Approximation of GIII Clean Best-Angle-of Climb Speed (V$_X$)

Question

What is GIII clean (cruise configuration) speed for best-angle-of-climb? Best angle of climb speed provides the maximum altitude gain for horizontal distance traveled (minimum ground distance to altitude). Flight at best angle-of-climb is appropriate:

1. Making a crossing restriction on a departure procedure. While the GIII's all engine operative (AEO) climb performance is good, there is no charted AEO climb performance for evaluating whether you can make departure climb restrictions.
2. When ATC asks for a "best rate" climb, they generally want a best angle of climb as they are trying to get altitude separation between two aircraft before they get too close. "Zooming" from normal enroute climb speeds to best angle of climb provides additional altitude in a short order.
3. Departing in the direction opposite of your destination, there is no reason to pick up the faster enroute climb speed until you are turned toward your destination. Best angle of climb may be a more efficient alternative until the aircraft is turned towards the destination.

An example that incorporates items 1 and 3 from the above list is the KLAX ORCKA4 departure with routing to the east. After takeoff from runways 24L/R or 25L/R, pick up the the assigned heading, clean up below 3000 feet, and then accelerate to best-angle of climb speed. When ATC provides vectors and climb, climb at best angle until reaching 10,000 feet. If you accelerate to 250 KIAS after takeoff, you may have trouble reaching KLIPR at or above 10,000 feet. Additionally, if you accelerate to 250 KIAS heading west, you are getting further from you destination.

Background

Other transport aircraft provide best-angle-of-climb via approximation in the flight manual, FMS, or via the PFD (these speeds have not been verified):

KC-135: "speed at end of flap retraction," $V_{CO} + 25$.

B737: best angle was flaps up speed + 20 knots, available via selection on FMS VNAV CLB page.

B747: from T.O 1E-4B-1: Best angle: $V_2 + 80$ below 15,000 feet, $V_2 + 100$ above 15,000 feet. On B747-400, available via selection on FMS VNAV CLB page.

B757: Flaps up min man + 20 knots (e.g. GW=213K, CMS = 217, Best angle = 236) or $V_{REF} + 80$, available on FMS VNAV CLB page.

B767: $V_{REF} + 80$, available via selection on FMS VNAV CLB page.

B777: $V_{REF, 30} + 80$, available via selection on FMS VNAV CLB page.

DC-8, from the Douglas DC-8 Flight Training Manual: $V_2 + 60$.

DC-10: $V_{SR} - 10$ ($1.4V_S$ – In clean configuration at V_{SR} -10, you don't have full maneuver margin)

C-17, from T.O. 1C-17A-1: V_{MMA}

C-130H / C-130J: 4-engine flaps up obstacle clearance speed.

Airbus 320/330/340/350/380: Green dot speed displayed on the PFD airspeed scale.

