

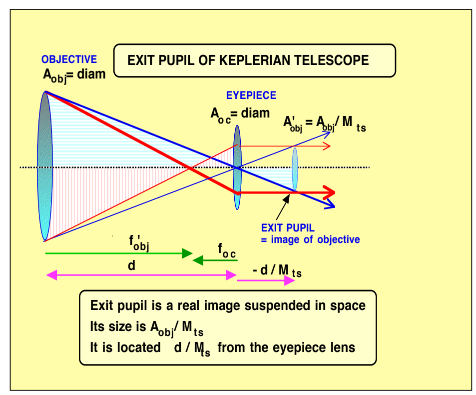
Relevant to Image Brightness

Relevant to Field of View

Can help understand imaging by telescopes

An important reference point

Can be used to determine magnification of TS



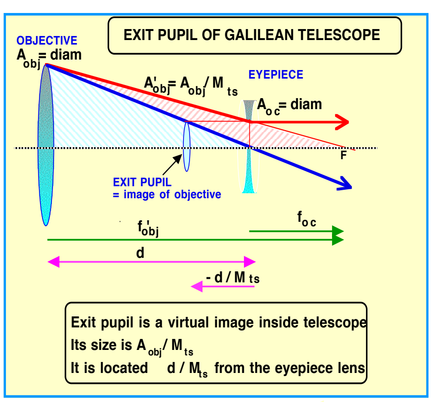


Image Brightness and Telescopes

REFLECTIONS AND ABSORPTION

All telescopes reduce brightness of real objects

Light loss (about 15-40%) from reflections from internal optical surfaces

Keplerian more light loss

More surfaces (compound eyepiece and prisms)

Surface coatings reduce light loss

BUT

TELESCOPES ENHANCE BRIGHTNESS OF POINT SOURCES

(STARS)

STARS OR POINT SOURCES

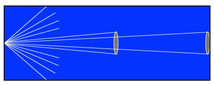
Retinal image is smaller than a receptor diameter

For Point Sources

As the eye gets closer to a point source, the pupil becomes larger in angular size and captures more light from the point.

The size of the image of the point is NOT changed.

Entrance pupil determines brightness



Inverse square rule for point sources
Image illuminance ∝ $1 / d^2$

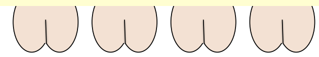
For extended sources (large objects)

Object does not get brighter

Retinal image of object gets larger,

but average retinal illuminance remains the same

Bottom line on brightness



FOR POINT SOURCES

Image brightness determined by the area of light capture

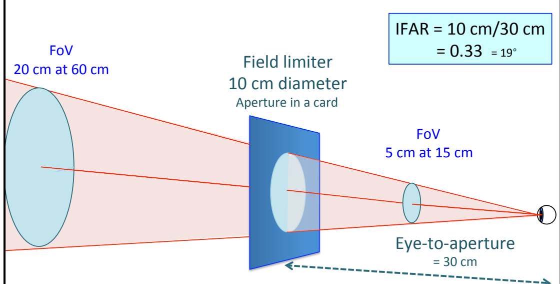
Either TS objective OR M times eye pupil,
(whichever is smaller)

FOR EXTENDED SOURCES

Image brightness determined by size of beam to enter eye

Either eye pupil OR exit pupil of TS,
(whichever is smaller)

All images from the system are within the Image Field Cone



FIELD ASPECT RATIOS

Image Field Aspect Ratio (IFAR)

Is the ratio of the diameter of image space aperture that limits the field to its distance from the eye point.

Object Field Aspect Ratio (OFAR)

Is the ratio of the diameter of object space aperture that limits the field to its distance from the object space representation of the eye point

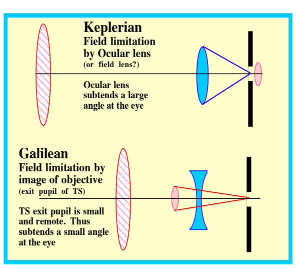
For Telescopes, IFAR = M (OFAR)

Field of View for simple Galilean and Keplerian telescopes

Keplerian

IFAR = A_2 / z

or IFAR = A_2 /(d/M)



Galilean

IFAR = (A_1 /M) / (z + d/M)