Theory
For a jet transport, best-angle-of-climb is the speed where there is maximum excess thrust. In the absence of a thrust deck, then best-angle-of-climb can be approximated by best L/D speed. This is a reasonable assumption for the GIII, powered by a low bypass turbo-fan that doesn't have large thrust changes with airspeed.
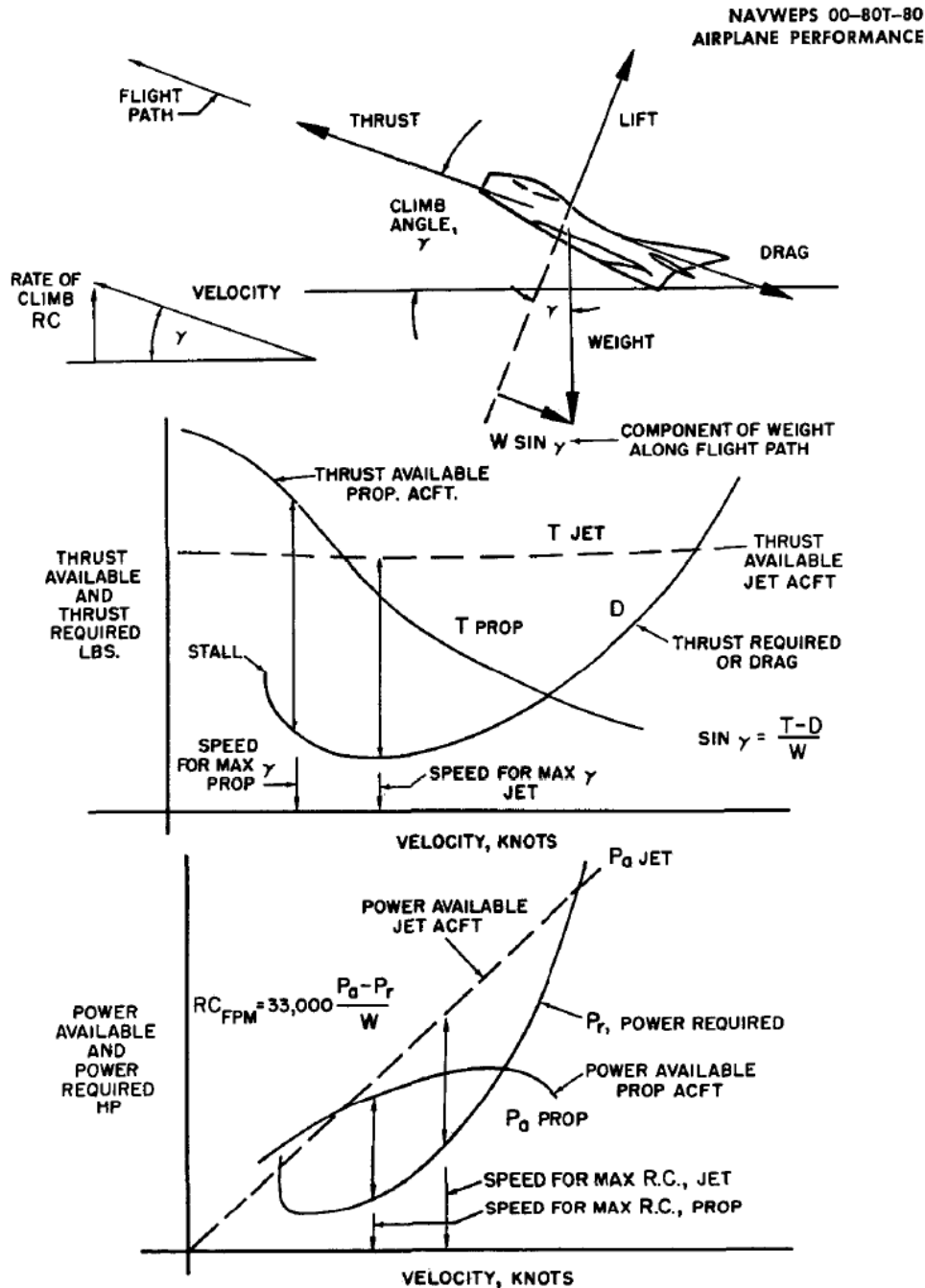
From "Aerodynamics for Naval Aviators"

For the GIII, maximum L/D is approximated by "Speed for maximum range glide all engines inoperative clean configuration" from T.O. 1C-20B-1-1, C-20B Performance Data:

MODEL: C-20B
ENGINES: MK511-8
DATE: MAY 1982
DATA BASIS: FLIGHT TEST

SPEED FOR MAXIMUM
RANGE GLIDE
ALL ENGINES INOPERATIVE
CLEAN CONFIGURATION

NOTES:
1. FLYING SPEEDS AS SHOWN SHOULD YIELD A MINIMUM GLIDE RATIO OF 1:16
2. MINIMUM SPEED FOR GUARANTEED AIRSTARTS (200 KIAS)

FIGURE 5-38.

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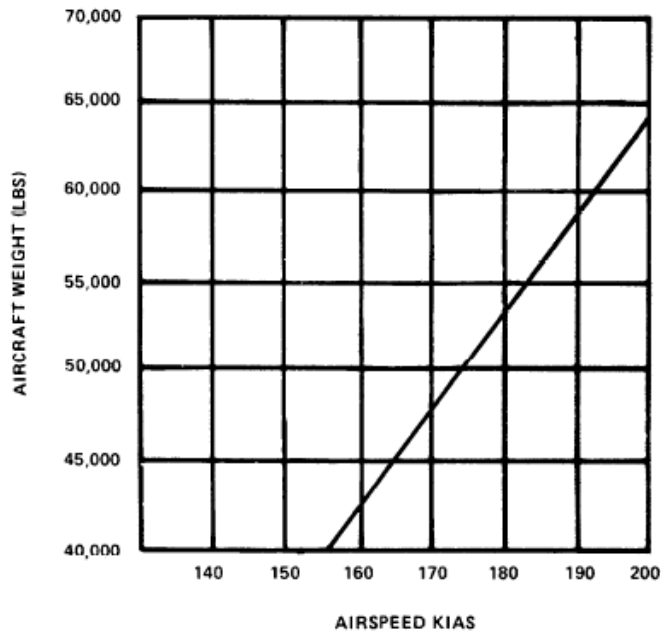
Charting various GIII speeds with Speed for maximum range glide all engines inoperative clean configuration (V_X):

Speed for maximum range glide all engines inoperative clean configuration:

Gross Weight	VSE	VSE+ 20	VREF	VREF + 50	Vmax Range (VX)
40000	134	154	113	163	155
45000	144	164	120	170	164
50000	153	173	126	176	174
55000	161	181	132	182	182
60000	168	188	138	188	191
65000	177	197	144	194	200
70000	186	206	150	200	209

The best approximation of best-angle-of-climb for the GIII throughout its weight range is V_{SE} + 20, although V_{REF}/V_2+50 is also a reasonable approximation. CAE indicated that 0.40 AOA might be another approximation (technique for drift down speed).