Rule of thumb for Fields of View of Telescopes

Keplerian telescopes *(Usually IFAR ≈1)*

FoV ≈ EVD

Galilean Telescopes *(Usually IFAR = $1/M_{ts}$)*

FoV ≈ EVD / M_{ts}

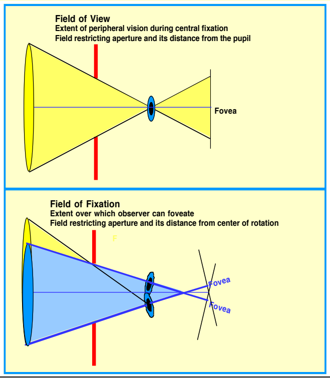
Depth of Field of Telescopes

DoF≈EVD^2

4x12 TS with +5.00D cap EVD = (20 cm / 4) = 5cm = 0.05m

DoF ≈ $(0.05)^2$ = 0.0025 m = 2.5 mm

Field of Fixation is smaller than Field of View



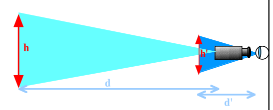
Imaging through afocal telescopes

finite object distances

Height of Image is SMALLER
than Height of Object
$h' = h/M_{ts}$

Image Angle at Exit Pupil is LARGER
than Object Angle at Entrance Pupil
$\omega' = M_{ts}\omega$

Image Smaller by M
and Closer by M^2
(exact, if referenced to exit pupil)



Imaging through telescopes

Image Smaller by M_{ts}...... and Closer by M_{ts}^2
(referenced to exit pupil)

Image distance
relative to exit pupil $v = u/M_{ts}^2$
relative to ocular $v = u/M_{ts}^2 + d/M_{ts}$

Image Vergence
$V_{xp} = M_{ts}^2 U_{obj}$ *(referenced to exit pupil)*

Fried's formula Emerging Vergence from Ocular
$V_{oc} = M_{ts}^2 U_{obj} \,/\, (1 - dM_{ts}U_{obj})$

$V_{oc} \approx M_{ts}^2 U_{obj}$

Vergence amplification

Implications

Small change in object distance
=> large change in accom demand

Focus range of TS might be insufficient to view close
May need to place chart at 4 m and use +0.25 D lens

Weak lens on objective => large change in BVP

Vergence amplification

Implication
Risky to measure BVP of TS on lensometer

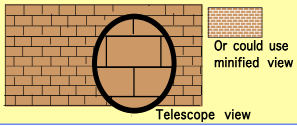
Lensometer for BVP of TS
difficult to ensure lensometer is in precise adjustment
(zero vergence should enter the "lensometer eyepiece")

Any error of lensometer-eyepiece focus is amplified by M_{ts}^2 of TS

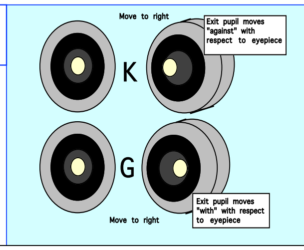
Methods for checking telescopes

1 Direct Comparison (G or K)
2 Exit pupil measurement (G or K)
3 Vergence change at lensometer (G only)
4 Longitudinal magnification (K only)
5 Lateral Magnification -direct (G or K)
6 Lateral Magnification - lensometer (G or K)

1 Comparison Method

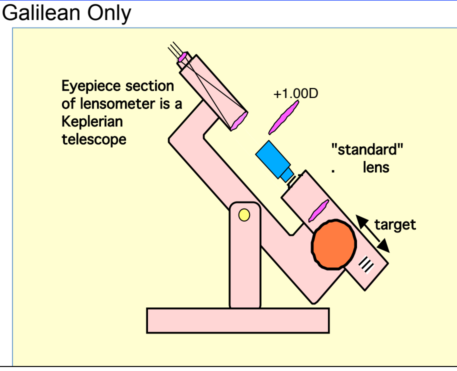


2 Entrance/Exit Pupil Ratio



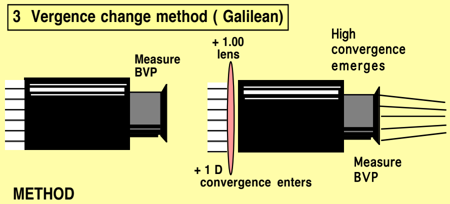
3. Lensometer method for measuring telescope magnification

Galilean Only



3. Lensometer method for measuring telescope magnification

3 Vergence change method (Galilean)



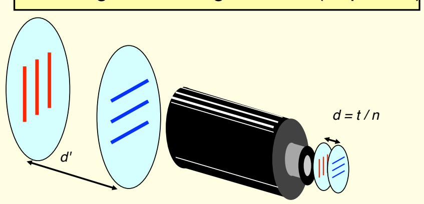
METHOD

Measure diff between BVP with and w/o + 1 D on obj lens
Estimate length of Galilean ts
Use table to determine magnification