GIII Clean Best Angle Climb Speed Approximation (Sea Level)
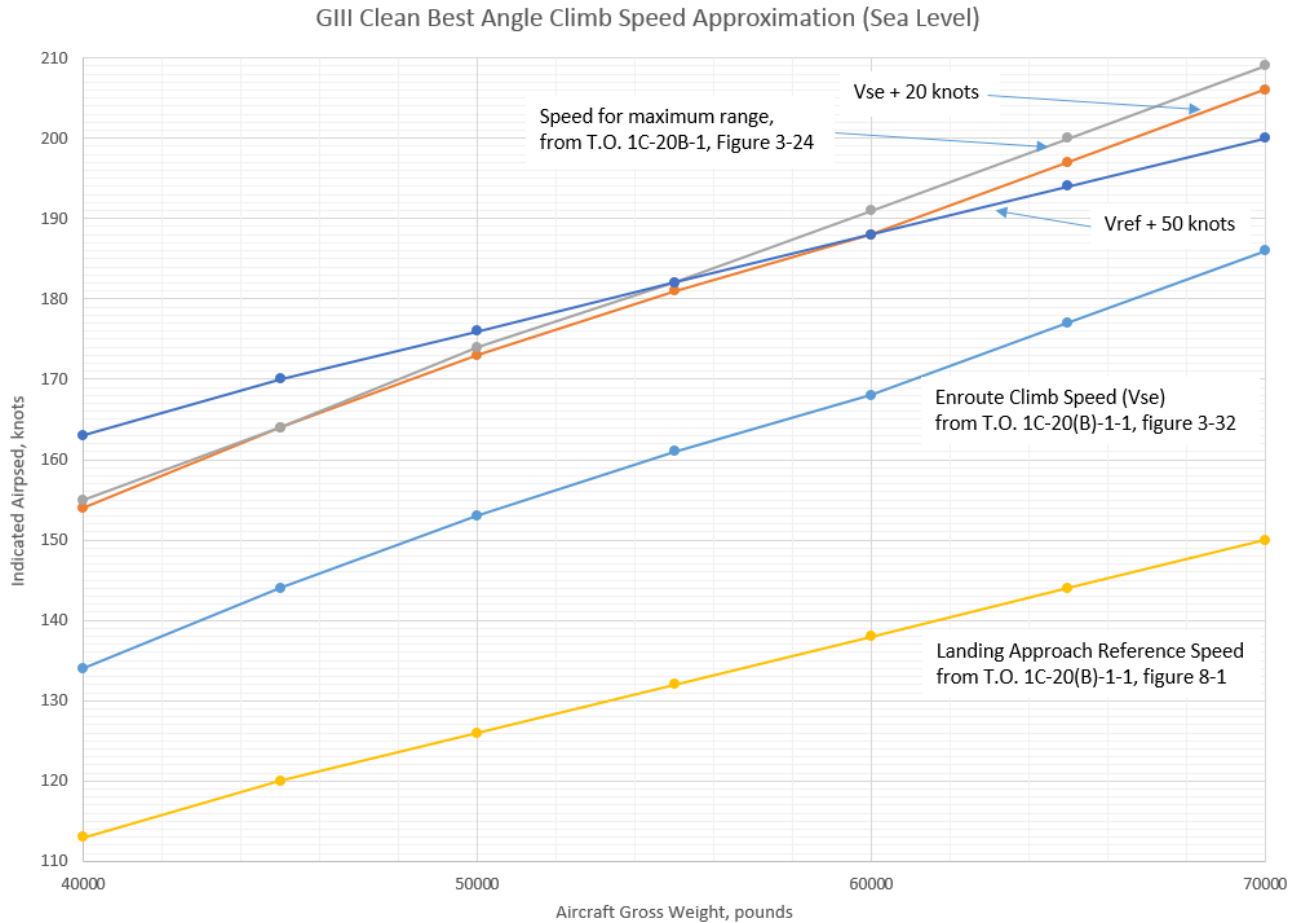
**Flight test determination of best angle of climb airspeed**