3. Lensometer method for measuring telescope magnification

BVP when +1.00 D added to TS on Objective	MAGNIFICATION FOR Telescope Length in mm =					
	10	20	30	40	50	60
4.00	1.98	1.96	1.94	1.92	1.90	1.88
5.00	2.21	2.19	2.16	2.14	2.11	2.09
6.00	2.42	2.39	2.36	2.33	2.30	2.28
7.00	2.61	2.58	2.54	2.51	2.48	2.44
8.00	2.79	2.75	2.71	2.67	2.64	2.60
9.00	2.96	2.91	2.87	2.83	2.78	2.74
10.00	3.11	3.06	3.02	2.97	2.92	2.88
11.00	3.26	3.21	3.16	3.10	3.05	3.00
12.00	3.40	3.35	3.29	3.23	3.18	3.12
13.00	3.54	3.48	3.42	3.35	3.30	3.24
14.00	3.67	3.60	3.54	3.47	3.41	3.35
15.00	3.80	3.73	3.65	3.58	3.52	3.45
16.00	3.92	3.84	3.77	3.69	3.62	3.55
17.00	4.04	3.96	3.88	3.80	3.72	3.64
18.00	4.15	4.07	3.98	3.90	3.82	3.74
19.00	4.26	4.17	4.08	4.00	3.91	3.83
20.00	4.37	4.28	4.18	4.09	4.00	3.91

4 Longitudinal Magnification (Keplerian)

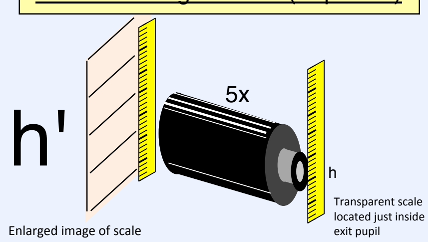


$d' = d\,M^2$

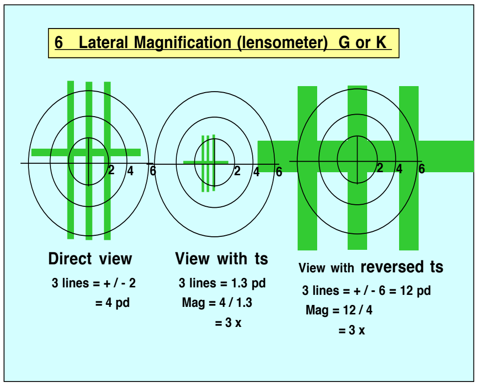
So $M = SQRT\,(d'/d)$

Thin test plate close to ocular
Closer than exit pupil
Distinctive marks on both surfaces

5 Lateral Magnification (Keplerian)

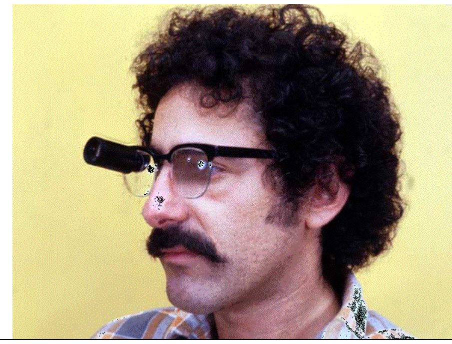


$h' = M\,h$

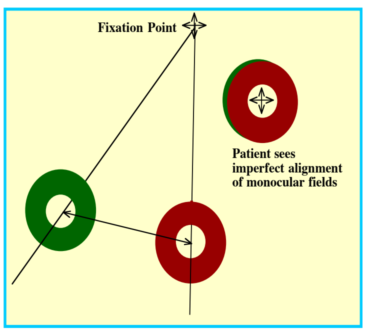


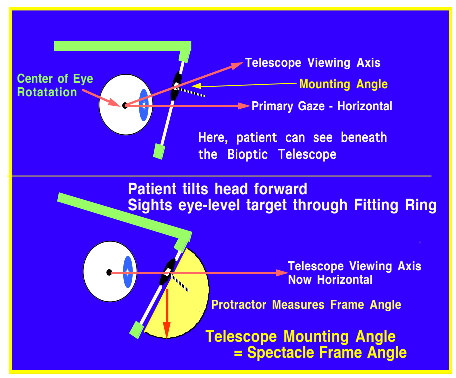
Mounting Telescopes

Telescope Viewing Point and Mounting Angle



Determining TVP's





Dangle-ometry

Determining Telescope Mounting Angle

1. Select telescope viewing point TVP (center of hole)
   Must be at least half diameter plus 3mm from eyewire
2. Locate a fixation point at eye level
   Ensures horizontal line of sight
3. Subject tilts head to align eye,TVP and fixation point
4. Protractor with plumb line *measures spectacle plane angle*