Flight Test Technique

Test flown as a series of 2,000 foot saw tooth climbs (from 8,000 to 10,000 feet pressure altitude) with climb power set. With aircraft starting below the target airspeed and ~500 feet below the altitude band (8,000 to 10,000 feet pressure altitude), climb power (490° TGT/94.5% HP RPM) and the aircraft pitched up to maintain the target airspeed. Each climb was timed and the resulting average TAS and vertical velocity used to calculate climb gradient. With a starting gross weight of 51,580 lbs, the calculated VSE (enroute climb speed) was 162 Knots.
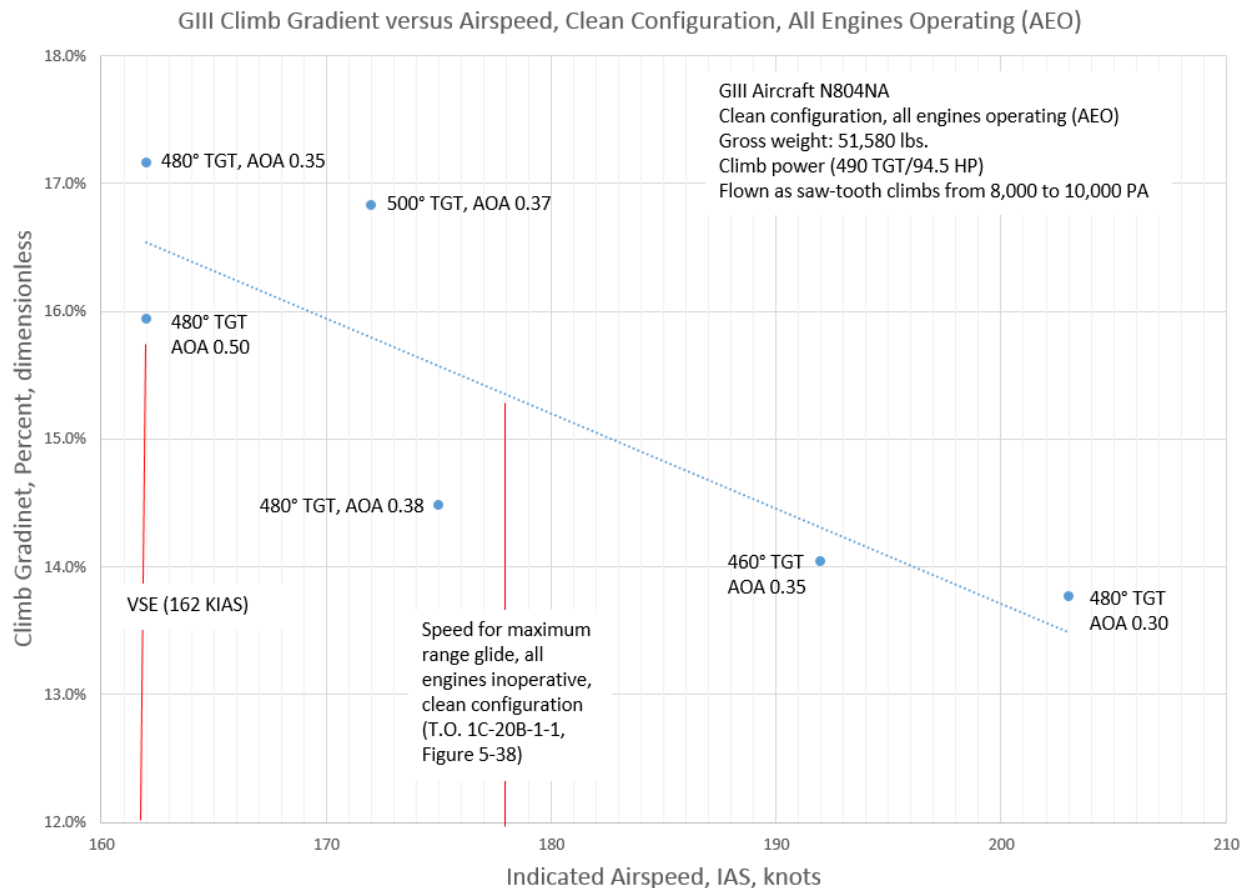
MODEL: C-20B
ENGINES: MK511-8
DATE: MAY 1982
DATA BASIS: FLIGHT TEST