When line of sight through TVP is horizontal,
THEN Spectacle Frame Angle = Mounting Angle

OPTICAL PARAMETERS of a few telescopes

Manufacturer's Specifications		Measured		Optical Factors				Optical Parameters				Physical		Size			Field	
Brand	Mag/diam	Magnification	Field IFAR	Exit Pupil	Closest focus	Myopic Limit	Hyperopic Limit	Objective diam	Ocular diam	Est. Power Obj	Est. Power Occ	Weight	Afocal Length	Max Length	Width	Height	Image Field	Object Field
	ratio/mm	ratio	ratio	mm	cm	DD		mm	mm	DD		g	mm	mm	mm	mm	deg	deg
Walters	2.75x8	2.8	0.60	2.7	14	>-20	+11	8	12	36	100	32	39	48	22		33	12
Walters	4x12	3.9	0.87	2.9	22	>-20	>+20	12	10	25	100	47	47	58	30		47	12
Walters	6x16	5.9	1.07	2.7	27	>-20	>+20	16	12	17	100	67	69	81	31		57	10
Walters	7x25	6.8	1.20	3.0	49	>-20	+5.5	21	17	15	100	157	113	136	42		62	9
Walters	8x32	7.8	1.02	3.9	66	>-20	+8	30	21	13	100	184	131	159	41		54	7
Specwell	2.75x8	2.7	0.67	3.1	13	>-20	+12	8	13	37	100	74	40	54	15		37	14
Specwell	3x9	3.0	0.60	3.0	21	>-20	>+20	9	11	33	101	32	44	50	24		33	11
Specwell	4x12	3.9	0.87	2.8	19	>-20	>+20	11	11	26	100	38	46	58	29		47	12
Specwell	6x16	5.7	1.10	2.7	22	>-20	>+20	16	12	17	100	81	65	88	31		58	10
Specwell	10x20	9.5	1.00	2.0	38	>-20	+20	19	12	11	100	86	105	136	32		53	6
Specwell	10x30	9.8	1.10	3.0	83	>-20	>+20	30	15	10	100	172	148	176	42		57	6
Selsi	6 x18	6.0	0.91	2.2	800	>-20	>+20	13	13	19	117	125	67	68	32	50	49	8
Selsi	6x15	5.6	0.83	2.6	281	-2.5	+13	15	12	20	113	51	54	54	35	35	45	8
Selsi	8x20	7.9	1.03	2.5	29	>-20	+20	20	12	13	100	79	89	120	32		54	7
Selsi	10x20	9.5	0.68	1.9	440	-15	>+20	19	7	11	105	125	82	83	44	33	38	4
Mayflower	6x15	6.0	0.83	2.5	234	>-20	+20	15	13	17	105	54	57	59	37	37	45	8
Mayflower	8x30	7.4	1.08	4.0	246	>-20	>+20	30	15	14	101	201	110	116	49	50	57	8
Designs fV	2.0*EFTS	2.0	0.72	6.8	18	-16	+2.3	14	16	50	100	30	45	52	23		39	19
DfV	3.0*EFTS	2.8	0.79	4.6	23	-14	+4	13	16	36	100	30	46	55	23		43	15
DfV	4.0*EFTS	4.2	0.77	4.8	27	>-20	+4	20	16	24	100	42	59	81	26		42	10
DfV	5.0*EFTS	5.2	0.85	3.9	28	>-20	+5	20	16	19	100	42	55	81	26		46	9
DfV	6.0*EFTS	6.9	0.84	2.9	31	>-20	+2.5	20	11	15	100	35	55	82	25		45	7
DfV	7.0*EFTS	8.0	0.92	2.5	35	>-20	+8	20	10	13	100	38	58	82	26		50	6
DfV	8.0*EFTS	8.1	0.91	2.5	35	>-20	+7	20	11	12	101	35	67	82	25		49	6
DfV	10*EFTS	9.9	0.64	2.0	32	>-20	+6.5	20	11	10	100	41	61	88	26		36	4
Beecher	4x20	4.2	0.97	4.2	77	-13	+11	18	12	24	102	116	54	57	41	47	52	12
Beecher	5.5x25	5.6	1.05	5.1	175	-11	+12	29	12	18	103	94	40	42	33	59	55	10
Beecher	7x30	6.8	1.04	4.5	224	-9	+10	30	12	15	101	105	38	43	35	59	55	8
Beecher	10x35	9.2	0.99	3.8	423	-20	+1.8	35	12	11	102	137	76	79	38	59	53	6