EN ROUTE CLIMB SPEED (V$_{se}$),
KIAS, FLAPS 0°, GEAR UP
MAXIMUM CONTINUOUS THRUST

ANTI-ICING OFF AND ALL ANTI-ICING ON OPERATIONS
EFFECTIVE FOR ALL AMBIENT TEMPERATURES

PRESSURE
ALTITUDE
-1000 FT

ENROUTE
CLIMB SPEED
V$_{SE}$ - KIAS

6
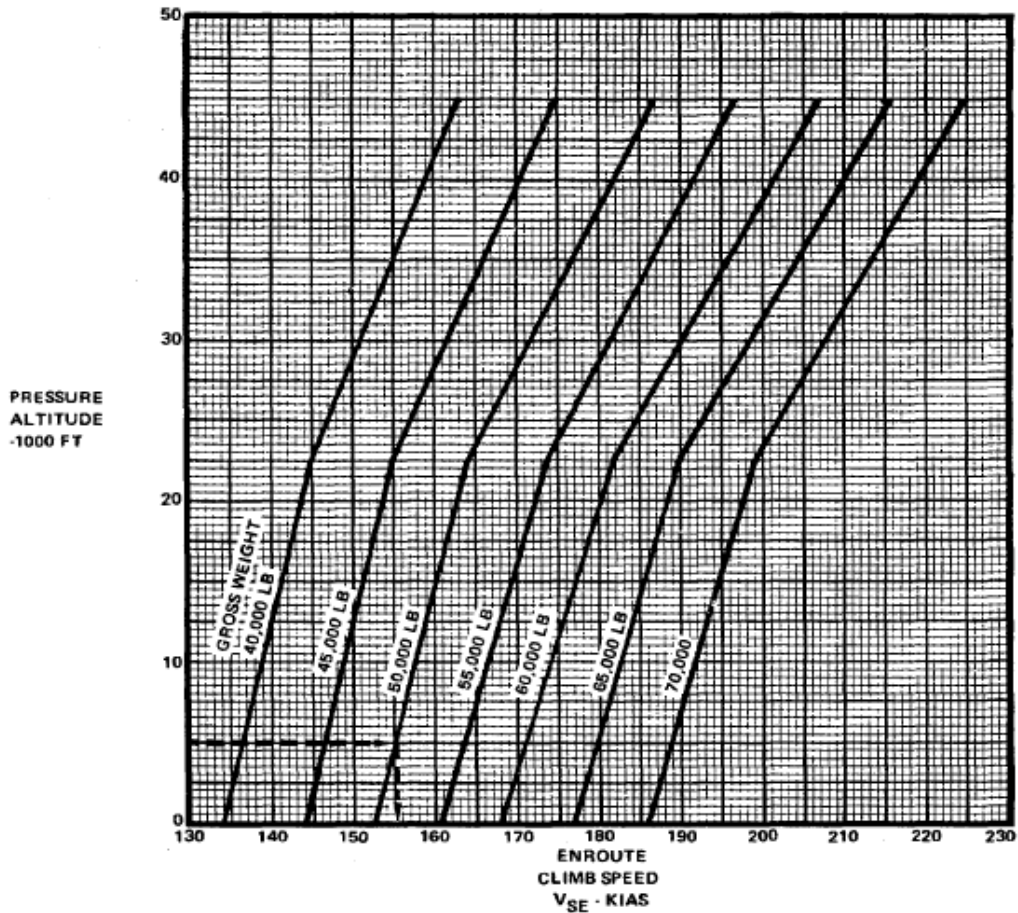
The largest variation in data quality was the inability to quickly and accurately setting climb power. Due to variations in the power setting, the data points are labeled with the actual TGT set for the saw tooth climb:

GIII Climb Gradient versus Airspeed, Clean Configuration, All Engines Operating (AEO)

GIII Aircraft N804NA
Clean configuration, all engines operating (AEO)
Gross weight: 51,580 lbs.
Climb power (490 TGT/94.5 HP)
Flown as saw-tooth climbs from 8,000 to 10,000 PA

480° TGT, AOA 0.35
500° TGT, AOA 0.37
480° TGT AOA 0.50
480° TGT, AOA 0.38
460° TGT AOA 0.35
480° TGT AOA 0.30
VSE (162 KIAS)
Speed for maximum range glide, all engines inoperative, clean configuration (T.O. 1C-20B-1-1, Figure 5-38)

Climb Gradinet, Percent, dimensionless
Indicated Airspeed, IAS, knots

Results
Clean configuration best angle of climb with climb power is V_{SE} or below; as the data show the climb gradient decreasing as speed increases above V_{SE}. From theory, I expected that best angle of climb would be the speed for L/D max, which is approximated by VSE + 20 knots (IAS) (from drift down speed chart).

Climbing at less than V_{SE} is probably not a good idea as you are maneuver limited to less than 30 degrees of bank.

The cockpit AoA is shown for each data point. There was a lot of scatter in the displayed cockpit AoAs, therefore cockpit AoA doesn't seem like a good reference for best angle of climb speed.

Recommendation
Use V_{SE} as best angle of climb airspeed for the GIII when in the clean configuration, all engines operating (AEO).